PIERCE-ARROW FOUR-PASSENGER ROADSTER
Courtesy of the Pierce-Arrow Motor Car Company, Buffalo, New York

Table of Contents

VOLUME I

*For page numbers, see foot of pages.
†For professional standing of authors, see list of Authors and Collaborators at front of volume.

SPRAGUE ELECTRIC DYNAMOMETER EQUIPMENT AT THE PLANT OF WEIDLEY MOTORS COMPANY, INDIANAPOLIS, INDIANA

Courtesy of Sprague Electric Works, New York City

Automobile Engineering

A General Reference Work

FOR REPAIR MEN, CHAUFFEURS, AND OWNERS; COVERING THE CONSTRUCTION, CARE, AND REPAIR OF PLEASURE CARS, COMMERCIAL CARS, AND MOTORCYCLES, WITH ESPECIAL ATTENTION TO IGNITION, STARTING, AND LIGHTING SYSTEMS, GARAGE EQUIPMENT, WELDING, FORD CONSTRUCTION AND REPAIR, AND OTHER REPAIR METHODS

Prepared by a Staff of

AUTOMOBILE EXPERTS, CONSULTING ENGINEERS, AND DESIGNERS OF THE HIGHEST PROFESSIONAL STANDING

Illustrated with over Fifteen Hundred Engravings

SIX VOLUMES

AMERICAN TECHNICAL SOCIETY
CHICAGO
1921

Authors and Collaborators

CHARLES B. HAYWARD

President and General Manager, The Stirling Press, New York City
Member, Society of Automotive Engineers
Member, The Aeronautical Society
Formerly Secretary, Society of Automotive Engineers
Formerly Engineering Editor, *The Automobile*

C. T. ZIEGLER

Automobile Engineer
With Inter-State Motor Company, Muncie, Indiana
Formerly Manager, The Ziegler Company, Chicago

MORRIS A. HALL

Editor, *Automotive Engineering*
Formerly Managing Editor, *Motor Life;* Editor, *The Commercial Vehicle,* etc.
Author of "What Every Automobile Owner Should Know"
Member, Society of Automotive Engineers
Member, American Society of Mechanical Engineers

DARWIN S. HATCH, B.S.

Late Editor, *Motor Age,* Chicago
Formerly Managing Editor, *The Light Car*
Member, Society of Automotive Engineers
American Automobile Association

GLENN M. HOBBS, Ph.D.

Formerly Secretary and Educational Director, American School of Correspondence
Formerly Instructor in Physics, The University of Chicago
American Physical Society

HERBERT L. CONNELL, B.S.E.

Late Lecturer, Automobile Division, Milwaukee Central Continuation School
Editorial Representative, *Commercial Car Journal* and *Automobile Trade Journal*
Member, Society of Automotive Engineers
Member, Standards Committee of S. A. E.
Formerly Technical Editor, *The Light Car*

Authors and Collaborators—Continued

HUGO DIEMER, M.E.

Professor of Industrial Engineering, Pennsylvania State College
American Society of Mechanical Engineers

HERBERT LADD TOWLE, B.A.

Specialist in Technical Advertising
Member, Society of Automotive Engineers
Formerly Associate Editor, *The Automobile*

ROBERT J. KEHL, M.E.

Consulting Mechanical Engineer, Chicago
American Society of Mechanical Engineers

EDMOND M. SIMON, B.S.

Superintendent, Union Malleable Iron Company, East Moline, Illinois

EDWARD B. WAITE

Formerly Dean and Head, Consulting Department, American School of Correspondence
Member, American Society of Mechanical Engineers

JOHN R. BAYSTON

Head, Automobile Engineering Department, American School of Correspondence
Member, Society of Automotive Engineers
Formerly Lecturer, Federal Association of Automobile Engineers, Chicago

W. R. HOWELL

President, W. R. Howell and Company, London, England

WILLIAM K. GIBBS, B.S.

Associate Editor, *Motor Age*, Chicago

JESSIE M. SHEPHERD, A.B.

Head, Publication Department, American Technical Society

Authorities Consulted

THE editors have freely consulted the standard technical literature of America and Europe in the preparation of these volumes. They desire to express their indebtedness, particularly, to the following eminent authorities, whose well-known treatises should be in the library of everyone interested in the Automobile and allied subjects.

Grateful acknowledgment is here made also for the invaluable co-operation of the foremost Automobile Firms and Manufacturers in making these volumes thoroughly representative of the very latest and best practice in the design, construction, and operation of Automobiles, Commercial Vehicles, Motorcycles, etc.; also for the valuable drawings, data, illustrations, suggestions, criticisms, and other courtesies.

CHARLES E. DURYEA

Consulting Engineer
First Vice-President, American Motor League
Author of "Roadside Troubles"

OCTAVE CHANUTE

Late Consulting Engineer
Past President of the American Society of Civil Engineers
Author of "Artificial Flight," etc.

E. W. ROBERTS, M.E.

Member, American Society of Mechanical Engineers
Author of "Gas-Engine Handbook," "Gas Engines and Their Troubles," "The Automobile Pocket-Book," etc.

SANFORD A. MOSS, M.S., Ph.D.

Member, American Society of Mechanical Engineers
Engineer, General Electric Company
Author of "Elements of Gas Engine Design"

GARDNER D. HISCOX, M.E.

Author of "Horseless Vehicles, Automobiles, and Motorcycles," "Gas, Gasoline, and Oil Engines," "Mechanical Movements, Powers, and Devices," etc.

AUGUSTUS TREADWELL, Jr., E.E.

Associate Member, American Institute of Electrical Engineers
Author of "The Storage Battery: A Practical Treatise on the Construction, Theory, and Use of Secondary Batteries"

BENJAMIN R. TILLSON

Director, H. J. Willard Company Automobile School
Author of "The Complete Automobile Instructor"

THOMAS H. RUSSELL, M.E., LL.B.

Editor, *The American Cyclopedia of the Automobile*
Author of "Motor Boats," "History of the Automobile," "Automobile Driving, Self-Taught," "Automobile Motors and Mechanism," "Ignition Timing and Valve Setting," etc.

CHARLES EDWARD LUCKE, Ph.D.

Mechanical Engineering Department, Columbia University
Author of "Gas Engine Design"

P. M. HELDT

Editor, *Horseless Age*
Author of "The Gasoline Automobile"

H. DIEDERICHS, M.E.

Professor of Experimental Engineering, Sibley College, Cornell University
Author of "Internal Combustion Engines"

JOHN HENRY KNIGHT

Author of "Light Motor Cars and Voiturettes," "Motor Repairing for Amateurs," etc.

WM. ROBINSON, M.E.

Professor of Mechanical and Electrical Engineering in University College, Nottingham
Author of "Gas and Petroleum Engines"

W. POYNTER ADAMS

Member, Institution of Automobile Engineers
Author of "Motor-Car Mechanisms and Management"

ROLLA C. CARPENTER, M.M.E., LL.D.

Professor of Experimental Engineering, Sibley College, Cornell University
Author of "Internal Combustion Engines"

ROGER B. WHITMAN

Technical Director, The New York School of Automobile Engineers
Author of "Motor-Car Principles"

CHARLES P. ROOT

Formerly Editor, *Motor Age*
Author of "Automobile Troubles, and How to Remedy Them"

W. HILBERT

Associate Member, Institute of Electrical Engineers
Author of "Electric Ignition for Motor Vehicles"

SIR HIRAM MAXIM

Member, American Society of Civil Engineers
British Association for the Advancement of Science
Chevalier Légion d'Honneur
Author of "Artificial and Natural Flight," etc.

SIGMUND KRAUSZ

Author of "Complete Automobile Record," "A B C of Motoring"

JOHN GEDDES McINTOSH

Lecturer on Manufacture and Application of Industrial Alcohol, at the Polytechnic Institute, London
Author of "Industrial Alcohol," etc.

FREDERICK GROVER, A.M., Inst.C.E., M.I.Mech.E.

Consulting Engineer
Author of "Modern Gas and Oil Engines"

FRANCIS B. CROCKER, M.E., Ph.D.

Head of Department of Electrical Engineering, Columbia University
Past President, American Institute of Electrical Engineers
Author of "Electric Lighting," Joint Author of "Management of Electrical Machinery"

A. HILDEBRANDT

Captain and Instructor in the Prussian Aeronautic Corps
Author of "Airships Past and Present"

T. HYLER WHITE

Associate Member, Institute of Mechanical Engineers
Author of "Petrol Motors and Motor Cars"

ROBERT H. THURSTON, C.E., Ph.B., A.M., LL.D.

Director of Sibley College, Cornell University
Author of "Manual of the Steam Engine," "Manual of Steam Boilers," etc.

MAX PEMBERTON

Motoring Editor, *The London Sphere*
Author of "The Amateur Motorist"

HERMAN W. L. MOEDEBECK

Major and Battalions Kommandeur in Badischen Fussartillerie
Author of "Pocket-Book of Aeronautics"

EDWARD F. MILLER

Professor of Steam Engineering, Massachusetts Institute of Technology
Author of "Steam Boilers"

ALBERT L. CLOUGH

Author of "Operation, Care, and Repair of Automobiles"

W. F. DURAND

Author of "Motor Boats," etc.

PAUL N. HASLUCK

Editor, *Work* and *Building World*
Author of "Motorcycle Building"

JAMES E. HOMANS, A.M.

Author of "Self-Propelled Vehicles"

R. R. MECREDY

Editor, *The Encyclopedia of Motoring, Motor News*, etc.

S. R. BOTTONE

Author of "Ignition Devices," "Magnetos for Automobiles," etc.

LAMAR LYNDON, B.E., M.E.

Consulting Electrical Engineer
Associate Member, American Institute of Electrical Engineers
Author of "Storage Battery Engineering"

BUICK MODEL-21, SIX-45, FIVE-PASSENGER TOURING CAR

Foreword

THE period of evolution of the automobile does not span many years, but the evolution has been none the less spectacular and complete. From a creature of sudden caprices and uncertain behavior, it has become today a well-behaved thoroughbred of known habits and perfect reliability. The driver no longer needs to carry war clothes in momentary expectation of a call to the front. He sits in his seat, starts his motor by pressing a button with his hand or foot, and probably for weeks on end will not need to do anything more serious than feed his animal gasoline or oil, screw up a few grease cups, and pump up a tire or two.

¶ And yet, the traveling along this road of reliability and mechanical perfection has not been easy, and the grades have not been negotiated or the heights reached without many trials and failures. The application of the internal-combustion motor, the electric motor, the storage battery, and the steam engine to the development of the modern types of mechanically propelled road carriages has been a far-reaching engineering problem of great difficulty. Nevertheless, through the aid of the best scientific and mechanical minds in this and other countries, every detail has received the amount of attention necessary to make it as perfect as possible. Road troubles, except in connection with tires, have become almost negligible and even the inexperienced driver, who knows barely enough to keep to the road and shift gears properly, can venture on long touring trips without fear of getting stranded. The refinements in the ignition, starting, and lighting systems have added greatly to the pleasure in running the car. Altogether, the automobile as a whole has become standardized, and unless some unforeseen developments are brought about, future changes in either the gasoline or the electric automobile will be merely along the line of greater refinement of the mechanical and electrical devices used.

¶ Notwithstanding the high degree of reliability already spoken of, the cars, as they get older, will need the attention of the repair man. This is particularly true of the cars two and three seasons old. A special effort, therefore, has been made to furnish information which will be of value to the men whose duty it is to revive the faltering action of the motor and to take care of the other internal troubles in the machine.

¶ Special effort has been made to emphasize the treatment of the Electrical Equipment of Gasoline Cars, not only because it is in this direction that most of the improvements have lately taken place but also because this department of automobile construction is least familiar to the repair men and others interested in the details of the automobile. A multitude of diagrams have been supplied showing the constructive features and wiring circuits of the majority of the systems. In addition to this instructive section, particular attention is called to the articles on Welding, Shop Information, Electrical Repairs, and Ford Construction and Repair.

EXPLOSION MOTORS

ELEMENTARY PRINCIPLES

General Description. The term *explosion motor* as herein used refers primarily to gasoline engines such as are used on aerial crafts, automobiles, motorcycles, motorboats, and small stationary installations. There is nothing mysterious about this form of engine, it being similar in most respects to the ordinary steam engine, except that the force which develops the power is derived not from the expansion of steam, but from the explosion of a gaseous charge consisting of a mixture of oil vapor and air

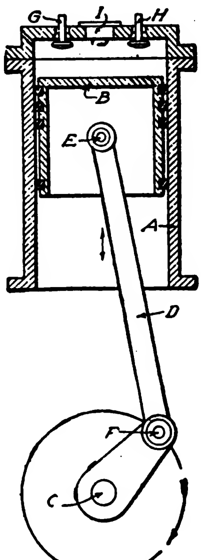


Fig. 1. Simple Explosion Motor

The simplest type of motor, Fig. 1, consists primarily of a cylinder *A* in which there is a hollow piston *B* (free to slide up and down), a crank shaft *C*, and a rod *D*, connecting the piston through the piston pin *E* to the crank on the shaft. As the piston moves up and down in the cylinder this reciprocating motion is converted by the operation of the connecting rod on the crank *F* into a rotary motion, as shown by the arrow near *C*. The whole action may be compared to that of a boy on a bicycle, *D* representing the boy's leg and *F* the pedal. At the head of the cylinder are shown two valves, *G* and *H*, and a spark plug *I*, whose functions are to admit the charge, explode it, and permit it to escape, by which operations and their repetition the reciprocating motion of the piston is set up and maintained. The successive explosions of the charges produce considerable heat and, therefore, in actual practice the cylinder *A* is usually surrounded by a jacket. Water is circulated around in the space between this jacket and the cylinder, thus cooling the cylinder. Another cooling method is by air, in which case the outer wall of the cylinder is constructed as shown in Figs. 16 and 17. In order, therefore, to secure the above action, the following mechanical devices must be provided: (1) A cylinder containing a freely moving piston, capable of being lubricated effectively; (2) a combustion chamber in whose walls are valves for the admission and exhaust of the gas, and valve seats so arranged that the joints will remain gas-tight when desired; (3) an outside, dependable means of ignition, with sparking points inside the combustion chamber; (4) a source of fuel supply, which, in the ordinary engine, must convert liquid into a vapor; and (5) a cylinder construction which will carry off the surplus heat or allow of its being carried off.

Historical. The first workers in this field were perhaps Huyghens, Hautefeuille, and Papin, who experimented with motors using gunpowder as a fuel in the latter part of the seventeenth century. A patent was obtained in England by John Barber, in the closing years of the eighteenth century, on a turbine using a mixture of gas or vapor and air for the fuel. A few years later Robert Street, another Englishman, built an oil engine in which the vapor was ignited by a flame at the end of the first half of the outward stroke.

From 1800 to 1854 several French and English patents were granted for internal combustion engines, most of the engines being double acting, *i.e.*, one explosion acting on one side and the next explosion acting on the other side of the piston, and some using electrical ignition. In 1858, Degrand made a big advance by compressing the mixture in the cylinder instead of in separate pumps.

First Practical Engine. The first commercially practical engine was developed about 1860 by Lenoir, who marketed in Paris a 1-horse-power, double-acting gas engine closely resembling a horizontal steam engine. This used what is now called jump-spark ignition and was made in sizes up to 12 horse-power. It gave considerable trouble in many cases, but the principal reason for its failure was the excessive amount of gas required, viz, 60 to 100 cubic feet of illuminating gas per brake-horse-power hour,* which was more than three times the consumption of a modern gas engine, and prevented competition with steam.

Otto Engine. The gas engine industry as we know it today was really started in 1861, when a young German merchant, N. A. Otto,

*Brake horse-power (b. h. p.) is the power delivered from the shaft of the engine. When delivered for one hour it is called a b.h.p.-hour.

developed an experimental engine in which admission, compression, ignition, and exhaust were accomplished in the one working cylinder. Otto failed to realize fully the great promise held out by his engine and temporarily abandoned its development.

De Rochas' Theory. In the year 1862 it was pointed out by a French engineer, Beau de Rochas, that in order to get high economy in a gas engine certain conditions of operation were necessary, the most important being that the explosive mixture shall be compressed to a high pressure before ignition. In order to accomplish this, he proposed that the cycle of operations should occupy four strokes or two complete revolutions of the engine and that the operation should be as follows:

(1) Suction or admission of the mixture throughout the complete forward stroke.

(2) Compression of the mixture during the whole of the return stroke, so that it finally occupies only the clearance space between the piston and cylinder head.

(3) Ignition of the charge at the end of the second stroke and expansion of the exploded mixture throughout the whole of the next forward stroke.

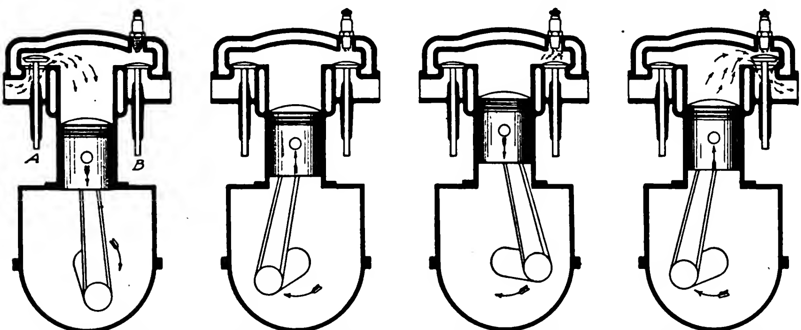
(4) Exhaust beginning at the end of the forward stroke and continuing throughout the whole of the last return stroke.

De Rochas had developed a brilliant theory but never put it into practical use. The pamphlet containing this idea remained practically unknown until about 1876, when it was discovered and published in the course of a patent-lawsuit against Otto and his associates, who were using this cycle in their engine, Otto having returned to the development of his engine in 1863. Although the original idea was perhaps Beau de Rochas', the credit really belongs to Otto, who made practical use of what would otherwise have been an unknown theory. In recognition of this fact the four-stroke cycle which Otto adopted in his engine and which is used in the majority of our modern motors is generally known as the Otto cycle.

EXPLOSION-MOTOR CYCLE

The cycle of the explosion motor, therefore, consists of four distinct steps, viz, (1) *Admission* of the charge of explosive fuel; (2) *compression* of this charge; (3) *ignition* and *explosion* of this charge; and (4) *exhaust* or expulsion of the burned charge. If this complete process requires four strokes of the piston rod in any one cylinder, the motor is designated as a four-cycle motor, although it would be more exact to call it a four-stroke cycle. If the complete process is accomplished in two strokes of the piston, the motor is designated as a two-cycle motor.

Four-Stroke Cycle. One complete operation of a single-cylinder Otto or four-cycle explosion motor is shown in Figs. 2, 3, 4, and 5. Fig. 2 shows the end of the first or suction stroke of the cycle. At the beginning of this stroke when about $\frac{1}{16}$ inch past the dead center the inlet valve *A* is opened by an eccentric rod whose movement is controlled by the eccentric on a secondary shaft driven through gears at half the speed of the motor. This allows the vapor supplied by the carbureter, which is an instrument for converting the liquid fuel



Figs. 2, 3, 4, and 5. Diagrams Showing One Complete Cycle of a One-Cylinder Explosion Motor

into a vapor or gas, Fig. 6, to be drawn into the cylinder by the suction produced by the downward-moving piston. During this stroke the exhaust valve *B* has remained closed.

The conditions shortly after the beginning of the second or compression stroke are shown in Fig. 3, both valves being closed. The piston, traveling as indicated by the arrows, compresses the charge to a pressure of about 60 pounds, when it is ignited at or before the end of the stroke by a spark taking place in the spark plug as shown in Fig. 4. Its arrangement is shown in detail Fig. 7, the spark passing between the points *A* and *B*. The force of the explosion drives the piston downward as shown in Fig. 4, which represents the power stroke. During these last two strokes, namely, the compression and working strokes, both valves if correctly timed should be completely closed.

Fig. 5 illustrates the conditions existing after the piston has begun the fourth or exhaust stroke. The exhaust valve *B* has been opened slightly before the end of the third stroke, and during this fourth stroke the gases are expelled from the cylinder through the open valve as shown. At the end of this stroke, piston and valves are again brought to the proper positions for the beginning of the suction stroke illustrated in Fig. 2.

Fig. 6. Typical Modern Carbureter with Water Jacket
Courtesy of Rayfield Carbureter Company, Chicago

Compounding. The pressure is high at the end of the expansion in the Otto cycle, and the efficiency (the ratio of work gotten out to work put in) of the cycle can be increased considerably if the gas is expanded more completely. Ordinary steam engine practice suggests that more complete expansion can be obtained by compounding. A compound steam engine has two or more cylinders. The steam or gas after doing work in the first or high-pressure cylinder completes its expansion in the other cylinder or cylinders. While the success of the compounded steam engine would lead us to expect the same increase in efficiency in the gas-engine type, no satisfactory compound gas engine has thus far been developed.

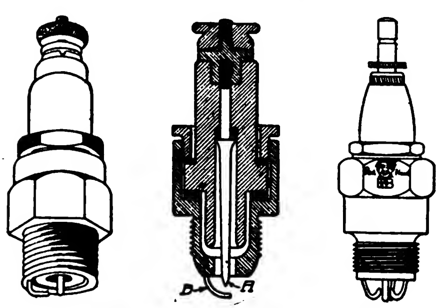


Fig. 7. Typical Forms of Spark Plug

Double-Acting. One of the main objections urged against the Otto cycle is that it requires two revolutions of the engine for its completion, so that the expansion or power stroke comes but once in four strokes. There results from this a very irregular driving effort, making large flywheels necessary if the main shaft is to rotate uniformly, or else requiring the use of several engines working on the same shaft. The power strokes can be made twice as frequent if the cylinder is double acting, with admissions and explosions occurring on both sides of the piston. Many double-acting engines are used for stationary power purposes but not for automobiles. For the latter, the irregular driving effort in single cylinders is overcome by using a large number of cylinders, as four, six, or eight, so arranged that the power impulses space out evenly.

Fig. 8. Vertical Section of Two-Cycle Smalley Motor

Fig. 9. Vertical Section at Right Angles to View in Fig. 8.

Two-Stroke Cycle. An increased frequency of the expansion or motive stroke can be obtained by a slight modification of the Otto cycle which results in the cycle being completed in two strokes, and which is consequently called the two-cycle method. Single-acting motors using the two-cycle method give an impulse every revolution, and consequently not only give a more uniform speed of rotation of the crank shaft, but also develop 60 to 80 per cent more power than four-cycle or Otto cycle motors of the same size. Moreover, they are generally of greater simplicity, having fewer valves than the four-cycle motors. An example is shown in Figs. 8 and 9 of a two-cycle motor of small size and of the two-port type; Fig. 8 is a vertical section showing the piston at the bottom of its stroke, and Fig. 9 is a vertical section in a plane at right angles to the previous section plane and showing the piston at the top of its stroke. As the trunk piston *A* makes its upward stroke, it creates a partial vacuum below it in the closed crank chamber *C* and draws in the explosive charge through *B*. On the downward stroke, the charge below the piston is compressed to about 10 pounds pressure in the crank chamber *C*, the admission through *B* being controlled by an automatic valve (not shown) which closes when the pressure in *C* exceeds the atmospheric pressure. When the piston reaches the lower end of its stroke, it uncovers exhaust port *K* and at the same time brings admission port *D* in the piston opposite the by-pass opening *E*, and permits the compressed charge to enter the cylinder *G* through the automatic admission-valve *F*, as soon as the pressure in the cylinder falls below that of the compressed charge. The return of the piston shuts off the admission through *E*, and the exhaust through *K*, and compresses the charge into the clearance space. The charge is then exploded, Fig. 9, and the piston makes its down or motive stroke. Near the end of the down stroke, after the opening of the exhaust port *K*, the admission of the charge at the top of the cylinder sweeps the burned gases out, the complete escape being facilitated by the oblique form, Fig. 8, of the top of the piston. The motor is so designed that the piston on its return stroke covers the exhaust port *K* just in time to prevent the escape of any of the entering charge. The processes described above and below the piston are simultaneous, the up-stroke being accompanied by the admission below the piston and compression above it, while the down-stroke has expansion above the piston and a slight compression below it. In large engines the charge is compressed by a separate pump, and not in the crank case.

Six-Stroke Cycle. A few of the early motors operate on the six-stroke two-cycle principle. This cycle was identical with the four cycle, two scavenging strokes being added after the exhaust stroke and acting as an internal cooling system. It was necessary to have a large number of cylinders to produce a continuous flow of power, as this motor developed only one power stroke in three revolutions; consequently it has been considered impractical.

TYPES OF EXPLOSION MOTORS

Automobile Motors. Modern automobile motors are multi-cylinder four-cycle engines, designed to run at speeds of 800 revolutions per minute, or over, with long strokes, battery ignition, and four or more mechanically operated valves; use gasoline as a fuel; are generally of the pair or *en bloc* type; and develop usually not more than 6 horse-power per cylinder at 1,000 revolutions. The power is commonly controlled by throttling with hand and foot adjustment.

The Autocar light truck still uses the double-opposed construction. The motor, Fig. 10, has two cylinders lying on opposite sides of the crank shaft, with their cranks set at 180 degrees.

Fig. 10. Typical Horizontal-Opposed Engine for Commercial Car Chassis
The Autocar Company, Ardmore, Pennsylvania

It is standard practice in automobile work to use a motor composed of four, six, eight, or twelve cylinders. The fours and sixes are always arranged in one plane. The eight consists of two sets of four cylinders set at an angle of 90 degrees. The twelve has two sets of six cylinders set at an angle of 60 degrees. A few racing motors are built with eight cylinders in one plane, thus eliminating the more complicated V construction.

Valves. There are several standard arrangements of valves in automobile motors. The two valves may be (1) both on one side of the cylinder; (2) one on each side of the cylinder; (3) both in the head; or (4) one on one side of the cylinder and one in the head. When more than two valves per cylinder are used, the arrangement varies from these just given, of course. With three valves, as used on the Franklin car at one time, there were two valves in the head and one on the side. The Holmes, an air-cooled motor, uses three valves, one intake and two exhausts. Racing motors, with four valves per cylinder, usually have all four in the head or two in the head and two in the side walls at a 90-degree angle to the axis of the cylinder. The Pierce-Arrow, Locomobile, and Stutz use four valves per cylinder. These cylinders are **T** head in form.

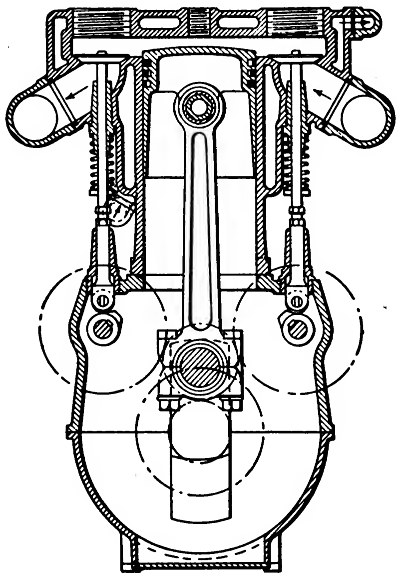


Fig. 13. Automobile Motor with Valves on Opposite Sides

The arrangement of an automobile motor cylinder with valves on opposite sides is shown in Fig. 13. This design requires two cam shafts, which are shown driven through an intermediate gear. Later practice uses a silent chain for this drive. The spark plugs may be over either set of valves or, when double ignition is used, they may be over both.

When the valves are placed on top, it is necessary to use levers between the push rods and the valves as in Fig. 17. Sometimes the inlet valves are placed over the exhaust valves.

The latter is operated directly by a push rod. The inlet is worked by a separate push rod through a rocker arm, working from a fulcrum on the cylinder head.

When valves are overhead, rocker arms may be used or an overhead cam shaft like that shown in Fig. 14. This shaft is driven by spiral gears through a vertical shaft, which is driven by the motor. A universal joint is mounted on the vertical shaft so that the cam shaft and cover can be swung to one side.

Fig. 14. Overhead Valves Driven by Overhead Cam Shaft
Courtesy of Maudslay Motor Company, Coventry, England

A marked departure in valve construction is that shown in Fig. 15, which is the Stearns-Knight type of sleeve valve motor. This valve action consists of two concentric sleeves sliding up and down between the piston and cylinder walls. These sleeves open and close the ports, which are side slots opening directly into the combustion chamber. These sleeves are moved up and down by small connecting rods from a crank shaft driven by a silent chain.

A modern tendency is toward the use of more valves, one development (following racing successes) having six per cylinder.

Motorcycles. The motor used in the motorcycle is of the ribbed, air-cooled, four-cycle, vertical type, usually single cylinder

PRIMING CUP
SPARK PLUG
WATER JACKETED

ROD
E
IAFT
NG
TRIC
T

OPERA
OIL TROUGH
LEVER
TC
LOWER PAR
CON
STF

Fig. 15. Part Section of Stearns-Knight Motor Showing Sleeve Valves
The F. B. Stearns Company, Cleveland, Ohio

Excelsior Motor Manufacturing and Supply Company, Chicago, Illinois

Fig. 17. Excelsior Twin Motor

or V-twin cylinder. Some of the later models, however, are showing four-cylinder motors. In Figs. 16 and 17 are shown the standard types of engines found in motorcycles.

Aeronautical Motors. The principal requirements of an aeromotor are greater power per pound of weight, reliability, simplicity, freedom from vibration, and fuel economy.

This field is just now receiving a great deal of attention from inventors and manufacturers. The motors are of the two-cycle or four-cycle type, either air-cooled or water-cooled, with vertical, horizontal, or revolving cylinders.

The principal aim of the majority of inventors seems to have been to reduce the weight. The average weight of these motors alone without accessories is about 3½ pounds per horsepower, few exceeding 4½ pounds, the lightest one weighing only 1.8 pounds per horsepower. However, it should be understood when considering this

Fig. 18. Intake Side of the Chalmers 1920 Power Plant

Fig. 19. Generator Side of the Chalmers 1920 Power Plant

remarkably light weight that sustained flight has been sacrificed to obtain it, although the flying life of a motor has been lengthened gradually so that it is now more than 100 "air hours."

MOTOR DETAILS

FOUR-CYCLE TYPE

Unit Power Plant. While discussions of explosion motors must deal in fundamentals, a practical study of a standard type will give the greatest benefit to the student. The Chalmers car has been chosen as the subject of this careful analysis of the func-

Fig. 20. Rear View Showing Transmission, Shifting Lever and Starter

tions of each part of the motor and of the relation of each part to the other parts. The motor is of the vertical, six-cylinder, four-cycle, water-cooled, L-head type. Fig. 18 is a plan view of the unit power plant showing the intake side of the motor. The transmission is mounted on the back of the crank case, which is the general method of mounting on the modern car. This mounting tends toward compactness and proper alignment of

mounted [illegible]
arrangement [illegible] is a very compa[illegible]
generator. [illegible] is also mounted on top of t[illegible]
case, and [illegible] The starter is bolted to the side of the transmissio[illegible]
the starter [illegible] this case is set in proper alignment with the flywhee[illegible]
mounted [illegible] is always in proper position. The oil pump is als[illegible]
case and [illegible] on this side. This pump draws the oil from the crank[illegible]
circulates it through the bearings a[illegible] [illegible]de of the motor.

Fig. 22. Crank Case of the Chalmers Motor with Crank Shaft in Place

parts. The clutch and the break pedal are also mounted on this casting, which ensures the proper relative location to the working parts.

In Fig. 19 is shown the right side of the motor. The generator, self-starter, oil pump, ignition system, and emergency break are mounted on this side of the motor. The generator is driven from the timing gears by a spur gear, while the ignition is driven by the generator shaft through a spiral gear. The distributor is

Fig. 21. Front View of the Chalmers Motor

mounted over the breaker points, thus making a very compact arrangement. The ignition coil is also mounted on top of the generator. The starter is fastened to the side of the transmission case, and as this case is set in proper alignment with the flywheel, the starter is always in proper position. The oil pump is also mounted on this side. This pump draws the oil from the crank case and circulates it through the bearings and inside of the motor.

Fig. 22. Crank Case of the Chalmers Motor with Crank Shaft in Place

Fig. 23. Ignition System of the Chalmers

Fig. 24. Thermo-Siphon Cooling System of the Chalmers Motor

A front and a rear view of this motor are given in Figs. 20 and 21. The timing-gear case, fan, and fan pulley are clearly shown in the front view, while the rear view shows an excellent detail of the universal joint, shifting levers, etc.

Crank Case and Cylinder Block. A view of the crank case and cylinder block with the cylinder head and oil pan removed is given in Fig. 22. By referring to Fig. 19, it is evident that the cylinder block and the crank case are cast as one piece. This method of casting is very popular, as it eliminates a great

Fig. 25. Differential and Ring Gear of the Chalmers Car

deal of expense, secures proper alignment, reduces the number of manifold connections, and also eliminates a great many oil leaks.

The crank shaft is of the three-bearing type, having a bearing at each end and one in the center, or between cylinders **3** and **4**. Crank pins **1** and **6** are in the same plane, as pistons **1** and **6** must travel together; **2** and **5** are also in the same plane; and 3 and 4. The angle between crank pins **1** and **2** and also between crank pins **2** and **3** is 120 degrees.

Valves. In Fig. 28 is shown a sectional end view of the motor, giving all details such as spark plugs, valves, valve springs, push rods, cams, etc. Each cylinder has two valves, an inlet valve and an exhaust valve. The cylinder head of this motor is detachable, which allows the valves to be removed very easily. The inlet valves are connected to the intake manifold, which is connected to the carburetor, while the exhaust valve is connected to the exhaust manifold, allowing the burnt gases to escape into the atmosphere.

Ignition. The ignition system, Fig. 23, is composed of a battery, ignition switch, spark coil, breaker, and distributor. The current is taken from the storage battery or generator and passes through the ignition switch, the high-tension coil, and the breaker points. When the points open, a high-tension current is induced

Fig. 26. Rear Axle Construction of the Chalmers

in the coil. This current goes to the distributor and from there to the spark plugs, where it jumps the gap and explodes the gas in the cylinder, driving the piston down. If current is taken from the battery, it must be recharged. The generator performs this work, generating current in proportion to the speed of the car. This current flows from the generator through the control instruments and into the battery, the circuit being completed through the ground to the generator. Charging the battery causes a chemical action in the battery, and electric energy may be obtained by reversing this chemical action, which is what happens when a battery is discharged. The battery ignition system, as illustrated, is a very popular type and is used on the majority of modern automobiles.

Cooling System. The water circulation system is clearly illustrated in Fig. 24. As the explosions develop a great deal of heat, the cylinders must be cooled so that proper lubrication can be accomplished. The cooling system of this car is of the thermo-siphon type. It is a well-known fact that hot water will rise to the top as it is much lighter than cold water. This

Fig. 27. Sectional View of the Transmission as Used on the Chalmers

principle is utilized in the thermo-siphon cooling system. The hot water rises to the top of the motor and enters the radiator through the top water connection. It then passes through the radiator where it is cooled by the continual flow of air. The cold water leaves the radiator at the bottom and enters the cylinder block through the lower water connection. This type of cooling offers some advantages, such as the elimination of the water pump.

Transmission. A cross-sectional view of the transmission is shown in Fig. 27. This transmission is of the three-speed forward and one reverse type, having two sliding gears on the main shaft, the low and reverse gear and the high and intermediate gear.

Fig. 28. Cross-Section of the Chalmers Motor

The main drive gear, which is connected with the clutch shaft, is continually in mesh with the countershaft drive gear. There are two other gears on the countershaft, one the intermediate-speed gear and the other the low-speed gear. When the low and reverse sliding gear is meshed with the countershaft low-speed gear, a low car speed is produced or, in other words, the engine runs faster than the main transmission shaft. To obtain second speed, the low-speed gear is placed in neutral position and the high and intermediate slide gear is meshed with the intermediate-speed gear on the countershaft. The motor is still running faster than the main shaft, but the main shaft has increased to a greater speed than when in low gear. To secure high speed, the high and intermediate gear on the main shaft is moved forward, interlocking with the main drive gear. The main shaft of the transmission is then operating at the same speed as the clutch shaft.

Differential Unit. The differential and the ring gear are shown in Fig. 25. The main drive shaft, Fig. 27, is connected to the ring gear by means of a drive shaft and spiral bevel gear. This gear, which is turned by the motor, continually meshes with the ring gear and turns the rear axles, thus causing the car to move.

Braking System. The emergency and foot brake arrangement of the Chalmers car is of the average construction. The emergency brake shoe is located on the inside of the drum, exerting its pressure outward, while the foot, or service, brake operates on the outside of the drum. As the service brake lever is pulled forward, the brake band will contract, which causes considerable resistance to the turning of the rear wheels.

In Fig. 26 is given a sectional view of the rear axle, which is of the semi-floating type. The axle is held in place with a Timken roller bearing. The wheel hub is mounted on the end of this axle shaft and is tapered. A long axle shaft key is inserted to prevent the wheel from turning. The entire load of the car is supported by the axle at the Timken bearing in this type of axle and the axle is also called upon to turn the wheels, thus performing a double duty.

The side elevation of the chassis, Fig. 29, shows the relative position of the units when assembled.

Crank and Firing Arrangements. The order in which the explosions should take place in the cylinders and the best arrangements of cranks for multi-cylinder four-cycle motors are shown in diagram in Fig. 35.

Two-Cylinder Motor. With the cranks set at 180 degrees, Fig. 35A, the two cylinders fire one-half revolution apart, and hence during one revolution there are two power strokes and at the next no power stroke.

Fig. 29. Plan View of the Chalmers Chassis Showing the Location of the Various Units

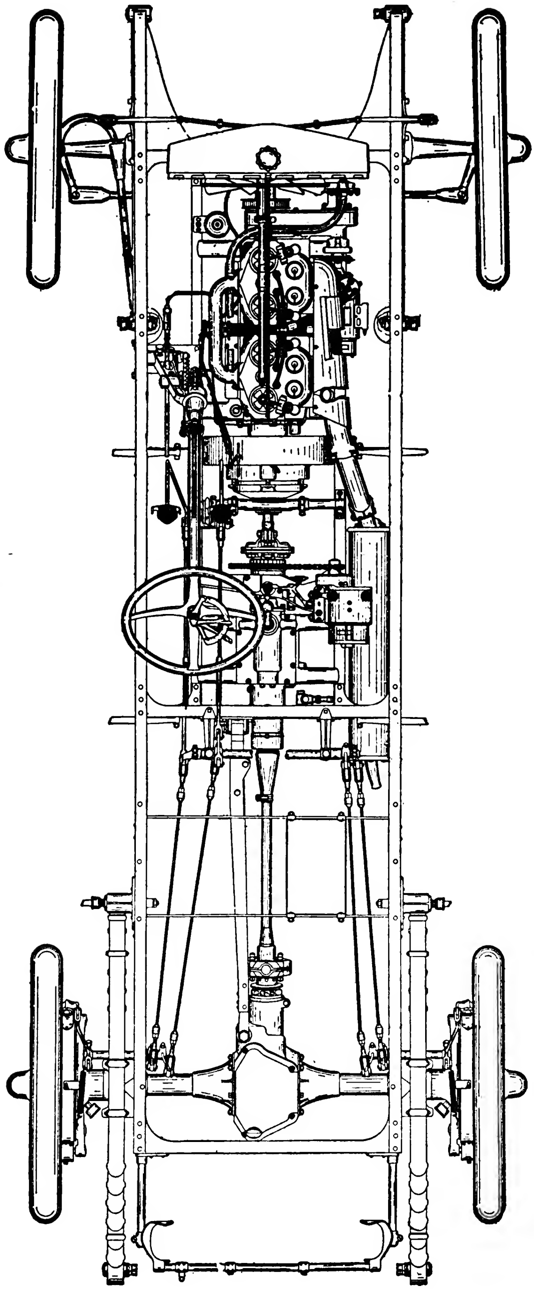


Fig. 34. Complete Chassis of Reo Car, Showing How Connection Is Made Between Engine Crank Shaft, Clutch, Drive Shaft, Transmission, Differential, and Rear Axle

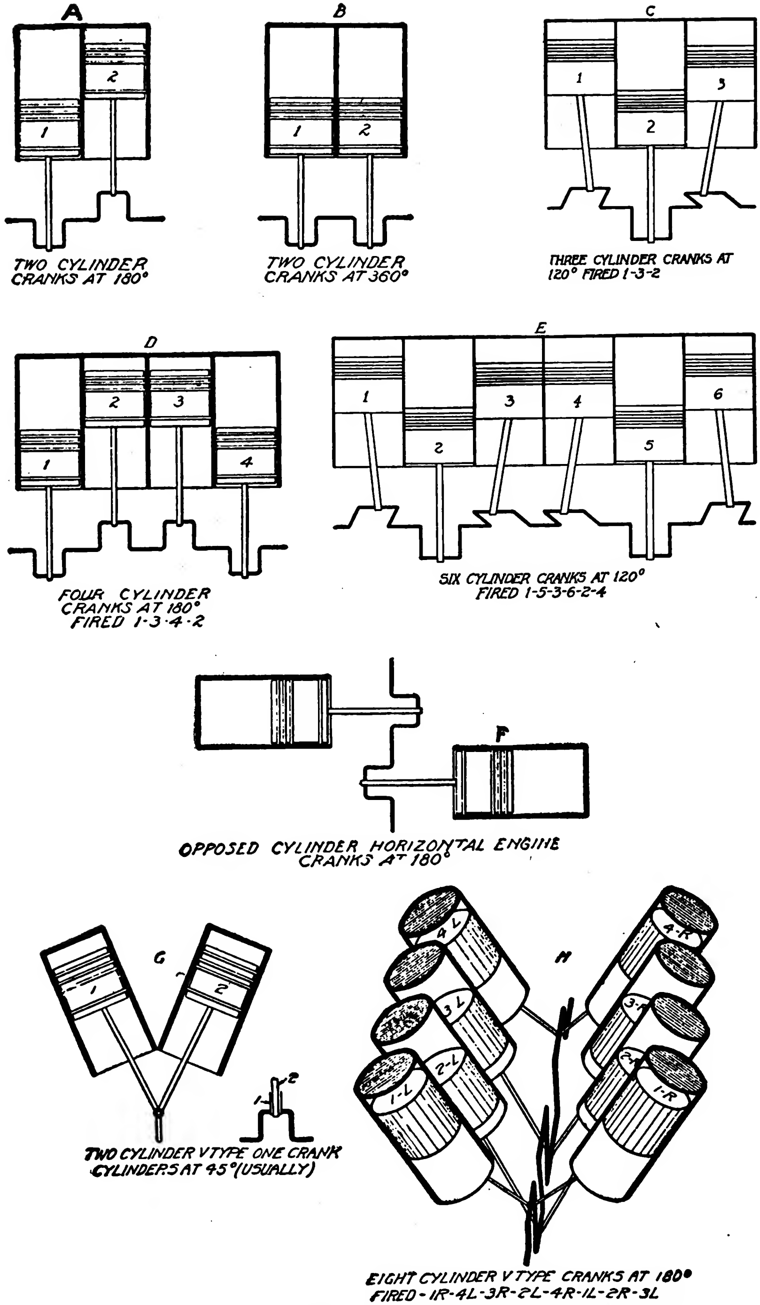


Fig. 35. Crank and Firing Arrangements for Multicylinder Four-Cycle Motors.

With the cranks set at 360°, Fig. 35*B*, we get a power stroke at each revolution. This arrangement, however, requires careful balancing to counteract the vibration which results from all parts moving in the same direction at the same time. The order of action in the two cases is given as follows:

180°		360°	
FIRST CYLINDER	SECOND CYLINDER	FIRST CYLINDER	SECOND CYLINDER
Suction	Exhaust	Suction	Firing
Compression	Suction	Compression	Exhaust
Firing	Compression	Firing	Suction
Exhaust	Firing	Exhaust	Compression

If the amateur finds the above difficult to follow, it may be simplified as follows: Duplicate the actions below those given, that is, repeat the action in two revolutions. Then mark off at the left the revolutions, indicating the first pair of actions for one, the second for two, etc. This applies right across the table. Then, one notes that the firing in the first cylinder comes on the second revolution and the first stroke, while that in the second cylinder comes on the same revolution but the second stroke. This gives two firing impulses on one revolution, followed by another with none, then two more firing, etc. In the cylinders set at 360°, it will be noted that the second cylinder fires on the first stroke of the first revolution, while the first follows, firing on the first stroke of the second revolution, then the second on the first of the third, and the first on the first stroke of the fourth, etc., thus distributing the firing evenly.

Four-Cylinder Motor. In the four-cylinder motor of the four-cycle type, we have two power strokes for each revolution of the crank shaft or flywheel. In order to secure smooth working, these power strokes should occur exactly one-half revolution apart. From Fig. 35*D* it will be seen that the four-cylinder crank shaft has two pairs of cranks just one-half revolution apart, pistons *1* and *4* moving up, while pistons *2* and *3* move down, or *vice versa*.

Suppose for instance, that piston *1* has just been forced down on the power stroke. Then pistons *2* and *3* will be up and *one* of these should be ready to receive the force of the explosion, and should have, therefore, just compressed an explosive charge in its cylinder ready to be ignited. For the sake of illustration let us choose piston *3* to make the next power stroke. Piston *3* now moves down and pistons *1* and *4* move up. Since it is evidently impossible to have piston *1* contain an explosive charge without giving it one more up and down motion, piston *4* must make the next power stroke. This piston, therefore, moves down as a result of the explosion in cylinder *4*, and it is now necessary for piston *2* to make the next power stroke. Thus the order of firing is 1-3-4-2.

A study of Figs. 35*C*, 35*F*, and 35*E* will show the method of firing in the cases of the three-cylinder, the two-cylinder horizontal-opposed motors, and the six-cylinder, respectively. In Figs. 35*G* and 35*H* will be found the corresponding methods for the two-cylinder and eight-cylinder V types. The last named is more difficult to follow out, but by treating it as a pair of fours which must fire first in one pair and then in the other, and considering this in conjunction with 35*D*, the scheme of arrangement will be plain. The actual order used on De Dion (French) and Cadillac motors is 1R, 4L, 3R, 2L, 4R, 1L, 2R, 3L.

Just as the firing order of the eight, or twin four, is followed through by considering it as a pair of fours, so the twelve or twin six may be considered as a pair of sixes. There is this important difference between the eight and the twelve, however; in the eight the two sets of cylinders are set at an angle of 90 degrees with each other, while in the twelve, the two "six groups" are usually set at 60 degrees. This makes a different interval in the firing; the firing order of any twelve might be 1R, 6L, 5R, 2L, 3R, 4L, 6R, 1L, 2R, 5L, 4R, 3L.

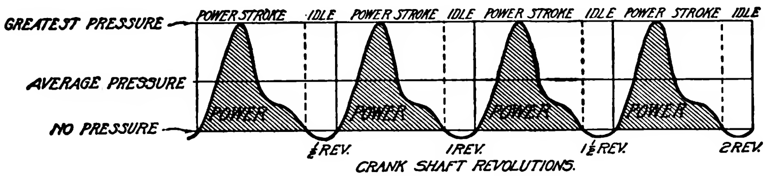
Theory of Crank Effort. *One-Cylinder Motor.* In a single-cylinder motor, four strokes of the piston are required to complete its cycle, *i. e.*, the suction stroke, compression stroke, power stroke, and exhaust stroke. Note that only one of these strokes, the third, makes power. Roughly speaking, power is not produced throughout even the entire part of this stroke, but only through about four-fifths of it. Hence, in a single-cylinder motor with a 5-inch stroke, the piston travel for one complets cycle will be 20 inches. In only about 4 inches of this distance is power produced. (See Figs. 36 and 37.) Hence four-fifths of the total piston travel is a non-producer of power.

Two-Cylinder Motor. In the two-cylinder motor we have two power strokes in two revolutions, as follows:

	Inches of Power
First Stroke	
Cylinder *1* Suction	0
Cylinder *2* Power	4
Second Stroke	
Cylinder *1* Compression	0
Cylinder *2* Exhaust	0
Third Stroke	
Cylinder *1* Power	4
Cylinder *2* Suction	0
Fourth Stroke	
Cylinder *1* Exhaust	0
Cylinder *2* Compression	0
Total inches of piston travel representing power. .	8
Total inches of piston travel.	20

Hence, the motor furnishes power during only 40 per cent of the cycle.

Four-Cylinder Motor. With the four-cylinder motor we have one power stroke during each half revolution of the crank shaft.



CRANK SHAFT REVOLUTIONS.

Fig. 36. Curves Showing Duration of Power in Four-, Six-, and Eight-Cylinder Motors

This gives us power during 16 inches of piston travel or power during 88 per cent of the entire cyle.

Six-Cylinder Motor. In the six-cylinder motor (the cylinders being the same size as those above considered, and the stroke the same) we have 4 inches of power produced by each cylinder, making a total of 24 inches of power with a total piston travel of 20 inches. On the basis of the percentage values given in the two- and four-

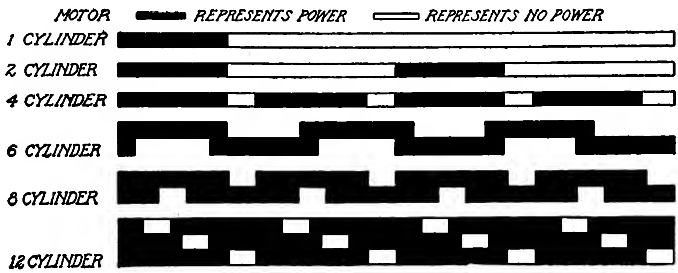


Fig. 37. Power Distribution Chart in Various Motors

cylinder types this would mean an application of power during 120 per cent of the cycle. As this is impossible and as the six cylinders are evenly spaced, the power in the cylinders must overlap each other. This results in continuous power. Diagrams showing the relation between the application of power in the four-cylinder motor, in the six-cylinder, and in the eight-cylinder, are shown in Fig. 36.

Fig. 38. Diagram of the "Dead Center" Problem

Eight-Cylinder Motor. In the eight-cylinder motor—the cylinders being of the same size as those considered previously, and the stroke the same—we have 4 inches of power produced by each cylinder, making a total of 32 inches of power with a total piston travel of 20 inches. On the basis of the percentage values given for the other types, this would mean the application of power over more time in the cycle than is possible, so, as in the case of the six-cylinder motor, there is an overlap. In this instance, however, the overlap is three times as great as in the six-cylinder, consequently the delivery of power is that much more even and continuous.

Twelve-Cylinder Motor. In the twelve-cylinder motor, with the same size cylinders as before, we have the same 4 inches of power in each cylinder, or 48 inches total, with a total piston travel of 20 inches, showing again a large amount of overlap. Here the overlap is seven times as great as in the six-cylinder form, consequently the output of power should be that much more even.

The diagram of Fig. 37 gives a clear idea of this distribution of power in the various motors discussed. The six-cylinder motor has a small overlap, while the eight-cylinder has a wide overlap. The twelve-cylinder motor has a power overlap of two cylinders continuously, while the power impulses from three cylinders overlap part of the time, thus giving greater flexibility.

Effect of Dead Centers. In both the two- and four-cylinder motors, the cranks being set 180 degrees apart, each piston is always one complete stroke ahead of the succeeding one. When the cranks of the motor are as shown in Fig. 38 (*a*) in direct line with the connecting rod, the entire motor is on dead center. Fig. 38 (*b*) shows the same condition with offset cylinders.

In the six-cylinder motor, the cranks are set at 120 degrees, Fig. 38 (*c*), and, therefore, we have no condition when the entire motor is on dead center. It is impossible to have more than two of the cranks on dead center at once. Hence, there is never a time in the six-cylinder cycle when the motor does not produce power.

In the eight-cylinder V-type motor, Fig. 39, the cranks are set 180 degrees apart, as in the four-cylinder, but the cylinders are set at 90 degrees, 45 each side of a vertical, as shown in Fig. 38 (*d*). The connection of the side by side cylinders of each pair of fours to a common crank pin—the two number one cylinders, for instance, working on the first pin, the number twos on the second, etc.—eliminates all dead centers. This is one advantage of the V-type over the straight-line type for the latter has a dead-center cylinder.

In the twelve-cylinder V-type motor (Fig. 40), the cranks are set at 120 degrees as in the six, but the cylinders are set at 60 degrees, 30 on each side of the vertical, the only difference from Fig. 38 (*d*) being in the angle. The crank-pin attachment in the twelve is similar to the eight, the first two cylinders working on the first crank pin, the second two on the second pin, and so on. Obviously the form of the crank and the setting of the cylinders at an angle eliminate all dead centers.

Sixteen or More Cylinders. The constant demand for more and more power, especially for airplanes, dirigible balloons, and fast motor boats as well as motor ships, has produced many engines with more than twelve cylinders. There is a limit to the power which can be produced from a single cylinder, so that more power has meant more cylinders.

The problem of securing a greater number of cylinders has been worked out in a number of ways; for example, large marine engines have been built which are practically two or three sets of four-cylinder engines set in line and with a single connected crankshaft for all eight or twelve cylinders. Other engines are of the sixteen-cylinder V type, that is, they are simply two eight-cylinder engines set at an angle and working on a single common eight-cylinder crankshaft. A more recent development consists of three sets of six-cylinder engines built in a fan shape with a common crankshaft, making an eighteen-cylinder motor.

The radial forms also have been used to produce high power, another unit and another crank being added. Thus, two five-cylinder engines together make a ten-cylinder, two seven-cylinders a fourteen-cylinder, two nines an eighteen-cylinder, two tens a twenty-cylinder, etc. The future cannot be predicted, but construction in the United States inclines toward the V forms and in England and France toward the air-cooled radial forms.

The firing order of a sixteen-cylinder engine follows that of an eight and a twelve, of a V type, that is, alternating from one side to the other and back and forth on the two sides according to the layout of the crankshaft. Similarly, eight or twelve cylinders in line depend upon the crankshaft layout for their firing order. The radial and rotating forms fire in alternations; thus, a five-cylinder engine would fire *1–3–5–2–4*, then begin over with *1*, etc.

In the sixteen-cylinder V-type motor, with the same size cylinders as before, there are 64 inches of power with a total piston travel of 20 inches, so that the overlap is so great as to give practically the smooth continuous operation of steam. By comparison, then, the respective cylinder forms show these relative overlaps, the piston travel of 20 inches being the same for all: six-cylinder, 24 inches; eight-cylinder, 32 inches; twelve-cylinder, 48 inches; and sixteen-cylinder, 64 inches. With the

Fig. 39. Front View of Eight-Cylinder V-Type Motor
Courtesy of Cadillac Motor Car Company, Detroit, Michigan

sixteen, as with the twelve, the dead-center consideration is entirely eliminated.

Power Exerted against the Pistons. In a single-cylinder, 48-horse-power motor the explosion of the mixture practically results in the striking of a hammer blow against the piston of 28,800 pounds. In a four-cylinder, 48-horse-power motor each piston receives a blow only one-fourth as great, or 7,200 pounds. In a six-cylinder, 48-horse-power motor each piston receives only 4,800 pounds. Similarly, in an eight-cylinder 48-horse-power motor each piston receives a blow of 3,600 pounds. Compared with the four-cylinder motor, this is a reduction of one-half; relative to the six-cylinder, it is a reduction of one-fourth.

So too, with the twelve-cylinder, 48-horse-power motor each piston receives a blow of only 2,400 pounds, one-half the blow exerted in the six-cylinder motor and two-thirds the blow exerted in the eight. It is this small amount of hammering which makes the multiple cylinder motor—in either eight- or twelve-cylinder

Fig. 40. View of Packard Twelve-Cylinder V-Type Motor Mounted in Chassis

form—much more quiet and easy running than can ever be the case with the four- or six-cylinder forms. In addition, the small size of the pistons for equal power development allows a much stiffer and stronger construction, even when a lighter metal, like aluminum or any of the various aluminum alloys, is used. The lighter reciprocating parts increase the output per cubic inch of cylinder, thus making the multiple type of motor relatively more efficient.

Repair Man's Interest in Multiple Cylinders. Every repair man should be well posted on eights and twelves for two reasons. In the first place, the average owner knows little about them, and as he considers that the repair man knows all about every kind of motor, he will go to him for information at the first sign of trouble. In the second place, the repair man should be able to handle and repair these forms of motor, for the fact that they have more parts and are more complicated makes them more likely to need skilled attention. Moreover the average owner, knowing of this greater complexity of construction, will be averse to turning his eight or twelve over to any but the best repair men—skilled mechanics with a thorough working knowledge of the principles of the new motors. Any intelligent repair man with a thorough knowledge of the principles around which these new motor forms are built, and with an equally thorough and intimate knowledge of how fours and sixes are constructed, adjusted, and repaired, need have no fear to tackle any kind of engine new or old.

SMALL GAS ENGINE

The general practice with small stationary engines differs quite radically from the standard motor practice just considered. However, as the fields of the two overlap, the discussion of the small stationary type at this point will not come amiss.

Fig. 41. Stationary Engine with Single Valve

Two-Cycle Type. A modification of the type of explosion motor shown in Figs. 8 and 9, which makes its construction even more simple, is the use of a single valve—an automatic valve which admits the charge to the crank case. In this engine, Fig. 41, the series of operations is precisely similar to that described for Fig. 8, the only difference being in the by-pass connection *E*, which has no valve between it and the cylinder. The exhaust is made to open a little earlier than the admission, so as to make sure that the pressure in the cylinder shall have fallen below the pressure of the slightly compressed charge when the admission port opens. If the opening of the exhaust and admission ports were simultaneous, as in the engine just described, some of the exhaust gases would force their way through *E* to the crank case, and, being at a high temperature, would ignite the charge there. The piston is so shaped that the entering charge is directed to the top of the cylinder, forcing out the burned gases before any of the charge can escape through the exhaust port.

In place of the automatic inlet valve at *B*, there is sometimes used a revolving disk valve turning with the crank and containing a slot which registers with the crank case inlet during part or all of the up-stroke of the piston. The disk is pressed against its seat by

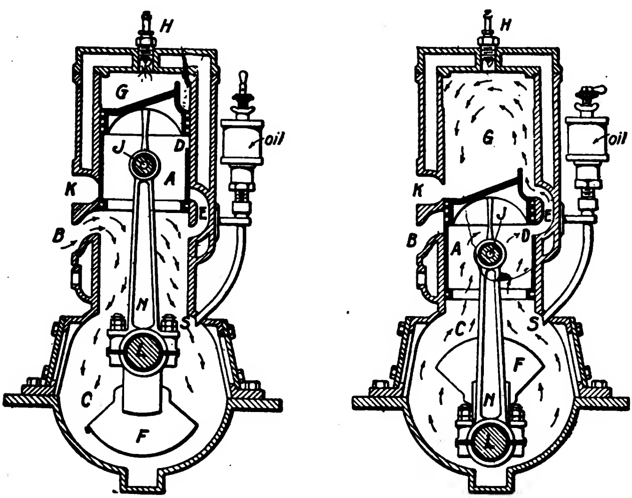


Fig. 42. Smalley Three-Port Two-Cycle Motor

a light spring. This arrangement controls the admission of the charge to the crank case, permitting of adjustment of the duration of admission, and consequently of the volume admitted. It sacrifices, however, the reversibility of the engine.

A further and last modification of this engine makes it entirely valveless and of the utmost simplicity. This feature is illustrated in Fig. 42. The admission of the charge is through the port *B*, which is covered and uncovered by the piston, and which consequently does not require any automatic valve. During the up-stroke of the piston, a vacuum is created in the closed crank case, till near the top of its stroke, when the admission port *B* is uncovered, and the explosive charge rushes into the crank case, filling it until the pressure there is approximately atmospheric pressure. The rest of the operations are exactly as in the engine just described, the charge being compressed in the crank casing during the down-stroke, and then

Fig. 43. Vertical Four-Cycle Stationary Engine
Courtesy of Fairbanks, Morse and Company

transferred through a port *D*, in the hollow piston, and through the port *E* in the cylinder wall, to the upper side of the piston when this latter is near the end of its down-stroke. This modification is generally known as the *three-port type* of the two-cycle motor.

Four-Cycle Type. Figs. 43 and 44 illustrate the details of a standard vertical four-cycle type of engine. This engine may be equipped with a carbureter as in automobile practice, but is more often provided with a pump, Fig. 45, which introduces the fuel directly into the cylinder in the form of fine spray.

Ignition. In this type instead of producing ignition by means of a spark plug, the spark is usually obtained by making contact

Fig. 44. Vertical Four-Cycle Stationary Engine
Courtesy of Fairbanks, Morse and Company

and breaking contact between the electrodes or contact points of what is called a "make-and-break" igniter, shown in Figs. 43 and 46.

The igniter plug in Fig. 46 has been removed from the cylinder head. The movable electrode *B* is at the end of an arm which is fastened to the spindle *C*. When the interrupter lever *D*, which is loose on the spindle *C*, and is connected to it through a coiled spring, is lifted by an arm from the cam shaft of the engine, it rotates the spindle *C* so as to bring *B* into hard contact with the stationary and thoroughly insulated electrode *A*. This completes a circuit and permits a current to flow from *A* to *B*. When ignition is desired the

Fig. 45. Pump for Liquid Fuels
Courtesy of Fairbanks, Morse and Company

Fig. 47. Spark Coil
Courtesy of Thordarson Electrical Manufacturing Company

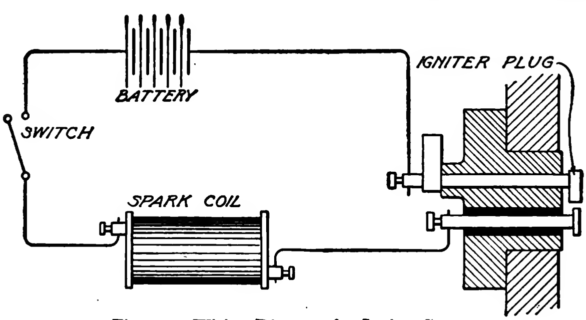


Fig. 48. Wiring Diagram for Igniter System

lever *D* is tripped and flies back, carrying with it the shaft *C*, abruptly breaking the contact and causing an electric arc to form between *A* and *B*. The spark from an ordinary battery is greatly increased by allowing the current to flow through a make-and-break ignition coil, Fig. 47, which consists of a coil of insulated copper wire in which a laminated magnetic circuit is used in connection with an air gap. The igniter circuit is arranged as in Fig. 48.

Governing. Stationary engines are governed by either the "hit-and-miss" governor or the throttling governor, the latter being the form used in practically all motors. The action of the throttling governor is such that more or less fuel is admitted at each charge, according to the load, the richness of the mixture remaining the same and the engine making regular explosions. With the hit-and-miss governor, a greater or less number of fuel charges are admitted to the cylinder according to the load on the engine, the mixture and the quantity of each charge always remaining the same. The result of this is that the number of explosions per minute will vary with the load.

THERMODYNAMICS OF THE EXPLOSION MOTOR

In explosion motors the explosive mixture in the cylinder consists of air mixed with a smaller volume of the vapor of the liquid fuel. This mixture will behave up to the time when explosion takes place, practically as if it were merely air. Also the products of combustion, after the explosion is completed, have physical properties differing only slightly from those of air, and consequently the working substance in the cylinder may without serious error be regarded as consisting entirely of air. In the discussion of what occurs in the engine cylinder, this assumption is made.

Indicators.* In order to more clearly understand what follows, it is necessary to have some knowledge of the indicator diagram. These are made by two forms of engine indicator, the modified steam engine form which is satisfactory up to about 500 r. p. m. and the manograph used above that speed. The former is described as consisting of a drum carrying a sheet of paper which, by rotation, is moved an amount proportional to the piston travel. An arm whose motion is governed by the pressure in the cylinder carries a pencil which traces on the paper a diagram whose vertical values are proportional at every point to the pressures in the cylinder.

*See also page 62.

Watt's Diagram of Work. James Watt was the first to see the need of accurate knowledge of the action of steam in the cylinder of a steam engine and to him belongs the credit of devising and using the first indicator. Fig. 49 illustrates the method adopted by Watt. The horizontal line *AC*, called the *abscissa*, represents the length of stroke and is divided into ten equal parts. The vertical line *AB*, called the *ordinate*, indicates the pressure of the steam.

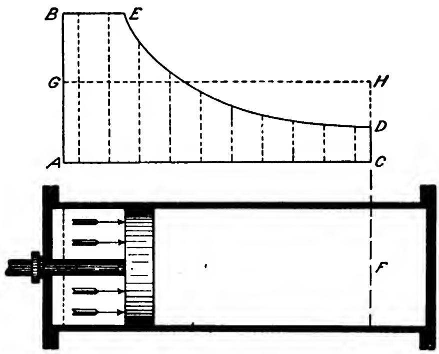


Fig. 49. Watt Ideal Diagram

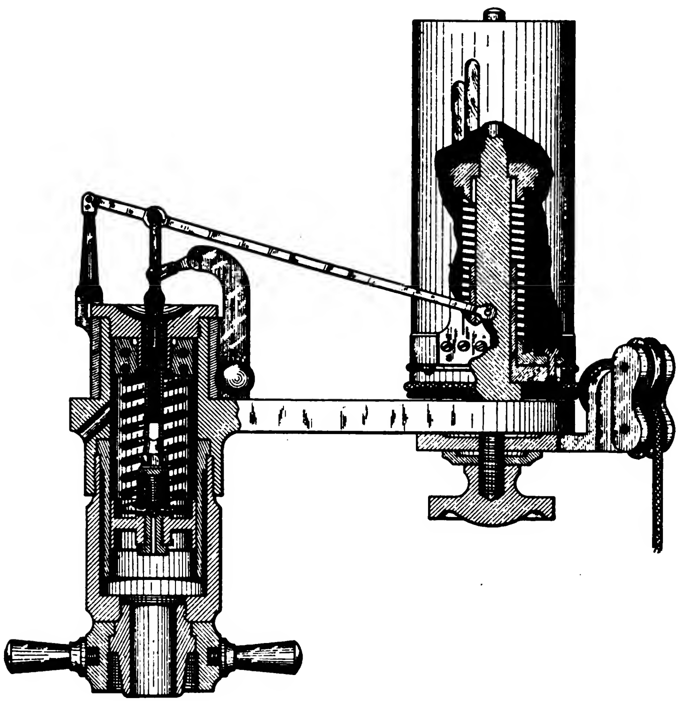


Fig. 50. Crosby Indicator in Part Section

When the piston has moved from *B* to *E*, the steam is cut off, that is. a volume of steam equal to one-fifth the volume of the cylinder

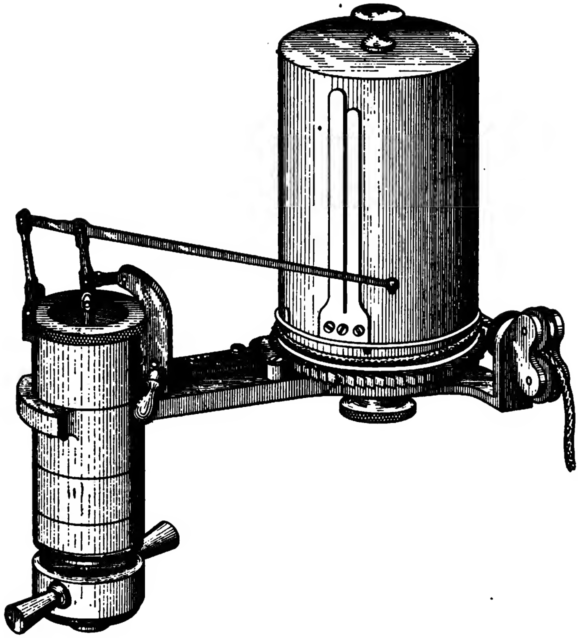


Fig. 51. Crosby Indicator Complete

Fig. 52. Crosby Indicator with External Springs

is allowed to expand until it fills the entire cylinder. The area of the figure *BEDCA* may be found by adding the several pressures shown by the vertical dotted lines, dividing by the number of divisions, and multiplying by the length *AC*. The study of similar diagrams on a small scale when drawn by an indicator represents the only method of obtaining a correct idea of the action of steam in the cylinder of a steam engine or of the mixture in the cylinder of an explosion motor.

Figs. 50 and 51 show an inside and an outside view of the Crosby indicator. In gas engine work, the spring located as shown in Fig. 49 is liable to be injured by heat. To lessen the difficulties due to this, most of the makers supply indicators with external springs, as shown in Fig. 52.

Manograph. As has been stated previously, the steam engine form of indicator is satisfactory up to speeds of 500 r.p.m., but as the majority of gas and gasoline engine work is above that—particularly automobile and aeroplane motors in which the speed may reach a maximum of 4,000 r.p.m., while 1,000 r.p.m. would be considered a slow speed and 1,800 an average—some other form is necessary. The reason for this lies in the fact that at speeds above 500 r.p.m., the inertia of the indicator piston, pencil arm, and other moving parts is so great that the diagrams become distorted and do not show a true shape compared with the events within the cylinder. Another difficulty lies in making the passages between the cylinder and the indicator large enough so that the pressure fluctuations in the motor cylinder will be followed exactly by those in the indicator cylinder and, consequently, be reproduced exactly in the diagram.

These difficulties have led to the use of a device called the manograph. In this a beam of light travels over a visible ground glass of a darkened surface so as to be visible to the observer all of the time; or by replacing this with a sensitized piece of paper, prepared for the purpose, a print is made which must be developed and fixed the same as any photographic print. When the engine is being tested out for faults in the design and construction, the latter method is followed and the cards are preserved for future study and as a matter of permanent record. However, when the design and construction are satisfactory and the engine is simply being tuned up to its best performance, the former method is followed and no permanent records are kept.

It can be seen at once that this is a tremendous advantage for the indicator diagram of the engine under test is visible at all times to the tester, who can increase or decrease engine speed and note at once the changes in the diagram, right in front of him; can alter carbureter or magneto settings and see at once the changes which these make in the diagram. To facilitate the use of this, it is made with as many compartments as the motor has cylinders, although all the illustrations which are shown indicate a single-cylinder outfit, which has, of course, only one compartment.

This result is obtained by the use of a small aperture through which a beam of light is admitted to the interior of the box. At one end of the latter, there is a small concave mirror, upon which the beam of light impinges. This mirror is connected to the crank shaft or other moving part of the engine in such a way that the rotation of the motor imparts to the mirror a horizontal rocking movement limited to a small angle of, say 20 degrees. This movement is, of course, at a speed which corresponds with the speed of the engine.

In addition, the mirror has a connection with the cylinders of the motor by means of which the pressures there are imparted to the mirror in a vertical direction, rocking it in that direction. The first motion—that of rotation—would make nothing but a straight horizontal line of a length proportional to the motor's stroke and at a rate proportional to its speed. But by adding the motion produced by the internal pressures, there is created a diagram or closed figure which represents accurately the events taking place within the cylinder.

Description of Manogragh. A general exterior view of a manograph, the Carpentier (French), is shown in Fig. 53, with horizontal and vertical sections at Figs. 54 and 55, and a detail of the mechanism which moves the mirror at Fig. 56. In Fig. 53, it will be noted that it consists primarily of a light-tight box *B*, which is generally mounted on a tripod for convenience. To one end of this is fixed a casting *A*, inside of which the mirror is secured, together with the mechanism for causing its movements. A ground-glass screen *C* is shown partially withdrawn from its position on the front of the box, but, as has been explained, when a permanent record is desired, an ordinary photographic plate holder is substituted for this. A lamp *D* with an acetylene burner communicates with the interior by means of the tube *E* and furnishes the beam of light.

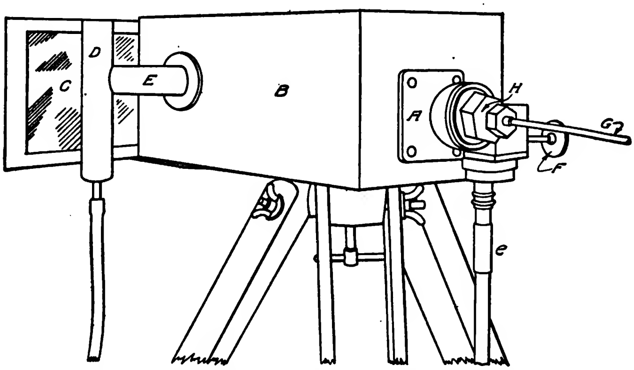


Fig. 53. General View of the Carpentier Manograph Mounted on Tripod Ready for Use

The horizontal movement of the mirror is brought about by a crank and reducing arrangement, actuated by the flexible shaft *e*. This is driven directly by the motor crank shaft, a special taper

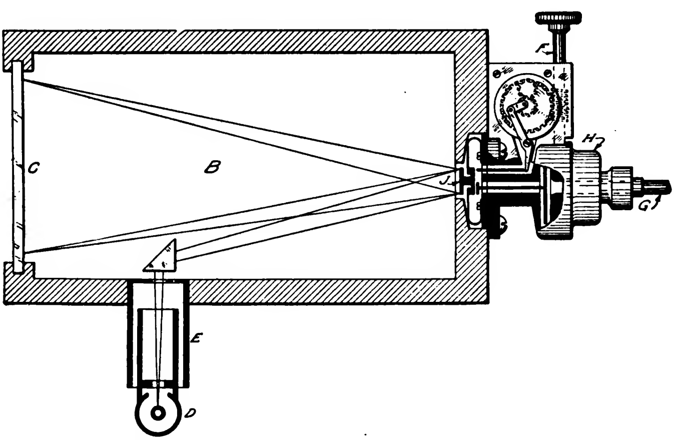


Fig. 54. Horizontal Section of Carpentier Manograph

socket being applied so that the flexible shaft may be connected or disconnected at will. In order that the motion of the beam of light and that of the piston shall correspond, an adjusting means is provided in the chamber at the right by means of the screw *F*.

The vertical movement which corresponds to the pressures in the cylinder is transmitted by means of the pipe *G*, which com-

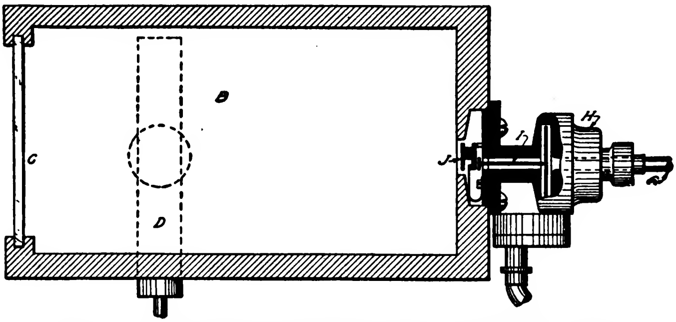


Fig. 55. Vertical Section of Carpentier Manograph, Showing Interior Arrangement

municates with a diaphragm within the nut *H*. A pin bears against the center of the diaphragm and also against the back of the mirror. This may be seen in the vertical section, Fig. 55, in which this pin is marked *I*, and the mirror inside the box is marked *J*.

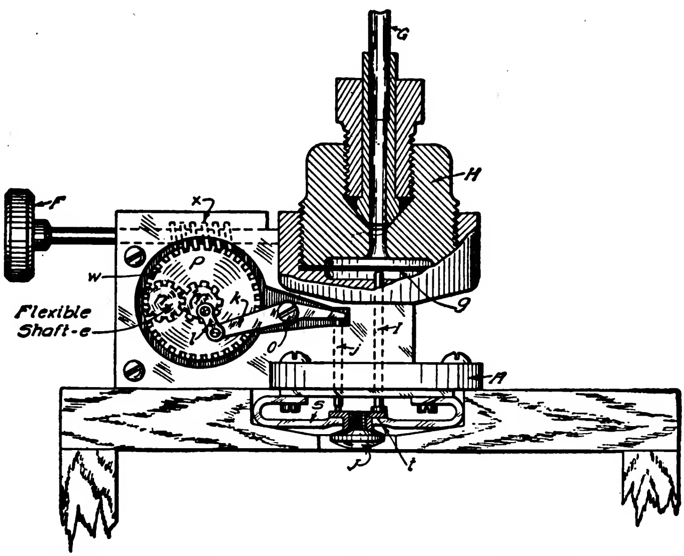


Fig. 56. Detailed Section of the Diaphragm of the Hospitalier Manograph, Which Is Similar to the Carpentier

In the horizontal section, Fig. 54, the interior arrangements are shown quite clearly, the lettering being the same as in Figs.

53 and 55. Note how the beam of light from the lamp *D* passes through the tube *E*, is deflected by the prism against the mirror *J*, and then thrown on the screen or plate *C*. Referring to the detail view, Fig. 56, *A*, *F*, *G*, *H*, *I*, and *J* are the same as before. Gears *n* and *m* have an equal number of teeth, *n* being driven by the flexible shaft *e*. It will be noted that *m* carries a pin to which is attached a small connecting rod *l*. This is attached to the lever *k*, which is pivoted on the small screw *o* shown about midway of its length. The far end of this lever presses against the pin *j*, which in turn rests against the triangular plate *t*, to which the mirror *J* is held by the spring *s*.

Fig. 57. A Four-Cylinder Manograph as It Is Rigged up Ready for Use, Indicating How the Four Cards Are Visible at One Time

From this it is apparent that the engine turns the gear *n*, which rotates the gear *m*. This carries the pin around and thus reciprocates the connection *l* and with it one end of the lever *k*. The movement of the other end of *k* moves the pin *j*, which moves the mirror *J*. The resistance of the spring *s* forces pin *j* against the end of lever *k* even when it is moving away from the pin. From the foregoing, it can be seen that the manograph is well adapted to taking diagrams from high-speed motors, for there is no limit to the speed of movement of the beam of light, while the error caused by the inertia of the few moving parts is so small as to be practically negligible.

A view of the complete manograph, rigged up for four cylinders and with the engine running, indicating the four diagrams simultaneously, is seen in Fig. 57. This gives a better idea of the device, its method of use, and very evident utility than anything which has been said on the subject. Note that the arrangement of the mirrors inside is such that the curves of each pair face each other, instead of all facing in one direction. This explains, also, the fact

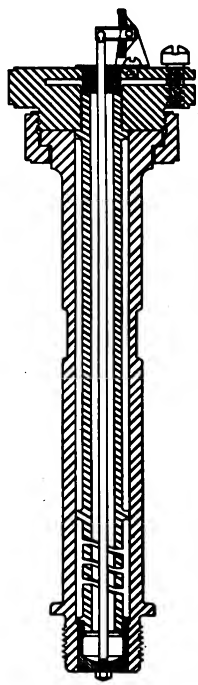


Fig. 57a. The Pressure Element

that some of the manograph curves, Figs. 66 to 70, face in different directions. The reader is referred forward to these diagrams, as showing just what is performed by the instrument described.

To return to the slower speed or steam engine form of indicator, this makes a neat diagram and one which represents, within its speed limits, the Otto cycle taking place within the cylinders.

Midgley Indicator. This instrument is not only designed to give accurate data relative to m.e.p. (mean effective pressure), but it also enables the engineer to make an accurate study of fuel behavior in the internal-combustion motor. The Midgley can be used to indicate either pressure-volume or pressure-time relations; the manograph is limited to the study of pressure-volume only.

This type of indicator produces optical cards which are visible at all times; a permanent record can be made merely by holding sensitized paper over the glass, no plates or films being needed. This instrument is composed of two units, one connected to the crank shaft and the other to the combustion chamber of the cylinder to be tested. These units are electrically connected when pressure-time cards are taken and mechanically connected when pressure-volume cards are taken.

Fig. 57b. Midgley Optical System

The pressure element, Fig. 57a, is connected to the combustion chamber. This element consists of a small cylinder containing a piston at its lower extremity. A small rod connects the piston to a pivoted arm at the top, a mirror being mounted on this arm. Pressure in the cylinder operates against the piston and causes a spring to be compressed. This vertical movement of the rod develops a variable angle between the mirror and its base, the angle being in proportion to the pressure exerted on the piston.

Optical System. The function of the optical system, Fig. 57b, is to provide means for indicating either the pressure-volume or the pressure-time relations within the cylinder by making use of a beam of light. This system consists of a light bulb (used as a

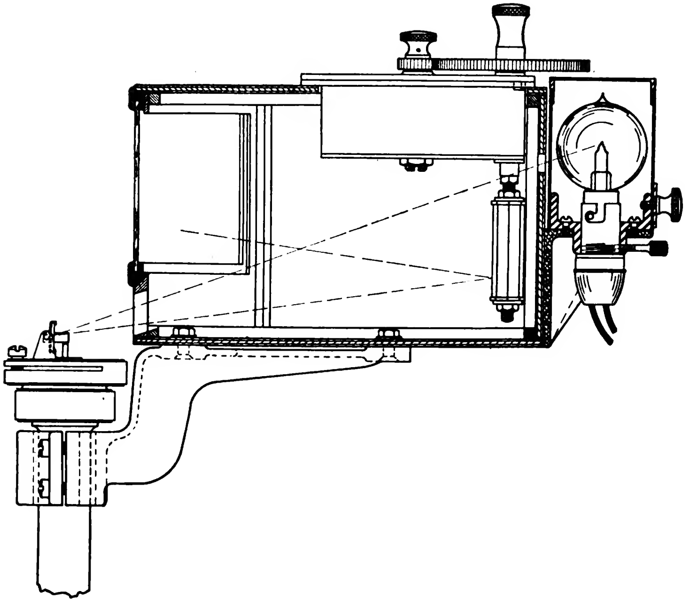


Fig. 57c. Section of the Optical System

Fig. 57d. The Photographic System

source of light), a box called the motor box, a concave mirror operated by the pressure element, and a mirror in the form of an eight-sided prism. When the system is in operation, the beam of light issues from a small opening in the metal case surrounding the light bulb. This beam of light passes through the motor box onto the concave mirror of the pressure element. It is then focused and reflected onto the eight-sided mirror on the inside of

Fig. 57e. The Pressure-Time Synchronizer

the box. This mirror may be either rotated or oscillated according to whether a pressure-time or a pressure-volume card is desired. The ray of light, after it is reflected by the eight-sided mirror, is projected forward upon a curved glass which forms the front of the motor box. This beam is moved both vertically and horizontally by the joint action of the two mirrors, thus tracing out an image on the curved glass. A section of the optical system is shown in Fig. 57c.

Photographic System. This system, Fig. 57d, is so constructed that a light is produced bright enough to develop a sharp black line on the photographic bromide paper during one complete cycle of operation only. To produce this bright light a 10-volt battery is used in connection with the original 6-volt battery. A device is connected to the crank shaft so that 16 volts can be applied to the bulb for one complete cycle of operation only. The

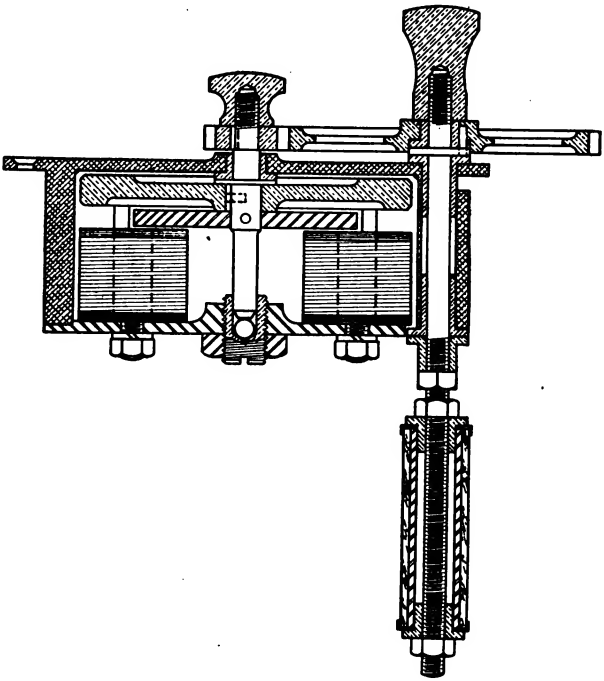


Fig. 57f. Section of the Pressure-Time Synchronizer

parts are so arranged that one operator can take a photograph with but little inconvenience.

Pressure-Time Synchronizer. The function of the pressure-time synchronizer, Fig. 57e, is to rotate the eight-sided mirror at a speed that will always bear an exact ratio to the speed of the engine. This instrument consists of a mechanism attached to the engine shaft and a synchronizer and rotating mirror located in the motor box. A sectional view is shown in Fig. 57f. The synchronizing is accomplished electrically through a distributor operated by the shaft of the crank shaft attachment. This synchronizer is geared to the revolving mirror so that the mirror revolves at exactly $\frac{1}{8}$ engine speed, and as the arc of the ground glass is 90 degrees, a beam of light reflected from the revolving mirror will move across the ground glass once for each revolution of the engine. As the beam of light reaches the limit of the screen, the next face of the rotating mirror engages the light and simultaneously reflects it to the other end of the ground glass. In this way the pressure-time relations within the cylinder for two revolutions, or one cycle of operation, are made completely visible on the ground glass as a pressure-time card.

Fig. 57g. Pressure-Volume Synchronizer

Pressure-Volume Synchronizer. The function of the pressure-volume synchronizer, Fig. 57g, is to oscillate the eight-sided mirror within the motor box in synchronism with the reciprocating motion of the engine piston. Included in the crank shaft attachment is a motor driven by a crank attached to the distributor head and having a reciprocating motion in a vertical direction. A fine wire connects this member with the eight-sided mirror, transmitting an oscillating instead of a rotating motion to the eight-sided mirror, one face only being used. In making a photograph, the optical system is used as previously explained, the mirror oscillating in synchronism with the engine piston instead

Fig. 57h. A Pressure-Volume and a Pressure-Time Card Taken by a Midgley Indicator

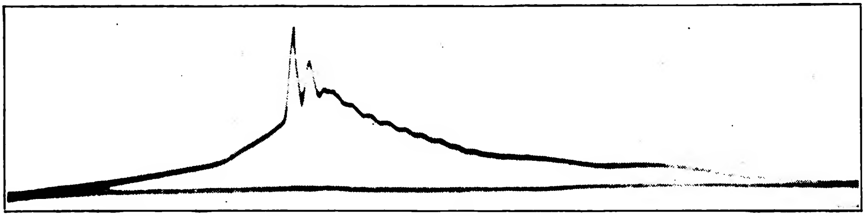


Fig. 57i. Two Cards Indicating Fuel Knock Taken by a Midgley Indicator

of rotating. The card produced indicates the pressure-volume relations within the cylinder. The relation between the moving parts is such that the pressure-volume card is one-half as long as the pressure-time card.

In Fig. 57h are shown a pressure-volume and a pressure-time card taken by a Midgley indicator. When these cards were taken, the engine was operating normally.

Two cards which show that a fuel knock is present are reproduced in Fig. 57i.

The pressure-time card shows that there are several explosions occurring after the first one. Note that the fuel knock occurs after the ignition point and is due to a very abrupt rise in pressure. A detailed description of fuel knock is given under the heading "Fuel Mixture."

IDEAL OTTO FOUR-STROKE CYCLE

Indicator Cards

Analysis of Ideal Diagram. Watt's work diagram may be profitably applied to the analysis of the ideal Otto cycle by means of the indicator diagram, Fig. 58. Vertical distances along the line *AB* represent pressures in pounds per square inch absolute,* while horizontal distances measured along *AC* represent piston travels or, as the cross section of the cylinder is constant, these distances may also represent cylinder volumes in cubic inches. Thus point *4* represents a pressure of 350 pounds per square inch in the explosion chamber of the cylinder when the volume in cubic inches of this chamber is V_c.

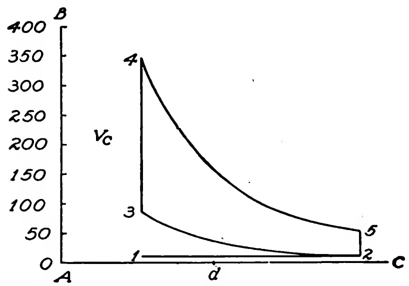


Fig. 58. Ideal Indicator Card of Otto Cycle.

As the line *1-2* represents the entire piston travel, any point *d* on *AC* represents a certain cylinder volume or marks the position of the piston at that point in the stroke.

Stroke One. At the beginning of the cycle the piston is at the end of its path, point *1*, and is about to begin its out stroke, Fig. 59(a). The clearance space V_c is full of products of combustion. The

*Absolute pressures are always referred to zero pressure, *i. e.*, a perfect vacuum, as a starting point. Atmospheric pressure, therefore, is 14.7 pounds absolute. Gage pressures, on the other hand, start at atmospheric pressure, so that 80 pounds absolute would be 65.3 pounds gage pressure.

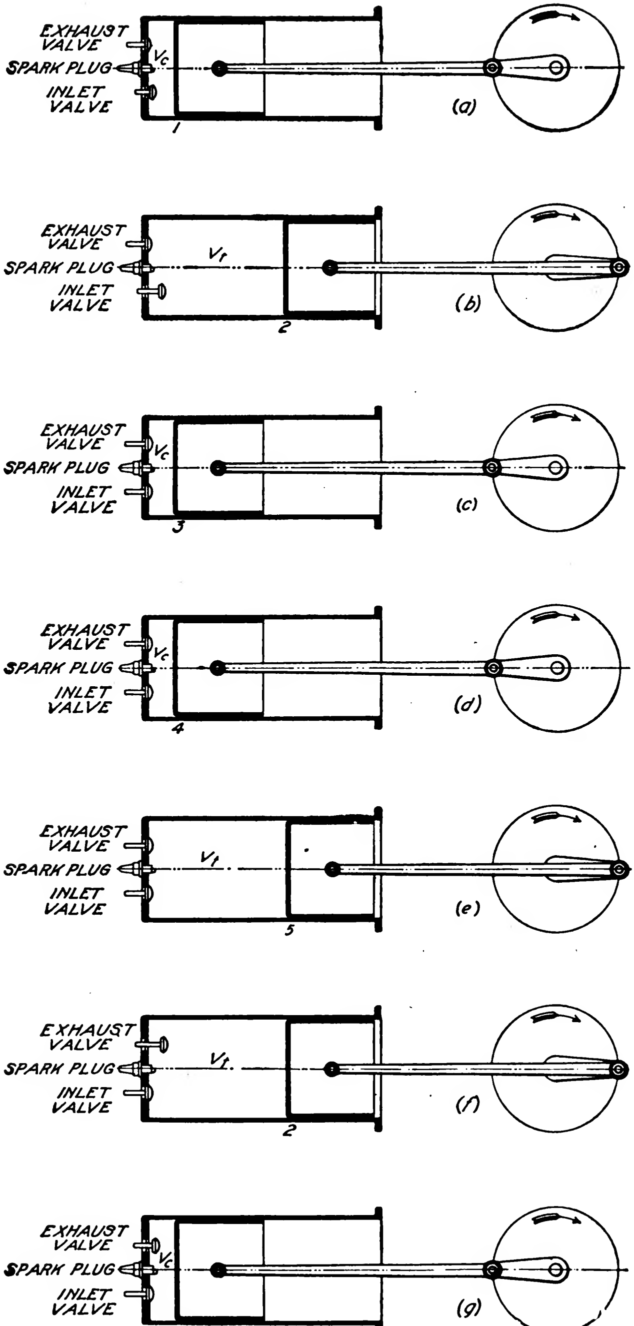


Fig. 59. Diagrams of Various Steps in an Explosion-Motor Cycle

pressure is atmospheric pressure (about 14.7 pounds per square inch) because the cylinder has been in communication with the atmosphere through the exhaust valve which has just closed. The conditions existing in the cylinder at this instant are represented in the diagram, Fig. 58, by the point *1*, which is at a horizontal distance from the vertical axis, representing the clearance volume V_c, also Fig. 59 (a) and at a vertical distance above the horizontal axis representing the atmospheric pressure. As the piston makes its outward stroke, the admission valve opens, admitting the charge to the cylinder throughout the stroke at atmospheric pressure. On the diagram the admission of the charge is represented by the line *1-2*, its length representing the volume of the charge taken in, or the distance through which the piston moves. The point *2* represents the condition at the end of the first stroke, the volume being V_t, Fig. 59 (b).

Stroke Two. The admission valve now closes and the piston makes its return stroke and, since all the valves are closed, the charge can not escape and is crowded into a smaller and smaller volume at increasing pressure until the piston reaches the end of its stroke, at which time the whole charge is compressed into the clearance space. This process is represented by the line *2-3*, which shows the rise in pressure resulting from the compression. At point *3* the volume is again V_c, Fig. 59 (c). A compression of this kind causes an increase not only in the pressure but also in the temperature of the gas, a fact often noted in the working of an ordinary bicycle pump. If it is assumed that during this compression the gas retains all of the heat formed and receives none from the outside, it is called an *adiabatic* compression. The relation between the pressure of air and its volume when subject to adiabatic compression is:

$$PV^{1.405} = \text{Constant}$$

In this equation P means the absolute, not the gauge pressure.

When the charge has reached the conditions represented by the point *3*, it is ignited and the heat generated by the explosion raises the temperature and consequently the pressure of the mixture. As the volume during the explosion will not have time to change, the gas will follow the general gas law, viz, that at constant volume the pressure P is proportional to the absolute temperature T, where absolute temperature is found by adding 461 to the temperature in degrees Fahrenheit. The rise of pressure during the explosion is shown on the diagram by the line *3-4*, the volume of the gas being constant at V_c, Fig. 59 (d).

Stroke Three. The hot products of combustion at point *4* are at a high pressure, consequently they now force the piston out and, expanding behind it, fall in pressure. This expansion is assumed to occur without communication of heat to or from the gas and is, therefore, an adiabatic expansion. It is consequently accompanied by a fall in the temperature of the gas, the expansion curve being shown in Fig. 58 as *4-5*. This curve is similar to the compression curve *2-3* and has a similar equation.

Stroke Four. At the point *5* the piston is at the end of its stroke and no more expansion is possible, the volume being again V_t, Fig. 59 (e). The exhaust valve now opens and the pressure in the cylinder falls immediately to atmospheric pressure, as shown by the line *5-2* in the diagram, the volume remaining V_t, Fig. 59 (f). Throughout the last return stroke *2-1*, the exhaust valve remains open, so that the pressure in the cylinder remains atmospheric, and at point *1*, the end of the cycle, the volume is again V_c, Fig. 59 (g).

Work Done by Motor. The work done by any heat engine is equal to the difference between the heat energy that goes to the engine and that which is rejected by the engine, for whatever heat disappears can not have been destroyed and must have been converted into work. In the Otto cycle, the heat taken in is the total heat which it is possible to liberate at the explosion of each charge. In the ideal cycle no heat is rejected from the engine except during the process represented by the line *5—2* in Fig. 58; because, when the charge gets back to the condition at *2*, it has returned to its original volume and pressure and consequently to its original temperature.

Thermal Efficiency. The thermal efficiency of the ideal cycle is the fraction of the heat supplied that is converted into work, or when expressed in ratio form, $\frac{\text{(heat input)—(heat rejected)}}{\text{(heat input)}}$.

In the theoretically ideal cycle, the thermal efficiency is calculated to be from 40 to 50 per cent, depending upon the conditions assumed. All departures from ideal conditions result in decreasing the actual thermal efficiency of the motor. This efficiency is always less than that of the ideal cycle, usually being only from 50 to 60 per cent as great.

OTTO FOUR-STROKE CYCLE IN PRACTICE

General Analysis

In the discussion of the ideal Otto cycle we assumed that the compression and expansion curves were adiabatic and that the walls surrounding the combustion chamber were impermeable to heat. We also assumed perfect and instantaneous ignition, that we had a charge of uniform composition possessing all the physical properties of air, and that combustion was complete. None of these assumptions are quite true in practice and each variation from the ideal condition has its influence upon the performance of the motor. In addition to the above, we did not consider the loss due to the necessary cooling of the cylinder. In fact, the water jacket around the cylinder (this applies to air cooling as well), without which the cylinder would be too hot to be properly lubricated, is the main cause

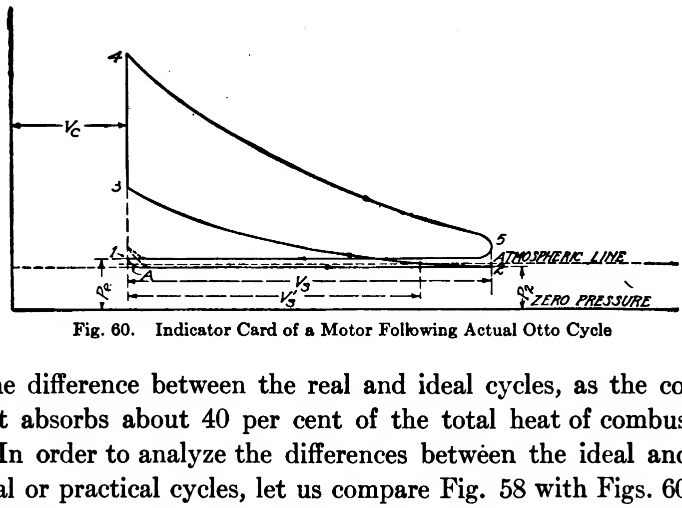


Fig. 60. Indicator Card of a Motor Following Actual Otto Cycle

of the difference between the real and ideal cycles, as the cooling agent absorbs about 40 per cent of the total heat of combustion.

In order to analyze the differences between the ideal and the actual or practical cycles, let us compare Fig. 58 with Figs. 60 and 61, which represent, respectively, the cards of a motor which is supposed to follow the actual Otto cycle, and of a four-cycle gasoline engine as found in practice.

Suction Stroke. At the end of the exhaust stroke, the clearance volume V_c, Fig. 60, is filled with burned gases at a pressure P_e and temperature T_e. Nothing definite is known of the temperature T_e, except that it varies from 1,200 to 1,800 degrees Fahrenheit, while P_e ranges from 16 to 18 pounds absolute pressure per square inch. At the beginning of the suction stroke the pressure decreases from P_e to the suction pressure P_2 along the curve determined by the re-expansion of the burned gases in the clearance space. This is the curve shown at *A*. The fresh charge can not be drawn into the cylinder until after this re-expansion of the burned gases. Anything—such as a badly formed exhaust port, restricted exhaust passage, or a too early closure of the exhaust valve—which may give us too high an exhaust pressure or too large a volume of exhaust gases remaining behind, will decrease the cylinder capacity and

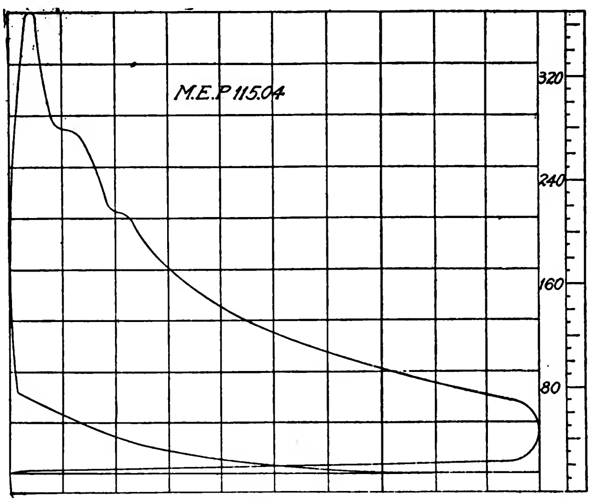


Fig. 61. Indicator Card of Four-Cycle Explosion Motor

hence materially reduce the efficiency of the cycle. The dotted line curves near *A* show how the above would affect the card.

Scavenging. If by any means we can reduce the effect of the clearance exhaust, we would increase the efficiency. This is actually accomplished by what is termed *scavenging.* Since the exhaust gases which occupy the clearance space are usually at a high temperature T_e, their mixture with the entering charge heats it, decreasing its density and, therefore, its amount. Consequently, it is very essential that these exhaust gases be excluded from the cylinder before the fresh charge enters. This clearing-out or scavenging of the cylinder with fresh air has been accomplished in several ways. The simplest method is by the use of an exhaust pipe of such length that the gases, exhausting from the cylinder with great velocity, create a vacuum in the cylinder near the end of the exhaust stroke. This vacuum causes the automatic air-admission valve to open; and the consequent rush of air from the air-valve to the exhaust port flushes out the cylinder, especially if the air and exhaust valves are on opposite sides of the clearance space. Scavenging may also be accomplished by pumping air through the clearance space.

Suction Pressure. Another factor affecting the efficiency is the suction pressure P_2, Fig. 60. Owing to friction losses in the admission valves and pipes through which the fuel enters, the admission pressure is less than atmospheric pressure, $12\frac{1}{2}$ pounds per square inch absolute being the average value for P_2 in this type of motor. Owing to this reduction in pressure, the charge, if it were brought to atmospheric pressure, would occupy a volume V'_s instead of V_s, Fig. 60. This reduction in the amount of the charge, of course, decreases the pressure developed at the end of the compression stroke and, therefore, reduces the heat developed by the explosion, which reduces the power developed within a given size of motor. Hence, the smaller the suction pressure, the less power we get, and the closer P_2 is kept to atmospheric pressure the greater will be the possible power output. We thus see that modifications occur at each end of the suction line which tend to decrease the efficiency of the cycle. This effect produced by the reduction of P_2 permits the motor to be governed by means of a throttle valve. P_2 is increased or decreased as required by the use of a control valve whose suction responds to the load on the engine, thus controlling the charge volume and hence the engine capacity.

The temperature t_2 of the charge has been found by experiment to be between 200 and 300 degrees Fahrenheit.

Compression Stroke. The compression is not adiabatic because it occurs in a cast-iron cylinder, which takes heat from the gas while it is being compressed and so makes the final temperature and pressure less than those calculated on the assumption of adiabatic compression. In general, however, the compression curve may be considered in actual practice to follow the general gas law. During the first part of the stroke the charge receives heat from the walls, but due to the heat generated by compression, this is soon overbalanced and during the last and greater part of the stroke the charge loses heat to the walls. As a result of this the compression curve is found to be between an adiabatic and an isothermal.* As a result of this exchange of heat, first *from* the walls and then *to* them, the exponent n in the general gas law equation $P V^n = \text{Constant}$ is not constant along the entire curve. In actual practice n is found to average about 1.35. We thus have in the actual cycle, $P_3 = 12.5 \frac{(1+c)^{1.35}}{c}$ instead of $P_3 = 14.7 \frac{(1+c)^{1.405}}{c}$ for the ideal cycle, where c is the percentage of clearance. (See page 58 and Table I.) The less effective the cooling, the greater will be the value of n. Any leaks past the piston or in the valves will result in a flattened compression curve which results in a decrease in the value of n.

Theoretically an increase in compression pressure P_3 will give an increase in efficiency. Practically this is true only up to a certain point.

The amount of compression that can be used is limited in two ways. First, it is not commercially practicable to construct motors which will work properly under very high pressures rapidly imposed by explosion. With an engine compressing a charge to 100 pounds and using a strong explosive mixture, the pressure in the cylinder rises suddenly to about 350 pounds and this is at present about the practical limit. If the explosive mixture is very weak, the compression may be increased as high as 200 pounds, resulting in a maximum pressure of about 300 pounds.

The second objection to the use of high compression is that the rise in temperature of the mixture resulting from the compression may easily be sufficient to explode the mixture before the piston has reached the end of its stroke. Such pre-ignition of the charge tends to force the piston back, giving rise to a great shock, which is not only very destructive to the engine but reduces its efficiency and consequently should be avoided. Pre-ignition may occur even with low compression, if any part of the clearance is not water jacketed, or properly air-cooled, or if there is any metallic projection in the clearance space. Lucke states that compression pressures of from

*Adiabatic compression, as already stated, is one in which all the heat resulting from the compression is retained in the gas compressed; in an isothermal compression, the heat is removed as rapidly as it is produced. In this case some of the resultant heat is retained and some of it is lost; therefore, the curve partakes of the properties of both adiabatic and isothermal lines and is found to lie between the two.

TABLE I

Effects of Clearance

Percentage Clearance of Otto Cycle Engine	Pressure at End of Compression Lbs. per Sq. In.	Efficiency of Otto Cycle	Efficiency of Cycle with Increased Expansion, but with Same Compression Pressure as Otto Cycle.
20	183.3	51.6	60.9
25	141.1	47.9	58.4
30	115.4	44.8	55.0
35	98.0	42.1	52.5
40	85.5	39.8	50.4

45 to 95 pounds per square inch are safe as regards the danger of pre-ignition in the type of motor under consideration.

Effects of Clearance. The efficiency of an engine depends not at all upon the temperature and the pressure at the end of the explosion, but only upon the ratio of the temperatures at the beginning and at the end of the compression. Since this ratio in turn depends only upon the ratio of compression, and since, further, the charge is always compressed till it occupies the clearance volume, the efficiency is seen to depend only upon the percentage of clearance. In other words, in engines using the same gas and following the Otto cycle, with the same percentage clearance, the percentage of the heat liberated in the cylinder that is converted into work is always the same, whatever be the size of the engine or the strength of the charge. The effect of the clearance on the efficiency is exhibited in Table I, where it is seen that the smaller the clearance the greater is the efficiency of the engine. The pressures at the end of compression are also given in the table, and are calculated on the assumption that the atmospheric pressure is 14.7 pounds per square inch absolute.

Explosion. The shape taken on the indicator diagram by the line representing the explosion of the charge depends mainly upon the inter-relation of three things, viz, the particular composition of the charge, the ignition point, and the piston speed.

For each power of engine there is a certain relation between the proportions of air and vapor in the mixture which will give the most rapid combustion. Any increase in the amount of air or burned gases contained in the charge will result in a lowering of the rate of combustion until a point is reached where the mixture will no longer

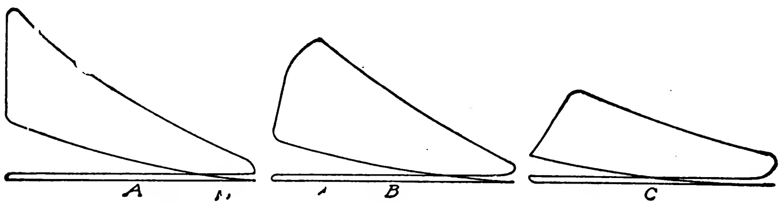


Fig. 62. Cards Showing Varying Rates of Combustion

explode. In Fig. 62, *A* is a diagram of a motor with throttle full open, speed constant, and proper ignition; *B* shows the conditions of the same engine after partly closing the throttle, thus increasing the proportion of burned gases contained in the charge; and *C* shows the conditions on further closing the throttle. Similar diagrams would have been obtained had the throttle been left full open and the proportion of air in the first charge considerably increased in *B* and *C*. A vertical or nearly vertical explosion line such as that in *A* indicates proper combustion. The more slanting the explosion line, the poorer the ignition. Referring to *C*, it is readily seen that the maximum pressure of the explosion does not begin to act on the piston until the piston has traveled a considerable distance out on the power stroke.

From the above, it will be seen that for each different fuel mixture and each different piston speed there will be a different point of ignition if we are to secure maximum results. This shows that it is advisable that each motor have adjustable ignition apparatus, because the only way to determine a proper time is by actual trial. Fig. 63 shows a set of diagrams given by Clerk which illustrates the results of improperly timed ignition. *A* is the normal diagram with proper ignition, while *B*, *C*, and *D* show what occurs as

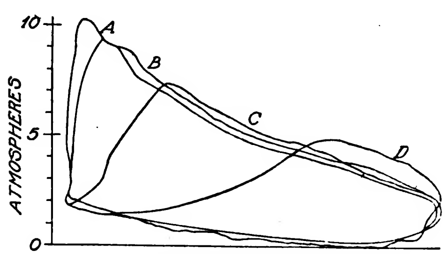


Fig. 63. Card Showing Results of Varying Time of Ignition

the ignition is made later and later. With the time of ignition remaining constant, successive increases in piston speed would have given diagrams similar to those of Fig. 63. The maximum pressure reached during combustion depends upon the heating value of the charge and should be reached at or before one-tenth stroke. The pressure ratio, $\frac{\text{maximum pressure}}{\text{compression pressure}}$, usually has a value of between 3 and 5, for gasoline.

The maximum explosion pressure (see point *4*, Fig. 60), even with proper ignition is never as high for the actual cycle as for the ideal cycle. The principal reason advanced for this is the loss of heat to the water jacket, or air, if air-cooled, this loss amounting to usually about 40 per cent of the total heat of combustion, *i. e.*, heat which results from the explosion of the charge. Some of the other

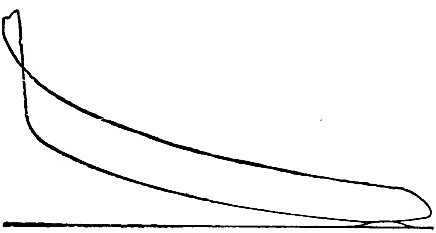


Fig. 64. Card Showing Result of Pre-Ignition

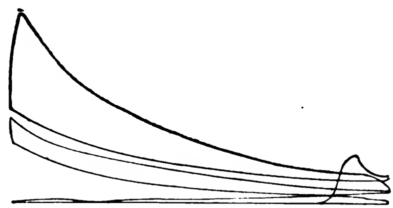


Fig. 65. Card Showing Case of Back-Firing

reasons are the rise in specific heat* of the gases with rise in temperature, and the fact that perhaps not all of the heat of the charge is liberated when the piston starts forward, which results in after burning.

Fig. 61 shows the card actually taken from a gasoline engine as given by Lucke. The engine had a compression of 80 pounds and a maximum pressure of 372 pounds. Fig. 64 shows the results of pre-ignition, the card clearly indicating that the explosion has occured before the end of the compression stroke and that considerable of the stored-up energy of the engine is spent in overcoming the maximum force of the explosion. This results in this particular case in cutting the power of the engine nearly in half.

*Specific heat of a substance is the ratio of the heat required to raise the temperature of a certain weight of the given substance 1° F., to that required to raise the temperature of the same weight of water from 62° to 63°F.

Fig. 65 shows the difference between a case of back-firing and the case of pre-ignition shown in Fig. 64. The explosion occurs in the suction pipe during the suction stroke. Back-firing, however, is more apt to occur in the exhaust pipe than in the suction pipe.

Power Stroke. The curve of expansion in the actual cycle follows the general law and, because of the loss of heat through the cylinder walls, should lie below the adiabatic curve. In practice, however, it is found that it does not fall off as quickly as expected, sometimes coinciding with the adiabatic, but usually being found between this and the isothermal. An evolution of heat along the expansion curve is supposed to be the cause of this. A great many theories have been advanced to explain this, nearly all trying to prove that, owing to certain reasons, after-burning takes place. However, up to the present time no really satisfactory explanation has been advanced. A value of 1.35 is a fair average value for n, thus making the general equation $PV^{1.35} = \text{Constant}$.

Exhaust Stroke. At the instant the exhaust begins, the velocity of efflux of the burned charge is from 2,500 to 3,500 feet per second. The exhaust valve should start to open at about one-tenth before the end of the stroke. The port should be so proportioned that the pressure has been equalized by the time the outer dead center is reached. If this is not the case there will be an increase in the work lost, due to higher back pressure, higher mean cylinder temperatures, and smaller cylinder capacity. In actual practice the pressure at the beginning of the exhaust stroke has been found in many cases to average about 25 pounds per square inch.

The movement of the burned gases out through the exhaust pipe is resisted by friction in the various parts. These gases are forced out against atmospheric pressure, hence the pressure inside the cylinder which expels them must be above atmospheric pressure. This pressure is maintained by the piston which follows up the retreating gases. The difference in pressure between that inside the cylinder and that outside, *i. e.*, the exhaust pressure and the atmospheric pressure, respectively, opposes the motion of the piston on the exhaust stroke and hence causes a loss. This loss is clearly shown in Fig. 60 by the fact that the exhaust line on the indicator card is above the atmospheric line, thus decreasing the area of the card which is proportional to the amount of work done.

Modifications for Modern Motors

Large Valve Ports. In modern motors; it has been found possible to modify the actual indicator card and the output of the engine very materially by slight modifications in the ports and their arrangement, as just pointed out. Thus, relative to drawing in the fresh charge of gas, after the exhausting has been nearly completed, it has been found that larger exhaust valves and ports would carry out the burned gases quicker and more completely, so as to leave a cleaner cylinder for the fresh charge to enter.

Similarly, larger inlet valves and ports have been found to give a quicker and more complete inflow of fresh charge. The two items combined—better scavenging and a more complete charge of purer gas—have had a material influence upon the efficiency. In the same way, larger intake ports and valves have operated to increase the suction pressure. As has been pointed out, this influences the pressure at the end of compression, and, therefore, the heat developed by the explosion, and ultimately the power developed. Thus, larger valves and ports producing increased suction pressure have increased the power output. This tendency has been carried up to the point where the diameter of the clear valve opening has been as close to one-half the cylinder diameter as was practicable, that is to say, a motor of four-inch bore nowadays would have valves with a clear opening of approximately $1\frac{15}{16}$-inch diameter, or just $\frac{1}{16}$ inch below half the cylinder diameter.

Exhaust Gas Friction. Also the exhaust gas friction produced by the pipes has been made an almost negligible quantity by making the pipes of much larger diameter, with fewer and easier bends, while larger mufflers of better design have tended to give a greater vacuum. With all these influences at work, it has been found possible to increase the speed of exhaust gases. Several recent motor designs have an important departure in that the the exhaust pipe, instead of turning directly toward the rear, has been carried forward in a long, easy bend, coming as close to the rear of the radiator as possible and then passing beneath the engine supports to the muffler at the rear. The close proximity of the exhaust pipe to the radiator and the cold air flowing through it have produced an internal cooling and condensing effect which has increased the vacuum pressure in the exhaust system and in this way has produced superior and more complete scavenging, which always results in greater power.

In some six-cylinder motors and all in the eight-cylinder forms now being produced, a similar result has been attained by using double sets of exhaust pipes, leading to a pair of distinct mufflers on opposite sides of the chassis or else to one unusually large one. In the case of the six-cylinder engines, usually the first three cylinders have been considered as one group with their own exhaust pipe and muffler, while the rear three formed the other group. In the case of eight-cylinder V-types, the right-hand group formed one unit for exhausting purposes, and the left-hand lot of cylinders the other.

Effect of Large Ports on Silence of Motor. While it has no bearing upon the subject under discussion, this seems a good place to mention the fact that anything tending to make more complete, easier, and quicker any natural function of the motor, as the inflow of fresh gas, the outflow of burned gases, etc., also tends to increase its silence, as well as to increase its volumetric efficiency. This combination, with the demand for more economical motor cars, has brought about the high-speed small-bore motor of today. To make this statement more pointed, it should be said that motors are now being constructed and sold in many popular types of car, which have a bore one inch less than it was considered practicable to build five years ago.

Manograph Cards. Before turning to the two-cycle form of motor and the diagrams, both theoretical and actual, it will be well to look at some manograph cards in order to see just what kind of cards the manograph makes and how they compare with those made by the steam-engine form of indicator.

In Fig. 66 is presented what might be called a good card. This was taken from a motor of 120-millimeter bore (4.72 inches, in round figures, $4\frac{3}{4}$) by 130-millimeter stroke ($5\frac{1}{8}$ inches), running at about 1,100 r. p. m. As will be seen at once, this is a combination of a number of successive diagrams, superimposed. The line *DB* indicates excellent admission, with a slight rise near the end of the line, showing a slight increase in pressure due to the inertia of the inflowing gases. Then *BF* shows a good compression line, indicating that the amount of gas admitted has been good, that is, that admission had been complete. Next, the vertical line from *F* upward indicates a first-rate explosion.

From the maximum explosion point down to *A*, the curve indicates the expansion. At *E* will be seen the variation in the successive cards, all of them good but varying slightly from one to another as a better or more complete charge was drawn in, a slightly higher compression pressure obtained, a better or hotter spark produced, or according to other conditions in the cycle. The sharp

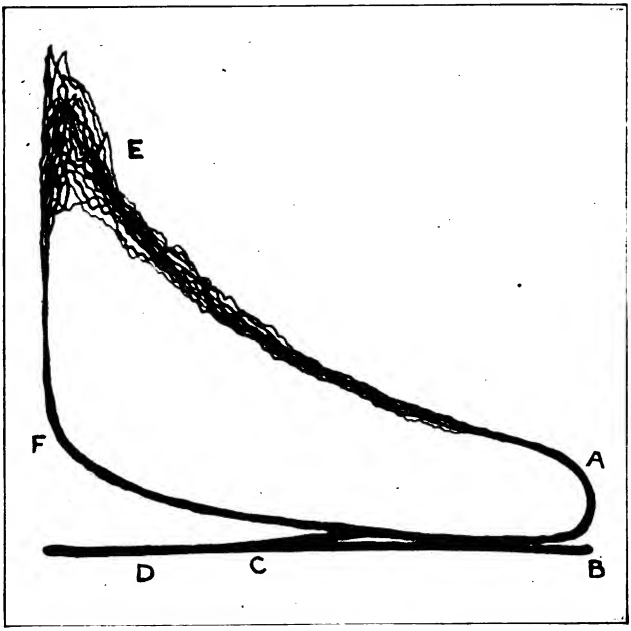


Fig. 66. A Good Manograph Card from a Medium-Sized Four-Cylinder Motor, Showing How a Large Number of Cards Are Taken at Once

end of the expansion curve at *A*, which indicates the opening of the exhaust valve, is very good, as is also the line from *A* to *D* and the end of the exhaust stroke. Near the end of this it will be noted that the exhaust line goes below the intake line, indicating a slight vacuum in the exhaust system.

Fig. 67 shows another card taken from the same engine but at a reduced speed, which was being lessened further as the card was taken. The mixture was good, and the charge very complete, while the slower speed allowed of a better mixing of gas, a superior diffusion of the gases in the cylinder, and a better explosion. The lower pressures of admission and exhaust do not show up as plainly, but the explosion line above *F* is very marked. The agitation in the gaseous mixture is plainly shown in the several waves of the first part of the expansion curve at *E*. Similarly, a good free exhaust is indicated from *A* to the base line and to the end of the stroke at *D*.

Fig. 67. Another Good Manograph Card, Taken on the Same Motor When Slowing Down, Consequently Showing a Smaller Area

Fig. 68 points out the evil results of retarded spark, this curve indicating the loss of power due to this cause. Note that from *F* upward the curve is not vertical as in the preceding diagrams but slopes off to the left. This, of course, indicates a loss of power. Note also the poor expansion curve from *E* downward, and the comparatively poor exhaust, starting too early and continuing too long and too slowly, as indicated by the length and slope of the curve around *A*.

Fig. 68. A Manograph Card from the Same Motor, Indicating the Disadvantages and Results from Over-Retarded Spark

The diagram at Fig. 69 indicates poor compression. This may be caused by leaking piston rings, a piston or cylinder which has worn oval, too small or restricted inlet ports or valves, and a number of other things. The curve *B C* represents the intake, in which it will be noted first that it starts higher than usual, the upturn at *B* indicating that the exhaust closes too soon, leaving gases under pressure in the cylinder. The droop in this line indicates the remarkably poor suction, which is followed by the line *C D E*, indicating the compression and expansion, while *EFA* indicates the expansion and beginning of the exhaust. It will be noted that all of these are poor, the fact of the expansion line being below the compression line indicating negative work, that is, this shows that more power was required to compress the gases than they gave out during their explosion and subsequent expansion. The exhaust line *AB* is fairly good, excepting only the early closing as previously pointed out, indicating that the trouble here lies mainly in the suction (carburetion system), compression, and expansion (cylinder construction and condition), with incidentally a poor spark (ignition system).

Fig. 69. A Manograph Card Indicating Remarkably Poor Compression and What It Produces in the Cycle

Finally, Fig. 70 shows a diagram taken from an engine with a suction inlet valve. This form is no longer used for automobile engines, but is of interest because it indicates that this form of valve had a considerable influence on the power of the motor. It will be noted that the inertia of the valve was considerable, and the suction not sufficient to hold it wide open all of the time. This can be noted in the waves of the admission curve. Its influence on the power can be seen in the poor explosion line, following a very good compression curve, and this in turn, followed by but a fair expansion. Finally, there is shown a poor exhaust, as indicated by the rising straight line. This means increasing pressure as exhausting proceeded, whereas it should show a drop, if anything.

Fig. 70. A Manograph Card Taken from an Engine with a Suction Inlet Valve. Note Variation in Suction Stroke

TWO-CYCLE MOTOR DIAGRAM

The compression, explosion, and expansion lines of the indicator diagram are the same for the two-cycle as for the four-cycle motor, the only difference between the two types being in the way the exhaust and charging actions are carried on. In Fig. 71 is shown the indicator diagram of a motor which exactly follows the ideal two-stroke cycle. The exhaust opens at *A*, the burned gases escape, the intaking of the charge commences and is completed at *B*, where compression commences. From the above it is seen that the exhaust and intake actions must be done during the time that the piston moves from *A* to the end of the stroke *C*, and back again to *B*.

Admission of Charge. The very short interval of time between the beginning of the exhaust and the admission of the new charge (which enters as soon as the pressure in the cylinder has fallen enough to permit the admission valve to open) makes premature ignition of the charge, or back-firing, of not infrequent occurrence. If the mixture is weak, or the speed is very high, so that the charge is still burning when admission begins, or if the frequency of the explosions brings any part of the cylinder to a red heat, the charge will be ignited on entering, and the explosion then travels back to the crank case, which has to be made strong enough to resist it.

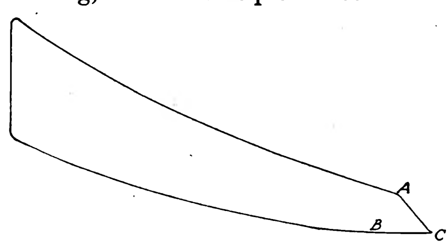


Fig. 71. Ideal Two-Cycle Diagram

In all explosion motors a certain amount of work has to be done in getting the explosive mixture into the cylinder during the suction stroke, and in expelling the exhaust gases during the exhaust stroke. This gas-friction work is represented on the indicator card of an Otto cycle motor by the negative loop, Fig. 72, which has to be subtracted from the positive loop in order to give the indicated horse-power of the motor. In the four-cycle motor this negative work is usually from 2 to 5 per cent of the total work, and is a dead loss. In the two-cycle motor, considerably more work must be done in order to get the gas into the cylinder. The time available for the admission of the charge is extremely short. In a small high-speed motor, it will be from one- to two-hundredths of a second; in a large two-cycle motor, it may amount to one-twentieth of a second. In any case it will not be more than one-third to one-fifth of the time available for admission in a four-cycle motor.

Pre-Compression. In order to overcome the back-pressure of the exhaust, and also in order to be able to enter with the very high velocity necessitated by the short duration of admission, the explosive mixture has to be pre-compressed to 8 or 10 pounds above atmospheric pressure before its admission to the cylinder. Whether this pre-compression is done in the crank case, as in small motors, or in separate compression pumps, as in large engines, it requires the expendi-

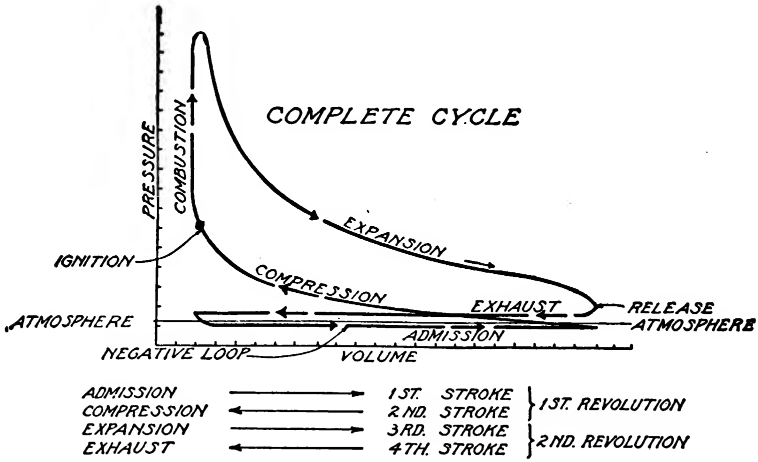


Fig. 72. Diagram Showing Operations of Four-Stroke Cycle. Lower Part of Diagram, Called the Negative Loop, near Atmosphere, Exaggerated

ture of a considerable amount of work—an expenditure which decreases the available power of the motor without giving anything in return other than the possibility of maintaining the cycle of operations. This loss of power in compressing the charge is ordinarily from 15 to 20 per cent of the total work done in the cylinder.

Valve Timing. Another loss of efficiency in the two-cycle motor results from the fact that the admission and exhaust ports are open at the same time. An endeavor is made to have the exhaust port close before any of the entering charge has reached it; but it is not practically possible to accomplish that—particularly in a motor which is to run at various speeds. If, in an endeavor to prevent such loss of charge direct to the exhaust, the exhaust port closes early, too large a volume of the exhaust gases will be retained in the cylinder; the amount of the charge which can enter will be correspondingly decreased; and both the efficiency and the capacity of the motor will suffer. In large engines, this trouble is to a great extent obviated by forcing air into the cylinder slightly ahead of the explosive charge, and closing the exhaust port when the charge of fresh air is passing through. This device is also valuable in preventing back-firing of the charge.

Scavenging. The success of the two-cycle operation depends primarily upon how thorough the scavenging action is carried out, since upon this depends the explosibility of the charge, as well as its volume, which in turn determine whether the engine runs at all, and if so what its efficiency will be.

For successful action, point *A*, Fig. 71, should be at atmospheric pressure, any increase above that given tending to increase the volume of exhaust gases remaining in the cylinder as well as the work done by the piston during exhaust. Practice has shown that scavenging, in order to be thorough, must be commenced somewhere between *A* and *C*.

Throttling. The power of a small two-cycle motor can be varied by throttling, that is, by varying the amount of the charge taken into the cylinder. This is accomplished either by throttling the admission to the crank case, or else by throttling in the by-pass between the crank case and the cylinder. There is probably but little to choose between these two methods.

Reversibility. Besides its simplicity and compactness, the two-cycle motor may claim reversibility as one of its advantages. The direction of rotation in the valveless two-cycle motor is determined solely by the timing of the ignition. It is possible to reverse such a motor merely by making the point of ignition very early. This causes an explosion well before the ending of the compression stroke and may develop sufficient pressure to stop the piston before it gets to the end of the stroke and start it going in the other direction. When once started in the other direction, the ignition, if unchanged, will be a very late ignition, giving comparatively small power; shifting the ignition back a little will give the motor its full power in its reversed direction. This process is practicable only in motors with light reciprocating parts; it is most convenient for small motorboat use.

Summary. In theory, the two-cycle motor develops about 65 per cent more power than a four-cycle motor of the same size and speed; it uses from 10 to 20 per cent more gas per brake horse-power. In actual practice, however, it has been difficult for two-cycle designers and advocates to show more than 10 per cent increase for equal size, while the two-cycle form cannot produce as low a minimum nor as high a maximum speed. The latter has a large influence on the power output, as the four-cycle engine develops the greater part of its power at the upper or high speed end of the power curve. Consequently, the maximum output of a four-cycle motor has always been greater than that of a two-cycle motor of equal size because of the greater speed possibilities of the former. Moreover, the majority of car manufacturers and independent designers have, in the past six or eight years, worked on the four-cycle form with the result that it has approached a high state of perfection. The same cannot be said of the two-cycle motor.

Except for the above-mentioned differences and the difference in the form of the diagram, as has just been pointed out, the thermodynamics of any two-cycle type of motor is exactly the same as that on any four-cycle type.

AVIATION MOTORS

Aviation vs. Automobile Motors. One of the great results of the War has been to produce some very large and high-powered engines for use in airplanes, seaplanes, and dirigibles and to call popular attention to them. This fact was perhaps most strikingly presented at the aeronautic show in Madison Square Garden in the spring of 1919, when there were exhibited no less than six different eight-cylinder, one nine-cylinder rotary, five different twelve-cylinder, two sixteen-cylinder, and one eighteen-cylinder motors, developing up to 800 horse-power.

The production of airplane engines by the thousands for war use and the wide publicity given to the details of these have produced much popular interest in the special airplane engine. This, it should be understood, is not by any means an automobile motor adapted to other work. The most important of the essential points of difference is the fact that the airplane engine requires first of all light weight, not just low weight, but the minimum weight possible, consistent with regularity of operation. This requirement has been the cause of much additional machining to remove useless weight and has forced the use of various light materials or of heavy materials in a new way. Both of these practices have had the effect of making the cost of air engines tremendously high, approximating $10,000 per engine, whereas a very good automobile engine can be produced for one-tenth of this sum, and a fair engine for a low-priced car, such as a Ford, a Maxwell, and the like, for one-hundredth of it.

Another point of difference relates to the service demanded of the motor. An automobile engine starts at low speeds and then probably runs first fast then slow, its speed constantly varying; in fact, it has been estimated that no average touring-car motor is run at its maximum speed in excess of 18 per cent of its useful life. The airplane engine, on the other hand, operates at high speed from the start all the time it is in use and then is shut off entirely; that is, it operates at high or highest possible speed for 90 to perhaps 97 or 98 per cent of its useful life.

There is also an important difference in the matter of regularity of operation. If an automobile engine does not work well or needs adjustment, the car can be stopped and the driver can get out and fix it; in an airplane, on the contrary, not only can this not be done, but such irregular operation or lack of adjustment may mean the death of pilot or passengers or all.

An automobile engine works always upon the level, with the exception of climbing or descending hills—and then the angle is comparatively slight. The airplane engine must work as well upside down as right side up; must work at all intermediate angles from zero to 90 degrees; and must work inclined sideways at any or all angles.

The automobile engine works practically always at the one altitude above sea level and consequently at the one air pressure and under the one set of air conditions. The aerial engine works at all altitudes and may pass from a level of a few hundred feet to an altitude of 15,000 to 20,000 feet within twenty minutes. The differences in air pressure and conditions at these radically different levels, succeeding one another with rapidity, have a tremendous influence upon the engine as well as upon the machine and the driver.

All these points have been emphasized because they indicate how and why the automobile and the airplane engine not only are at present but always must be radically different in design, construction, and use. In outward appearance and in number and functions of parts and units used the two may be alike, but there the resemblance ceases.

Moreover, aside from differences in details of design and construction, the search for maximum power and speed, combined with minimum weight and minimum space occupied, or, more correctly, minimum head resistance, has brought out many types of motor not used for any other purpose. Thus, the rotary form of engine was used on only one automobile, which was built in very small quantities and given up many years ago. It is widely used in airplane work, its use is steadily increasing, and there are dozens of different designs. Similarly, the radial form of engine with stationary air-cooled cylinders has never been tried for motor cars, but finds wide and increasing use in airplanes. These two forms also involve the use of an odd number of cylinders. Except for the one car already mentioned (which had a five-cylinder motor) and another of about the same general description and fate (which had a three-cylinder vertical compound engine), all automobiles of recent years have had an even number of cylinders, such as two, four, six, eight, and, most recently, twelve. For airplane use the three-, five-, seven,- and nine-cylinder forms are common; doubles of these are also used, giving ten, fourteen, and eighteen cylinders.

The air-cooled motor is coming into more prominence, as its construction is better understood, and since its efficiency is much higher than that of the water-cooled motor. The Franklin and Holmes are both air-cooled motors, the Holmes being a comparatively new car in this field. For aeroplane work, the air-cooled motor is fast losing its prestige. American makers are using the water-cooled motor and almost all altitude and speed records are now held by planes equipped with water-cooled motors.

The crying demand for speed and more speed and the equally great outcry for enormous carrying capacity have produced some airplane engines of tremendous size, and have brought about their use in multiples. The practical limit of output per cylinder in airplane engines having been found to be between 45 and 50 horse-power, the matter of securing great power has now settled down to a question of how many cylinders can be used per engine advantageously and with very high powers, such as 2,000 horse-power, how many units used and where located.

TYPES OF AVIATION MOTORS

Classification. The general differences which have been outlined lead up to a classification of the types and forms of engines now in use, which may be put in tabular form as follows:

Air-Cooled*	Two-Cycle		4 cylinders (air-cooled V)	
			5 cylinders (air-cooled rotary)	
			6 cylinders	
	Four-Cycle	Radial	3 cylinders	and doubles: 6 cylinders
			5 cylinders	10 cylinders
			7 cylinders	14 cylinders
			9 cylinders	18 cylinders
			10 cylinders	20 cylinders
		Rotary	5 cylinders	and doubles: 10 cylinders
			7 cylinders	14 cylinders
			9 cylinders	18 cylinders
		Opposed	2 cylinders	
			12 cylinders	
		V type	4 cylinders	
			8 cylinders	
			12 cylinders	
Water-Cooled*	Radial		9 cylinders	
			10 cylinders	
	Vertical		6 cylinders in line	
			8 cylinders in line	
			12 cylinders in line	
			8 cylinders in 2 parallel lines of 4 each	
			16 cylinders in 2 parallel lines of 8 each	
	V-type‡		4 cylinders	
			8 cylinders	
			12 cylinders	
			16 cylinders	
	Fan, or **W**, type		12 cylinders in 3 sets of 4 each	
			18 cylinders in 3 sets of 6 each	
	X-type		16 cylinders in 4 sets of 4 each	

* These represent only the types and forms now constructed, not all the possible forms.

‡ V-type engines are made with varying angles between the cylinders (as the fan, or W, types probably will be also), but for this tabulation this difference is disregarded.

It will be interesting to note the construction of some of the principal types of engines in as much as the subject is a live one and airplane engine success is expected to be reflected in automobile work; thus, the use of small valves and high gas speeds in

Fig. 73. General View of Frederickson Five-Cylinder Two-Cycle Rotating Motor

airplane engines having been proved successful, it is now being tried on automobile engines. The use of more than two valves per cylinder, having found a great, in fact, almost universal adoption in aviation engines, is now being tried on motor car engines. The advanced metallurgical practice and shop practice necessary in aircraft engine construction is about to be reflected in better-built medium- and low-priced automobiles.

Air-Cooled Engines. *Frederickson.* There are very few two-cycle airplane engines, and not very many five-cylinder forms, so that the Frederickson motor shown in Fig. 73 presents several novelties. Its construction can be seen better in Fig. 74, where it will be noted that the connecting rods each carry a cone-shaped sliding sleeve actuated through a ball joint at the upper end to move sideways as the rotation of the crankshaft moves the rod sideways. In so doing the sliding sleeve opens and closes the con-

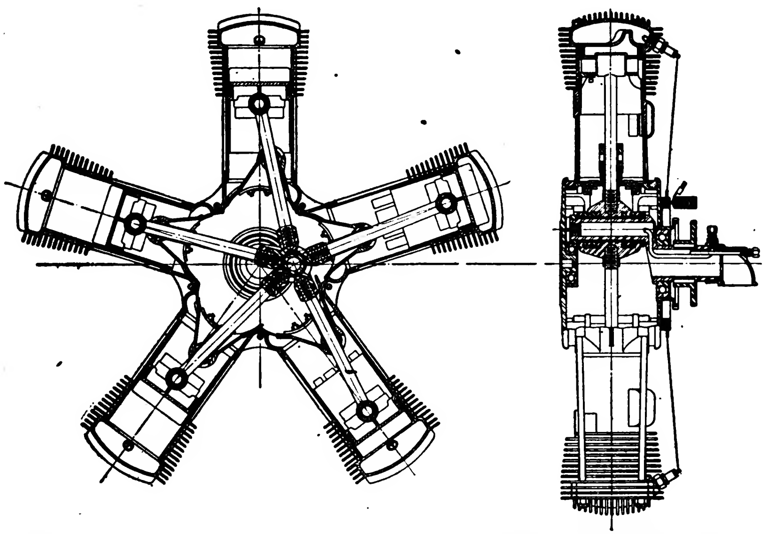


Fig. 74. Drawings Showing General Construction of Frederickson Five-Cylinder Motor

necting port between the crankcase where the charge is drawn in and compressed and the by-pass through which this partly compressed combustible mixture passes into the cylinders. To make this movement more clear, Fig. 75 shows it in flat projection, representing the successive steps in each cylinder base. At *A* the slide closes the port; at *B* it is beginning to open, and the piston has passed its lowest point and is beginning to rise. At *C* the piston is almost at the top, with the chamber full of gas; and the by-pass is cut off. At *D* the piston has passed the top center; the charge is presumably exploded; and the slide has cut off the connecting port.

This motor has five air-cooled cylinders, a $4\frac{1}{2}$-inch bore and a $3\frac{3}{4}$-inch stroke. It is rated at 70 h.p. and develops slightly more

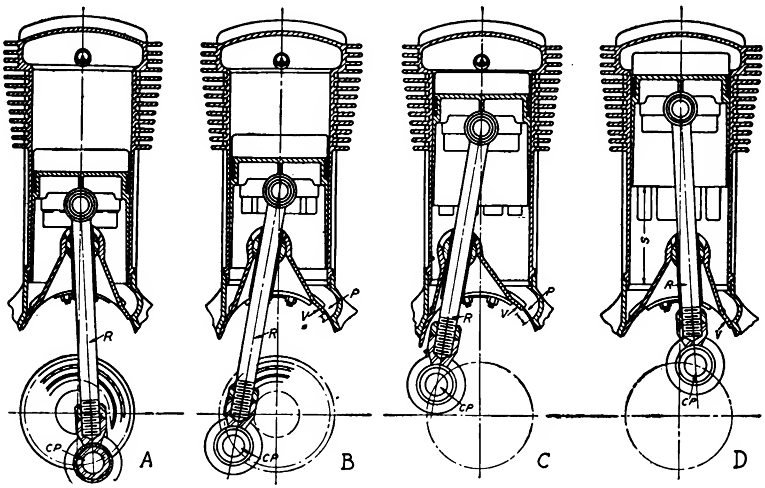


Fig. 75. Sketches Indicating Operation of Frederickson Sliding Port Valve
Courtesy World Motor Company, Burlington, Illinois

than that, and its weight, bare, is 180 pounds, giving 1 h.p. for each $2\frac{1}{2}$ pounds. This, it will be noted, is a single-crank engine,

Fig. 76. View of Marlin-Rockwell Two-Cylinder Airplane Engine
Courtesy Marlin-Rockwell Corporation, New Haven, Connecticut

as are, in fact, all radial and rotary engines, this feature contributing largely to their light total weight.

Marlin-Rockwell. A novel development for small one- and two-place sporting planes is the two-cylinder engine, like the Marlin-Rockwell shown in Fig. 76. Generally, the two-cylinder opposed type has shown such a lack of balance that it has gradually gone out of use, but for aeronautic work it is so compact and takes up so little space as to warrant its use. The engine shown is actually running, the shadow of the propeller being visi-

Fig. 77. Wasp Seven-Cylinder Radial Airplane Engine

ble. The bore is 5 inches, the stroke 6 inches, compression about 86 pounds, weight 134 pounds, power 72 h.p. at 1,825 r.p.m.—1 h.p. for each 1.86 pounds weight. This engine will be produced in a ten-cylinder radial air-cooled form, which is expected to develop 500 h.p. and weigh about 1½ pounds per h.p. Special attention is called to the fact that the cylinders are steel, machined out of a solid bar, whereas those shown in the preceding case were cast iron.

Wasp. Originally it was thought to be impossible to construct an air-cooled engine that would be efficient with a bore greater than 4½ inches, but the British ABC engine proved this sup-

Fig. 78. View of Jupiter Nine-Cylinder Radial Engine, Showing Operation of Four Valves per Cylinder

position to be wrong. The Wasp model shown in Fig. 77 is one of this type. It is a fixed radial seven-cylinder unit with 4¾-inch bore and 6¼-inch stroke and develops 200 h.p. at 1,800 r.p.m. It weighs but 320 pounds, which is 1.6 pounds per h.p. This motor is fitted with two carburetors feeding a circular inlet manifold, from which the separate radial inlet pipes to the cylinder heads lead.

Jupiter. As has been stated previously, the majority of airplane engines have more than one inlet and one exhaust valve per cylinder, the various designers using all the following combina-

Fig. 79. Front Appearance of Mercury Fourteen-Cylinder Radial Engine, Consisting of Two Staggered Sets of Seven Cylinders

tions: two inlets and one exhaust; two exhausts and one inlet; two of each; three inlets and two exhausts; and three exhausts and two inlets. In Fig. 78 is shown the Jupiter, another fixed radial air-cooled form, viewed from above so that the valve tappets and springs for the four valves per cylinder are plainly seen. This model is constructed by the Cosmos Engineering Company, Bristol, England, and has nine cylinders of $5\frac{3}{4}$-inch bore and

$7\frac{1}{2}$-inch stroke. It has a circular inlet manifold fed by three carburetors which is somewhat similar to that in the Wasp. The engine weighs 662 pounds and the normal output at 1,800 is 450 h.p., although the engine rates at 500 h.p. The former output gives 1.47 pounds per h.p., the latter 1.32 pounds.

All these forms are single-crank engines (which is also true of Fig. 80 discussed later); that is, all the connecting rods are attached to a single crankpin or, as is usually the case, to the master connecting rod. One rod is bolted to the pin, and all the others are either of the forked type and bolt around this master rod or are attached to ears constructed on it. This means that what might be called the thickness of the engine is equal to the thickness of a single cylinder.

Mercury. When a pair of motors is coupled together and a two-throw crank used, we get a double such as indicated in the tabular analysis of aerial engines. Thus, the fourteen-cylinder engine shown in Fig. 79 consists of two batteries of seven cylinders each. These are of the air-cooled fixed radial type and have a bore of $4\frac{3}{8}$ inches and a stroke of $5\frac{13}{16}$ inches. The normal output is 315 b.h.p. (brake horse-power) at 1,800 r.p.m., and the weight 587 pounds, or 1.86 pounds per h.p. There are three valves per cylinder, one inlet and two exhausts, while ignition is supplied by two seven-cylinder magnetos, and mixture by two carburetors feeding a circular manifold.

B.R.1 Type. The rotary form much resembles the fixed radial, the difference being merely in the valve-operating mechanism, ignition gearing, and the like, due provision being made for these to function as the cylinders rotate. Some of this mechanism may be seen in Fig. 80, which presents a detailed view of the B.R.1, a famous British war engine. This is a nine-cylinder rotating air-cooled form, of 4.72-inch bore and 6.66-inch stroke. It develops 150 h.p. at 1,250 r.p.m. on a weight of 2.67 pounds per b.h.p. In a larger size this engine as the B.R.2 developed 250 h.p. on 1.9 pounds per b.h.p.

Water-Cooled Engines. Coming next to the water-cooled forms, the six cylinders in line so often found in motor cars is not very widely used in airplanes. For one thing, it does not produce sufficient power, and furthermore, it occupies considerable space in from a vertical shaft at the front of the engine. It will be noted that the propeller is direct driven, not geared down. The Hall-Scott is a very reliable motor and was much used in aviation work during the War.

Curtiss V Type. No one form of engine has made as much headway in the United States as the V type, in which two groups of cylinders, usually normal four-, six-, or eight-cylinder groups, are used on a common crankcase with a common crankshaft, thus forming a single larger power unit. To achieve this result satis-

Fig. 85. Intake Side of Hall-Scott Six-Cylinder Vertical Type Airplane Engine
Courtesy Hall-Scott Motor Car Company, San Francisco, California

factorily, the cylinders are mounted at an angle, which varies from 90 degrees (45 degrees each side of the vertical) down to as little as 30 degrees. The larger angles were used at first to secure better balance in the running of the engine. Subsequently, it was found that the smaller angles not only gave a more compact and more accessible member but reduced head resistance also, which is a very important point in airplane engines. Beginning with two-cylinder V's used for motorcycles, the popularity of this form and its successful use have continued until now it is made in fours (two twos), eights (two fours), twelves (two sixes), and sixteens (two eights).

The most popular engine for high-power output, approximating 400 h.p., which type of motor was imperatively needed in the War in large quantities, is the twelve, or twin six. Among the most widely used forms of the twelve are the Curtiss, the Liberty, and the Packard.

The Curtiss was actually produced before the War, but has been so refined as a result of war experience that it is now pre-

Fig. 86. General View of Curtiss Twelve-Cylinder V-Type Aviation Motor
Courtesy Curtiss Aeroplane and Motor Company, Buffalo, New York

sented as a post-war model which is quite different from the antewar model. It will be noted in Fig. 86 that the six cylinder bases on each side (twelve in all) and the upper half of the crankcase are cast as a unit, the separate cylinder covers for each group being bolted on. The large cylinder-crankcase unit is of aluminum, and the cylinder liners, which are steel forgings machined all over with the cylinder heads integral, are threaded and screwed into the cast cylinder covers.

Fig. 87. End View of Liberty Motor at National Bureau of Standards, Washington, D.C.

The bore is $4\frac{1}{2}$ inches, the stroke is 6 inches, and the normal power rating is 400 h.p. at 2,500 r.p.m. while 420 h.p. is actually developed at 2,650 r.p.m. With this high rotative speed, a geared-down propeller is used, the regular gear reduction being 5:3. Two two-spark six-cylinder magnetos are used and two duplex carburetors. The motor without oil or water weighs 680 pounds, giving a dead weight per rated h.p. of 1.70 pounds.

Liberty V Type. The Liberty motor was developed purely and simply for war work by American engineers, along American lines, and specifically for American methods of production. It was not strictly an original design, many major elements and groups of elements being adopted bodily from existing American engines, notably the Packard aviation engine and the Hall-Scott. This made possible quick production, for these two companies started immediate manufacture of these adopted parts and in addition

Fig. 88. Side View of Liberty Motor Ready for Tests at National Bureau of Standards

started at once to instruct subcontractors on these same parts. All this was done practically without waiting for the design to be completed, tried out, and improved as a result of the try-outs; in fact, many thousand changes were made as production proceeded. More than 20,000 engines were produced, of which number more than 14,000 were delivered before November 11, 1918, and more than 16,000 during the calendar year 1918.

In Fig. 87 is shown an end view and in Fig. 88 a side view of a completed Liberty motor ready for tests at the Bureau of Standards. Fig. 89 gives a cross-section of the form using a cast cylinder, showing incidentally the crankshaft and connecting rods, piston and cylinder construction, valve location and operation, and water-jacketed inlet manifold.

Fig. 89. Cross-Section of Liberty Motor with Cast Cylinders

This motor has a bore of 5 inches and a stroke of 7 inches, and the cylinders are set 45 degrees apart ($22\frac{1}{2}$ degrees each side of the vertical). It normally develops 400 h.p. at 1,750 r.p.m., but 420 h.p. is produced in all tests and a special type, with special fuel, has produced 526 h.p. The weight is given as 806 pounds, but there is every reason for believing that this has been increased to approximately 825 pounds, 1.96 pounds per h.p. for the normal output and 1.56 pounds for the maximum. There are two duplex carburetors, two valves per cylinder, and battery ignition with two distributors, one on the end of each overhead camshaft and each one firing all twelve cylinders. A novelty is that the cylinders are hollow steel forgings with water jackets and valve port cages welded on.

Packard and Liberty. It has been stated that many parts of the Liberty design and subsequent construction were taken bodily from the Packard aviation engine, and it almost might be stated that without the Packard engine available as it was and when it was, the Liberty motor would have been quite different—perhaps not nearly so good—and certainly it would have been produced more slowly.

The original Packard was a small engine with a piston displacement of but 299 cubic inches, having been designed to be below the 300 cubic-inch racing-car motor limit established by the A.A.A. In the engine which was brought out late in 1915 the size was increased to a 4-inch bore by a 6-inch stroke, giving 905 cubic inches piston displacement. This engine, in turn, was improved late in 1916 and again early in 1917. Model 3 was the engine which immediately preceded the Liberty, the latter, however, having a larger bore and stroke because of the need for greater power. This process of development is shown in Fig. 90, the last motor at the right being a Packard-built Liberty motor, Model B. The similarity of this design to that of the preceding Packard motor will be noted.

Duesenberg. Among the very large motors must be mentioned the Duesenberg sixteen-cylinder V. This has a bore of 6 inches and a stroke of 7½ inches, the largest dimensions in the world with the exception of those of the large Fiat model, which has a bore of 6.69 inches and a stroke of 8.27 inches. In as much as the Fiat has only twelve cylinders while the Duesenberg has sixteen, the latter probably can be considered the largest single aviation

Fig. 90. Four Steps in Packard Aviation Engine Development Leading to Liberty Motor
Courtesy Packard Motor Car Company, Detroit, Michigan

Fig. 91. Sixteen-Cylinder Duesenberg Motor Under Test by Sprague Electric Testing Set Consisting of Three 300-Horsepower Dynamometers
Courtesy of Duesenberg Motors Corporation, Elizabeth, New Jersey

unit. It develops 700 h.p. driving the propeller direct and 800 h.p. driving through gears at 1,350 r.p.m.; it is rated at 850–900 h.p., so it must have reached a maximum between these two figures in the block tests. It has four $2\frac{1}{4}$-inch carburetors located on the outside of the cylinders, and ignition is provided either by two eight-cylinder magnetos or by battery ignition with distributors on the ends of the overhead camshafts, much as in the Liberty. As Fig. 91 shows, there are three valves per cylinder, arranged to work horizontally in the individual cylinders, although mounting the cylinders $22\frac{1}{2}$ degrees out of vertical brings these

Fig. 92. Sunbeam-Coatalen Eighteen-Cylinder Fan-Type Aviation Engine

valve axes just that much out of horizontal. With direct drive the weight is 1,390 pounds, and with gear reduction, 1,575 pounds, both less than 2 pounds per h.p.

Sunbeam-Coatalen Fan Type. Just as the radial and rotating engine builders have found it advantageous to produce high power by doubling or tripling the number of units used, thus producing the eighteen-, twenty-, and twenty-one-cylinder units, so in the production of high-powered V-type motors it has been found possible to double up. This gives a fan, or W type, the three sets of cylinders radiating from a common crankcase and crankshaft. Notable examples of this form include the Napier Lion twelve-cylinder unit consisting of three sets of four cylinders each, the central set being vertical and the two outer ones each inclined at an angle of 60 degrees.

In the Sunbeam eighteen, Fig. 92, there are three groups of six cylinders each. Six carburetors are used, each serving a block of three cylinders. There are six enclosed magnetos, each of the six-cylinder form, two sparks being furnished each cylinder. There are four valves per cylinder, two inlets and two exhausts, located in the head and operated by overhead camshafts. The engine is rated at 475 h.p. and takes no more space fore and aft than the same firm's six-cylinder engine of the same bore and stroke.

FUELS

Explosion motors can be made to work with any explosive mixture, those of air with *gaseous* fuels being naturally the mixtures most easily made and controlled. Mixtures of air with *liquid* fuels offer generally no particular difficulty, but those with *solid* fuels (such as powdered coal), although they have been tried, are not practicable on account of the ash which remains in the cylinder and rapidly abrades it. The single exception to the above statement is naphthalene. As will be described later, this is a solid fuel which has to be converted first to a liquid and then to a gas. It has been used with very great success abroad, and at a surprisingly low cost. A number of French and English commercial vehicles are now being operated with it.

Recent tests have shown that ether and kerosene are violent burning gases which produce a great many fuel knocks. Pennsylvania commercial gasoline is composed of compounds which cannot be separated and consequently does not produce many knocks. California gasoline—composed mainly of paraffin and naphthalene hydrocarbons—is distilled at a lower temperature than Pennsylvania gasoline and produces a little better results.

Mixtures of two different kinds of liquid fuels, and of a solid and a liquid fuel have generally been successful in cases where the two components were carefully chosen as to their suitability. As an example of this last statement, kerosene and gasoline mixtures will operate successfully where kerosene alone cannot. Many drivers economize on their fuel bills in this way, adding kerosene in quantities up to 40 per cent of the total to their gasoline. Similarly, with gasoline and alcohol, kerosene and alcohol, naphthalene in gasoline or kerosene (when the fuel is preheated), and others.

Table II gives the heat values for most of the commercially available fuel materials for explosion motors.

The liquid fuels are the only ones with which we are concerned, and of these gasoline is by far the most important, since it is the one almost exclusively used in the motors which we are considering.

Petroleum Products. Crude petroleum furnishes us the following commercial products for power purposes: Gasoline, naphtha, kerosene, gas oil, and crude oil.

These products are separated from the crude petroleum by distillation, *i.e.*, the crude petroleum is heated and its various products are given off as vapors; the lightest or most volatile product is given off first, then as the temperature is raised still higher, the next most volatile ingredient is given off, and so on through the entire list.

Rhigolene, sp. gr.* 0.60, distills off at 113° F.; cymogene, sp. gr. 0.625, at 122° F.; gasoline, sp. gr. 0.636 to 0.657, at from 140° to 158° F.; C. Naphtha, sometimes called benzine, sp. gr. 0.66 to 0.70, at from 158° to 216° F.; B. Naphtha, sp. gr. 0.71 to 0.72, at from 216° to 250° F.; A. Naphtha, sp. gr. 0.72 to 0.74, at from 250° to 300° F. Various authorities differ concerning these values, but the ones here given are safe average figures.

Gasoline. What we in America know as gasoline is really a combination of the above fractional distillates whose specific gravity runs from 0.63 to 0.74†. The boiling point of gasoline such as is usually used in explosion motors ranges from 150° to 180° F., and

*Specific gravity.

†Specific gravity is figured in two ways, one a decimal quantity and the other an arbitrary figure, as determined on the scale of an instrument known as a Baumé hydrometer. The latter figures are called degrees Baumé. This quantity is used in America more than the actual specific gravity, although the former is usually spoken of as the specific gravity. The increase in weight of the usual fuels, as we pass from the lighter gasoline up to kerosene, and beyond that to heavier forms, would be reflected by the specific gravity. As everyone knows, however, we speak of gasoline as getting poorer, now we get but 56 whereas we used to get 76, etc. These figures refer to the Baumé scale, which gives a lower reading for a heavier liquid. Thus specific gravity may be figured from degrees Baumé by adding the Baumé reading to 130, and then dividing 140 by the result, or

$$\text{Specific Gravity} = \frac{140}{130 + \text{Baumé}}$$

Using this on the figures given above, we find that 56 Baumé equals .75 s. g. and 76 Baumé, .68 s. g. The remark then translated into actual specific gravity would read, now we get .75 gasoline, whereas we used to get .68. This is correct, for present-day fuel is heavier than that of

TABLE II

Explosion Motor Fuels

Gases, Vapors, Liquids, and Solids	Heat Units* per Pound	Heat Units per Cubic Foot
Hydrogen	61,560	293.5
Carbon	14,540	
Crude Petroleum	18,360	
Kerosene	22,000	
Benzine	18,450	
Gasoline	18,000	
Alcohol, Methyl	20,000	
Denatured Ethyl Alcohol	13,000	
Acetylene	21,490	868
19-can. power Illuminating Gas		800
16-can. power Illuminating Gas		665
15-can. power Illuminating Gas		620
Gasoline Vapor	18,000	692
Natural Gas, Leechburg, Pa.		1050
Natural Gas, Pittsburg, Pa.		890
Water-Gas		290
Producer-Gas		150
Suction-Gas		135

*A heat unit or British thermal unit (B. T. U.) is, practically speaking, the quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit.

the flashing point‡ of the liquid ranges from 10° to 14° F. A mixture of one part of this gasoline vapor to 7.3 parts of air produces what is theoretically a perfect combustion mixture. A decrease in the proportion of air may leave, as a residue in the exhaust, unconsumed vapor, while an excess of air up to a limit of 10 parts of air to 1 part of vapor may increase the fuel efficiency. As a matter of fact, the modern automobile engine will operate on any mixture between 5 to 1 and 15 to 1.

A sample of gasoline of specific gravity 0.71 showed 83.8 per cent carbon, 15.5 per cent hydrogen, and 0.7 per cent impurities, and had a heating value of 18,000 B. T. U's per pound. The various grades of gasoline differ mostly by the percentage of hydrogen

five years ago. By referring to the s. g. of kerosene, it can be figured out readily that the actual case is that fuel now sold as gasoline contains a considerable amount of what was formerly sold separately as kerosene. Except for the name this is no disadvantage, but on the contrary an advantage so long as the carbureter will handle it, for kerosene contains a greater number of heat units per pound.

‡The flashing point of a substance is the lowest temperature at which it gives off vapor in sufficient amount to form with the surrounding air a mixture which is capable of burning when ignited.

contained. A gallon of liquid gasoline will in the form of a vapor fill about 160 cubic feet, or about 1,200 times its liquid bulk. Gasoline of 0.74 specific gravity will weigh 6.16 pounds per gallon, and its pure vapor, which occupies about 26 cubic feet per pound, has a heating value of 690 B.T.U's per cubic foot. The recent shortage of gasoline has produced many efficient kerosene vaporizers and caused a wide use of kerosene, both straight and mixed.

Kerosene. Kerosene is distilled from crude petroleum at a temperature of 300° to 500° F. Its specific gravity is 0.76 to 0.80.

Coal Gas. Coal gas has a specific gravity of 0.80, given off above 500° F. Crude oil remains after the above distillation process.

Miscellaneous Distillates. The former simple division of crude petroleum products into four parts, gasoline, kerosene, coal gas, and crude oil, is no longer correct. The tremendous demand for motorcar and boat fuels has brought about the need for a larger percentage of gasoline, which has been supplied by making it heavier through the inclusion of much of what was formerly sold as kerosene. To keep up the quantity of the latter, this too has been made heavier by the inclusion of considerable quantities of what formerly was distilled over as coal gas. In addition, the distillation is further split up by the separation of the naphthas, first the lighter benzine naphtha, then naphtha, then benzine. Finally, what was formerly lumped as crude oil remainder is now split up into a number of different oils, with the final remainder, now called "residuum" or "tailings". The latter is sometimes fluid, but more often a viscous semi-solid dark-green or dark-brown substance with an unpleasant odor. As a matter of fact, several carbureters have been developed on the Pacific Coast, by means of which this former waste material can be first liquefied, then converted into a gas and burned in motor truck engines. When this is done, an important economy is effected, for this material sells for about three cents a gallon, and in some localities as low as 1½ cents, when sold in barrel lots.

Denatured Alcohol. There are two kinds of alcohol, viz, (1) ethyl alcohol (C_2H_6O), which can be made from corn, rye, rice, molasses, beets, or potatoes, by a process of fermentation and distillation; and (2) methyl or wood alcohol (CH_4O), which is obtained from the destructive distillation of wood. Ethyl alcohol is that which is present in alcoholic beverages; wood alcohol is a virulent poison. Denatured alcohol is ethyl alcohol which has been rendered unpalatable and unfit for consumption by the addition of wood alcohol and a little benzine or other substance. It gives up about 11,800 B. T. U's per pound on burning; consequently it does not give up much more than one-half as much heat per pound as gasoline or kerosene. The weight and volume of denatured alcohol required to develop a given power in a motor is considerably greater than the amount of gasoline for the same power; and, therefore, if a gasoline motor is to be used with alcohol, the orifices in the carbureter or other spraying device have to be enlarged so as to admit a greater volume of the liquid. Wood alcohol can not be used by itself in a motor, as it corrodes the cylinder. Denatured alcohol, in its volatility, lies between gasoline and kerosene, the amount of vapor which it gives off to air that passes over it being generally sufficient to give an explosive mixture, if the temperature of the air and alcohol are above 70° F. With an ordinary spray carbureter a considerable excess of alcohol may be sent to the cylinders, as such carbureters act also as atomizers.

Recent tests have demonstrated that any gasoline or kerosene motor can operate with alcohol without any structural changes, and that about 1.8 times as much alcohol as gasoline is required to develop the same power. Alcohol can be used with greater compression, as there is little danger of pre-ignition through too much compression on account of its comparatively high ignition temperature and also because it is always mixed with some water. An alcohol motor can be made to give somewhat higher power than a gasoline motor of the same size. It is not as sensitive to poor adjustment of the explosive mixture; that is, it will work with a great range of strength of mixture, and it does not accumulate a deposit of carbon inside the motor. An explosion motor of good design should use about 1.15 pounds of alcohol per brake-horse-power hour; of gasoline, 0.7 pound.

Despite all these advantages, denatured alcohol as a fuel has not come into wide use, partly because of its high price as compared with gasoline and kerosene, partly on account of poor distributing facilities, and partly for other reasons. It has, however, attained a considerable use among motor car owners as an anti-freezing solution and as a decarbonizer. For the former, a small quantity is added to the water in the radiator in the winter months, reducing the temperature at which this will freeze, according to the quantity added. It is possible to add enough to give a solution which will not freeze until 32 degrees below zero is reached. As a decarbonizer or remover of carbon formations in the cylinder, denatured alcohol is excellent, while its use is the essence of simplicity. It is to be hoped that the production will be materially increased in the next few years so as to reduce the price, increase its availability, and thus help out the fast-failing gasoline supply.

Other Automobile Fuels. *Benzol.* In England, a fuel called "benzol" is used to a considerable extent. This is a by-product of the destructive distillation of coal, that is, it is produced in the manufacture of coal gas. In large plants a considerable quantity can be made, for the yield is something like three gallons per ton of coal burned. It is naturally a foul-smelling, dark-brown liquid, but by a refining process is made a transparent white, like water, and the odor partly removed. It has a specific gravity of .88 at 60 degrees F., a flash point of 32 degrees F., and a heating value of about 17,250 B. T. U's per pound. Although not as volatile as gasoline, it starts readily and, when carefully refined, does not leave a residue, or carbonize in the motor. In Germany the lack of gasoline has brought forth a benzol-alcohol mixture. Up to 1 benzol to 5 alcohol it gives better mileage than gasoline or pure benzol.

Electrine. In France, a mixed fuel composed of half benzol and half denatured alcohol is much used, this bearing a number of trade names. One of these, "Electrine," has an s.g. at 15° C. of .835.

Naphthalene. Mention has been made previously of a solid fuel, naphthalene. This is a white solid substance, produced during the manufacture of gas from coal, and previously was a waste product. It now sells at a few cents a pound. In a less pure state it is well known to all in the form of camphor balls, so-called. To use this as a fuel in an automobile engine, it must be melted to a liquid, then turned into a gas and mixed with the right proportion of air. None of these offer any particular difficulty, and it has been used abroad with marked success, particularly on a long test by a 40-horse-power motor truck. After the trip, the cost, using naphthalene, figured out to 0.6 of a cent per horse-power hour, while a similar truck, running side by side with this one, on gasoline cost 2.6 cents per horse-power hour. In its first trial then, this fuel showed four times the economy of gasoline.

Solid Gasoline. A number of attempts have been made to produce gasoline in a solidified form so that it could be handled more easily and much more safely. In Europe, this has been accomplished satisfactorily, the resulting substance being of about the consistence of jelly. In general its properties are about the same as liquid gasoline, except that it occupies less space, a gallon when solidified taking up about 185 cubic inches as compared with 231 before. The principal argument against its use is the size of the vaporizing device needed to change it to a gas and add air.

War-Time Fuel Developments. It took the War and its tremendous demands for fuel for thousands of war trucks, cars, airplanes, motor patrol boats, airships, tanks, and other automotive units to show the public how scant was the margin between the actual production of crude oil and the motor fuel produced from this and the actual consumption. Patriotic efforts and the high price of all oil products brought about greatly increased production in 1918; the total crude petroleum produced in the United States in that year reached 345,896,000 barrels, the average monthly production having been increased from about 25,000,000 barrels to almost 30,000,000 barrels. At the same time the Mexican oil field outputs, imported mainly into this country, were increased very materially. From the domestic total about 2,250,000,000 gallons of motor fuel were produced, this being slightly over 15 per cent of the total world supply.

Against this fuel production there are now in use more than 7,700,000 automobiles, while the year 1920 will add 2,700,000 pleasure cars and trucks. At the end of 1920, it is authoritatively asserted there will be more than 10,000,000 automotive units in service, exclusive of aeroplanes and allowing 400,000 to go out of use for various reasons. Each unit consumes approximately 400 gallons of fuel per year, which makes a total of 4,000,000,000 gallons a year. With these figures in view, it will be necessary to develop the gas motor to a higher point of efficiency so as to utilize the available fuel to the best advantage.

During the War many special fuels were developed to meet the demands, and some of these must be used, or modifications of them, in peace times, as the above figures indicate. Among the methods presented for increasing the fuel supply are the following: more efficient distillation methods to stop refining losses; raising the end point in distilling to make more but uniformly heavier fuel; recovery of gasoline now lost in refinery operations; and wider use of "cracking" processes. With the use of the first three methods an increase of 30 per cent in fuels suitable for automotive units is predicted, and by adding the fourth an additional 100 per cent.

There are the further possibilities of a huge production of alcohol by breweries, which are preeminently fitted for this work, of a big production of benzol from by-product coke ovens, and of the addition of large quantities of fuel from the shale beds of Colorado and Utah, from extensions of the natural-gas condensation processes, and from other sources. The idea is to mix all these to make a single fairly uniform fuel, which will not be gasoline, but will be heavier than the present gasoline and will contain practically all the elements of the present kerosene and benzol, most of the elements of alcohol, and all the other fuels.

The so-called Liberty fuel was developed in this way by mixing, and it was found that it consists of approximately 65 per cent benzol, 25 to 30 per cent kerosene, and the balance amyl acetate, naphthalene, alcohol, other volatile liquids not yet determined, and dissolved solids. This fuel has a B.T.U. content of 18,590 per pound and a heating value of 131,200 B.T.U.'s per U.S. gallon. Its specific gravity is 0.848 at 60° F. and its Baumé is 35.0 degrees, a gallon weighing 7.07 pounds. Equal power output and fuel consumption only 3 per cent greater than commercial gasoline were shown in actual tests of various engines for car, airplane, and truck uses. In a few instances greater power was developed.

Subsequently, it was found that this fuel produces gumming to an almost impossible extent, the tendency being to gum up carburetors, spark plugs, cylinder heads, and other parts. It was discovered further that it crystallizes at 18° F. and solidifies completely at 15° F., so that it would be impossible to use it at any low temperature. Thus, despite its apparent value and desirable qualities, it is not suitable for wide use. Moreover, its high benzol content makes the possible output of Liberty fuel small as the total benzol now produced in the United States is only 3,500 barrels a day; this means that this country could produce a maximum of only 82,000,000 to 83,000,000 gallons a year of Liberty fuel, too small an amount to warrant the risks of gumming, freezing, and possible bad odor.

The fuel problem is thus very little nearer solution, although some progress was made during the War. In spite of its serious defects, the performance of Liberty fuel showed that there is the possibility of developing a substitute for gasoline, it being in many ways the equal of commercial gasoline and yet containing no gasoline whatever, but only the heavier kerosene and liquids or substances not produced from crude petroleum.

In England 32,000,000 gallons of benzol were produced in 1918, 11,000,000 gallons by gas companies and 21,000,000 gallons from coking ovens. This was 16 per cent of a total of 200,000,000 gallons of motor spirit consumed in Great Britain. It is now pointed out that by diminishing slightly the legal calorific value of gas, the gas companies could increase their output to 40,000,000 gallons of benzol a year, making the grand total 61,000,000 gallons. Attention is also called to the fact that many London busses are running regularly and successfully on a mixture of 25 per cent benzol and 75 per cent duty-free domestic alcohol. On this basis the benzol produced in 1918 would make (with the suitable alcohol addition) half the country's total motor spirit, without using any gasoline or kerosene whatever.

Future Fuel a Mixture. These items indicate that the motor fuel of the near future will be a mixture and not a single separate liquid, as gasoline, kerosene, benzol, or alcohol. Moreover, this mixture will have qualities the present fuel does not, and its universal use will modifiy engine design in general and carburetor design in particular.

Gas and Gas Generators. Scarcity of fuel and unusually high prices in the last two years have brought out the use of gas in various forms. An English truck (and motor bus), which has been very successful, uses ordinary gas from the city's mains, compressed into tanks and diluted with air as carbureted and used. A car has been developed to use a very high grade gas produced from peat. American workers have brought out a device which will handle water, gas, and other forms having high fuel value and which can be compressed readily. In outward appearance, these cars do not differ from any other, the carburetor or gasifier and the extra tank, which is larger than an ordinary gasoline tank, being the only differences. This use of gas opens up wide possibilities for the future.

FUEL MIXTURE

Explosibility. There is no one process in the cycle of operations in an internal combustion motor which has more influence on its reliability than the proper mixing of the gasoline vapor with the air and its introduction into the cylinder. If a combustible vapor be mixed with air in certain proportions, the result is an explosive mixture. When a portion of the mixture is ignited—say, by a spark from the ignition system—the combustion travels to the surrounding mixture at a rate depending upon (1) the chemical affinity of the gas or vapor for oxygen; (2) the heat of combustion of the gas or vapor; (3) the proportion of atmospheric oxygen present in the mixture; and (4) the pressure. Now when a substance, like gasoline vapor, enters into union with oxygen, it does so in certain definite proportions. Therefore, when the mixture contains an insufficient supply of air (a rich mixture, as it is called) there will be a quantity of unburned gas or vapor left over. On the other hand, if there is present any excess of air over the amount required for the reaction (a lean mixture), this excess in turn will be left over. The highest pressures and temperatures result from the explosion of those mixtures which contain just sufficient oxygen to support the combustion of the explosive vapor contained in the charge. According to Clerk, the highest velocity of flame propagation occurs when the vapor is a trifle in excess of that contained in the ideal mixture.

The proper proportions of gas and air depend on the nature of the gas and differ in every case. The range between the minimum and maximum proportions by volume required is termed the *explosive range* of that gas or vapor.

Any variation in the composition of the mixture either way from the theoretical ratio results in decreasing the maximum pressures and temperatures of combustion and in making the explosion occur more and more slowly until finally we have a slow combustion, *i.e.*, the mixture ceases to be explosive. It has been found that approximately 15 pounds of air are required per pound of gasoline for the true explosion mixture.

In actual practice, to make sure that complete combustion results, an excess of air is usually employed, the latter being beneficial also in that the maximum temperatures are reduced, which reduce the per cent of heat lost to the cooling water. This excess also reduces the danger of pre-ignition. The theoretical ratio of the number of volumes of air per unit volume of gasoline vapor for the true explosive mixture is between 25 and 30, while the explosive range of the mixture extends below these values to about 19.5 and above them to a value of about 40.5.

FUEL KNOCK

General Analysis

Fuel Knock. There are a variety of causes for the many different knocks which are continually developing in motors. Among these knocks is the one like a sharp clang, often called a pre-ignition knock, as it disappears when the spark is retarded. But this knock is not an explosion occurring before the piston has reached upper dead center, for it has been proved by accurate tests that it occurs after the piston has started down.

The question then arises: How can an explosion which occurs after upper dead center cause such a loud "slap" at the moment the knock occurs? The answer is: There are a great number of small explosions occurring simultaneously when the fuel changes its chemical construction. These small explosions combine to form violent explosions, hence the result is the fuel knock.

Gasoline is a very complex chemical compound, its main constituents being carbon and hydrogen. Before going farther, it is advisable to consider a few principles of chemistry. Water, for instance, is a chemical compound; its formula is H_2O. This symbol means that there are two parts of hydrogen to one part of oxygen in each particle (or molecule) of water. These parts are called atoms, and therefore two atoms of hydrogen mix with one atom of oxygen, forming one molecule of water. Gasoline and kerosene are chemical compounds. Neither of them has an exact chemical representation, as the component elements occur in variable proportions according to the temperature required when refining takes place.

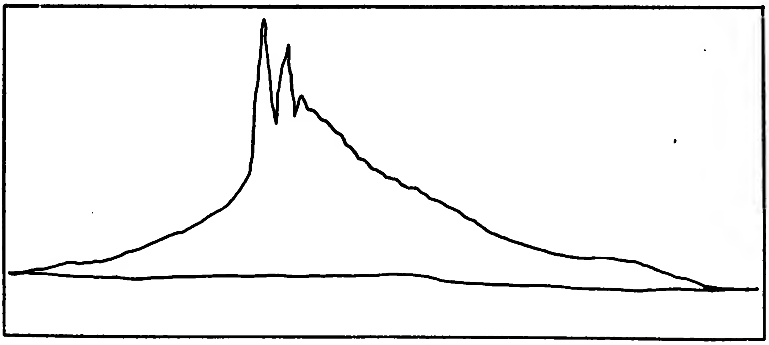


Fig. 92a. Card Showing the Kerosene Fuel Knock

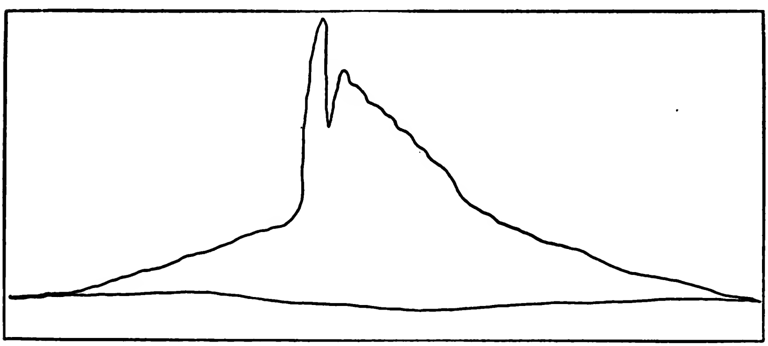


Fig. 92b. Card Showing the Ether Fuel Knock

The formula C_6H_{14} represents a good grade of gasoline. As gasoline is a blended mixture of various grades of refined hydrocarbons, its representation will vary between the limits of C_5H_{12} and C_8H_{18}. It should now be easily seen that gasoline is made up of fractional distillates. When a spark occurs, there is a certain lapse of time between the moment of ignition and complete combustion or burning of the fuel. The fuel which is most volatile will be ignited first and burn much quicker than the fuels having a heavier gravity. The less volatile fuels will be consumed in an order determined by their gravity, the heaviest fuel burning last. Just after the spark occurs, the fuel undergoes a complete chemical change. The fuel particles start to slide on one another, so breaking up their structure that the atoms—which had previously formed molecules—now represent something else. This action is similar to the bursting of a flywheel, where the force causes a few molecules to give way and allow the wheel to separate into several pieces, but the molecules in these pieces are unchanged. In the case of the fuel, the millions of molecules, sliding around on each other, cause a serious detonation or piston "slap"; this develops the fuel knock. The first detonation occurs when the heat and the pressure are sufficient to cause the fraction of the fuel with the highest flash point to catch fire. The burning of this distillate raises the temperature and pressure to a point where the distillate of the next highest gravity will ignite. In like method, the burning of all the different fuels is accomplished.

A great number of these free atoms combine to form compounds of hydrogen and carbon, as atoms having unlike polarity have a mutual attraction. A few hydrogen atoms become scattered through the mixture, and as hydrogen burns very rapidly, a series of small explosions occur at various points in the combustion chamber. When these explosions combine into one explosion, a fuel knock is produced. As the hydrogen is free, it burns very rapidly and the flame darts from one atom to another with great rapidity. There are perhaps several million of these atoms catching fire at the same instant, the atoms belonging to the most volatile fractional distillates igniting first. A few of the remaining atoms then unite with the next lowest fractional distillate and cause a second detonation, and so on until the entire explosive mixture is consumed.

This knock may be reduced or completely eliminated by lowering the compression, but to do this is not advisable, as it will also decrease the power and efficiency of the motor. If the compression is decreased, the temperature of the explosion will also be decreased, but this temperature will not be hot enough to start the series of auxiliary hydrocarbon explosions. If a compound is added which will combine with the left-over hydrogen atom, a fuel of uniform burning rate will be formed, thus eliminating the knock. If 1.5 per cent of iodine, by weight, is added, the necessary element will be furnished which will combine with the free hydrogen.

Many engines built prior to 1913 and operated on the present fuel are susceptible to this fuel knock. The compression pressure of these motors is fairly high, ranging between 75 and 90 pounds, which, in some cases, is 20 pounds greater than that used in the modern motor. A fuel knock will vary to a great extent as the result of slight changes, for instance, changes in the spark-plug location, the valve sizes, the manifold arrangement, the shape of the combustion chamber, and the carburetion.

HORSE-POWER AND RATING CALCULATIONS

The unit of mechanical power, the *horse-power,* is equivalent to the performance of 33,000 foot-pounds of work per minute. In a four-cycle motor, as an explosion occurs every two revolutions, there are twice as many revolutions as explosions or cycles per minute. To calculate the horse-power of such a motor, therefore, the number of foot-pounds of work done at each explosion (call it W) must be multiplied by the number of explosions or by one-half the number of revolutions per minute $\left(\frac{\text{r.p.m.}}{2}\right)$, and this product divided by 33,000. The result will be the horse-power (h. p.) of the motor. Expressing this in equation form it becomes

$$\text{h.p.} = \frac{W \times \text{r.p.m.}}{2 \times 33{,}000}$$

Indicated Horse-Power. In actual practice the indicated horse-power of an automobile engine means little or nothing. What is needed is a simple, easily understood formula by means of which anyone can figure out a rating horse-power. This is used for purposes of comparison, for a basis of automobile taxation, for legal purposes, handicapping races, and otherwise. In gasoline engines for stationary power purposes, and, at times, in automobile motors, the indicated horse-power is desired for figuring. When this is the case, it is figured from the indicator card by means of the following formula:

$$\text{i. h. p.} = \frac{PLANK}{33,000}$$

in which P is mean effective pressure (m.e.p.) in pounds per square inch; L, length of stroke in feet; A, piston area in square inches; N, number of cycles per minute or one-half the number of revolutions per minute; and K, number of cylinders.

The mean effective pressure P is obtained from the indicator card by going around it with a planimeter* in the way in which it was traced, that is, in order *1-2-3-4-5-1*, Fig. 93. The indicator card consists really of two areas or loops, of which *3-4-5* represents positive work, and *1-2* negative work. The total work done on the piston is represented by the difference between these two areas. The small area *1-2* represents the work done in overcoming the friction resistance of the gas when being admitted to and expelled from the cylinder. It is work that has to be done by the motor; is a definite loss of power; and should be made as small as possible. The area *3-4-5* is the work that is actually done on the piston, less the work required to compress the gas; it is the true work of the cycle, all of which would be available for driving the engine, were it not for the gas-friction resistances represented by the area *1-2*. See also the negative loop, Fig. 72. If a planimeter is made to trace the diagram in the order in which it was drawn, it will go around the area *1-2* and *3-4-5* in opposite directions; that is, if it goes around one clockwise, it will go around the other counter-clockwise. The consequence is that the readings of the planimeter will give the desired difference in square inches between the two areas *3-4-5* and *1-2*. The mean effective pressure is then obtained in the usual manner by dividing this area by the length of the diagram and multiplying by the "scale" or constant of the indicator spring.

Mechanical Efficiency. The figures just given refer to the indicated horse-power (i.h.p.), which is the work done upon the piston by the charge. The object of the motor, however, is to drive some other machine or apparatus. It is, therefore, important to rec-

* A planimeter is an instrument which indicates the area of an irregular figure by tracing the boundary of the figure. The area of the indicator card may be approximated by dividing it into a series of rectangles and taking the sum of the areas.

ognize the distinction between the indicated work done in the cylinder and that quantity of work, always smaller, which the motor does against external resistance. This work against external resistance is termed the *brake horse-power* (b.h.p.), or *delivered horse-power* (d.h.p.). The term brake horse-power is usually applied to the power absorbed by a friction brake attached to the rim of the flywheel or to the shaft.

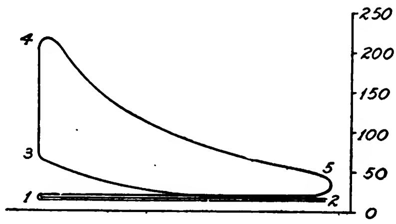


Fig. 93. Indicator Card from Otto Cycle Motor

Prony Brake. The most commonly applied form of friction brake is that one known as a prony brake, one form of which is shown in Fig. 94. This device consists of a series of wood blocks *D* connected by a leather or iron strap and arranged so as to rub on the surface of the flywheel of the engine to be tested. The two arms of the brake rest on a pair of scales. The hand wheel, shown at *E*, is for varying the amount of friction. The horizontal distance *R* from the center of the wheel to the end of the arms is known as the brake arm.

In using the brake, the load is applied by turning the screw *E* and is measured by the reading on the scale. Before the load is applied, and the brake arms are resting on the scale, as shown in the figure, the scale must be read to determine the amount required to balance the overhanging brake arms. This amount must be deducted

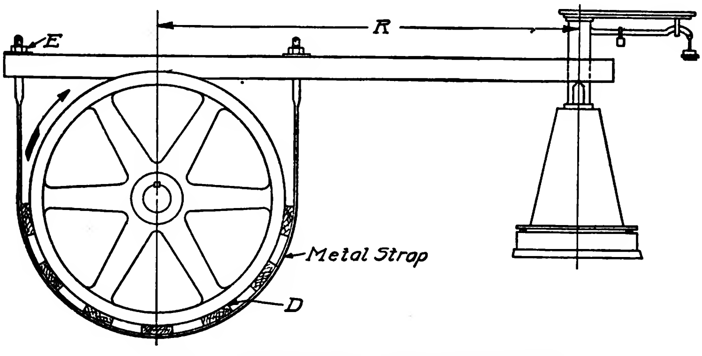


Fig. 94. Prony Brake for Testing Motor Efficiency

from the reading of the scales when the load is applied, in order to give the net load. This may be done in either one of two ways:

The scales can be turned back and readjusted so as to record nothing when the break arm is resting on the scales; or, without correcting the scales, the deduction can be made when the final power is figured out, that is, the weight which the brake arm alone depresses on the scale beam must be subtracted from the total scale reading to give the net load on the scale.

The b.h.p. is calculated by the formula

$$\text{b.h.p.}=\frac{2\pi anW}{33{,}000}$$

in which n is revolutions per minute; a, length of brake arm in feet; W, the net load on the scales; and π, 3.1416.
The formula then assumes the form

$$\text{b.h.p.}=\frac{anW}{5252}$$

and with any given brake, the length a will be a fixed quantity, so that that also can be inserted. Suppose it happens to be 4 feet. Then the formula becomes

$$\text{b.h.p.}=\frac{nW}{1313}$$

All the repairman needs to construct a brake of this kind is the scales, a good hardwood beam of about 3 x 5 inches in section, a band of strap iron, a few wooden blocks to fasten to it, and a thumb nut with which to tighten it. For general use, it is best to have a special shop flywheel and make the band to fit this. Then when an engine is to be tested, the flywheel can be removed and the shop wheel bolted on in its place. Otherwise, there would be a lot of bother with the difference in the sizes and shapes of various engine flywheels, and the consequent difficulties of making the brake fit.

The brake horse-power is less than the indicated horse-power by an amount whichréspresents the loss due to friction of one kind and another in the mechanism of the motor itself.

The ratio of the b.h.p. to the i.h.p. is the *mechanical efficiency* of the motor, that is,

$$\text{mechanical efficiency}=\frac{\text{b.h.p.}}{\text{i.h.p.}}$$

Good motors have a mechanical efficiency of from 80 to 95 per cent, referring to modern automobile motors. Other motors, as stationary gasoline or gas engines, have a lower figure, say from 70 to 80 or, possibly, 82.

Estimating Motor Horse-Power. An inspection of the i.h.p. formula above given will show that if we are able to presuppose some certain mean effective pressure (m.e.p.), we have the most practical way of estimating the horse-power of any explosion motor whose length of stroke, piston area, and revolutions per minute are known.

The mean effective pressure secured in gasoline engine practice ranges from a minimum of 45 or 50 pounds to the square inch, to a maximum of about 125 pounds to the square inch. For the above purpose, 60 pounds may be assumed as very close to the m.e.p. of most automobile motors, though in sleeve valve and other types in which the combustion chamber is approximately spherical, the mean effective pressure will often be as high as 85 pounds. In any case, for a given type of motor there is never any considerable variation from a certain mean effective pressure that is characteristic of its type. This pressure being known, it becomes a matter of simple arithmetic to calculate the power from a given stroke, cylinder diameter, or piston area, at a given number of revolutions per minute, *i.e.*, by a direct substitution in the formula for i.h.p. given on page 114.

For two-cycle motors the compression is usually lower than in the four-cycle type, and it is safe to assume that the m.e.p. is not over 70 to 75 pounds. In applying the formula for the i.h.p. to the two-cycle motor, N becomes the number of revolutions per minute, since there is an explosion in each revolution.

Electric Dynamometer. The electric absorption type of dynamometer is a testing device, operating on the same principle as the Prony brake. It is, however, more accurate, more complete, easier to use and, in other ways, has a distinct advantage over the older form of hand-applied brake, which is now nearly obsolete, as well as over other forms of absorption brake, such as the coil of rope form, the water brake, the centrifugal pump, the air fan, and others. The electric type is practically a measuring dynamo, which is driven by the engine being tested and, when so driven a magnetic action is set up between its field pieces and armature, which can be measured precisely in electrical units. When this is done, the quantity, in foot-pounds of energy exerted through a given radius, is an exact measure of the torque or turning power of the engine.

The radius, like that of the brake arm of the hand-operated form, may be of any desired length, but if $15\frac{25}{32}$ inches is used, this simplifies the usual Prony brake formula to

$$\text{b.h.p.} = \frac{\text{weight in pounds} \times \text{r.p.m.}}{4{,}000}$$

in which the weight is measured by means of a pair of scales, usually of the double-beam type, with a fine reading to pounds and tenths on one beam and a rougher reading for quick but approximate determinations on the other. The revolutions will be indicated by

Fig. 95. Electric Dynamometer for Testing High-Speed Automobile Engines
Courtesy of Sprague Electric Works, New York City

means of an electric speedometer, supplemented usually by a form of tachometer to be used as a check. With but two variable quantities, the weight and speed, it is possible to lay down the curves for every possible combination of speed and weight, so that the power can be read at a glance by simply following out the two lines to their point of intersection.

With this form of device, it is possible to have the electric loading arranged in such a manner that it resembles the well-known rheostat used on trolley cars, and like it is turned on by means of a rotating handle or wheel. In that case, the tester simply sits at a table making his readings and gradually turning the wheel to increase or decrease the load.

Auxiliary Apparatus. When using electrical testing apparatus of this kind, it is possible to have many additional auxiliary features of value. For instance, by turning on the electric current, the dynamo acts as a starting motor to turn the engine over, until it starts. In case the test is to be a long-drawn one, the electrical energy generated need not be wasted as with other forms of brakes, but can be wired to electric motors elsewhere in the plant and utilized, this disposition of it having no influence whatever upon the measurement of the energy. In addition, automatic or self-registering instruments may be had, so that an operator is not needed, after the test has been started, except to stop it. Further, an automatic gasoline-measuring scale may be had, which is electrically operated, this being constructed to register the number of revolutions and the elapsed time for each pound of fuel consumed.

Fig. 95 shows the complete dynamometer with scales and measuring devices, as made by the Sprague Company, while Fig. 96 shows the complete layout of a similar outfit as made by the Diehl Manufacturing Company, this indicating the actual test of a six-cylinder motor.

In Fig. 97 is shown a modern testing room with a number of 8-V motors mounted for testing. This view shows the importance attached to preliminary testing of motors by big manufacturers.

Importance of Testing to Repair Man. It is particularly important that the repair man be well equipped in the matter of testing apparatus. In fact, every well-equipped garage should have some form of horsepower testing outfit, either one of those just described or else some similar homemade affair. What is needed by the repair man, however, is not so much a measuring apparatus as a loading device, whereby loads may be thrown upon engines which have hidden troubles, or which have just been repaired, so as to allow the motor to act as it would when actually pulling the car with a standard load.

An advantage of a loading device of this kind is that troubles which are otherwise hard to find can be discovered in a short time inside the shop instead of after long, extended, and expensive outside runs to determine the exact part which is at fault. With a loading device, a stethoscope (such as is described elsewhere in this work), and a full set of electrical testing instruments, a garage or repair man, who is onto his job, can in a short time locate the trouble with any engine, transmission, or any other part of a complete car. With the trouble located, the difficulty is half overcome.

Fig. 96. Electric Dynamometer Coupled up to Six-Cylinder Engine for Test
Courtesy of Diehl Manufacturing Company, Elizabeth, New Jersey

The repair man can buy at a reasonable figure testing outfits which are designed solely for the purpose of finding out electrical sources of troubles (and many others) in the shortest possible time. These are called trouble-finding or trouble-shooting outfits, and a number of them are now marketed.

Lacking a stethoscope to use with a testing or loading outfit, many garage men make use of a substitute in the form of a plain steel rod of small diameter. By holding one end of this rod between the teeth with the other end placed on or near the suspected engine part, one can train the ear to recognize, by means of the vibrations

Fig. 97. Typical Modern Well-Equipped Testing Room, Showing Seventeen Eight-Cylinder Motors on Test
Courtesy of F. B. Stearns Company, Cleveland, Ohio

which come to it through the rod and teeth, whether or not the part is running exactly right. In many cases, such a testing or loading outfit is a good preventive of trouble, enabling the owner to locate the trouble and correct it before it can get serious enough to cause excessive difficulty or expense. The adage "A stitch in time saves nine" applies equally well to an automobile and many owners would have much less trouble if they or their chauffeurs understood this better.

Rating. At one time practically all automobile engines were given a hyphenated rating, as for instance, 30-60 horsepower. This represented the power developed at a normal speed and the maximum output of which it was capable. In general, the difference was not as great as in the example given, although this represents an actual rating of a well-known American car motor. As has been stated, rating allows of a comparison when the same basis is used by everyone; that is all it is for. Now, ratings are worked out from various formulas. The one used throughout the United States is that known as the S.A.E. formula, after the Society of Automotive Engineers, sponsors for it. This was formerly called the A.L.A.M. formula because the now-defunct Association of Licensed Automobile Manufacturers placed their seal of approval upon it, and brought it into general use in this country. It originated in England, where it is still in universal use as the R.A.C. formula. It is as follows:

$$\text{h.p.} = \frac{D^2N}{2.5}$$

in which D is the diameter of the cylinder bore in inches and N is the number of cylinders. As N is usually 4, 6, or 8, it is possible to simplify the formula to:

$$\text{h.p.} = 1.6D^2 \text{ (for four cylinders)}$$
$$\text{h.p.} = 2.4D^2 \text{ (for six cylinders)}$$
$$\text{h.p.} = 3.2D^2 \text{ (for eight cylinders)}$$

While no account of the stroke appears to have been taken in figuring this out, yet in the original determination of the value of the constant 2.5 used, 1,000 feet per minute was considered as a fair average piston speed. As the length of the stroke determines the piston speed, it is apparent that consideration was given to the length of the stroke, and that this factor is in the formula. However, for the benefit of those desiring the length of the stroke L incorporated, the following formulas have been developed and are in use: Roberts' formula,

$$\text{h.p.} = \frac{D^2 L N R}{1800}$$

Dendy-Marshall formula,

$$\text{h.p.} = \frac{D^2 S N}{12}$$

substituting the number of cylinders, this becomes

$$\text{h.p.} = .33\ D^2 S \text{ (for four cylinders)}$$
$$\text{h.p.} = .5\ D^2 S \text{ (for six cylinders)}$$
$$\text{h.p.} = .66\ D^2 S \text{ (for eight cylinders)}$$

White and Poppe formula,

$$\text{h.p.} = \frac{D S N}{16}$$

in which, however, the diameter D and the stroke S are in *centimeters*. Substituting the number of cylinders as before, this becomes

$$\text{h.p.} = .25\ DS \text{ (for four cylinders)}$$
$$\text{h.p.} = .38\ DS \text{ (for six cylinders)}$$
$$\text{h.p.} = .5\ DS \text{ (for eight cylinders)}$$

Racing Boat Formulas. The following formulas are for high-speed racing boat engines of four-cycle type, and are based on 1,000 feet per minute piston speed. For engines of ordinary design, two-thirds of the above values should be taken; 10 per cent should be added to the ratings if the charge is forced into the cylinders by any mechanical device.

American Power Boat Association,

$$\text{h.p.} = \frac{D^2 N}{2.5338}$$

For motors of less than 6-inch stroke,

$$\text{h.p.} = \frac{D^2 L N}{15.20}$$

Two-Cycle Formula. The following are two-cycle engine formulas, the first being by Roberts for racing-boat engines and the next two by the American Power Boat Association:

$$\text{h.p.} = \frac{D^2 L R N}{13{,}500}$$

$$\text{h.p.} = \frac{D^2 N}{2.1008}$$

$$\text{h.p.} = \frac{D^2 L N}{12.987}$$

The above formulas by the American Power Boat Association are only for racing-boat engines. For ordinary two-cycle-boat engines two thirds of the value resulting from the use of these formulas should be taken. For engines having one or more displacer cylinders, the above rating should be increased in the ratio that the displacer pistons' displacement bears to that of the working cylinders.

Comparison of Power of Two- and Four-Cycle Motors. It will be noticed that in a two-cycle engine having double the number of power strokes of a four-cycle, the h.p. would be multiplied by 2. This, however, would give an erroneous result, as there are many inherent conditions connected with two-cycle engine design which tend to lower its horse-power output, such as the lower compression, lower m.e.p., due to inefficient scavenging, etc. For these reasons the output varies more in two-cycle engines than in four-cycle engines, and is very often taken as approximately 1.35 of that of a four-cycle engine of the same bore and stroke. There are, of course, exceptional cases where two-cycle engines have shown considerably better than this value, but it is considered an average result.

Other Testing Work. There is considerably more to testing than the simple use of a form of dynamometer or prony brake. After bearings have been rescraped and set up, after new pistons or new cylinders, new crank shaft, new cam shaft, or any other important new parts have been added, "running in" is fully as important as testing. After a car has been worked on and important changes made, as new transmission gears, new axle, new driving shaft, new springs, or others of equal import, "running in" on the roads is more important even than testing. The "running in" process makes certain that everything is working right and will continue to work correctly continuously. In the case of important engine changes it smooths out any rough spots left in machining. Running in of engines after important changes is usually done by driving the engine from an overhead line shaft by means of a leather belt. When this is done, a heavy oil is used for the lubricating system, much heavier than will be used later, this being forced around the system by the power drive. On many cars and trucks, the running in process takes more time, is given more attention, and costs the manufacturer much more than the actual testing. Every good mechanic and repair man should run in each engine or car repaired before delivering it, if only to assure himself that a good job has been done. The running in and testing are in a sense the proof of the work.

SUMMARY OF EXPLOSION MOTOR INSTRUCTION

Q. To what is the term explosion motor applied?

A. The term explosion motor is generally applied to the gasoline engine used as a source of power in automobiles, motor trucks, motor cycles, aeroplanes, motorboats, and small gas and gasoline engines as well. A recently coined term for this entire field is *automotive*. The explosion motor is frequently called the internal-combustion motor.

Q. Is there anything strange or mysterious about this source of power?

A. No. It works very much the same as a steam engine, except that the expansion of ignited gasoline vapor which has been highly compressed is used instead of the expansion of steam.

Q. Describe the efficiency of the internal-combustion motor?

A. The efficiency of the internal-combustion motor, which is a heat engine, is the proportion of useful work obtained to the amount of heat put into the motor.

Q. What is a cycle?

A. A cycle is a series of events occurring in regular sequence between the explosions, or power strokes.

Q. What is the cycle of an explosion motor?

A. The cycle of the modern automobile motor consists of four strokes: (1) the suction, or intake, stroke; (2) the compression stroke; (3) the explosion stroke; (4) the exhaust stroke.

A. No. There are two general types of engines, those in which the cycle is completed in four strokes and those in which it is completed in two. The former are called four-stroke cycle engines, generally abbreviated to four-cycle, and the latter two-stroke cycle engines, usually spoken of as two-cycle. The former are also quite often spoken of as Otto-cycle engines because of the pioneer Otto who developed this type.

Q. Are there other than these two arrangements of the cycle?

A. Yes. Engines have been built to operate on a six-stroke cycle, the two extra strokes being used to draw in cold air and thus keep the engine cool, with the primary idea of dispensing with water-cooling apparatus. In addition, other cycles have been proposed from time to time by inventors. But the two- and four-cycle engines are the only successful ones.

Q. What is the generally accepted type of automobile motor?

A. Automobile motors are, as a rule, multi-cylinder four-cycle vertical forms, designed to run at 800 to 900 r.p.m., or higher, with long strokes, magneto ignition, four or more mechanically operated valves, using gasoline as fuel, and having speed control by means of spark and throttle levers and foot accelerator. The vertical four-cylinder and six-cylinder are the most popular forms, although a considerable number of eight- and twelve-cylinder V-type or inclined-cylinder engines are now being built. Practically all automobile engines now have two or more mechanically operated valves per cylinder, the latest development being the use of four valves per cylinder. By long stroke is meant a longer stroke than the bore, generally longer in the ratio of 1.1 (or higher) to 1.

Q. What is standard practice in cylinder arrangement?

A. The two most popular cylinder arrangements are those in which the cylinders are cast in pairs, and those in which they are cast in a block, or single unit. The latter is gaining way rapidly, its simplicity and compactness being big arguments in its favor.

Q. What is the usual practice in valve arrangements?

A. With two valves per cylinder, there are three general arrangements and one combination form. These are: (1) both valves on one side; (2) one valve on each side; and (3) both valves in the cylinder head. The combination arrangement is one valve on one side and one in the head, usually directly over the other.

Q. Do these valve arrangements change the type of cylinder?

A. The cylinder form is ordinarily named from the valve arrangement or from the shape of the combustion, or explosion, chamber which this arrangement brings about. Thus, the type where both valves are on one side of the cylinder is called an L-head, because the combustion chamber has the shape of an inverted letter L with the valves in the projecting arm. When the valves are on opposite sides of the cylinder, it is called a T-head cylinder because the combustion chamber has the shape of a letter T with one valve in each branch of the top. When the valves are both in the head, the cylinder is called an I-head, or valve-in-the-head. The form in which one valve is in the side and one in the head, is called an L-head also because the combustion chamber has an L-shape.

Q. What is the Knight, or sleeve-valve, motor?

A. A motor similar in appearance to other motors but having, instead of the usual poppet valves, a pair of sliding sleeves which have openings, or ports, through them. By the operation of these sleeves up and down, the inlet and exhaust ports are opened and closed in a manner similar to the ordinary poppet valves.

Q. How is this action brought about?

A. The two sleeves are cylindrical, and fit between the cylinder and the piston. Both have holes, or ports, on the two sides, corresponding to the valves on opposite sides of a T-head motor. The sleeves are moved up and down by rods attached to eccentrics operated by an eccentric shaft. When the movements of the two sleeves bring together the inlet ports and bring these into register with the port in the cylinder walls on the inlet side, the inlet opening is completed and the piston draws in its mixture. Similarly, when the ports in the two sleeves and that on the other side of the cylinder register, the exhaust opening is completed, and the burned gases are forced out. At other times, the ports do not register and the cylinder is practically sealed, this being the case on the compression and expansion strokes.

Q. In what way is this an advantage?

A. The valve timing always remains the same, never varying with time, wear, lack of care, or anything else, which is not true of poppet valves. Again, the movement of the sleeves can be such as to give a quicker opening and quicker closing; that is, it can produce a wide-open port more quickly, and close from a wide-open port to no opening at all more quickly than the poppet form, because the sleeves do not move up and down together. They can be made to move in opposite directions so that a port is opened or closed with double the usual speed. There is no possibility of leakage of gases either by time, wear, lack of care, or other factors. All of these things make for a larger and a more regular power output throughout the motor's life.

Q. What is the usual form of motorcycle engine?

A. Usually the motorcycle is a one-cylinder vertical, or two-cylinder V-type air-cooled engine, although a few four-cylinder vertical air-cooled ones have been built and are still being turned out. All these are of the four-cycle form except the Shickel which is two-cycle.

Q. What is the firing arrangement of explosion motors?

A. The firing arrangement varies with the number of cylinders and in engines of the same number of cylinders, varies with the form of the crankshaft, and often varies in similar crankshafts.

Q. What is the general two-cylinder firing arrangement?

A. Two-cylinder motors with the cranks set at 180° (that is, the horizontal opposed form like the Autocar commercial car) fire one-half revolution apart, so that they have two power strokes on one revolution and none on the next.

Q. How does the engine continue to run with an arrangement like this?

A. After the first explosion, the flywheel supplies the power necessary to carry the engine over the idle strokes, in fact this is the function of the flywheel—to store up energy or rotation on the firing or explosion strokes and give this back on the idle, or suction, compression and exhaust strokes.

Q. What other two-cylinder firing arrangement is used?

A. That in which the cranks are set at 360°, or in the same position. In this form, there is an explosion each revolution, but excessive vibration results from all the parts working in the same direction all the time. That is, both pistons go down together, then both go up, etc. The evenness of firing is overbalanced by its excessive vibration.

Q. What is the usual four-cylinder firing arrangement?

A. As a rule the cranks are at 180° in pairs, cylinders 1 and 4 being together, and cylinders 2 and 3. This allows of two very similar firing arrangements, as 1-3-4-2, or 1-2-4-3. There is little choice between them, although the first is more popular.

Q. What is the general six-cylinder firing arrangement?

A. Usually, the cranks are set at 120° apart in pairs, 1 and 6 acting together, 2 and 5, and 3 and 4. The firing can be any combination of these in which the first comes from one group, the second from another, the third from a third, then the fourth, fifth, and sixth come from the remaining member of each group in the same order. Thus, 1-5-3-6-2-4, or 1-5-4-6-2-3, or 1-2-3-6-5-4, or 1-2-4-6-5-3.

Q. What is the usual eight-cylinder firing arrangement?

A. The eight-cylinder firing is always the firing that a single group of four cylinders on one side would have with that same form of crankshaft, and this firing order is applied first to one side and then to the other. Thus a typical four-cylinder firing order of 1-3-4-2 applied to an eight-cylinder, similarly arranged, would be 1R-4L-3R-2L-4R-1L-2R-3L. If these are repeated a second time it will be seen that the 1-3-4-2 order follows out on both sides, only one starts in later, and the two alternate from right to left, thereafter.

Q. What is the theory of crank effort?

A. Only one of the four strokes of the motor is a productive one, and not all of that, so in the one-cylinder engine 20 per cent of the cycle must produce all the power. In the two-cylinder this is increased to 40 per cent, in the four-cylinder to 80 per cent, and in the six-cylinder to 120 per cent. This last indicates the overlap at various points, for the cycle like anything else can never have more than 100 per cent power. In the eight-cylinder it is 160 per cent, and in the twelve-cylinder 240 per cent, indicating the relatively greater overlap, and consequent smoother running.

Q. How does the average small two-cycle motor work?

A. The mixture is admitted to the crankcase, which is built very close to the revolving parts, and in this way the downward movement of the piston compresses somewhat the charge in the crankcase. At a certain point in the downward movement of the piston an opening through it registers with a by-pass which leads up into the combustion chamber with suction inlet valve. Thus the single downward stroke of the piston compresses the charge and fills the cylinder with it. This gas really flows in at the end of the combination power and exhaust stroke, but as the exhaust port is at the bottom of the cylinder, little or none of the incoming gases flow out through it. On the return of the piston, the gas is compressed, and at the end of that stroke when the piston is ready to descend, is ignited and expands. Just before the end of this power stroke, the exhaust port is uncovered and, being rather large, the exhaust gases flow out very quickly, the entire cylinder being emptied in a very short portion of the stroke. Consequently, when the end of the power stroke is reached, the exhaust also has been completed. In this way, the entire cycle is performed in two strokes of the piston.

Q. What are the disadvantages of this?

A. The preliminary compression is not sufficient to force in a full charge, nor is the suction strong enough to hold open the suction-operated valve and draw in a full charge at the same time. Consequently, the inlet, or suction stroke, is seldom efficient. Further, not all of the exhaust gas is removed, the balance remaining to dilute, or offset, fresh gas, thus further lowering the suction or charging efficiency. If the exhaust port is so made as to give a good full-cylinder charge, some of the incoming gas is likely to sweep over and out with the exhaust, thus being wasted. Either arrangement gives an inefficient exhaust; for with the one, exhausting is not complete, with the other, the power part of the stroke is cut down. The result is that instead of giving double the power from a given size of cylinder as compared with a four-cycle engine, the relative output is about $1\frac{1}{3}$ times the four-cycle of equal size.

Q. How is this form sometimes varied?

A. By adding an automatic inlet valve to the crankcase and eliminating the suction-operated valve in the cylinder head. This also shortens and simplifies the by-pass. The exhaust is made to open a little earlier than the suction connection to the cylinder, and the piston is made with a projecting lip to deflect the incoming fresh gases upward while the exhaust gases are flowing downward. This method reduces the dilution of the incoming charge and the losses of fresh gas flowing out of the exhaust opening, and the engine is made more simple and slightly more efficient.

Q. What general disadvantages render two-cycle engines unsuitable for automobile and motor-truck work?

A. The two-cycle engine will not throttle down, so as to run slowly, but must be kept turning at a fairly high rate of speed. This is a double disadvantage when the car or truck is standing idle at the curb, as it makes a noisy engine and uses much fuel. In addition the engine will not run at very high speeds, its normal maximum being close to or below 1500. This means a small gear reduction to give fair speed in the average car, and that in turn raises the lower speeds too much, or else complicates the gear box. Further, the two-cycle motor does not respond well to sudden changes of speed.

Q. Is there any work for which these are not disqualifying conditions?

A. Yes. On the motorboat, particularly on the smaller sizes. In a motorboat, after starting, the speed is generally continuous and even; there are no sudden spurts, no slowing down, no speed changing. For this all-day running at constant speeds the two-cycle motor is quite suitable. In addition, it is a very low-priced motor to build, and as the smaller motorboats must be sold at an extremely low price, it is quite suitable. The fact that it has no parts which can be changed or adjusted renders it quite suitable to the unmechanical class which buys this form of boat. However, even for this kind of work, it seems to be going out of favor.

Q. How is the power of a gas engine measured?

A. In one of two ways, theoretically on the indicator or manograph, or actually by means of the dynamometer or Prony brake.

Q. How do the Midgley and the manograph cards differ?

A. The Midgley indicator produces both a pressure-volume and a pressure-time card, while the manograph produces a pressure-volume card only. The pressure-time card is of such a shape that the length of time required for each change in pressure and the time taken for the gas to burn can be readily determined. The pressure-volume card indicates the m.e.p. in the same manner as the manograph.

Q. Are there several ways of measuring actual power?

A. Yes. The dynamometer gives its measure in electrical units, which in well-designed apparatus, can be read off directly on the electrical instruments. The Prony brake gives a measure of the power output in weight on the scales which the engine will support, and by figures the power output can be worked out from this.

Q. What is the mechanical efficiency of an engine?

A. The proportion of the power which the engine should give, as measured by the indicated horsepower, to that which is actually given, as measured by the brake horsepower (either Prony or electrical dynamometer). By dividing what the engine gives by what the indicator card says it should give, a figure is obtained for the mechanical efficiency.

Q. What is the usual horsepower formula now in use?

A. All automobile engines in this country, England, and many other foreign countries, are rated by means of the formula which was originated by the Royal Automobile Club of England, adopted by the Association of Licensed Automobile Manufacturers, then by its successor, the National Automobile Chamber of Commerce, and, finally, by the Society of Automobile Engineers. Its form is

$$\text{h.p.} = \frac{D^2 N}{2.5}$$

in which D is the bore of the cylinders, N the number of cylinders, and 2.5 a constant worked out from tests on a number of automobile engines. In other words, to find the rating horsepower of a motor, square its bore, multiply by the number of cylinders, and divide by 2.5.

The formula can be simplified to the following form:

$$\text{h.p.} = D^2 N \times 0.4$$

that is, the square of the bore times the number of cylinders times 0.4 will give the S.A.E. rating. It must be remembered that the result obtained from this formula is the horsepower developed at a piston speed of 1,000 feet per minute. Suppose a motor has a stroke of 5 inches; the piston would then travel 10 inches, or $\frac{10}{12}$ foot, in one revolution of the crank shaft. In order to travel 1,000 feet, it would be necessary to operate at a speed found by dividing 1,000 by $\frac{10}{12}$, which is 1200 r.p.m. If the motor had a stroke of 6 inches, the piston would then travel 1 foot in one revolution. The rating would then be at 1,000 r.p.m.

Sectional View of the 1920 Marmon Six-Cylinder Motor

GASOLINE AUTOMOBILES

PART I

INTRODUCTORY

Of all the applications of the internal-combustion motor, it is safe to say that none is more important than that applied to the propulsion of the modern motor vehicle—the automobile—which nowadays throngs the roads and streets of nearly every country in the world, and serves a myriad of utilities as they never have been and never could be served by animal transportation.

Standardized, inexpensive to buy, and inexpensive to operate, almost unfailingly reliable, and proved capable of use in the hands of even the most unmechanical of operators, the automobile is at last coming fully into its own. Its design has become recognized as a branch of engineering by itself, its manufacture constitutes one of the greatest of the mechanical industries, and its use is a common necessity.

Naturally, in so tremendous a development, there is sustained by the general public every possible sort of relationship with the automobile, from that of the merely casual observer and occasional user, to the more interested owner; and thence on, in ever closer touch with the full significances of this field of engineering, to the high-skilled and well-paid drivers of cars, the experts who repair them, the shopmen who build them, and the engineers and draftsmen who design them.

All along this line there is an increasing need for knowledge—a demand for definite, specific, usable information concerning the science upon which the motor vehicle is based, and the practice upon which its construction and performance are founded.

In no other important field of engineering is there such a lack of correct and authoritative literature as in the automobile field.

This undoubtedly is due to two conditions that have been involved in the rapid growth of the automobile from a mere experiment to an achieved and commercial fact. The first condition is the circumstance that the men who have deeply studied the automobile from an engineering standpoint, and who are best informed about it, have not had the time to place upon paper the facts with which they are acquainted. The second condition—resulting from the rapid development of automobile design and engineering practice has left no time for the establishment of a formulated science, upon which textbooks of a genuine and permanent authority may be based.

What follows will be an advanced and comprehensive treatment of the very latest devices applied in automobile engineering. All are carefully described, their essentials fully analyzed, and their important details fully illustrated.

Historical material of any kind is useless in a work of this sort, which is intended primarily for the man in the shop, who does the actual work of completing the car in the first place, and the man in the garage who keeps it in running order thereafter. It will suffice to say that while most of the worthy efforts and early progress in the development of the explosion motor and the automobile were made abroad, American designers and American workmen have since shown the way in this field to the whole world, so that today we import a negligible number of motors and cars, while we export to every other country of the world.

GENERAL OUTLINE OF MOTOR-CAR CONSTRUCTION

In general, all motor cars follow along the same broad lines. So much has this become the case in the last few years that a large number of the parts, units, and accessories entering into the construction of the car have become standardized and may, to a certain extent, be taken off one car and placed on another without extensive alteration. This has been done, too, without interfering in any way with the initiative of the various designers.

Groups and Parts. Practically all modern gasoline motor cars may be divided, in a mechanical sense, into six groups of parts or units. These are: (1) the engine, or power-producing group; (2) the clutch group, needed, as will be explained later on, with all forms of explosion motor; (3) the transmission, or gearset, for producing the various car speeds and different powers, while the engine gives a practically constant speed and power output; (4) the final drive group, which connects the speed variator or transmission with the rear wheels, and thus propels the car. Of necessity, this includes the rear axle, while the front axle is usually grouped with the rear; (5) the steering device, for controlling the direction of motion; and (6) the frame, upon which all these and their various accessories are hung, with the springs for suspending the frame upon the axles of the car. There is, of course, a seventh group, the body, but that need not be discussed here, since reference is now made only to the mechanical parts.

Chassis Assembly. In the large diagram of a modern motor car, Fig. 1, the relative positions of the various units are clearly shown. In this, note that the engine is placed at the front of the outfit. This is now the position all the modern motor-car manufacturers use. The engine is to generate the power by drawing in, compressing, and exploding gas from gasoline.

Cylinder and Crankshaft Sub-Group. All this work is actually done within the *cylinder,* which really forms the basic working medium of the engine. The actual drawing-in of the gas, its compression and explosion are accomplished by the movements of the *piston* up and down in the cylinder bore. The piston is moved upward and downward by the rotation of the *crankshaft* except when the explosion reverses the situation, and the piston moves the crankshaft, to which it is attached by means of the *connecting rod.* The piston is made to fit tightly in the cylinder by means of *piston rings,* which are compressed into slots formed in the outside of the piston for this purpose. The connecting rod is forced to rotate by its attachment at the lower end to one of the *crankpins* of the crankshaft, which is held in the *crankshaft bearings* fastened in the *crankcase.* It is enabled to turn slightly at the upper, or piston, end by being pivoted on the *piston pin* or *wrist pin.* For convenience the crankcase is usually made in two parts, called the upper and lower *halves.* The cylinders are usually made with a removable *cylinder head* or a smaller removable *cylinder cover.*

Carburetion Sub-Group. The production of the gas necessitates what is called a *carburetor,* a good-sized *fuel tank,* and piping to connect the two. The fuel is not always pure and must be filtered through a *strainer.* There is a cock in the piping for turning gasoline from the tank to the carburetor on and off, while the gas produced is taken into the engine through an *inlet*

Fig. 1. Plan View of the 1920 Marmon Chassis

manifold. These and other parts, the functions and construction of which will be explained in full later on, constitute the carburetion sub-group.

Inlet and Exhaust Valves. In order to get the gas, which is produced by the carburetion group, into the motor cylinders at the proper time and in the proper quantity, *inlet valves* are necessary. These valves are operated by *cams* on a *camshaft.* The camshaft, which will be explained in detail later, is driven from the *crankshaft* of the engine. After the gas has been admitted into the cylinders, compressed, and exploded, it is of no further use and must be removed from the cylinders. As this must be done at the proper time, and as the proper quantity must be removed, additional valves known as the *exhaust valves* are necessary. These are also operated by cams on a camshaft, driven from the crankshaft.

Exhaust System. The exhaust gases pass from the cylinder through a particular pipe, known as the *exhaust manifold,* and thence to the back of the car. As there remains considerable pressure in these gases when allowed to escape freely, they make much noise and considerable smoke, so that all cars are required by law to carry and use a *muffler.* The exhaust gases pass through this and thence out into the atmosphere. This whole group of parts is called the *exhaust system.*

Ignition System. The *explosion* comes in an intermediate stage. It is produced by means of an *electric spark,* made within the cylinders by means of a *spark plug.* The electric current, which is the original source of this spark, may be produced by a rotary current producer, known as a *magneto,* or it may be taken from a *battery.* In either case, the current must be brought up to a proper strength, and the various sparks must be produced at the exact time they are needed. All this calls for auxiliary apparatus. Moreover, the current producer, if it be a magneto, must be driven from some rotating shaft, and there must be a suitable place provided on the engine to attach it in such a way as to provide for quick and easy removal. All this, as a complete unit, is called the ignition system. A complete treatment of this subject will be found under "Electric Equipment for Gasoline Cars".

Cooling System. A great amount of heat is created by the following explosion and subsequent expanding and exhausting of the gas. Some idea of this may be gained from the two following statements: The explosion temperature often runs up as high as 3000° F., and the exhaust temperature frequently is as high as 1500° F. In order to take away this heat, which communicates itself to the walls and to parts of the engine wherever it comes in contact with them, and, by conduction, to other parts with which it does not contact, the parts which are exposed to the greatest heat are surrounded by hollow passages, called *jackets*, through which water is forced, or allowed to flow. This might be called a collector of the heat, for it is then conducted to the *radiator*, a device for cooling the water. It is there cooled off and then used again. In order to circulate the water, a removable *pump*, driven from some rotating shaft, is used. All this, with the necessary piping to connect the various parts, is called the *cooling system*.

On some cars, notably the Franklin, and on motorcycles, there is another type of engine with an *air-cooled* system. This type will be taken up later.

Lubrication System. To make the various parts rotate within one another, *bearings*, or parts specially designed to facilitate easy and efficient rotation, must be used. In and on all such bearings a form of *lubricant* is necessary, also between all sliding parts. In order to have a copious supply of oil at certain points, various forms of *lubricators* or *oil pumps* are needed to circulate it; pipes must be provided to carry it; a *sight feed*, or visible indication that the system is working, must be placed in sight of the driver (usually on the dashboard); an *oil tank* for carrying the supply must be provided; and a location found for the lubricator or pump, as well as means for driving, removing, adjusting, and cleaning it. All this comes under the head of the lubrication system. This system covers, in addition, isolated points requiring lubrication and the different ways used to supply them.

Starting System. In order to start the engine, a *starting handle* is provided on all older cars, with possibly a *primer* working on the carburetor, and other parts. On modern cars, this work of starting is done by electricity, which requires a *starting motor*, a *battery*, a *switch* for connecting the two, wiring, buttons, and other parts. All this combined is called the *starting system*. For a complete treatment of Starting and Lighting Systems see the article on "Electrical Equipment."

Lighting System. Nearly all modern motor cars have an *electric lighting system.* This includes an *electric-current generator;* a *battery* to retain the electric current until needed; suitable governing devices to control the generation and flow of current; *lamps* to use the current; *wiring* to connect them with the source; *switches* to turn the current on and off; and other parts.

Flywheel. At one end of the engine shaft is the flywheel. This is a large, wide-faced member of metal, comparatively heavy, the function of which is to store energy (by means of rotation) as the engine produces it and to give it back to the engine at other parts of the cycle when energy is needed, and none is being produced. In short, it is a storehouse of energy, absorbing the same from the engine and giving back the excess when it is needed. In general, this effect is greatest when the mass of metal is farthest from the center, consequently flywheels are made of as large a diameter as is possible, considering the frame members. Note this in the illustration, Fig. 1.

Clutch Group. The *clutch* is generally located inside the rim of the flywheel. This is a device, by means of which a positive connection can be made with the engine or a disconnection from it effected at the driver's will. When such disconnection is made with the engine running, it will continue to run idly, and the car will come to a standstill. Conversely, when the positive connection is made, the motor will drive the clutch and such parts beyond it as are connected-up at the time. This arrangement is necessary because of a peculiarity in the gas or gasoline engine which cannot start with a load, but must be started and allowed to get up speed before any load is thrown upon it. The function of the clutch, then, is to disconnect the balance of the driving system from the engine, so that it may attain the necessary speed to carry a load. When this has been done, the proper gear is engaged, the clutch is thrown in, and the engine picks up its load.

Like other groups, this must have a means of connecting and disconnecting, a proper place, proper fastenings, means for adjustment and removal, means for lubrication, and easy access to its parts. All this, collectively, is called the clutch group.

Transmission Group. As has just been pointed out, the gasoline engine cannot start with a load; it must get up speed first. When the load is first applied it must be light. This necessitates certain *gearing,* so that, when starting, the power of the engine may be multiplied many times before reaching the wheels and applied to the propulsion of the car. Furthermore, it has been found convenient to have a series of such reductions or multiplications. These correspond to the various speeds of the car, for, obviously, if the power is multiplied by means of gearing, it is reduced in speed in the same ratio. This whole group of gearing is the *transmission* or *gearset,* and the various reductions are the *low, intermediate,* and *high speed* in a *three-speed gearbox;* and *low, second, third,* and *high* in a *four-speed gearbox.* A gearbox is always spoken of by its number of forward speeds, but there is in all of them, in addition to the forward speeds, a *reverse speed* for backing the car.

In the usual form, these gears are moved or shifted into and out of mesh with one another, according to the driver's needs. For this purpose, *shifting gears* must be provided within the *gearbox,* that is, the arrangement must be such that the proper gears can be moved back and forth, with a *shifting lever* outside for the driver's use, and proper and accurate connections between the two. The gears must be mounted on *shafts,* these in turn on *bearings,* the bearings must be supported in the *gear-case,* and this must be supported on the frame. In addition, there must be suitable provision in the *gear-case cover* for inspection, adjustments, and repairs; all the moving parts must be lubricated; all parts must be protected from the dust, dirt, and moisture of the road, etc. All this comprises the *transmission* or *gearing group,* which properly ranks second to the engine group in importance.

Final Drive Group. *Driving Shaft.* The connection from the transmission to the rear axle in pleasure cars is usually by shaft, called the *driving shaft.* On the majority of motor trucks, however, it is by means of the worm drive, which will not be discussed here. This shaft is sometimes inclosed in a hollow *torque tube,* with suitable connection at the front end to a frame cross-member, and at the rear to the *axle housing.* Its construction is generally such that it contains a *bearing* for the driving shaft at both front and rear ends. In addition, the majority of final drives contain at least one *universal joint,* and many of them contain two. As its name indicates, this will work universally, that is at any angle, its particular function in the driving shaft of an automobile being to transmit power from a horizontal shaft—that of the engine clutch and transmission—to an inclined one—the driving shaft—with as little loss as is possible.

Rear Axle and Differential. The driving shaft drives the rear axle through some form of gear, either *bevel, worm,* or other variety, and is usually a two-part shaft. The reason for cutting the rear axle is that each wheel must be driven separately in rounding a curve, for one travels a greater distance than the other. This seemingly complicated act is produced by a simple set of gearing called the *differential,* which is located within the driven gear in the rear axle. Each half of this is fixed to one part of the *axle shaft.* All these gears and shafts must have bearings, lubrication, means for adjustment, etc. On the outer ends of the axle shafts are mounted the *rear wheels,* which carry some form of tires to make riding more easy. The *brakes* are generally in a hollow drum attached to the wheels. All this goes to make up the driving system.

Steering Group. The front wheels perform a different function. They are hung on the *steering pivots,* so that they can be turned to the right or the left as desired. In order to have the wheels work together, a rod, called the *cross-connecting rod,* joins them, while the motion is imparted to them by means of another rod, called the *steering link,* which joins the *steering lever* or *arm* with the right-hand, or left-hand *steering pivot.* The last-named lever projects downward for this purpose from the *steering-gear case* and is moved forward and backward by the rotation of the *steering wheel* in the driver's hands.

The transformation of the rotation or turning motion of the hand wheel into a longitudinal movement is accomplished within the steering-gear case by means of a worm and gear, a worm and partial gear, or by a pair of bevel gears. All these parts need more or less adjustment, lubrication, fastening means, etc., the complete group being designated as the steering group.

In addition, the steering wheel and post carry the *spark* and *throttle levers,* with the rods, etc., for connecting them to the igniting apparatus (magneto, timer, etc.) and the carburetor, respectively. The purpose of the spark lever is to allow the driver to vary the power and speed of his engine by an earlier or later spark, according to his driving needs. Similarly, the throttle lever is for the purpose of opening or closing the throttle in the intake manifold of the carburetion system and regulates the amount of gas entering the engine, thereby increasing or decreasing its power output, or speed. Actually, these are parts of the ignition and carburetion systems, respectively, but they are usually classified with the steering group, because they are located on the steering wheel and post.

Frame Group. Little need be said about the frame. The *side members* are generally supported by the *springs* at the front and rear ends. The springs are connected to the axles and support the car. The *front cross-member* usually supports the radiator and sometimes the front end of the engine, too. The *rear cross-member* usually supports the gasoline tank when a rear tank is used. The other cross-members may support the engine, transmission, shifting levers, and other parts, according to their location. In general, the number and character of frame cross-members is slowly changing; the modern tendency is toward their elimination. By narrowing the frame at the front, the engine can be supported directly on the side members. With the units grouped, the same is true of the other important units.

Formerly, practically all motors and transmissions were supported on a *sub-frame,* but it has been found that the same results can be obtained when this extra weight is eliminated. Fig. 1 shows a sub-frame.

When the shifting levers are placed on the outside, they are fastened to the frame, as is the steering gear; all step, fender, and body parts, the *under-pan,* or *splash-pan,* for protecting the mechanism from road dirt; and usually the headlights. The frame is constructed with this idea in view, six bolts generally being used. The muffler is usually hung from a rear-frame member. When electric lighting and starting are used, the battery is very often hung in a cradle, supported by the frame, while the *hood* or *bonnet* is supported equally by the side members of the frame (usually covered with wood), and by a rod running from radiator to dash.

In Fig. 1 it will be noted that the engine group and the clutch group are together, forming one unit. The transmission is mounted on the front end of the drive shaft, thus forming another unit. When the motor and the transmission are so located, they form a two-unit power plant. The single-unit power plant, in which the transmission and the motor are in one unit, is the most used construction at the present day. A few manufacturers still mount the transmission on the rear axle.

ENGINE-GROUP ELEMENTS

GENERAL FEATURES

In the following pages, the general grouping just outlined will be followed consistently, so that the student and worker will be able to follow through the construction and repair of the entire car in a reasonable and logical manner.

The principles of engine design, and the methods and details of engine construction are second to none of the other factors that combine to produce the complete modern automobile.

How automobile engines operate, the reasons underlying the various details of different designs, and the relative merits of different constructions are all too little understood by most of those who have to do in a practical way with the new conveyance.

Four-Stroke and Two-Stroke Cycles. The word cycle is used customarily when referring to the internal-combustion engine. When we speak of a four-cycle motor, we omit the word "stroke," but if we want to be exact, the four-stroke cycle is the correct expression. In other words, a cycle is a series of operations which generates heat and then transforms that heat into mechanical energy, at the same time expelling the unused heat. This process is a true cycle and is generally composed of four strokes of the piston.

A four-stroke cycle is composed of four parts, as follows: The downward movement of the piston, taking in a fresh charge of gas; the upward movement of the piston, compressing this gas; the working stroke, where the gas is expanded by the heat of the explosion and drives the piston down; the upward movement of the piston, forcing the burnt gases from the cylinder. The cycle starts at the beginning of the intake stroke and finishes at the end of the exhaust stroke.

A two-stroke cycle is composed of two strokes, four operations taking place in these strokes. In this cycle the piston is driven down by an explosion. As the piston reaches the lower end of the stroke a port is uncovered, allowing the exhaust gases to escape. This is the first work of the cycle. At the same time that the exhaust gases are escaping, a fresh charge is coming in at the intake port at the opposite side of the cylinder. This gas is under compression and tends to force the burnt gases out at the exhaust side. On the second stroke of the cycle, the piston is driven upward and thus compresses the gas when it is fired and the explosion takes place as described.

With the succession of suction, compression, explosion, and exhaust strokes afforded by the four-cycle motor, a very positive and reliable functioning is secured; and by the expedient of a sufficient cylinder multiplication to afford good mechanical balance and frequent power impulses, its flexibility, durability, and practical quality

Fig. 2. Eight-Cylinder V-Type Motor of Cadillac Car, Shown Installed in Chassis

can be brought to a very high standard in a well-designed and honestly built motor.

At the same time, the fact that so much more attention has been paid to the four-cycle motor than to any of its possible competitors for popular favor, undoubtedly accounts in some measure for its present pre-eminence, and it is an open question with many engineers as to just what virtues might or might not be realized with other constructions, were they as exhaustively experimented with and exploited.

Cylinder Multiplication. There seems to be no reasonable limit to the extent to which cylinder multiplication can be carried in the effort to improve the mechanical balance and to even the torque of gasoline motors. But established practice has, nevertheless, settled upon four-cyclinder vertical engines as those most suitable for the propulsion of the average automobile, as this is the least number of vertical cylinders with which mechanical and explosion balance can be secured.

The use of six cylinders, with the crank throws 120 degrees apart and the explosions occurring once for every 120 degrees of crankshaft rotation, affords a smoother-running motor than the four-cylinder.

Still better than the "six," from every standpoint except that of cost, which has prevented its wider application to automobiles, is the V-shaped, eight-cylinder motor, of the type illustrated in Fig. 2,

Fig. 3. Overhead View of Stearns-Knight Eight-Cylinder Sleeve-Valve Motor
Courtesy of F. B. Stearns Company, Cleveland, Ohio

which gives a good view of the unit power plant of a well-known American machine. In both of these, a four-throw shaft, similar to the ordinary four-cylinder crankshaft, is used, is much cheaper to manufacture than a six-cylinder crankshaft, and the two rows of cylinders, each practically constituting a separate four-cylinder engine, are made to work upon the common crankshaft at 90 degrees apart.

The most recent tendency in car motors is toward the eight-cylinder V-type, following the marked success of this form in aviation use.

Not only has the V-form been produced in the poppet-valve form, but also in the Knight sleeve-valve type an example of which is shown in Fig. 3. Furthermore, a considerable number of twelve-cylinder V-type motors have been built, a good example being shown in Fig. 4.

An answer to the demands of the car owners for the flexibility and power of the multi-cylinder types has been recently given by the issue of a very flexible and quick starting four-cylinder motor with 16 valves, two intake and two exhaust valves in each cylinder. Four of these of widely varying design have already been announced—Stutz, White, and Drexel Motor Car Companies, and Wisconsin Motor Company. The details of the Wisconsin motor are given in the section on "Valves". The large increase in the size of the valve openings makes clean mixtures and adequate scavenging easily obtainable, with a corresponding gain in the flexibility and power of the motor.

Fig. 4. Side View of National Twelve-Cylinder V-Type Motor
Courtesy of National Motor Vehicle Company, Indianapolis, Indiana

In aviation work, no form of motor has made as great progress as the rotating-cylinder type, which has been built usually with an odd number of cylinders, as five, seven, or nine; or when these are paired with an even number, as ten, fourteen, or eighteen. As yet, this type has not been applied to motor cars, but considering its advantages, it would not be strange to see this done at an early date. These motors have a single-throw crankshaft of very light weight; the rotation of the cylinders at a rapid rate allows of their being air-cooled and also very light in weight, eliminating all of the parts and also the weight in the water-cooling system. The large revolving mass does away with the need for a flywheel, while the practical elimination of reciprocating parts reduces vibration to a minimum.

In the extreme, motors of the V-type have been constructed with sixteen cylinders, eight in each group. These have been very successful in aeroplanes and motorboats, particularly the latter.

GENERAL ENGINE TROUBLES AND REPAIRS

Engine Troubles

Deposits of Carbon in Cylinder. These are loosened by introducing two or three tablespoonfuls of kerosene, put into the cylinder when warm through spark-plug hole. Replace the spark plug, but do not connect up the wires. Turn the engine over slowly to work kerosene back of rings. Allow it to stand a few minutes. Then connect the wires and start the engine running out of doors, as dense smoke will come for a time. Clean spark plugs and replace.

Knocking. Knocking should not be permitted. It is likely to result in injury to the engine. Ordinarily, knocking is avoided by retarding the spark. In starting up a hill where considerable power will be needed, an open throttle with advanced spark should be employed before beginning the climb. Should the motor begin to knock when part way up the hill, the spark should be gradually retarded. Continued pounding is caused by the connecting rod and main-shaft bearings becoming loose.

Failure to Start. Try the following remedies:

See that current is switched on.
See if throttle valve is open.
Be sure gasoline tank is filled.
Be sure gasoline valve is open.
See that air can enter filling cap of gasoline tank.
Flood carburetor.
If weather is cold, prime cylinders by squirting a little gasoline in through each compression relief cock.
See that spark plugs are clean.

Missing of Explosions. See "Troubles with Ignition System."

Popping in Carburetor. Snapping or popping in the carburetor is caused by lack of gasoline, so that the mixture fed to the motor is not rich enough, and as a result it burns so slowly that one of the admission valves may be open before the charge is completely burned, and part of the burning charge is forced back through the pipe leading from the carburetor to the combustion chambers. If adjustment of carburetor is such that a weak mixture should not occur, inspect the gasoline piping system carefully for an obstruction. Popping in the carburetor may also be caused by a leaky joint in the piping and by connections between the carburetor and the combustion chambers.

Poor Compression. Valve stem may be broken and sticking. Valve spring or valve stem may be clogged with dirt. Cylinder or explosion chamber may be cracked. Piston rings may be broken or turned so that cuts line up, allowing pressure to escape. Cylinder may be gummed. Cam may be loose. Water may leak into cylinder through plugs in cylinder head. Valves may not seat properly due to being covered with soot. Valves may have to be reground.

Engine Starts, but Stops, after a Few Revolutions. Engine bearings may have seized from lack of lubricant. There may be too much oil in crankcase. Water may be entering cylinder through cracks or through plugs in cylinder head. Carburetor float may be sticking. Poor water circulation may be due to broken pump shaft or clogged water piping.

Engine Runs Well on Slow Speed but Not on High Speed. Muffler may be stopped up. Carburetor air valve not properly adjusted.

Engine Pulls on High Speed but Not on Low Speed. There may be a leak in the inlet pipe. Carburetor adjustment not proper.

Knocking Continues Even after Spark Is Properly Adjusted. There is a possibility of the flywheel being loose, of loose or worn bearings in the engine, or of something broken inside the engine.

Repairs

General Instructions. By far the most important part of the car is the engine, and this should, therefore, receive the greater portion of the time and attention during any repair or overhaul work, even by going so far as to take it out of the chassis if the trouble is at all serious. For this purpose, all ignition wires and carburetor and magneto operating rods are detached. Next, the various manifolds are removed, the water system is drained, and all hose connections are broken. Usually it is necessary also to take the radiator

Fig. 5. Dismounting Engine for Repair

Fig. 6. Engine Dismounted, Showing Cylinders Removed

off. When this is done, the appearance of the vehicle and of the work is very much like that presented in Fig. 5, which shows two men engaged in loosening up certain parts of the engine preparatory to taking it out.

When all accessories have been removed or loosened up, the holding bolts are taken out, the clutch disconnected, and the motor is left free to be swung out by means of a small crane or hoist. In some cases, the work can be completed without disturbing the base of the motor, as in Fig. 6, which shows a big car partly disassembled for repairs, the radiator and cylinders having been removed at this stage. The trouble here was found within the cylinders, hence, as soon as they had been removed, the balance of the six-cylinder motor and its chassis could remain undisturbed.

Hoists and Cranes. *Yale & Towne Form.* For lifting out an engine or other unit approximating several hundred pounds (possibly 500 pounds in the case of a big engine) an efficient form of overhead hoist is needed. There is nothing better than the Yale & Towne triplex hoist, although this is not a cheap form. It can be attached to any channel or I-beam built into the roof of the building, or if that is impossible, it can be hooked into any wire or rope loop over a ceiling beam. It multiplies the power which one man can apply to such an extent that one man can lift out a 500-pound engine with it very readily.

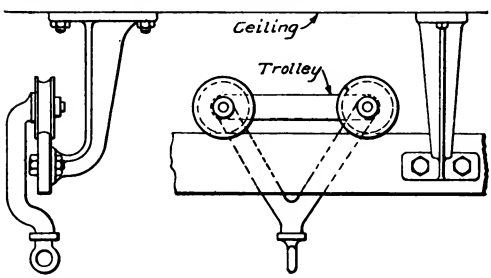


Fig. 7. Method of Constructing Track Attached to Ceiling of Shop

Home-Made Ceiling Hoist. Lacking one of these, a substitute can be made as indicated in the sketch, Fig. 7. The track is plain rectangular metal, known as ½ inch by 2 inches flat, while the brackets supporting it can readily be forged by any good blacksmith. The trolley consists of a forged and bent arm for one side and a straight bar for the other. The wheels can be found in any hardware store. The bottom end should be drilled and tapped, and the ring made in the lathe to fit into it. For this purpose, the threads should be large and numerous. The ring could be forged integrally, but that would complicate the job. When hung, any crane, hoist, or any block and tackle, can be hooked into it and when the load has been lifted clear, it can be run along the track until the desired point is reached.

If this expense is too great, the same results can be obtained by taking a sliding-door track and suspending it from the ceiling beams. Then the two door carriers can be joined by the large end of a V-shaped piece of steel, not less than ½ inch by 2 inches in section; while the carriers are separated and held separated by a simple straight distance piece. The lower end, or point of the V, supports the hook or eye, whichever is used. That is, from an old sliding door,

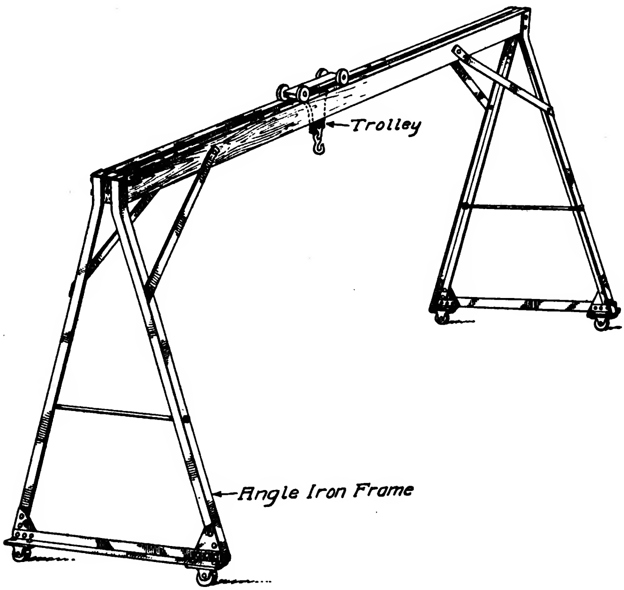


Fig. 8. Overhead Support and Trolley, Used When Roof Trusses Are High or Weak

a traveling hoist can be constructed easily and quickly to handle engines or other large and heavy units.

Floor Type of Hoist Support. When the construction of the roof, or ceiling, is such that it will not permit a suspended hoist, one which works from the floor can be constructed. This consists, as Fig. 8 shows, of a double track beam supported on castor-mounted triangular ends, which extend as high as the garage will allow. By this means, the weight can be lifted clear, and the entire structure moved to the desired place. It is constructed a good deal like those just described; the ends are fair sized angles, say 2 inches by 2 inches by $\frac{3}{16}$ inch; the braces lighter stock, say $1\frac{1}{2}$ inches by $1\frac{1}{2}$ inches by $\frac{3}{16}$ inch; and the castors are anything that is available. It is not necessary that the track be metal; wood can be used if it is wide enough to withstand the wear of the wheels and deep enough to carry the heavy loads.

Commercial Forms. If sufficient money is available to purchase a hoist, these makeshifts are, of course, unnecessary. There are a number of portable cranes for garages on the market, costing from $90 up. These usually have a U-shaped base of heavy cast iron with two castors at the points, and one at the back of the U. At the back also is a vertical pillar about 6 feet high, with a curved extension. At the end of the extension is a grooved pulley carrying a chain hoist. The crane runs back to a sheave and set of gears for winding it up. It has a suitable handle for this, as well as a long folding handle for moving the crane around. Among those available are: the Champion, 550 pounds shipping weight, of $\frac{3}{4}$-ton capacity, with a lift of 4 feet $8\frac{1}{2}$ inches; the Franklin, which will lift 2000 pounds, and weighs 480 pounds; the New Jersey, which will lift 6 feet 8 inches, weighs 600 pounds, and has a capacity of 2000 pounds; the Canton, which will handle 2000 pounds, and lists at $100; the Hilite, which is built in two capacities and four different lifts; and others.

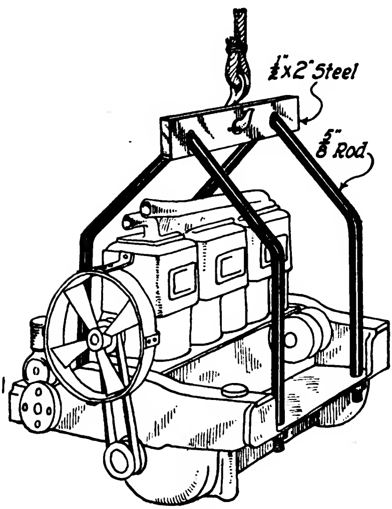


Fig. 9. Sling for Engine Which Saves Much Time in Attaching

Form of Cradle. Many times, even with a suitable crane or hoist, it is necessary to make a cradle for the motor because of difficulty in attaching the chains or ropes to it, difficulty of balancing it safely, or for other reasons. A cradle for a six-cylinder motor is seen in Fig. 9. This is, of course, applicable only to this particular motor, but in a shop handling one car continuously, there is enough saving to warrant making such an outfit. The four bars are made from two pieces of round stock, put through the drilled holes in the upper or supporting bar, then bent over and shaped. Before anything is done, the ends of the bars must be turned down and threaded. In this instance, there is a hole at the four points on the shelf of the motor, so these holes govern the size of the ends of the rods and also their spacing. On almost every motor, there will be some means of attachment which can be studied out in advance, and the rig built to fit it.

Portable Engine Stands. If the engine is removed from the chassis, the first thing needed is a suitable engine stand. One of these is shown in Fig. 10, a form that can be purchased at a reasonable price, and which possesses many excellent features. The frame is made

Fig. 10. Handy Form of Engine Stand Constructed from Piping
Courtesy of Shewalter Manufacturing Company, Springfield, Ohio

of tubing, which gives a maximum of strength in a minimum of space. The oil drip pan beneath is a good feature, as is the shelf arrangement at the open end. The large castors allow it to be moved around readily and can be clamped to hold it any place. One can be constructed out of heavy galvanized pipe and pipe fittings at a moderate cost.

This form of engine stand holds the motor in its natural, or upright, position. But it is not always desirable to have the engine in that position; in fact, when working on crankshaft bearings and other parts on the under side, it is necessary to have it inverted. There also is work which makes an intermediate position desirable. For this purpose, an engine stand is needed which can be turned to any desired angle and fastened there. Such a stand is shown in Fig. 11, which represents one made by the International Motor Company, Plainfield, New Jersey, for its own use. It would hardly pay to make one of these, as the ends are castings which require a pattern, but if a couple of garages wanting, say two each, would go in together, it would pay to have patterns made for the four. After making castings for their own frames, the garage owners could later make them for sale if they wanted to go into the business. The sketch explains the construction, but this explanation might be added: the central part, projecting from

Fig. 11. Engine Stand Which Allows Motor to Be Turned to Various Positions

the left-hand member is attached to the rear crankcase arms, and when the engine is turned, this turns with it. The central rotating member on the upper part of the right-hand unit is made to take the starting crankshaft, and the clamp at the upper left is to lock it in the desired position. Eight holes are provided, but a person making one could have as many as he wished, since they are drilled. As will be noted, there are six pieces, but the two bases are made from the same pattern, so five patterns are all that would be needed.

CYLINDER AND CRANKSHAFT SUB-GROUP

CYLINDER FORMS AND CONSTRUCTION

Materials Used. Gasoline-engine cylinders are variously made of cast iron, cast steel in the form known as semi-steel, forged steel, aluminum alloys, and other materials. For durability, and the ability to withstand high temperatures without warping, nothing has been found superior to cast iron, even though the lightness of steel and of aluminum alloys has commended them for aviation use and in some cases for racing automobiles.

Method of Classifying Cylinder Forms. Cylinders are generally named according to two things: first, the method in which they are cast or produced; and second, the shape of the combustion chamber, or arrangement of the valves. Thus, according to the first method, they are divided into those which are cast separately, that is, each cylinder by itself; cast in pairs, or each two cylinders cast together; cast in threes, a modern modification fitted to the six-cylinder engine;

Fig. 12. Typical T-Head Cylinder Units with Other Cylinder Parts
Courtesy of Locomobile Company of America, Bridgeport, Connecticut

and cast together, or *en bloc*, that is, all of the cylinders cast as a single unit.

According to the second method of naming, cylinders are of the L-head type, in which the combustion chamber has the shape of an inverted capital letter L, formed by the placing of all valves on one side; of the T-head type, with the combustion chamber shaped like a capital T, because the valves are equally distributed; of the I-type, or valve-in-the-head type, so called because the combustion chamber is left perfectly straight and round by placing the valves in the head; and modifications of these.

Usually in speaking of the cylinders, both names are used as one, as, for instance, those of Figs. 2, 3, and 4, all of which happen to be alike, would be spoken of as L-head blocks, Figs. 12 and 13 as T-head pairs, etc.

Methods of Casting Cylinders. *Cast Separately.* The early and still common practice in the building of multi-cylinder gasoline motors is the casting of cylinders separately. This policy makes it easier to secure sound castings, simpler to machine and finish them, and less

CROSS SECTION OF ENGINE

Fig. 13. Section through Locomobile Cylinder Shown in Fig. 12

troublesome to disassemble parts of the motor without disturbing the rest.

In a number of cases, where extremely light weight was desired, this method was followed, but the cylinders were machined all over and a sheet-copper water jacket was applied in assembling. This has been most successful in aeroplane work and also for motor cars, but when the Cadillac changed to the form shown in Fig. 3, this construction lost its principal American adherent. In addition to this construction, there have been a number of motors built with an applied water jacket of sheet metal of the built-on form. These have shown splendid cooling abilities, but, under the twisting and racking of automobile frames, particularly in later years, with the use of more flexible frames, they have shown too much tendency toward leakage to become popular.

Cast in Pairs. Just as soon as two-cylinder and four-cylinder engines were produced, the cast-in-pairs form of cylinder appeared and is almost as widely used today as then. While the modern tendency toward smaller bores, compactness, and light weight has greatly increased the number of cylinders cast *en bloc,* the paired

Fig. 14. Studebaker Six-Cylinder Motor, Showing Block Castings of the Six Cylinders

form, including the cast-in-threes modification for six-cylinder engines, holds its own.

Cast Together. The great advantage of having the several cylinders of one motor cast together—*en bloc,* as the French term it—is that the alignment and spacing of the different cylinders is thus rendered absolute and permanent, regardless of any differences in adjustment that may otherwise occur in assembling.

This construction has been applied to a large proportion of the small and of the medium-sized fours, a fair proportion of the larger fours, and to a considerable number of sixes, Fig. 14.

Fig. 15. Part Section of Ford Motor
In this engine cylinders are cast together

Another advantage is, that the water connections, exhaust and intake manifolds, etc., are rendered simpler both in their form and the number of their points of attachment.

In some advanced motor designs, the passages for the incoming mixture and for the exhaust gases, and in one case even the carburetor itself, are all incorporated in the main casting.

Fig. 16. Section Through Continental 7R Cylinder Showing the L-Head Valve Construction

Another example of simple construction is that illustrated in Fig. 15, which depicts one of the latest Ford motors, in which the cylinders and the upper half of the crankcase are all cast in one piece. The lower half of the crankcase and the gearbox are similarly constituted of another simple pressed steel unit, while a second casting is used for the heads of the cylinders and for the water connection.

Cylinders Classified as to Fuel Chamber or Valves. L-*Head Forms.* In the L-head form, the valves are all located on one side, and usually because of this, all the accessories are on the same side. This makes a lop-sided engine, with carburetor, inlet pipe or manifold, magneto and wiring, exhaust manifold, and sometimes electric generator and other parts all grouped on one side, with little or nothing on the other. While a disadvantage in four- and six-cylinder motors, this is somewhat of an advantage in eight- and twelve-cylinder forms, for all the parts and auxiliaries can be grouped in the V between the cylinders, leaving the outside clear. On the other hand, where this grouping has been found undesirable for four- and six-cylinder motors, it has been possible to overcome it in part by taking the magneto and carburetor over on the other, or plain side, of the cylinders, leading a conduit back for the wires in the one case, and a long inlet manifold in the other. An L-head cylinder is shown in Fig. 16.

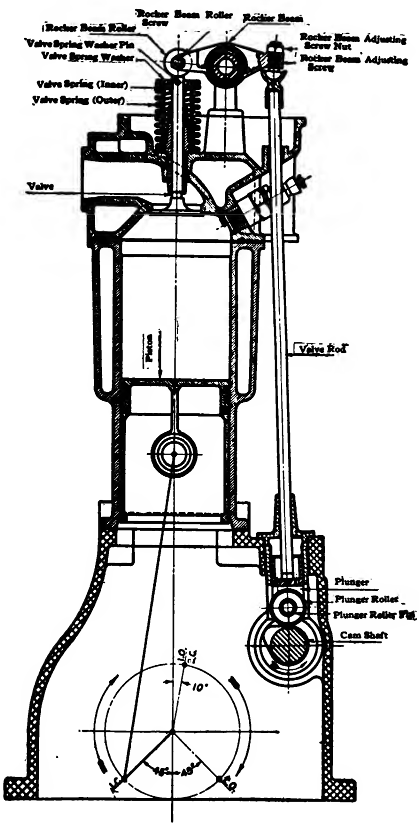


Fig. 17. Section through Dorris 1920 I-Head Cylinder as Used with Valve-in-Head Motors

T-*Head Forms.* A desire for more symmetry and a better arrangement has brought about the T-head form, which has the inlet valves, carburetor, and inlet manifold on one side, and the exhaust valves and manifold on the other. This separation gives more space on both sides, and allows the distribution of the other engine accessories so that each has more accessibility. This is important, for some parts, like the magneto, do

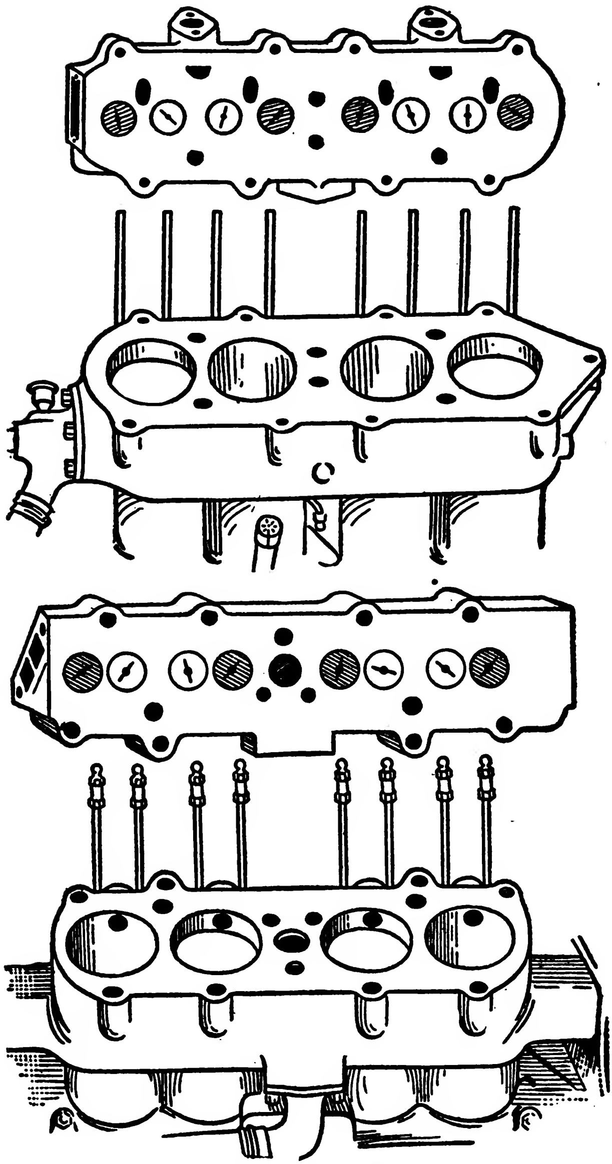


Fig. 18. Cylinder and Cylinder-Head Assembly of the 1920 Chevrolet Showing the Valve in the Head Construction

not withstand the heat well, and consequently should be far away from the heat of the exhaust manifold. See Figs. 12 and 13.

I-Head Forms. The valve-in-the-head, or overhead valve, motor requires an I-head cylinder, because, with this location of the valves, there is no necessity for the valve pockets of the other forms. Consequently the cylinder can be straight and plain, while the head, which is separate, is fastened on instead of being cast integrally. It may have either the L- or T-form, according to the location of the valves and the inlet and exhaust manifolds. Fig. 17 shows an I-head in which the manifolds are located on the opposite side. Note that in this form the cylinder head is removable, the valves being set directly in the head, as shown in the view of the Chevrolet motor, Fig. 18.

Fig. 20. Detail of Marmon Cylinders Showing Cast-iron Sleeves Inserted in Aluminum Casting

The forms are not so clearly separated as they were formerly, for the inclusion of cylinder heads in one case, and their exclusion in another; the integral casting of manifolds, water passages, etc.; the casting of crankcase upper halves and also of gear covers, flywheel enclosures, transmission cases and other parts, all of which are quite common; no longer leave the cylinder casting as a single simple clear-cut unit.

An I-head motor with a removable head is also shown in Fig. 18. In removing the valves on this motor, the rocker arms and shaft should first be removed by taking out the shaft bearing bolts. Care should be taken in marking the rockers, as they will operate best in their original position.

The cylinder head is then removed and the valve keys taken out of the valve stems. This valve construction predominates when the motor is of this type. Better valve cooling is secured by having the valve seat in the cylinder head proper instead of in a removable cage.

Cylinder Repairs

Removing Carbon. *Scraping.* The two standard methods of removing carbon are by scraping and by burning with oxygen. If the carbon is to be removed by the scraping process, the cylinder head is first taken off and the carbon then removed with a putty knife or carbon scraper. While this is a satisfactory method, it requires considerable time. This operation can be done with but little expense if the cylinder head is easily removed.

Oxygen Process. In removing carbon by the oxygen process, first a spark is applied to a mixture of carbon and oxygen and then combustion takes place. The carbon will continue to burn until it is completely exhausted or until the supply of oxygen is cut off.

Setting the Motor. The motor should be turned by the crank until piston *1* is on upper dead center, ready to fire. When the piston is in this position, both valves are closed and the carbon on top of the piston is nearer the oxygen supply. The spark plugs are then removed and a little oxygen allowed to escape from the torch into the combustion chamber through the spark-plug hole. This is done so that there will be sufficient oxygen to support combustion when a match is dropped through the spark-plug hole before the oxygen torch is inserted. After the regulator, Fig. 21, has been adjusted to a pressure of about 15 pounds, the torch nozzle is inserted through the spark-plug opening, which causes the carbon to burn very rapidly. It is important always to have at hand a reliable fire extinguisher as some sparks or hot carbon may drop in the oil pan and cause a fire. It is unnecessary to turn off the gasoline supply to the carburetor or to remove the carburetor, as the closing of the inlet valves prevents any

Fig. 21. Oxygen Regulator for Carbon Burning

chance of a fire in this instrument. Fig. 22 shows an operator removing carbon by this method.

Sequence of Burning. After the carbon is removed from cylinder *1*, the crank should be turned until the piston of the next cylinder in firing order is at upper dead center. If the motor is a six-cylinder type, the crank may be turned one complete revolution and the carbon then removed from cylinder *6*. It will then be necessary to find the firing position of cylinder *2* and, after burning, the crank should be turned one complete revolution; then cylinder *5* will be in its firing position and ready for the burning process. After the carbon has been removed from this cylinder, it is necessary to find the firing position of cylinder *3*, and after the carbon is burned, the crank should be turned one revolution and then cylinder *4* will be in position for carbon burning.

Fig. 22. Burning Carbon with Oxygen

If the motor is a four-cylinder type, the same method may be used; first finding the firing position of cylinder *1* and cleaning it and then removing the carbon from cylinder *4*, after the motor has been turned a complete revolution. The firing position in cylinder *2* is then found, and after one complete turn of the crank, cylinder *3* will be in position for carbon burning.

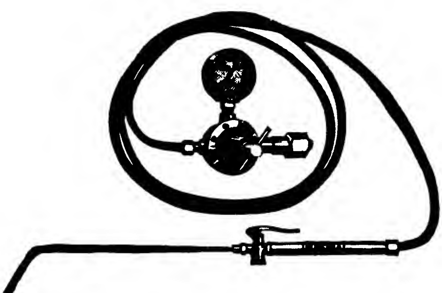


Fig. 23. Imperial Oxygen Burning Outfit. (Without Oxygen Tank)

Finding Firing Position. There are several methods of finding the firing position. If the motor is equipped with battery ignition, the best and quickest method is to turn on the ignition switch, having the spark lever fully advanced and holding No. *1* spark-plug wire near the ground. The crank should be turned until a spark jumps. The ignition switch is then turned off and the carbon removed from cylinder *1*, as this is its firing position. The firing position of the other cylinders is found by the same method. In any four-cylinder motor, cylinder *1* is ready to fire when exhaust valve *4* has just closed. In the case of any six-cylinder motor, cylinder *1* is just ready to fire when exhaust valve *6* just closes.

Precautions. In burning carbon one should guard against using a too high pressure on the oxygen nozzle as this is likely to cause sufficient heat to melt the nozzle, thereby making it necessary to stop the operation and refit a new nozzle.

It is also important to see that the valves are seated, as they are likely to warp if not in this position.

A supply of oxygen may be secured from any reliable manufacturer in tanks of several capacities, the most used, however, being the 100- and 200-foot tanks.

The oxygen regulator hose and torch, Fig. 23, can be purchased from welding equipment supply houses or from the manufacturers.

Removing Carbon by Scraping Tools. When the carbon cannot be burned with oxygen, the repair man must go back to hand scrapers. In any case, these are the most simple and fully as effective as any provided the extra time needed to use them and do a good job is available. When the offending member has been brought out so it can be handled, the removal of the carbon can be accomplished in a few minutes. A flat piston head can be scraped off with any knife or chisel, but a special scraper made from an old file, flattened out at the end and ground down so as to present one sharp edge is better. Every garage man should accumulate from five to a dozen shapes and sizes of scrapers for various work, including a flexible one with which to reach into corners. The carbon is brittle and comes off readily. After its removal the surface should be cleaned with air and gasoline to make it smooth, in order to delay the formation of a second coat. This is true of carbon in other places, but usually it is impossible to smooth the surface, in which case the process must stop when the part is scraped clean.

There are a number of excellent plain and special forms of carbon scrapers which the average garage should have. Old files prove to be splendid material.

Compression Indicating Gage. Before taking off the cylinder to look for trouble inside, the repair man should do all he can to find out what and where the trouble is. A compression gage is handy, as this indicates the pressure in each cylinder. These should all agree

Fig. 28. Using Stethoscope to Listen to Engine Noises

when the motor is right, but if pistons or rings are not right, or if the cylinder is scored, the gage will show a lower figure than the other cylinders.

Such gages can be purchased or they can be made from old materials which lay ready at hand, as, for instance, an indicator made from an old spark-plug shell and a tire gage. The stem of the latter was set inside the shell and firmly fixed there by means of babbitt after both were scored so the metal would take a firm hold. Whenever a motor acts peculiarly, the spark plug is removed from each cylinder in turn, the home-made gage inserted, and the reading noted (with the motor running or being turned over by hand). Many times leaky valve pistons or valve-stem guides will cause a miss which nine persons out of ten would blame to the carburetor. This gage will show up these leaks.

Locating Noises by Means of a Stethoscope. Besides this, it should be borne in mind that there are many sources of noise in and on the engine other than that produced by valves and valve motions. In fact, the noises made by the valves, while an indication of loss of power, do not represent anything like the possibilities for trouble indicated by a piston slap, a crankshaft or connecting-rod pound, the whirr of worn timing gears, and others. In order to locate such sources of noise exactly, at a time when the beginner lacks familiarity with the motor and its troubles he should purchase or borrow and learn to use a stethoscope, Fig. 28. A modification of the surgeon's well-known instrument is now made for use in automobile trouble finding.

The stethoscope, or its modification, simply magnifies all noise; its construction is such that one end is held against the suspected part, while the other end constitutes an ear piece. When the engine begins to make a great deal of noise, particularly heavy pounding noises, this should be brought into play. With the motor running, place the free end against the various parts of the engine, going slowly from one to another. In this way it will soon be found where the trouble lies.

A piston slap is not so easy to define or so easy to repair. It may be called a noise which comes from within the cylinders, traceable to the pistons, or to one piston, as the case may be, which sounds very much like a shaft pound, except that it is a louder noise. It occurs when pressure is put on the piston, as at the beginning of compression, at the time of explosion, or at times at the end of each stroke. It is said to be due to different causes. Some say it is caused by a loose piston pin, but the writer knows of two cases in which a new tight pin left the piston slap just as clear and distinct as before. Others say it is caused by rings which are loose up and down in their grooves, but in the cases above, new rings which fitted tightly in this way did not help any. It has been ascribed to a piston which was out of round, so that it did not fit the cylinder, and also to a groove and shoulder having been worn in the cylinder surface, the piston striking this each time. Whatever is the real cause, and the writer is inclined to blame it to a poorly fitting piston, nothing will really remedy it but a new piston, complete with rings.

Making Gaskets. Anyone who is going to do much repair work will soon have to learn the art of making gaskets, for, in almost every case, the removal of a paper gasket is accompanied by its breakage, so it is rendered unfit for further use. A gasket, it might be explained, is a formed sheet of heavy paper, cardboard, or special material fitted between two surfaces of a joint which must resist the leakage of gases or liquids under pressure. By means of the bolts or screw threads which hold the two parts of the joint together, the gasket is compressed and, in its compressed state, it resists the internal pressure.

The following method of making gaskets applies alike to round, oval, and odd-shaped ones, which cannot be said of special tools and fittings for gasket cutting: Select a good piece of heavy brown wrapping paper or special gasket paper without too many wrinkles, and free from cracks or flaws. Clamp the part for which the gasket is to be made in a vise to steady it and lay the paper over it. Then go around the edges of the part, tapping lightly on the paper with the flat face of a hammer, holding the paper in position meanwhile with the other hand.

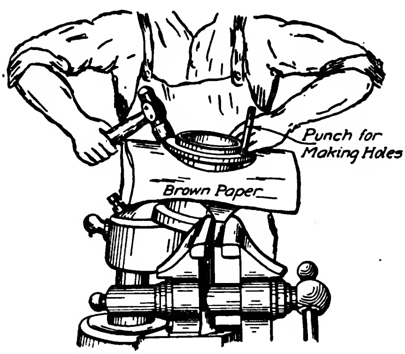


Fig. 29. Cutting Gaskets on the Parts with a Hammer Is the Best and Quickest Method

This method is illustrated in Fig. 29, where a workman is shown making a gasket for the base of a cylinder. In this particular instance, holes must be made through the gasket for the cylinder bolts. These are made with the round or peen end of the hammer or with the punch. When made, the punch is stuck into the hole to help hold the paper steady. In this case, too, it was necessary to cut the inside of the gasket out first, then this material (the paper from the inner or smaller hole) was removed, the sheet put back in place on the base of the cylinder, and work started on the exterior cutting.

If the hammer be held at a sharp angle with the edge of the part for which the gasket is being cut, each blow will cut through, or partly through, the paper. By repeating this operation enough times, going around the part meanwhile, the result is the finished gasket which will fit the desired place exactly.

Cylinder Heads. A great many motors have detachable heads, and their quick removal is a great convenience, when there is carbon to be scraped off, pistons to be looked over, or other internal work to be done. However, replacing them is never quite so easy as removing them, partly on account of the cylinder heads themselves and partly on account of the pistons. The latter are particularly troublesome when the cylinder head is hinged. The cylinder head should be replaced with great care, and after replacement it is fully as important to bolt it on properly. If one bolt or a series of bolts is tightened too quickly and too hard, it is likely to result in cracking the cylinder casting or the head casting or both.

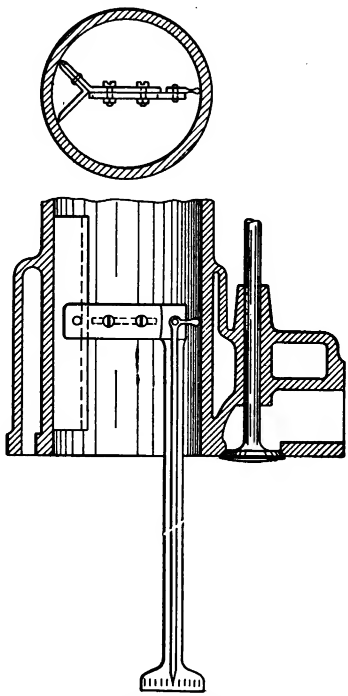


Fig. 30. Construction of Simple Rig for Measuring Worn Cylinder Bores

Proper Method of Bolting on Head. Usually, on an L-head type of motor, there are three rows of bolts for the cylinder head—one row along the middle, screwing into one side of the cylinders; another row screwing into the other side of the cylinders; and a third along the valve side. These should be tightened in order: first the middle bolts of the middle line, working out to the ends; next in turn, the middle bolts of the back of the cylinder, the middle bolts of the valve side, the ends of the cylinder; and finally, the end bolts on the valve side. All these should be tightened but a few turns at a time, and after all are down, a second round should be made in about the same order, to give each bolt a few more turns. In this way the cylinder head casting, which is both large and intricate, is slowly pulled down to the cylinder straight and true so that it is not warped or twisted. Moreover, if the cylinder is pulled down straight in this manner, all the bolts can be tightened more than if the first bolt were tightened very much, for the latter would result in cocking up the opposite side.

Checking Up Cylinder Bore. Before any work is done upon the cylinder bore, such as turning, grinding, etc., it should be checked up very carefully. An expert workman, accustomed to the tool, would use an inside micrometer, but when this tool is lacking, as well as the experience necessary to use it, a fairly simple tool which can be used by almost anyone may be constructed as follows: As shown in Fig. 30, a short angle iron forms one side of the bore-measuring part; its length is sufficient to keep the entire tool perfectly vertical when the cylinder is vertical, and thus gives an accurate right-angle measurement of the bore. A central arm is fastened to this and the framework adjustably

Fig. 31. Grinding Engine Cylinders
View Shows Exhaust for Dust, Jig for Holding Cylinders, and Eccentric Wheel Spindle
Courtesy of Heald Machine Company, Worcester, Massachusetts

bolted to it. This includes the indicating dial at the top. At the lower corner is the indicating member, which is simply an **L**-shaped piece with a very short base and a very long stem; this is pivoted at the center of the bend. It is held against the side of the cylinder by means of a light spring. After adjusting the tool to the approximate cylinder bore, it is inserted, and a reading is taken; the tool is then moved, and another reading taken. The length of the arm is so great that any movement of the small arm is magnified about 15 times. In this way a difference of $\frac{1}{1000}$ in the bore shows as $\frac{15}{1000}$ on the dial, or $\frac{1}{64}$. In a shop where most of the work is on one motor, the micrometer could be improved by eliminating the adjustable feature and making the frame and angle face a solid piece.

Grinding Out Cylinder Bore. As the usual amount of metal which would be removed from a worn cylinder would not exceed a few thousandths of an inch, grinding should be the process used. Other processes, except possibly lapping or hand grinding, are too inaccurate. For this reason, a typical grinding set-up is shown in Fig. 31. This shows the cylinder bolted against a large angle plate, attached to the grinding machine table. The angle plate is drilled out to take the bolts which hold the cylinder casting to the crankcase. When bolted up for work, the air hose is connected up through the cylinder head to blow out the dust or particles ground off. Not more than three or four thousandths of an inch should be taken off at one time; if more must be removed, a second operation over the surfaces is necessary.

If the cylinder is worn badly enough to warrant re-boring, which calls for new pistons and rings, it should be borne in mind that a standard set of oversizes has been adopted by the Society of Automobile Engineers, and that all manufacturers are working to them, by stocking pistons and rings according to these dimensions:

Oversize Standard	Inches Large
For 1st Oversize	10 thousandths (.010″)
For 2d Oversize	20 thousandths (.020″)
For 3d Oversize	30 thousandths (.030″)
For 4th Oversize	40 thousandths (.040″)

Methods of Cylinder Lapping. When the cylinder must be lapped or ground out to a true surface, not re-bored, and when no old piston is available for this purpose, there are several methods available. One is to use a standard lead lap, that is, a solid round bar of cylinder size. The abrasive may be either emery and oil, carborundum dust and oil, or, in some cases, ground glass and oil imbedded in the soft surface of the lead, yet it projects enough to abrade the

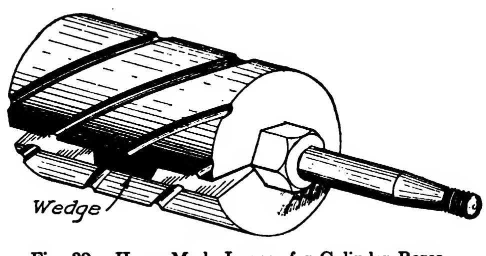


Fig. 32. Home-Made Lapper for Cylinder Bores (Note Spiral Grooves)

cylinder surface a little at each revolution. Another good way of doing this is to use a round block of wood, as shown in Fig. 32. This is made a close fit in the cylinder, with spiral grooves cut in its surface, and a split along one side. Into the latter a wedge is driven to adjust for wear. The emery and oil is put on the surface, and the lapping is done as usual. The spiral grooves distribute the abrasive evenly so that a true surface results.

Another way of doing this is to make a large special boring bar, say 2 inches in diameter, and drill a hole into this at right angles. Then, a small round section of carborundum, say ½ inch in diameter, is placed in this hole with a spring back of it to keep it up against its work. This arrangement can be used on a lathe, the bar being rotated in the usual way, and the cylinder fed up to it either by the carriage feed or by hand. It will give a very fine cylinder surface, and use up very little of the carborundum, which costs very little to begin with. The advantage of this method is that the same outfit can be used on many different sizes of cylinders.

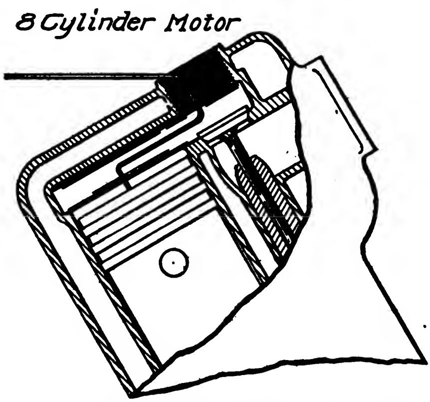


Fig. 33. Tool Made from Wire for Indicating Dead Center in V-Type Motors

Simple Dead Center Indicator. In a great deal of engine work, it is necessary to know when the pistons in the various cylinders are on dead center, either the upper or the lower center. For this purpose a form of indicator which is simple, easy to use, and accurate, is needed. A good one is shown in Fig. 33. This consists of nothing more than a ⅛-inch steel wire, or narrow steel strip, bent to the form shown. It is indicated as setting into one cylinder of an eight-cylinder V-type motor, but with slightly more bending it is applicable to any form of V-type or vertical cylinder motor. The bent end is inserted, and the engine gradually turned by means of the crank until the tip end of the wire extending from the cylinder stops moving. This point is the upper dead center, and the lower center is found similarly. The advantage of the shape shown and of the long extended end is that a very minute movement of the piston is magnified and shown as a considerable movement at the end of the wire. Thus, it is possible to determine the dead center point very exactly.

Repairing Cracked Water Jackets. Very often the first cold spell of fall will catch the owner napping in the matter of heat for his motor, and will freeze up the water, which finds a weak spot in the water jacket and cracks it. When the crack is small and localized, it can be repaired very simply as follows: Drill each end of the crack as shown at *A* and *B*, Fig. 34, and screw in small $\frac{1}{8}$-inch brass plugs to prevent the crack from spreading. Then cut back the outer sides of the crack with a small cold chisel to permit inserting a considerable amount of rusting compound, being careful not to cut away any quantity of good metal. Then fill the crack up very fully and carefully with the compound consisting of two parts iron filings and one part sal-ammoniac. Just enough water should be added to this to make a paste which can be handled better than the dust or powder. After inserting, let the cylinder stand for a day or two, and if it does not seal up quickly and entirely, add a little water. If this does not complete the job, it may be necessary to go over it again, adding more of the rusting compound. After a couple of tries, almost any skillful repair man will get the hang of this job, and be able to seal a water jacket crack perfectly every time.

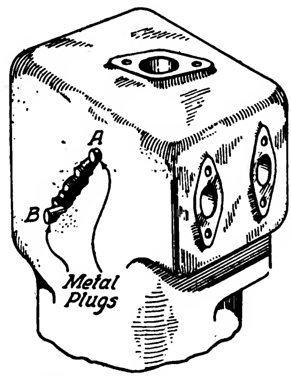


Fig. 34. Method of Plugging Small Crack in Water Jacket

Welding Breaks in Cylinders. Welding is used very frequently now on cylinder breaks, probably more than any other method, since it has proved to be quick, accurate, and cheap. It has all the desired qualities, which cannot be said of any other process. Moreover, it can be used with almost any form of metal, which also cannot be said of any other method. A separate chapter deals with welding, very exhaustively. It is recommended that every repair man study it; then get an outfit and learn to use it, for it represents a source of large profit when its use is once mastered. With a welding outfit, the method of procedure is often the reverse of other processes. Thus when a water jacket is cracked, the first operation is generally the cutting away of sufficient metal to enable the workman to see the whole extent of the crack and also to permit getting at all the surface with the welding torch. With a crack of small size, such as that just described, enough of the sides should be cut away to allow working the torch in between them. This crack should be gradually refilled with new solid metal, melted in from a fuse bar or melt bar. The sides should be cut away so as to take off more on the inside if possible, as this gives the new metal a natural hold on the inside in addition to the fusing together of the old and new metal.

When the crack is larger, but still not a big one, as a small curved or circular shape, say 2 inches long, a formed steel plate can very often be cut which exactly fits around and over the crack. This is then welded into place. This steel-plate method is particularly effective where the pieces of the water jacket are cracked out in chipping the hole or crack, or when a single piece to be welded is broken into two or three pieces during the chipping. Another similar water jacket crack repair is that necessary when the forward cylinder water jacket containing the boss in which the steel fan shaft is screwed, becomes wholly or partly cracked or broken away. This is shown, and the repair partly indicated, in Fig. 35. The difficulty here is to make a repair which will withstand subsequent tendencies to crack, that is, to make the repaired part stronger than it was in the first place. This can be done as follows: Starting at the bottom of the crack, all work proceeds upward. A hole is first burned through, as at *A*. By starting here and working upward on the right side, the hole is gradually filled with new iron from a melt bar as indicated at 2. In all this work, excess iron is left both inside and outside.

Fig. 35. Process of Welding Cylinder Jacket

Having reached the top, the work starts again at the bottom and proceeds up the other side to the top. When this is reached, and the two welds joined, the job is completed. It has the appearance shown in the sectional plan at 3, with extra metal inside and out, all around the crack. In work of this kind, precaution must be taken not to melt or otherwise weaken the cylinder wall inside.

Another cylinder weld frequently met is a flange cracked around a holding bolt. In such a break the fracture is usually confined to the flange, no part of the cylinder wall being broken or cracked. Thus, all the repair work is external, and proceeds more easily and quickly than would be the case when dealing with the more accurate cylinder wall. This is a simple repair, and is performed entirely from the outside by cutting the crack away on both sides to allow new metal to be added without increasing the thickness, then setting the piece

Fig. 36. Method of Re-Assembling Piston Mechanism

carefully in place, clamping it there and fusing new metal from a melt-bar into the V-slot formed by chipping. In case the crack does extend to the cylinder walls or bore, it is advisable to stop the weld about $\frac{1}{16}$ inch from the interior surface of the bore. In this weld, as in previous ones, excess metal is left on the outside; in fact, this is done whenever and wherever possible, as the excess metal compensates for the somewhat brittle character of the weld and guards against a recurrence of the trouble by making the break stronger than it was in the first place.

Working in Valve Cages. In overhead valve engines, when the valves are set in removable cages, it is often necessary to put in a new cage. This is worked in or seated in the cylinder by grinding it down to a perfect seat the same as a valve. Oil and emery are placed on the seat in the cylinder, the cage set in place and gradually worked around and down, until a perfect surface is obtained. The same is applied to renewing the seat when a valve cage shows signs of leakage.

Replacing Pistons in Cylinders. When cylinders or pistons have been removed to be worked on, replacing these is a difficult job. There are two ways of doing this: viz, by a special form of ring closer, and by hand, using a string. The former is a shaped device which is clamped around the ring and squeezed together with pliers, using one hand, while with the other hand the ring is guided into the groove. The second and more usual method is illustrated in Fig. 36, and requires two men, unless the cylinder is of such a shape that it can be clamped in a vise. As the picture brings out, one man holds the cylinder while the other forces the piston carrying the rings into place. The piston is shoved in until the expanded top ring prevents further movement, when a heavy cord is placed around the spring, and the ends are crossed, thus closing up the ring and allowing the piston to slide in as far as the next ring. The operation is repeated successively for the other rings. This is a very simple method but it requires patience.

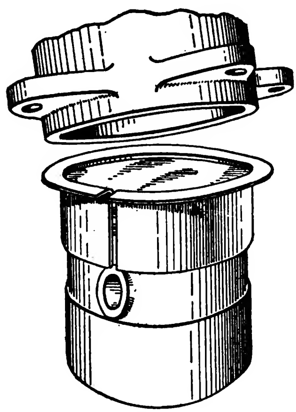


Fig. 37. Simple Rig to Assist Pistons Entering Cylinder Casting

When a block cylinder is to be replaced, this job is not so easy, for all the pistons, four or six as the case may be, must be lined up, and two of them entered at one time. This requires either special apparatus to help hold them or the services of several men. Most cylinders have a small bevelled edge at the bottom to facilitate this, but it is best to make a rig for a motor which is handled in sufficient numbers to warrant this. A handy form, and one easily made, is that shown in Fig. 37. This consists of a sheet-iron band of a depth equal to the total depth of the rings in the upper part of the cylinder and is flanged over at the top to give it extra stiffness and prevent its entering the cylinder. It is made a little bit small for the size of the pistons over which it is to be used, so it will have to be sprung into place. When this is done, it will have a tight hold on the rings, compressing them so they will enter the cylinder. In applying it, care should be used to put it on squarely, and similarly in pushing it down by forcing the piston upward into the cylinder, as it should not be moved off of a ring until that ring has been entered in the cylinder enough so it is held therein. That is, the spring clamp should not be moved down below a ring until that ring is engaged and held within the cylinder. Its use is restricted to one size of motor, which is no hardship in a big shop where one make of car is handled exclusively.

Fig. 38. Marmon Two-Piece Piston as Used on the 1920 Car

The small shop handling a variety of work would find half a dozen different sizes useful and economical. Moreover, the cost of this device is very small.

A modification of the above device consists of a similar small-sized band of sheet metal, made very wide but without the upper flange. It is made, however, with a pair of right-angle lips where the two sides meet; these are drilled for a clamping bolt. This bolt has a wing nut with clamping rings to compress the lips of the band.

Another modification of this is a loop or strap of narrow sheet metal having an additional loop to go over the two ends. These ends are made with a right-angle bend close to the piston-curve portion, and the compression of the rings is effected by pressing the sides of the clamp tightly against them, then sliding the small loop along the ends to hold this tightness.

Piston Construction. The pistons of automobile motors have long been made of cast iron, with the piston pin held in bosses on the piston walls. For all ordinary service this construction, well carried out, serves every purpose, but with the development of very high-speed motors, with piston speeds twice and three times as high as past practice has sanctioned, there is a growing tendency to substitute steel for cast iron in this important reciprocating element.

Particularly in aviation motors has this been the case; the pistons of one well-known revolving motor, for example, are machined to the thinnest possible sections, out of a high-grade alloy steel. In this motor, the connecting rods are hinged to the head of the piston instead of to the walls, which can be made much thinner than otherwise would be possible. This practice has been followed to a slight extent by some automobile manufacturers. There are now a few stock cars of established quality provided with pressed-steel pistons.

In cars, too, the movement toward smaller bores and higher efficiency has brought about the use of much lighter pistons; this is done by making them thinner and shorter. The latest development has been the use, not only of aluminum pistons and die-forged aluminum alloy connecting rods, but also of aluminum cylinders having cast-iron sleeves driven in to form the actual cylinder surfaces.

Marmon Two-Piece Piston. The body of this piston, Fig. 38, is of aluminum, and the cast-iron sleeve is bolted on to this body. The aluminum part is die cast and carries three rings and the piston pin as well as the four studs which hold the skirt of the piston. The skirt is a light cast-iron cylinder whose only connection with the head portion is at the flange, where they are bolted together. This construction allows the aluminum head to expand or contract without effecting the cast-iron skirt and thereby combines the aluminum and cast-iron pistons.

Modern Tendencies. The modern tendency is to cut down the weight. This has been done by lightening the piston all over and by taking out rings. With fewer rings, it is necessary that each should be more efficient, consequently there has been much experimenting done with new forms. The lightening of piston weight has not materially changed the old open-end trunk form, although the use of aluminum has modified its straight shape somewhat in the hour-glass and similar forms. Attempts to utilize so-called free pistons,

Fig. 39. Old and New Types of Pistons
Former Heavy Piston at Left; Present Lighter Type at Right
Courtesy of Locomobile Company of America, Bridgeport, Connecticut

in which the upper part is flexibly connected to the lower, and the use of combinations of pressed steel and other metals have done much to modify the general form.

Both these tendencies are well shown in the illustrations, Figs. 39 and 40. The former shows how a certain piston was lightened by taking out two rings at the top, one rib inside, and generally using thinner metal. The old form is shown at the left, the new at the right. The other tendency is seen in Fig. 40 which is an aluminum alloy. Note how this is cast to have less metal at the piston boss and also to be strong without extra ribs.

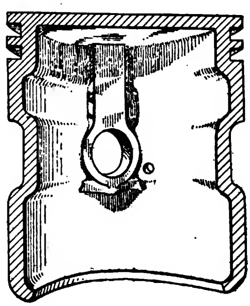


Fig. 40. Typical Piston Cast in Aluminum Alloy for Minimum Weight

Characteristics of Piston Rings. Cast iron for piston rings, long used to the exclusion of everything else, is in slight degree yielding its pre-eminence for this purpose also. This is because it has been found, in aviation motors with steel cylinders, that bronze affords greater durability and smoother running against the steel-cylinder wall, for which reason bronze rings—with steel or cast-iron springs, or "bull rings", behind them—have been found most advantageous. Multiple rings, three or more in a groove, are finding favor. Their thinness necessitates the use of steel.

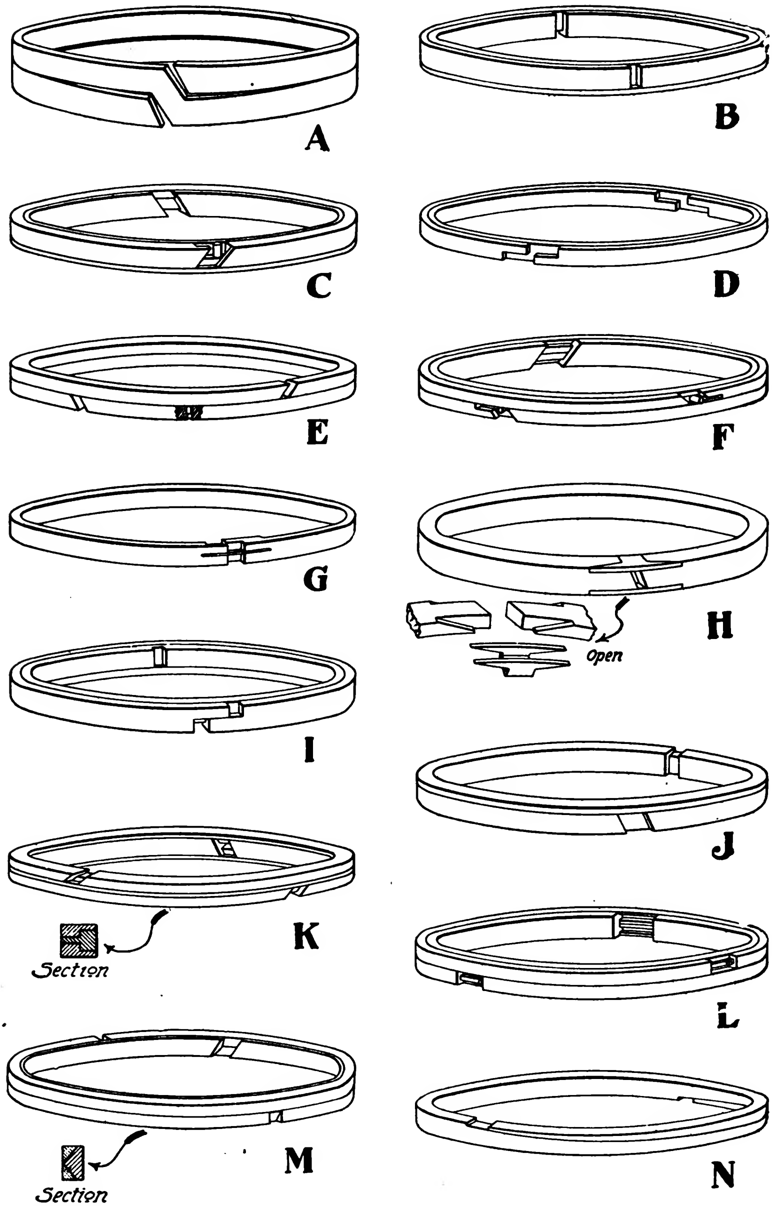


Fig. 41. New Types of Piston Rings Designed to Retain Compression and to Increase Power, at the Same Time Reducing Wall Friction

Types of Piston Rings. Where formerly three or four plain rings were used, each one filling a groove, many pistons are now equipped with multiple rings of various patented forms, for which many advantages are claimed. Some idea of the variety of these may be obtained from Fig. 41 which shows a number of different forms.

Thus, *A* indicates a ring with a double form, yet really it is one continuous piece, cut so as to appear as two. It is difficult to see any advantage in this, while it is much more expensive than the old-fashioned form. At *B* is seen a type which has an outer thin but high ring within an L-shaped inner form, both with plain vertical slots, and without holding pins of any kind. A somewhat similar form is seen at *C*, but with this difference, the inner ring has two steps instead of one, both have diagonal slots, and a pin keeps the outer one from turning.

The form at *D* has a pair of thin and very flexible high rings, set one within the other. They are concentric, and both have stepped joints. The extreme flexibility would appear to take all the value out of their use as compared with the ordinary form. Another seen at *E* differs in that one part is placed above the other and held from rotating by a pin. Both have diagonal joints. Both are eccentric and the pins hold them so the slots are 90 degrees apart. In the form at *F*, there are three pieces, including an inner one of full height with a deep outer slot, a modified U. The two outer parts are L-shaped and the L-projections fit into the slot of the big ring. All have diagonal slots and are pinned in place.

An eccentric form, which has a tongue-and-groove arrangement at the open or thin end, is shown at *G*. The makers call this the lock joint. Practically the same effect is produced in the form shown at *H*, except that the opening is closed by a separate piece. This is called a guard, and it is machined to fit under one portion of the master ring and on either side of the slender ends, so that it makes up the full width. This use of the old-fashioned simple ring seems good.

The form at *I* is that of *B* reversed, that is, the small square ring is placed on the inside of the L-shaped ring, and has, in addition, a horizontal step joint, while the outer member has a vertical step joint. An entirely different principle is utilized in the form at *J*, the inner L-shaped member having a taper, and the outer thin but high member having a corresponding taper to fit against it. The idea of the taper is that the spring of the two rings, slightly opposed, will work through this to hold both against the cylinder walls. The outside of the inner ring is knurled to hold the outer one from rotating. Both have diagonally cut slots.

In the form shown at *K*, there are three parts, divided vertically, but in such a way that the top and bottom are really dependent upon the middle to hold them in place both vertically and horizontally. It is difficult to see greater merit in this form than of three plain rings. The form at *L* is somewhat like that at *F*, except that the inner full-height ring has a pair of projecting ridges in place of the single central slot. Each of the small half-width outer rings has a central slot, or groove, and end ridges to fit around this. Like *F*, this has the small outer rings pinned, but differing from it, all have diagonal slots.

In the form seen at *M*, three parts are used, but the center full-height piece has its outer surface in the form of a double taper, upon each half of which one of the small half-height outer rings of triangular cross-section rests. In that shown at *N*, the ring is a continuous spiral, being somewhat similar to *A* in this respect. Its cut, however, is upon a slope all the way, so that its thickness varies continuously. It is made of heat-treated steel. It is difficult to see how the vertical spiral effect can make it tighter in a horizontal direction.

Piston Pins. Piston, or wrist pins, as they are variously called, are usually very simple. In general, when the pin is a light drive fit or any easy fit in the piston, it is made from a high quality of carbon steel tubing of considerable thickness, ground on the outside to size, and drilled for the locking pin (when one is used). It is then hardened and finish ground. In some instances it is simply a tight fit, with a ring fitted around the outside of the piston at its center, to form a lock. In other forms it is clamped in the connecting rod and turns in bushings in the two piston bosses. The general method, however, is the use of a hollow pin, the variation coming in the method of locking. Thus there is the use of two locking pins which project into holes; of two set screws which bear against grooves for this purpose; expansion plugs screwed into the split ends; spring plungers in holes in the piston; and of complex built-up pin sections with tapers bearing upon each other so as to be self-locking. The really important point is to have the pin so locked in place that it can never work out and score the cylinder walls, and yet be easy to disassemble.

Piston and Ring Troubles and Repairs

Removal and Replacement of Pistons. Speaking of pistons, there are several things that the beginner should learn about their removal and replacement. While it is not a difficult matter to pull a piston out of a cylinder, when both have been previously lubricated, and all proper precautions taken to loosen connecting parts, there are a few important things to remember.

The piston should be drawn out as nearly parallel to the axis of the cylinder as is possible, accompanied by a twisting motion not unlike taking out a screw, in case it sticks a little. If the piston

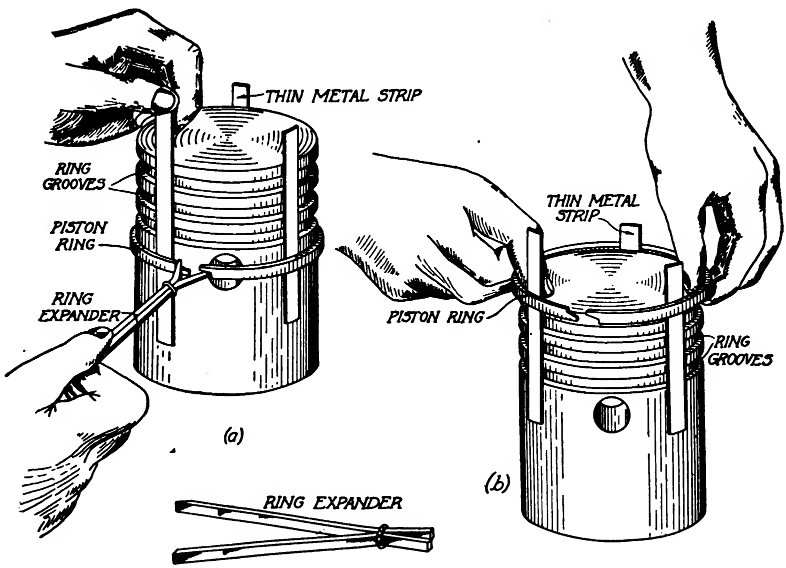


Fig. 42. Method of Removing Piston Rings

sticks badly, pour in a little kerosene and work the piston in and out so as to distribute the kerosene between the two surfaces.

To get at the spaces the rings must be removed, and as they are of cast iron and very brittle, this is a delicate task. Two methods of accomplishing this are illustrated in Fig. 42. If the owner has a pair of ring-expanding pliers, the rings can easily be expanded enough to lift them over the edge, as shown in (*a*). As very few owners possess this useful tool, however, a more common way is shown in (*b*). Secure a number of thin, flat steels about

$\frac{1}{2}$ inch wide and $\frac{1}{16}$ inch thick—corset steels, flat springs, or hack-saw blades may be used, although the latter require more care on account of the teeth along one edge. The length of these steels should be

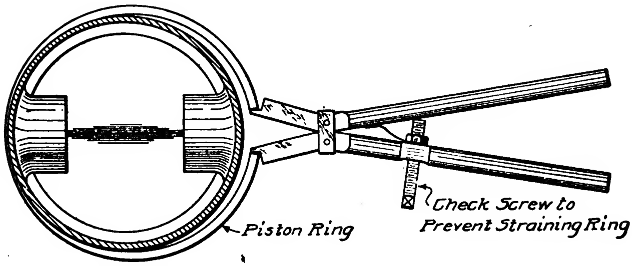


Fig. 43. Tool for Moving Piston Rings Which Prevents Breakage

such as to reach from about an inch below the last ring, to the top. Lift out one side of the ring with a small pointed tool and slip one of the steels between the ring and the piston, then move around about one-third of the way and insert another, taking care to hold the first in place; repeat the operation with a third steel. When these are in place, the steels will hold the ring out from the piston far enough to be slid over the "lands" between the grooves and along the steels to the top.

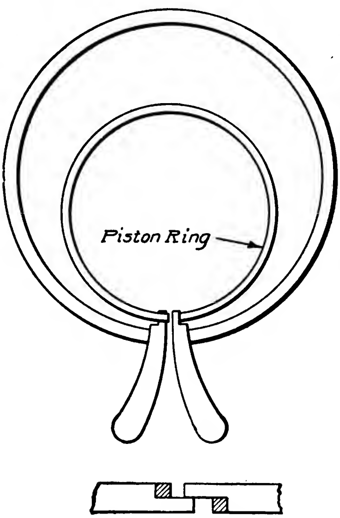


Fig. 44. Simple Piston Ring Remover

Always begin at the bottom and work up when removing rings, and just the opposite, from the top down, when replacing them. After one is mastered, the removal of the others is a simple matter of repetition. The grooves can now be scraped free of the offending carbon, a process which is but an inversion of the previous method. After this it will be necessary to replace the rings.

A modification of the simple home-made ring spreader just shown is that depicted in Fig. 43. This is made with a stop, which prevents opening the pliers beyond a predetermined distance and thus prevents breaking a ring by continued pressing on a stiff or stuck one until it gives suddenly and is then spread beyond the resisting ability of the iron. It is applicable to all forms of rings, except those with diagonal slots. In addition to the construction shown, it is desirable to fit a spring which will draw the handles together when not in use. This closes the jaws and keeps them closed, ready for immediate use.

An even better and more simple form, but without the safety feature of that just mentioned, consists of a large diameter steel spring, shaped not unlike a very big piston ring, which has a pair of handles fitted to the ends. This is shown in Fig. 44, which indicates how the nubs on the two handles are shaped so as to take hold of stepped joint rings. By making these nubs differently, any form of ring can be handled. A device of this sort saves the repair man lots of time.

Loosening Seized Pistons. When the pistons and rings freeze into the cylinder, or seize because of a lack of lubricant, there is nothing quite so good nor quite so quick acting as kerosene. The cylinder head should be opened as quickly as possible, and the kerosene poured in liberally on top of the pistons. This should be done in each cylinder. Kerosene is thin and will work down between cylinder wall and piston rings, gradually cutting away the two where they have frozen together. If kerosene is not available, take the thinnest lubricant at hand; heat it so that it will be still thinner and more penetrating, then pour it in. At times, olive oil can be combined with kerosene to advantage.

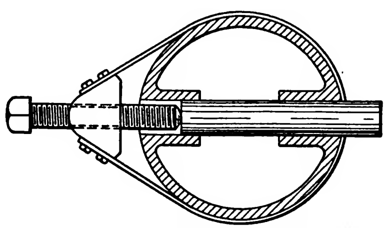


Fig. 45. Simple Piston-Pin Pulling Outfit

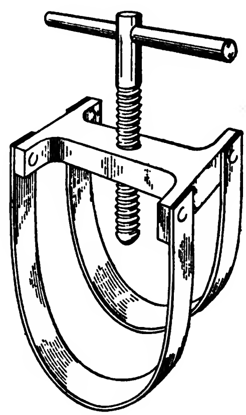


Fig. 46. Piston Ring Puller Which Allows for Exit of Pin

Freeing Wrist Pins and Bushings. When the piston pin or wrist pin is inserted directly in the piston, it is usually a tight fit, so tight, sometimes, that the repair man experiences difficulty in getting it out. To overcome this difficulty, a piston pin puller is needed. One of these, shown in Fig. 45, is made from a piece of steel, a steel strap, and a large cap screw. This piece of steel is drilled and tapped for the cap screw, and for the bolts to hold the steel strap. Then the latter is fastened so as to be about ¼ inch larger in diameter than the piston, or still larger if a long cap screw is available. When a pin is to be removed, the strap is put around the piston and the cap screw screwed in until it bears against the end of the pin. This can be done by hand. Then a wrench is applied, and as the screw is forced in, the pin is forced out on the opposite side. Be careful to see that the far side of the steel band is below the piston pin hole, so the pin will be able to come out without touching it.

This can be simplified by having an endless steel band with a nut on the inside of it to form a backing for the cap screw to work against, or, the steel band can be welded to the nut.

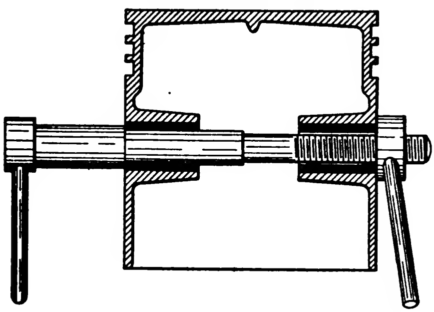


Fig. 47. Piston Pin Bushing with Shouldered Mandrel

A form which removes the above difficulty is that shown in Fig. 46. This is made so that it holds around the piston at two points, above and below the piston pin, leaving room for the pin to come out. While more elaborate than the first one described, it is still very simple. For hollow piston pins, a different form of tip on the screw is needed, as the point, or tip, must press against the outer circular ring instead of against the center. This can be obviated, however, by laying a special round piece of metal over the end of the hollow pin before starting to apply pressure to force it out.

Bushing Removers. When the piston pin is fixed in the connecting rod and rotates in bushings in the piston bosses, it is sometimes necessary to remove these bushings. A somewhat similar device will do this work, except that a shoulder or stop is needed to come up home against the side of the bushing, while the screw or threaded end must be small enough to pass through the hole in the bushing, and long enough to come out on the other side so a nut can be applied. One of these is shown in Fig. 47. The disadvantage of this type is that the nut shown on the right, which is operated to force the bushing out, must rest against the surface of the piston while being turned around. If a small U-bar be made to rest against the piston side, with a central drilled hole through which the threaded end passes, the nut will bear against the outside surface of this, so that even if the nut should scratch, no harm will be done to the piston. These pullers are used as substitutes for an arbor press, but this is desirable, as the use of the press is likely to distort the more or less delicate piston. With aluminum and the lighter weight cast-iron pistons, this is a thing which it is desirable to avoid.

Some motors have the wrist pin locked in place by means of an expanding nut with a sunken square hole for turning. To start these, a wrench with a square projection or tit to fit this is needed. Such a wrench is used on certain lathe chucks, so one can always be borrowed in a machine shop or tool room.

Mandrel for Turning Pins. Because of its being hollow in many cases, the wrist pin is difficult to handle when any work must be done upon it. For this purpose, a mandrel is needed. The method of constructing and using this is shown in Fig. 48. This consists of a shaft with a taper at one end and thread at the other, for a tapered nut. The wrist pin is slipped on the outer end, the taper nut put in place against it, and the backing nut put on behind that. Then these are screwed up until the two tapers hold the pin firmly, after which it may be placed in the lathe and work done upon it.

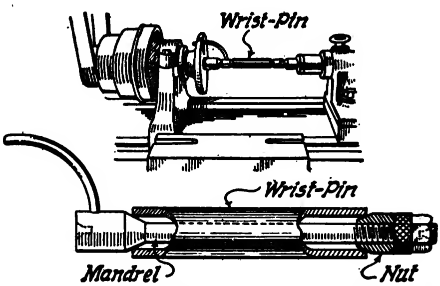


Fig. 48. Tapered Mandrel for Holding Hollow Piston Pin for Lathe Work

Speeding Up Old Engines by Lightening Pistons, Etc. As will be pointed out later under "Cams", one way to speed up an old engine is to replace the old camshaft and cams with new ones giving more modern timing. Another and a less expensive and troublesome way in which this can be done is by lightening the pistons and the reciprocating parts. This the repair man will surely be called upon to do, as the manufacturer probably would refuse.

In order to get out any amount of metal worth the trouble, it will be necessary to drill from 12 to 20 or more holes of from ½-inch up to 1-inch diameter, depending upon the size of the piston as to bore and length. In a six-cylinder motor, this amounts to almost 100 holes (even more in some cases), and as these must be drilled with considerable similarity in the pistons, it is well worth while to construct a fixture to aid or speed up this work.

One idea of the way such a lightened piston should look when finished is given in Fig. 49, which shows the steel pistons used in the Sunbeam racers. These are made this way to give the maximum of lightness with strength. Although made from steel, this is done simply to get very light side walls, and the general appearance of the skirt with its many drilled holes is just what the repair man should try to get when he starts to cut down the weight of standard pistons for racing or speed purposes.

Fig. 49. Appearance of Piston Lightened for Racing Purposes

Clamp for Pistons. The first requisite is a clamp, Fig. 50, to keep the piston from turning, so that it will not break the drill. A good way to begin is to construct a base with a pair of uprights having deep 90-degree V's in them; this is made so that it can be bolted to the drill-press table. The V's should be lined with leather or fabric. Discarded clutch or brake linings answer this purpose

Fig. 50. A Home-Made Wooden Stand to Facilitate Drilling Out Pistons

very well. To one of the uprights is pivoted a long handle, having a lined V which matches with that of the upright below it, and gives a good grip on the piston.

Drilling Holes. When drilling to save weight, the holes are put in close together and in regular form, the idea being to take out as much weight of metal as is safe. In doing this, it is well to work out a scheme of drilling in advance, to make a heavy brown paper template, and fasten to each piston in turn.

Ring Repairs. When rings are turned either for reducing thickness or for truing up the face, a wooden faceplate should be made with a slightly tapered groove for the ring to fit into. The ring should be pressed into the groove, and its natural spring will hold it in place. When working on the outer diameter, the face of the wood will have to be cut away sufficiently to allow the ring to project, or, instead of a single large central hole, an annular ring can be turned in the wooden faceplate, the ring being fitted over the outside of it.

Fig. 51. Method of Grooving and Drilling Piston to Overcome Excessive Lubrication and Smoking

Curing Excessive Lubrication. *Holes in Pistons.* When it comes to drilling holes to provide an outlet for the excess oil in the cylinders and so to reduce smoking, small holes, $\frac{1}{8}$-inch for example, are sufficient. They may be drilled in on any spiral plan by simply beginning near the bottom and working up close to the piston-pin bosses along a spiral track. The advantage of the spiral arrangement is that no hole is above another; the dripping from each hole is therefore distinct, and the quantity which runs down is greater.

Grooving Pistons. Another method of curing the excessive lubrication to which the older cars—particularly those with splash lubrication—are subject is to turn a deep groove in the bottom of the piston, about like a piston-ring groove but with a lower edge beveled off. When this is done, about as shown in Fig. 51, a series of small holes—made with a No. 30 drill—are put in at the angle of the bevel; six or eight holes, equally distributed around the circumference, are probably enough. The sharp upper edge acts as a wiper and removes the oil from the cylinder walls into the groove, whence it passes through the holes to the piston interior and there drops back into the crankcase. No ring is placed in the slot as it would prevent the free passage of the oil. This device stops the smoking immediately.

Loose Pistons. Many times the pistons will wear just enough so that they are loose in the cylinder all the way around. This causes leakage of gas, piston slaps, and other similar troubles. If the owner of the car does not care to buy new pistons, or if the car is an "orphan", or if, for other reasons, pistons cannot be obtained, the clever repair man can remedy the trouble at small expense. The process consists in heating and expanding the old pistons. The heating is done in charcoal and must be done very carefully and slowly. After the pistons become red hot the fire is allowed to go out slowly, so that the piston is cooled in its charcoal bed. Sometimes as much as $\frac{4}{1000}$ of an inch can be gained in this way. When the pistons are so far gone that they cannot be handled in this way, they must be replaced with new ones.

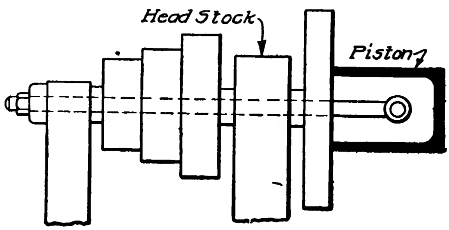


Fig. 52. Rigging for Holding Piston against Face Plate of Lathe

Mounting Pistons on Lathes. It is difficult to handle a piston in the lathe, or machine the outside in any manner, as a chuck does not get enough of a hold on it, and is likely to mark the surface. When work on it is necessary, the piston can be handled effectively by using a small rod with an eye at one end. This is made to fit the piston pin in the case of an old piston. The rod is run through the hollow spindle and bolted at the outer end. The tightening of the nut on it pulls the piston up against the face plate as Fig. 52 shows. This same method can be used when making a new piston. In the latter case, it is held in the chuck to finish the outside and inside, then the wrist-pin hole is drilled, bored, and reamed, and the wrist pin fitted. Finally, the finishing cut, or grinding of the outside, is completed.

CONNECTING RODS

Design Characteristics. *H-Section Form.* Established practice in connecting-rod design is almost all in favor of the common

H-section rod, usually with two bolts to attach the cap. In some cases four bolts are used, since with four bolts a flaw or crack in one is less likely to cause damage than is the case when only two are used. The old scheme of hinging the cap at one side is now practically obsolete, having been discarded because it made accurate adjustment of the bearing surfaces almost impossible.

Tendency to Lighten Rods. The modern tendency toward lightening the weight has extended to the connecting rods, since a portion of the rod is considered as reciprocating. This lightening has been accomplished by external machining. Thus, in the typical connecting rod of forged alloy steel, shown in Fig. 53, the form at the left is that formerly used, while that at the right is its present shape. Note how the rounding sides of the H-part, necessary in forging, have been machined off; how the fillets at big end and piston end have been machined down; how the upper end has also had its central rounding part machined off; and the whole, file finished. Another excellent feature of the work done to lighten the rods in this way is that they can be brought to an absolute standard of weight, so that every rod weighs exactly the same as every other. This was not possible previously, as the variation of the exterior surfaces, due to differences in forging, made considerable difference in weight. In both, the bushings are in place.

Fig. 53. Old and New Connecting Rods Showing How They Can Be Lightened
Courtesy of the Locomobile Company of America, Bridgeport, Connecticut

Tubular Rods. Tubular rods, in place of the H-section, are giving good service in several of the long-stroke foreign motors, and it is difficult to see why this form is not superior to that in common use.

The question of cost, however, is a consideration, since it is necessary to bore the hole through the inside of the rod, whereas a forged rod of H-section requires no machining except at the end.

The wonderful progress in welding, however, has made it possible to construct a tubular connecting rod at a very low expense, and, owing to its many advantages, this is finding much favor for small motors. The two ends are machined and a section of tubing welded to them.

One advantage of the tubular rod, in addition to its superiority for withstanding the compression load to which a rod is chiefly subject, is that it can be used as a pipe to convey oil from the big end to the piston-pin bearing.

Fig. 54 shows an example of a very light-weight, high-quality, aviation-motor connecting rod, machined out of a solid bar of alloy steel, and provided with four bolts in the cap.

Connecting-Rod Bearings. *Usual Types.* Connecting rods have two different forms of bearings. This is due to the difference in their service. At the upper or piston end, the bearing is usually a high-grade bronze tubing, machined all over and pressed in place. When in place, it generally has a central oil hole drilled through rod and bushing, and then a couple of oil grooves are scraped in by hand to start from this hole and distribute the oil outward in both directions on its inner surface.

At the lower or, as it is usually called, big end, the connecting rod must have a better bearing. This end is bolted around the crankshaft pin and must sustain high rubbing speed, as well as the load of explosions. Bolting it on, and the need for removing it occasionally, call for a form which is split horizontally. Generally, this bearing is of high-grade bronze with a softer, or babbitt, central lining which can be replaced easily and quickly. The harder bronze back will sustain

Fig. 55. Connecting Rods for V-Type Engine, Showing Method of Forking One Rod
Courtesy of Cadillac Motor Car Company, Detroit, Michigan

the stresses of bolting up tight and stand up under the constant pounding, while the softer and renewable center takes all ordinary wear. These bearings are fitted with great care. They are reamed by hand after machining, and then hand scraped to a precise fit. They are pinned in place, drilled for oil, and grooved to distribute it.

Eight- and Twelve-V-Types. The eight- and twelve-cylinder V-type motors have altered the design of connecting-rod bearings somewhat, in that there are two connecting-rod big ends working upon one crank pin, that is, an eight-cylinder V-engine uses a four-cylinder form of crankshaft with two connecting rods on each pin. This modifies what was good connecting rod bearing practice, one of two different forms being utilized. When the rods are placed side by side with individual bearings, the pins are made very large and as long as possible, in order to give adequate bearing surface. The other form is the forked rod in which one rod works within a slot in the

Fig. 55A. Triple Lite Piston and Connecting Rod Manufactured by the Laurels Motor Company, Anderson, Indiana

other. In this type, a split bearing of the usual form is placed in the forked or long rod, and the outer surface of the central part of this prepared as a pin surface for the other or central rod. The requisite area of the smaller rod bearing is made up by its larger diameter. This is well shown in Fig. 55, where the rods and bearing are shown assembled, and the separate big-end bearing is shown at the right. In another type of V-motor connecting-rod bearing, the larger bearing is slotted for the central rod and its bearing, the slot being made large enough to permit a rotation, which never exceeds a quarter of a turn. This arrangement is more complicated to install and repair than the form shown.

Aluminum Connecting Rods. A number of manufacturers are now developing aluminum connecting rods as this metal is very light and will combine very readily with other metals, thus forming an alloy of great strength. The lighter the reciprocating weight, such as the piston and connecting rod, the greater will be the efficiency, power, and speed of the motor. It is for this reason that the engineers desire to develop a much lighter rod. While it is true that the entire rod does not act as reciprocating weight, in general practice, the upper half of the rod is considered reciprocating while the lower half is rotating weight.

The Triple Lite connecting rods—an alloy with aluminum as its base—shown in Fig. 55a are constructed with a section somewhat different from the ordinary drop forged connecting rod. A comparison with Fig. 55 shows that the *H* section in the Triple Lite connecting rod has its flange between the bearing pins while the flange in the drop forged steel rod is at the side of the bearing pins. The Triple Lite is also used as a bearing making it unnecessary to equip these rods with a babbitt bearing face. This rod weighs but 14 ounces.

Connecting Rod Troubles and Repairs

Classification of Troubles. In general, all connecting-rod troubles come under one of four headings: straight rod, proper bearing adjustment, mechanical work (scraping bearings, straightening rod, or other work), and special equipment for doing connecting-rod work.

Straightening Bent Rod. The need for a straight and true rod is apparent, but it is surprising how many rods are not straight, particularly in old motors Many erratic and bad-sounding motors have all their trouble caused by a bent rod. A connecting rod can be bent either of two ways, and one gives as much trouble as the other. If bent in the plane of rotation, the rod will simply be shortened, the piston will not go as high as it should, and it will go down a little lower than normal. Moreover, the bend will press it with unusual force on the cylinder wall on one side and cause it to wear more than the other.

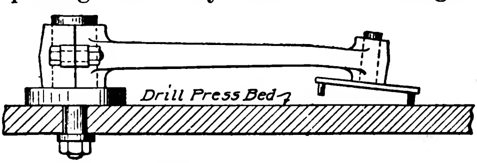


Fig. 56. Method of Testing Connecting Rods with two Mandrels

The combination will soon result in trouble. When bent in a longitudinal direction, that is, fore and aft, the upper end of the rod will run against one side of the piston or perhaps only knock against it on each stroke. At any rate, this too, will give trouble.

Methods of Testing Straightness of Rods. The first thing to do when a connecting rod is suspected is to take it out and test it. One way of doing this is to attach the lower end to a mandrel, which can be bolted into a drill-press table, as shown in Fig. 56. Before doing this, the small end is also fitted with a mandrel, the lower part of which is of considerable length and has two short vertical pegs. When the big end is bolted down, if both the small pegs on the other end touch, it proves at least that the two holes (big end and small end) are parallel. If one of these pegs is off the table as shown,

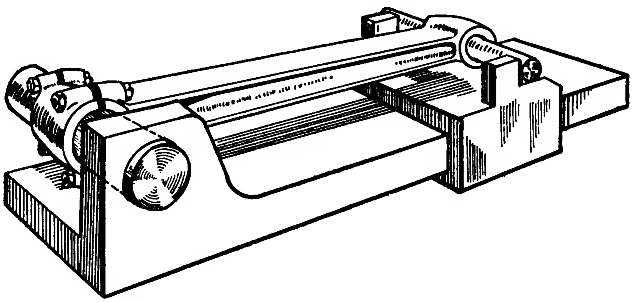


Fig. 57. Complete Connecting-Rod Testing Fixture

it proves that the two holes are not parallel. In the latter case, the rod would need to be straightened, as nothing but the bending of the rod would throw the holes out of parallel when they were bored correctly.

Another method, which is very similar, consists in forcing two mandrels of equal length into the two holes, until each is centered in the rod. Then, if the rod be placed on supports on the surface plate, or other similar true surface, so that one mandrel is horizontal, the surface gage will show at once if the other end is also horizontal, and thus, if the rod is straight and true. It will also show how much it is twisted, if out of true. If the mandrels are made long enough, ordinary calipers can be substituted for the surface gage with equally accurate results.

A method almost the same as that just described is utilized in the testing fixture shown in Fig. 57. The advantage of such a fixture is that it always works the same, while the use of surface gages and calipers varies from one workman to another, and even with the same man, from day to day, according to his moods and feelings. As the sketch shows, there is a mandrel for each end of the rod, that for the big end being pivoted in the fixture. When the rod is forced into this, and the other mandrel put in place in the piston end, if rotated down to a flat position (as shown), the small end mandrel should touch both of the fixture stops. If badly twisted, it will not be able to go down on one side.

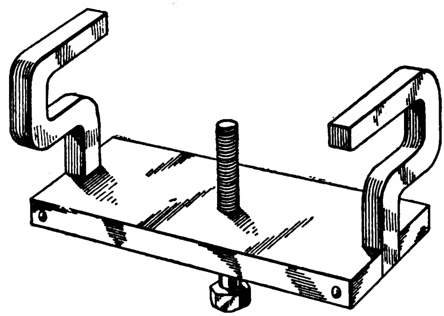


Fig. 58. Connecting-Rod Straightener Constructed from Three-Quarter-Inch Bar Stock

Straightening Jigs. When it has been proved that the rod is not straight, it is necessary to have a device for applying pressure in order to straighten it. The simplest way is an ordinary straightening press consisting of a pair of ways with V-blocks upon which the work is supported and a lever or screw to apply the pressure in the middle. The work is supported on the V-blocks, the distance apart varying with the amount it is to be bent—far apart for a big bend, close together for a small one. For as short a member as a connecting rod, however, this is not sufficiently accurate, and besides, the form of the rod does not suit it to good results by this method.

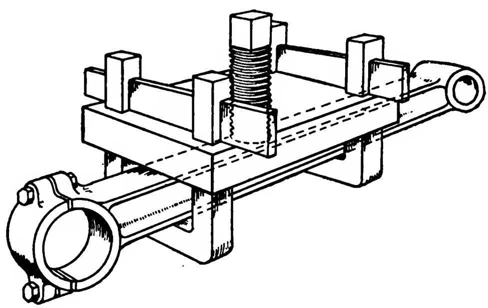


Fig. 59. Box Type of Connecting-Rod Straightener

A simple fixture for bending a rod, shown in Fig. 58, consists of a pair of hooks for holding it and a central screw for applying power. The rod is slid into place inside the hooks and the screw turned until the rod is straightened. Then to prevent its springing back when the pressure is released, it is peened on the side opposite the screw. The advantage of this method is that it throws all stresses upon the rod itself and none on the bearing surfaces. The hooks are forged from high-carbon steel of $\frac{3}{4}$-inch square section. The screw should be not less than $\frac{5}{8}$ inch to $\frac{3}{4}$ inch in diameter and fine threaded.

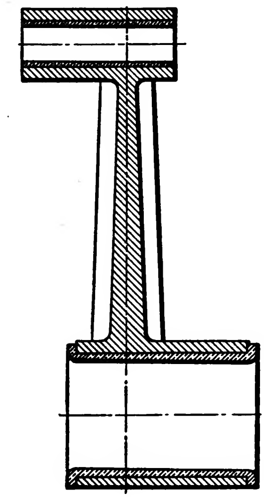


Fig. 60. Offset Connecting Rod Showing How Bearings Wear

Another fixture is on the box order, shown in Fig. 59. This has a pair of end clips which hold the rod tight by means of wedges which are driven into place. When this has been done, the rod is straightened by means of the central screw. As will be noted, the principal difference between the two forms, Figs. 58 and 59, is in the holding method. There are other forms, as well as forms of mandrels for lapping in big-end bearings, which are so constructed as to give a check on straightness and to allow of remedying the situation if the rod is not straight. Some of these will be described.

Offsetting Causes Trouble. Many motors have been constructed with offset connecting rods, that is, the perpendicular center line of the wristpin, located in the piston, where the pressure is applied, is not upon the center line of the bottom end. This resultant wear on the bearings is exaggerated in Fig. 60, which indicates also how this situation causes wear on the upper left end and lower right end of both bearings. The sketch also shows how this unequal wear is greater on the crank end, which is offset, than upon the piston end. The cause of this wear is simple, the pressure is unbalanced on the left side, so a downward push on that side is taken up by extra wear there, and on an upward push, as on the compression stroke when the flywheel is driving the pistons, the extra resistance of the left side causes unusual upward pressure on the right side. So the ends continue to wear, until

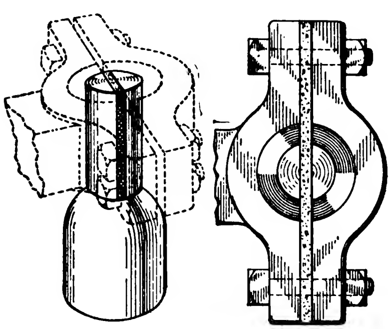


Fig. 61. Wooden Core for Babbitting Connecting-Rod Bearings

a rocking motion of the pins results, and this causes a noise. New bearings help temporarily, but a stiffer connecting rod will often remedy it more or less permanently.

Adjustment of Connecting-Rod Bearings. *Babbitting Bearings.* As has been stated, the majority of connecting-rod and crankshaft bearings are bronze shells or backs, lined or faced with babbitt as a wearing metal. The bronze provides the stiffness and long life, the babbitt, the softer wearing face which is easily and cheaply replaced. In this replacement, a form or jig to simulate the crankpin and approximate its size must be used for a center. A form made of wood is shown in Fig. 61. This is simply a round member of hard wood, turned up slightly smaller than the actual crankpin at the upper end, while the lower end is left large to form an under surface for the metal. Next, the upper part is split or rather has a cut taken across it, equal in thickness to the shim to be used when the bearing is

Fig. 62. Home-Made Creeper

assembled in place. Then, when the babbitt is poured in, a metal member is set across the rod to form the shim, which is shown in the smaller sketch at the right.

This method has the advantage over that of using the pin when pouring the metal in position, because it gives a little surplus to machine off, and thus makes the surface more accurate before it is scraped. If broaching to harden the surface of the metal is resorted to, it gives a little metal to broach down. Moreover, by making it so simple and easy to handle, the work of babbitting is made easy. This cannot be said of trying to babbitt in place. The core need not necessarily be of wood; it can be of metal or of anything else desired. But the wood has the advantage of being easily worked, or of being cheap and quickly obtained.

Kinks in Adjusting Bearings. Usually, crankshaft and connecting-rod bearing adjustment is a difficult job. This is particularly true when the engine is not removed from the chassis. The connecting-rod bolts are tight and hard to reach, and the operator, who is lying on his back, has all dislodged dirt or oil dropping in his face. Work like this calls for an easy means of getting under the engine and out again. For this, a form of creeper is necessary. There are many forms made and sold, but a simple one which any repair man can construct for himself is shown in Fig. 62. This consists of a wood frame with casters at the four corners and longitudinal slats for the floor. By making the ends concave, the surface is made concave. With a pillow or other head rest, it is more comfortable to use.

Another way in which this work may be facilitated is to make a special socket wrench for connecting-rod nuts and to make it deep enough to hold four nuts, one over the other. Then with a spring-stop arrangement, Fig. 63, the nuts from two rods can be taken off without stopping; or if lock nuts are used, the nuts and lock nuts may be removed from one rod. This is accomplished by means of four spring-operated pins. When the first nut is removed, it sticks in the end of the tool, but pushing this into the second one moves the first nut on up inside the socket. In replacement, when the upper pins are pulled, a nut drops down and is held by the lower pins enough to start it on the bolt end. When tightened, the socket can be pulled off, and the next nut dropped down and fixed in place by hand. The four pins have hardened ends, and the springs are old clock springs to which the upper pair of pins are brazed. The lower pins can be free. This form of socket wrench can be used with equal advantage in many other inaccessible places. Its single drawback is that it can only be of one size; and a set of them have to be constructed to take care of all needs.

Fig. 63. Spring Clips on Socket Wrench for Use in Inaccessible Places

In ordinary bearing adjustment, the nuts are taken off, the connecting-rod cap removed, and the shims taken out; say, a shim of .001-inch thickness for very small wear, .002 inch for considerable wear, and .003 inch for severe wear. If more than this has been worn off the bearings, they need re-scraping, as this is about the maximum that can be taken out without scraping. Usually, when

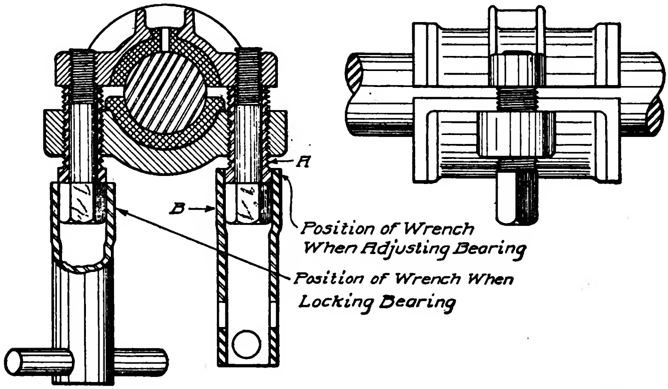


Fig. 64. Connecting Rod and Main Bearings Constructed without Shims
Courtesy of Reo Motor Car Company, Lansing, Michigan

the bearings have been taken up in this way, the caps are put back on pretty tight, a little bit tighter than they were previously. Then they are flooded with oil and run in this condition. The combination of excess oil and tight caps soon gives the entire bearing surface a fine polish which will last for many miles.

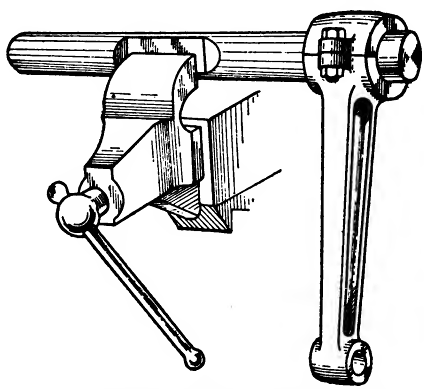


Fig. 65. Standard Mandrel Method of Lapping Big-End Bearings of Connecting Rods

Special Sleeve Replaces Shims. In one motor (Reo), the shim is replaced by an ingenious arrangement of a threaded sleeve around the bearing bolts. This is shown in Fig. 64 in which the sleeves are marked *A* and the bolts *B*. It will be noted that the sleeves rest against the upper part of the bearing and have a head against which the bolts rest, so that the latter can be tightened only as far as the sleeves allow. With this construction, when it is desired to tighten a bearing, the socket wrench is slid on so as to hold the heads of both bolt and sleeve, and then turned to unscrew both.

Then the socket is drawn off the sleeve head, in the position shown at the left, and the bolt screwed back to pinch the bearing together and lock it. As will be noted, the two halves of the bearing metal are separated a considerable distance so that this arrangement is good for many thousand miles. Two years' running will usually exhaust the possibilities of the original bearing and its shims, which calls for re-babbitting, re-scraping, new shims, or for an entirely new bearing. This form of construction could be used anywhere that the bearings are likely to need frequent readjustment.

Mandrel for Lapping. In order to give the connecting-rod bearings the best possible surface, a mandrel should be used to lap them in. This is the equivalent of running in. The rod, with bearings in place, is put on the mandrel, and the bolts tightened a little; then it is worked back and forth, until the flattening down of the surface will allow more tightening of the bolts. This is continued until, with a mandrel the exact size of the crankpins, the bolts can be pulled up dead tight. Then the rod is removed; it is finished. Such a mandrel, shown in Fig. 65, is usually a piece of steel turned up on one end to the exact size of the crankpin, with a flat spot machined in the other end to allow holding in the vice. By making it perfectly straight, a try square against the mandrel will show the correctness of the rod. On the other hand, if the outer end be made with a very slight taper, it is easier to work the rod on and off and easier to inspect the inside surface without unbolting.

Drilling Thin Shims. When thin brass shims are used, and the shape is formed by the workman, it is difficult to get a good true hole because of the extreme thinness of the metal. By collecting a number of these together and clamping them between two blocks of wood, a straight true hole can be bored through wood and brass with an ordinary bit and brace. The use of laminated shims avoids all this, as they come in the required thickness and are drilled to size. With these, adjustment is simply a matter of peeling off one of the laminations.

CRANKSHAFTS

Material. The crankshaft in all but heavy slow-running motors should be made of the finest alloy steel obtainable, for it carries the practical equivalent of thousands upon thousands of heavy blows.

Variation of Design. The greatest variations in automobile crankshaft design, aside from those permitted or made necessary by differences in the quality of material, are due to the conditions involved in the different combinations of cylinders that can be utilized. Thus the number of crank throws, as well as their position, varies with the type of motor.

As the repair man knows crankshafts today, they are of two kinds. The first is the four-cylinder form, in which all throws are in a single plane. This type of shaft has four pins, one for each connecting-rod big-end bearing. It may have either three bearings, as shown in Fig. 66, or five bearings. The second type, which the repair man is likely to meet, is the six-cylinder shaft, which will have six pins for connecting rods; these are grouped in pairs, and each pair in a different plane, the angle between them being 120 degrees. This type of shaft may have either four or seven bearings. In the four-bearing form, there is a bearing at each end, and another between each pair of cylinders, as shown in Fig. 67, with pistons and con-

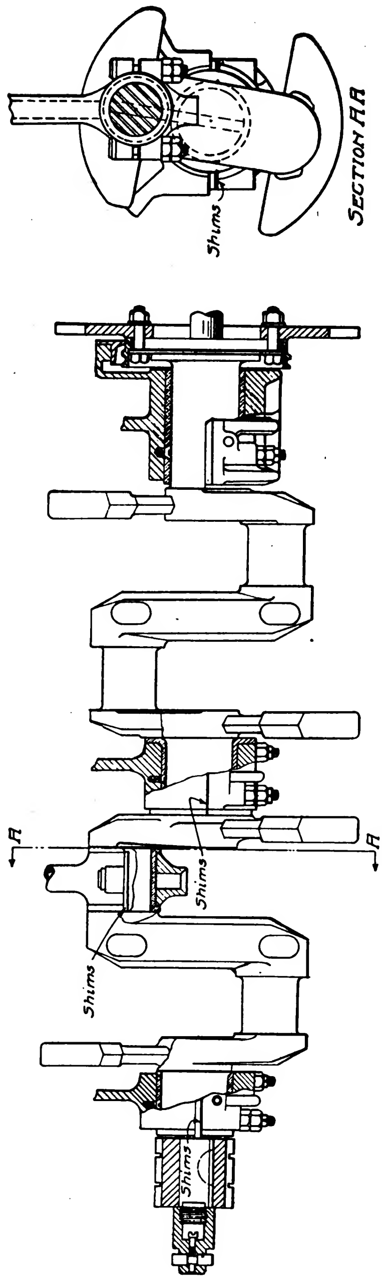


Fig. 66. Four-Cylinder Three-Bearing Balanced Crankshaft
Courtesy of F. B Stearns Company, Cleveland, Ohio

necting rods attached. In the seven-bearing form, there is a bearing on each side of each connecting rod. These are the modern types, but older shafts may be encountered occasionally, in the way of four-cylinder shafts with two bearings, one at each end only; also with

Fig. 67. Six-Cylinder Four-Bearing Crankshaft with Pistons and Connecting Rods Assembled
Courtesy of Nordyke & Marmon Company, Indianapolis, Indiana

four bearings, the latter having the usual center bearing eliminated. The modern tendency is toward simplification, compactness, and lowered first cost; and the shafts with the fewer number of bearings are on the increase.

Fig. 68. Typical Drop-Forged-Balanced Crankshaft
Courtesy of Park Drop Forge Company, Cleveland, Ohio

Crankshafts may be found which are drilled out for lubricant passages. In such cases, the repair man must look for attachments which feed the oil into the hollow interior. Also, he may meet a ball-bearing form of shaft which has been built up to allow the bearings to be assembled. Such a shaft should be handled with extreme care.

Eight-cylinder engines generally use a four-cylinder form of shaft, with two connecting rods on each of the four pins. This is explained previously under connecting rods. Similarly, twelve-cylinder motors have a typical six-cylinder crankshaft, with two rods on each of the six pins.

Balanced Crankshafts. While not an assembled shaft in the sense just referred to, the balanced form is meeting with great favor, and is being widely adopted. This will be met by the repair man in two forms. One is like Fig. 66, except that the weights are machined to fit on the crank cheeks and bolted there. The repair man should not remove these unless it is absolutely necessary, as they vary in size and weight. They are fitted in place with extreme care and fastened extremely well. The other type—the kind being introduced into the latest models—has its counterweights forged as a part of the crankshaft, Fig. 68. In this type, the weights are adjusted to make the proper balance when the shaft is being machined.

Crankshaft Bearings. The bearings of the crankshaft in the crankcase do not differ materially from the connecting-rod bearings just shown and described. They may be a little longer, but the type is the same. They are pinned or otherwise fastened in the crankcase so as not to rotate, while the connecting-rod bearings are fastened in the connecting rods so as to rotate with them. A few shafts will be met which have ball or roller bearings, but the great majority have the split bronze-backed, babbitt-faced bearing described for connecting rods.

Crankshaft and Connecting-Rod Bearing Shims. Practically all split or two-piece bearings for either crankshafts or connecting rods are assembled in place with shims. These are very thin flat pieces of metal set between the two halves of the bearing when it is assembled new to spread it apart. The shaft bearings are scraped to an exact fit on the pins with these shims or expanders in place. Then when wear occurs in the bearing, so that its inside diameter is enlarged, the bolts may be taken out, a shim or shims of the required thickness removed, and the bolts put back and tightened. This removal reduces the diameter of the inside of the bearing. To facilitate this action, the shims are generally put in, in such a way as to allow taking out a number of thousandths of an inch, there being two shims of $\frac{1}{1000}$, two or more of $\frac{2}{1000}$, possibly one of $\frac{5}{1000}$, and a thicker one, or more of the very thin ones. These shims enable the taking-up of wear amounting to $\frac{1}{1000}$ of an inch, when one of the thinnest shims is removed; $\frac{2}{1000}$ by removing one of that thickness; $\frac{3}{1000}$ by removing a $\frac{1}{1000}$ and a $\frac{2}{1000}$; $\frac{4}{1000}$ by taking two 2's, etc.

Of course, a crankshaft bearing or a connecting rod-bearing will not wear entirely round, but the work of adjusting either bearing is reduced to a minimum by the use of shims. When the wear is very bad, the bearings should be re-fitted and the shims left out.

An entirely new form is the laminated shim. The total thickness required is built up of very thin laminations, either one or two thousandths of an inch thick, so that in adjusting a bearing as many laminations are peeled off as are necessary to take up the wear, then the original shim, slightly lessened in thickness is replaced.

In Fig. 66, the end view shows both connecting-rod and crankshaft bearing shims in place, and indicates how they perform their function of holding the halves of the bearing apart when the bearing is being fitted.

Crankshaft and Bearing Troubles, and Remedies

Bearings. Bearings of the two-piece, or split, type give the auto repair man fully as much trouble as anything, in fact, the crankshaft bearings should not be tackled until considerable repair experience has been had. In general, wear on the bearings is due to one of two causes: either to a soft metal which has caused vertical wear on the inside or outside of the lower half of the bushing, or to a vibrating shaft which has worn an oval hole somewhere in the length of the shaft, as at the inner or outer end.

In the former case, the height of the worn half must be reduced. This is usually done by taking as much metal from the upper face as is necessary. When this has been done—either by filing or by rubbing across emery cloth wet with oil—the two halves of the bushing will approach so close together that the hole will be smaller than the shaft. This will necessitate scraping out, or reboring, according to the amount which has been taken off. In the case of very small amounts, this wear can be taken up by removing shims, as mentioned above.

When the second form of wear is found, that is, when the bushing is worn oval by a wobbling shaft end, the only remedy is to bring the bearing halves together as before and re-bore. It may be that this operation robs the bearing plates of so much metal that they will not fit the holes in the case; or possibly the wear may have communicated itself to the case, so that the hole there is out of true. If this be slight, refilling the cases with babbitt metal or building-up may be resorted to, but if the wear is considerable, a new set of bearings is the only remedy. In building up the bearing, strips of soft metal are placed in the worn spots, after cutting or filing them to fit as closely as possible, and the bearing driven down upon them as firmly as possible. In this way, it is often possible to build up a worn crankcase to answer for many thousand more miles running.

Bearing Wear. In this connection, it is important to know how and why bearings wear. Normally, between the crankshaft bearing and the pin, there is a space of perhaps .002 inch divided into .001 inch all around, and this space is occupied by a film of lubricant. So long as this is the case, if the metal remains hard and does not give under the constant pounding, and the film of lubricant stays unbroken, it remains a perfect bearing. But the film does get broken or reduced, and the softer metal does give, so we have a condition shown at *A*, Fig. 69. Instead of a cylindrical pin centered in a cylindrical hole, one or the other is worn oval. This is usually the bearing, for the weight of the

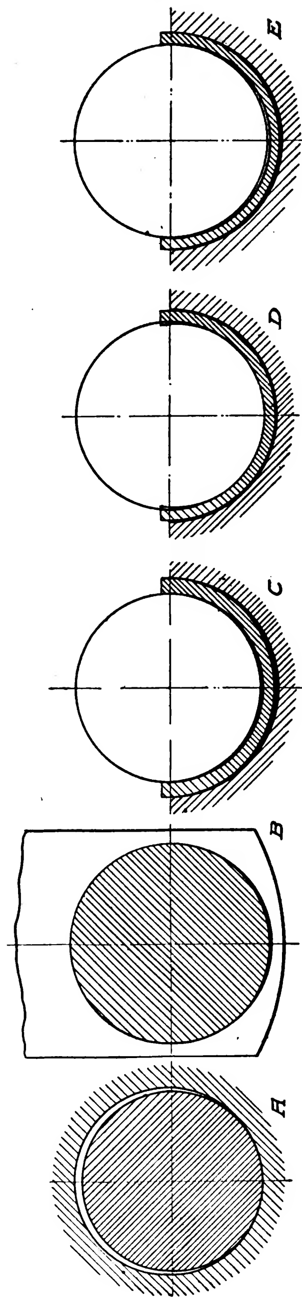


Fig. 69. Wear in Crankshaft Bearings. *A*—Section through Worn Bearings; *B*—Flat Spot on Shaft; *C*—Incorrectly Fitted Shim; *D*—Bearing at *C* Fitted by Scraping Bearing and Case; *E*—Bearing at *C* Fitted by Scraping Shim only

shaft, coupled with the pressure on it, keeps it at the bottom of the hole. The tendency, then, is to increase this eccentricity. In this condition, the pin is running against the bearing metal at only one very limited surface, so all the pressure and all the wear are concentrated there. If the bearing is hard, or if a hard spot develops, the pin is likely to wear flat on the bottom side, as shown at *B*. When the bearing is fitted to the case, great care and accuracy are required. If care is not taken, an incorrect fitting, shown at *C*, results. Here the shim does not entirely fill the opening for it, and the bearing metal rests on the case at one point; on the shim at another; and does not touch either at a third. This is remedied by scraping both bearing and case, as shown at *D*, or the shim alone as seen at *E*. In the former it will be noted how the full shim has raised the bearing so that its points project into the pin, where scraping will be needed. In the latter case, also, scraping the bottom of the bearing will be necessary, for using a fully fitted shim has raised the center more than the sides.

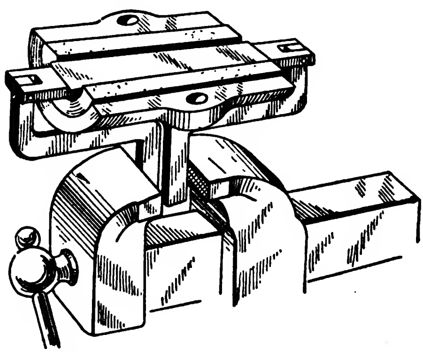


Fig. 70. Holding Fixture for Crankshaft Bearing Caps

Crankshaft Pounding. When the dull throbbing noise is found to come from within the crankcase, possibly between two of the bearings, this indicates a crankshaft or a connecting-rod pound. That is to say, either the rod is loose on the shaft or the shaft is loose in one of its bearings. Whenever the force of an explosion comes on the piston and drives it down, this looseness is taken up quickly, and the dull pounding noise is made. This is a serious trouble and, if long continued, may wreck the engine. That is, the loose rod may become entirely loose and free so as to thrash around and, in so doing, wreck the crankcase; or, if the pound comes from the shaft, the bearing may continue to loosen and finally that part of the shaft become entirely free to thrash around. Both these troubles can be overcome by tightening of the bearing caps.

Test for Tightness. When a connecting rod has been fitted to a crankpin and is ready for use, a simple test of correct tightness is this: If the rod is placed vertical, it will stay there, but if pulled over past 20 degrees from a vertical, it will swing down, of itself, to the bottom position and stop there without continuing to swing. If it will do this, it is just tight enough. If it will not swing down at all or continues swinging, it is either too tight or too loose. To a certain extent, crankshaft bearings are delicate, and they can be ruined by having the big ends too tight.

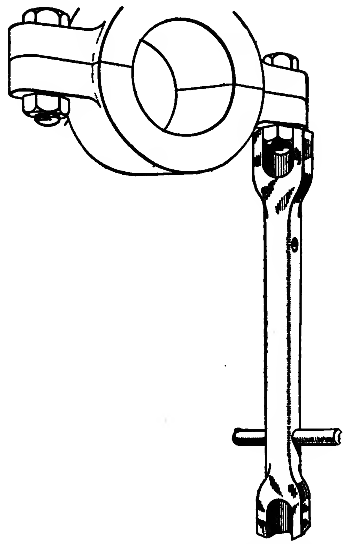


Fig. 71. Semi-Socket Wrench for Crankshaft Bearing Nuts

Holder for Bearing Caps. When a number of bearing caps have to be scraped, or filed down, it is worth while to make a holder for them. A plain form is shown in Fig. 70. This consists of a semicircular piece of metal which fits into the hollow part of the bearing, with each end pivoted on two L-shaped members. The members are held tightly in the vise, and the tighter they are gripped the tighter the bearing cap is held. This jig holds the cap with the desired

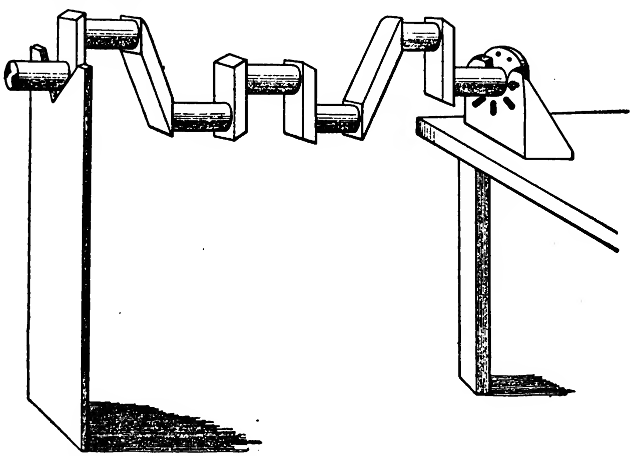


Fig. 72. Set-Up for Supporting Crankshafts Out of Motor

firmness, yet it leaves the whole upper surface free and clear so the workman can work at it readily and do a neat quick job of filing.

The same layout is suitable for connecting-rod caps, except where they have an oil scoop or other central projection which interferes.

Another Handy Wrench. The form of the crankshaft-bearing cap and also of the connecting-rod bearing cap are such that no space is wasted. Very often the nut is so close to the cap that it is difficult to turn, unless the cap is taken out of the motor where the wrench can be applied at right angles. The use of the socket form of wrench,

Fig. 73. Dogs for Use in Turning Four-Cylinder Crankshafts

however, does not make it necessary to take the cap out of the motor. Aside from the socket wrench it is hard to get any other form of wrench to use on these nuts that is not so small and thin that it has no particular strength. In Fig. 71, however, a form is shown which has all the strength of the very stiffest forms, and yet it can be applied to these inaccessible nuts with ease. Moreover, its construction is such that it can be applied and used readily. It consists, as the sketch shows, of a solid socket wrench, as distinguished from the form made of tubing, and has part of one side of the socket cut away. This makes its quick application to the nuts easy, although it also limits the amount of turn possible. Generally the case nuts are different in size from the connecting-rod nuts; so it is advisable to make the wrench double ended with a size at one end for the rods, and one at the other end for the case.

Holding the Crankshaft. When the shaft has been removed from the engine, and work is to be done upon it, it is an awkward thing to handle. It is just delicate enough so that it cannot be handled carelessly, yet its size and weight make it difficult to move around. Thus, in lapping the shaft pins, in fitting connecting-rod bearings, or doing other work upon it, a support which is simple, easily moved around, yet adequate, is needed. Ordinarily a shaft is clamped in a vise, but this is not always satisfactory when working on an end bearing. The method shown in Fig. 72 has many advantages. This consists of a special bench fixture and a notched board. The latter should be at least 1-inch stock, that is, it should be $\frac{7}{8}$-inch when dressed on both sides. The former is simply a metal angle with a series of radial slots to take the flywheel bolts, with a central hole for the shaft to rest in. The metal above the hole is well cut away to facilitate putting the shaft in and taking it out.

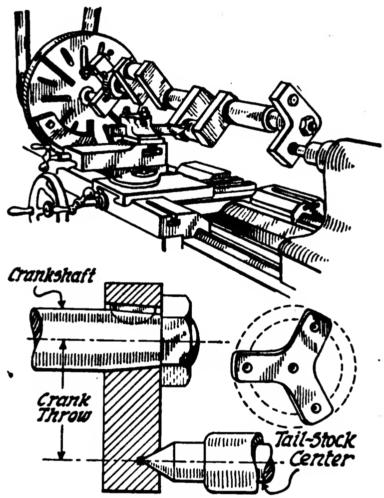


Fig. 74. Fixture and Lathe Jig for Turning Six-Cylinder Crankshafts

Handling Shaft in Machines. When the crankshaft is to be machined, no matter what the form of lathe, grinder, or other machine, the fact that the pins are eccentric necessitates a special dog or jig for holding it. If an ordinary flange is bolted on the end, the main pins can be turned, smoothed down, or ground, but the crankpins cannot. What these latter need is a form of flange or plate with two exact centers on either side of the central one at distances exactly equal to the crank throw. One is shown in Fig. 73, which is attached to a four-cylinder shaft all ready for the machine. Above will be seen another shaft without machining flanges. The bolts which attach the flanges to the shaft can be seen beyond the right-hand flange and at the far end. The rack in the background, on which these shafts are placed, is of interest also, forming, as it does, a simple and efficient means of holding the shafts, yet it is convertible for holding other parts or units. It is simply a stout form of horse, rather high, and with three legs instead of the usual two. The braces are all put on the inside to leave the surface clear, while the supporting pins differ only in length. In this case they have been made

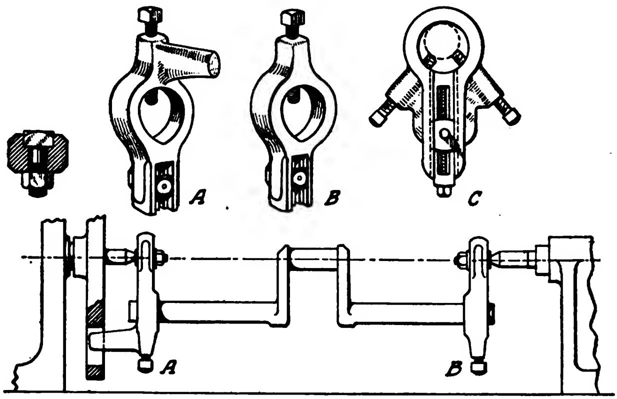


Fig. 75. Dogs with Adjustable Centers for Handling Crankshafts

long enough and strong enough to hold two or three shafts at once. In this way, the one horse can hold some 48 shafts at once.

Handling Three-Throw Shafts. The rigging just described is for four-cylinder shafts only, as these have the throws all in one plane, so that, although three different centers are required, they lie in one straight line, and the flange can be very simple for this reason. With a six-cylinder shaft, on the other hand, this is not the case; and a much larger flange is needed, for the three pin centers are spread out fan-like around the main bearing center. A form is shown in Fig. 74, which can be used for a shaft of this general type, although the one shown in the lathe provides for two pins only, not for three. For a six-cylinder engine of ordinary crankshaft construction, this would have to be like the triangular sketch at the lower right, if it is carried out on the same plan; or with the same bearing and pin centers, and a round outline as shown by the dotted line, if there was no necessity for saving metal.

Adjustable Crankshaft Flanges. In the small shop the general run of work varies so much that the principal difficulty lies in having flanges, dogs, or fixtures for handling the variety of crankshafts that come in. Diameters vary so much that a wide range of central holes is needed, because throws are all different. This gives a different center to center distance; then, too, there are still one- and two-throw, and other old forms of shafts in use, which come in occasionally for repairs. For these reasons, it is not wise for the small shop to go too far into special crankshaft fixtures; it should stick to simple dogs, with adjustable center distances, like the three shown in Fig. 75. While the shaft indicated is a single-cylinder form, dogs of this type can be used on other forms. This constitutes their biggest advantage. The variation in the three is self-explanatory to any machinist.

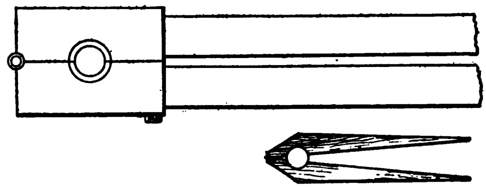


Fig. 76. Lapping Fixture of Simple Construction for Crankshaft Pins

Crankshaft Lapping. The pins of a crankshaft need lapping the same as other pins where a grinding machine is not available. There are two ways of doing this: by hand, which is slower but more simple so far as apparatus is concerned; and by machine, which requires special fittings for this purpose. In the sketch, Fig. 76, a form of hand lapper is shown. This consists of a pair of hinged members, with a central hole large enough to take various sizes of bushings, such as would be required on different shafts. A long handle is provided; also a bolt to hold the two halves together when the bushing has been inserted. The babbitt bushing must be split and have end flanges to hold the halves in place sideways. The handle gives leverage for working the tool, which is made effective by the application of fine emery and oil on the pins to be lapped. In the same way, the pins are pol-

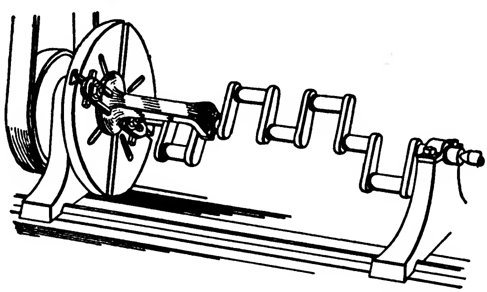


Fig. 77. Lathe Set-Up for Lapping Crankshaft Pins

ished by means of a pair of long wooden clamps, shown below, and made in somewhat the same way. There is a hinge at the back; and the abrasive used is fine emery cloth, which is flooded with oil.

The throws on the crankshaft can be lapped in the lathe by putting it between centers for the main bearings and by using a special flange for the other pins. A method which can be used is shown in Fig. 77. This consists of a special fixture, made from a large casting with a base to fasten to the face plate; a long extension arm, having a split end for attaching and detaching, to encircle the throw to be lapped. When this is used, the shaft is supported in V-blocks, somewhat flexibly it is true, but sufficiently.

Welding Shafts and Cases. The welding of broken crankshafts and crankcases, such as central breaks, breaks around the cylinder supporting surface, bearing supports, and supporting arms will be found fully discussed under the subject of welding, with full directions as to the preparation of the work, the materials, and other details.

CRANKCASES

Function of Crankcase. The lower part of the motor car, truck, or tractor engine is generally enclosed for the purpose of assisting the circulation of the lubricant, and for keeping the dirt and dust out. This enclosure is called the crankcase, and covers the crankshaft, the connecting rods, the bearings for both, and the lubricating system and lubricant reservoir. In general, the crankcase forms the support for the entire engine, as arms extend from it for this purpose. It also supports the cylinders upon its upper face or faces, and the crankshaft bearings upon inner integrally cast bosses. This is worded in this way, for formerly many marine engine cylinders, and even today, all high-powered marine engine cylinders are set upon posts and the sides between the cylinders and crankshaft left entirely open.

Crankcase Construction. Most crankcases are split longitudinally along the center line of the crankshaft. The upper half supports the cylinder and crankshaft and the weight of the engine on the chassis frame, and also has proper provision for the support of the various accessories upon it. The lower half, in such cases, is formed as a simple enclosing pan, with oil reservoir in the bottom. When the lubricant is circulated by pump, this is generally attached to the lower half of the crankcase, either inside or outside.

A section through a modern crankcase is shown in Fig. 78, which illustrates a twelve-cylinder motor. Note the inclined upper surfaces of the upper half to which the cylinders are bolted and the stiffening rib at the center line where the two halves meet. Note also how the lower half is simply an enclosure, carrying only the oil strainer (shown) and the oil pump (not shown). It has cooling fins cast on its lower surface to keep the temperature of the oil down. The shelf, which is cast on the upper half to close the space between the

Fig. 78. Section through Crankcase of Box Type for Twelve-Cylinder V-Type Packard Motor

sides of the crankcase and the chassis frame, serves the double purpose of a protecting pan to keep out road dirt and water and of a supporting shelf for accessories. Fig. 79 shows the same engine from the front.

Crankcases are made mostly in two forms: the box type, which has more or less straight sides, with a flat top and bottom; and the barrel type, which is round or a modified round with a flat bottom and top. The one shown is of the box type; the barrel type is generally not split along the center line, but it has removable end plates which allow the insertion of the crankshaft and a very simple bottom plate which carries the oil supply. The one-piece type is supposed to give greater rigidity, but this is at the expense of accessibility.

Modern Tendencies in Design. There are two modern tendencies shaping toward a modification of, or the entire elimination of, the lower half of the crankcase as it is now known. One is the minimizing of its functions, so it can be made of pressed steel, when it becomes a cover only, and the oiling system is made such that the supply is carried elsewhere. The other is the casting of parts of the crankcase integrally with the cylinders. This has been done successfully with the Marmon, the Ford, and with others, in which the cylinder block and the upper half of the crankcase are cast as one. If

Fig. 79. Assembled Motor Shown in Section in Fig. 78
Courtesy of Packard Motor Car Company, Detroit, Michigan

this casting is considered as a cylinder unit, there is no upper half of crankcase. By extending this practice a little further, the lower half may be combined with cylinder block and upper half, so that the crankcase as we know it now would cease to exist.

All these combinations save weight and reduce cost. They also reduce the number of parts and make the car as a whole more simple. In some cases they go hand in hand with large production, as the pressed steel lower half of the crankcase calls for a big expenditure for dies. On the other hand, they may make the repair man's work greater. As, for instance, when the cylinders are combined with the crankcase, it is an all day's job to take out a piston and replace it. When the cylinders are separate, cast in pairs, or bolted on, a piston can be taken out and replaced in a couple of hours.

Crankcase Materials. It is important that the repair man should know the materials of which both upper and lower halves of the crankcase and the gear cover are composed, for these may need repairing. In general, crankcases are of aluminum alloy, the exact composition varying. When this is the material, the gear cover is of aluminum alloy also. A few crankcases are made of cast iron, on very low priced cars. Others have the pressed-steel oil pan, previously mentioned. A few high-grade cars have bronze crankcases; these are either government bronze or vanadium bronze.

Crankcase Arms and Engine Supports. The engine is generally supported by crankcase arms extended from the sides or ends of the upper half of the crankcase and cast integrally. However, this is not always the case. In many unit power plants, the rear pair of supporting arms may be fixed to the flywheel housing or to the transmission case. Moreover, separate supporting members bolted or hinged in place may be used. These are heavy steel forgings, stout bronze castings, or heavy gage steel tubing. This may be done to allow the engine freedom of slight rotation and relieve it of twisting due to road inequalities; it may be done because of lack of confidence in the strength of the crankcase material as an engine support; it may be done to facilitate foundry work on the crankcase, and thus reduce its cost; or for other reasons. In taking out an engine, the repair man should find out about this, as it may simplify or complicate the removal.

Gear Cases, or Gear Covers. At the front end of the great majority of engines, the gears which determine the working of the engine and its accessories are placed. These may include the crankshaft driving gear and any or all of the following driven gears: camshaft gear, magneto gear, water-pump gear, lighting-generator gear, oil-pump gear, and sometimes fan gear and air-pump gear. These may be driven directly by gear contact or by means of silent chains. In either case the gears are enclosed by a case or cover, variously called the gear case, gear cover, or cam-gear cover. This housing is generally of as simple a shape as possible, and is bolted in place with as few bolts as possible in the lower half of the crankcase, so as to facilitate its removal for crankshaft or other bearing inspection or for repair.

Other details of the crankcase parts, not previously discussed, will be taken up under the groups in which they belong; for instance, camshafts and cams with valves and valve parts; lubricating parts, drilling in crankshafts for lubricating purposes, oil passages in the crankcase, etc., under lubrication; and others under their respective groups.

Crankcase Troubles and Remedies

General Nature of Troubles. The most general crankcase trouble, aside from bearing trouble, is breakage. The usual bearing troubles previously outlined occur as well with main crankcase bearings. These require similar attention, and in their handling much special apparatus, such as stands, jigs, fixtures, and tools, can be developed by the ingenious repair man. Worn main bearings cause a knock. If this comes from any one bearing, it can usually be traced quickly. The use of the stethoscope is recommended for any crankcase or gear-cover noises or troubles. A squeak from any part of the crankcase usually means a lack of oil or the rubbing of parts which should not rub.

Mending Breaks. If the case is of aluminum, it should be watched carefully for breaks or cracks. If a crack develops, it should be drilled, plugged, and welded, as cylinder water jackets. This will prevent the crack from spreading. Any fairly large break means either undue stress or a weakness in the metal. The latter can be remedied by patching, by building up in the welding operation, or by the use of a new part. The repair man who is in doubt about his ability to repair a break or crack should always consult a welding expert, for welding can be done, and is being done daily, which would astonish those unfamiliar with the scope of the process. Moreover, it is relatively inexpensive. Quite often, a weld which would not cost more than $4 or $5, can be made the same day even by a fairly busy shop; otherwise it would mean a new case at a cost of perhaps 10 or 12 times as much, two weeks' delay or longer for delivery of the order, and the additional time and delay of detaching all the old accessories and fittings from the old case, and re-attaching them to the new case.

Cleaning Aluminum. Aluminum can be cleaned, externally, by means of a weak sulphuric-acid solution, say not more than 10 per cent sulphuric acid. This should be well scrubbed into the surface with a stiff brush, then washed off with water. Care should be taken to wash well enough and long enough to remove all the acid. Moreover, it should be kept from clothes or from any wood parts, as it is strong enough to attack fabrics and wood.

The aluminum oil pan should be cleaned out at least once a season, for the strainer will separate a lot of dirt and dust, as well as other foreign matter, from the oil in the course of 8 or 9 months. This will be found in the bottom of the oil pump or beneath the oil proper, as a kind of slush or sludge. Sometimes it is thick enough to need scraping, particularly in sandy country where the car gets little or no care. Generally, a kerosene bath will clean it out. This is followed by a "once-over" with gasoline to clean off the kerosene

Fig. 80. Method of Boring Crankcase Bearings with Special Boring Bar
Courtesy of Pierce-Arrow Motor Car Company, Buffalo, New York

and the last of the dirt. If any gasoline remains, it will evaporate and leave a crankcase which actually is clean. The porosity of aluminum emphasizes this need for a thorough cleaning, which is not needed so badly with pressed-steel oil pans.

Machining Crankcases. Generally speaking, the repair man will not be called upon to do any machining on crankcases, beyond something like chipping or filing, or in the case of a break, patching or welding. But in case such a job should come along, it is important to know how to handle it, for there is no more important crankcase job than the machining of the main bearings. The necessity here is to keep them in perfect alignment, and this necessitates machining all of them at once with a long boring bar, as shown in Fig. 80. The method of support upon the flat upper, or cylinder, face will be noted, also the holding down blocks bolted to the table of the machine, after being bolted to the cylinder studs. The provision for lubricant on each one of the boring cutters will be seen in the small copper pipes above and at the back. As the average shop does not have a boring tool of this kind, this work will have to be approximated. It could be done by hand, using the now well-known Martell aligning reamer, to ream the bearings out and put in new and larger bushings. This also has a series of cutters, much like the boring bar shown, and is actuated by hand. So the principal requisite would be a large flat surface on which to work. Possibly this will be found at the drill-press platen, the planer table, or the working table of whatever large machine tool the shop possesses. In this job, the workmen should remember that unless the case is held firmly throughout, it is likely to give or spring, and this will spoil the whole job, no matter how good it may be otherwise.

In all crankcase repairs, the repair man should remember that the case is really the foundation of the engine, and if it is not firm of itself and firmly supported, the action of the engine cannot be positive nor continuous. Consequently the case should be handled with unusual care. Gear-cover troubles are few and far between, consisting mostly of breaks or trouble inside the cover with gears or driving chains. These will be discussed elsewhere. Usually, too, gear-cover lubrication is automatic, that is, one end of the crankshaft and crankcase-bearing lubrication system is continued forward to the gear cover, so that it gets all the surplus oil. In this way lubrication is cared for automatically, but the repair man should take no chances on this with cars under his care. He should remove the gear cover occasionally for inspection. Gear noises, too, emanate from the timing gears and are often due to a lack of lubricant there, or, to not enough thick lubricant to deaden the sound. Sometimes the construction of a gear causes a ringing noise, according to the form of construction used. Often whirring noises from the gear case are caused by burred teeth. The repair man can remove the burr with a file. Sometimes a chip of metal will get in between two gears and be pressed into the softer of the two; from that time on, it will cause noise continuously, and will also cut the other gear.

SUMMARY OF GENERAL AUTOMOBILE INSTRUCTIONS

Q. Into how many main groups can the mechanical parts of the car be divided?

A. Practically all motor cars can be divided into six general groups as follows: (1) engine, or power-producing, group; (2) clutch, or engine connecting and disconnecting, group; (3) transmission, or speed-varying, group; (4) final-drive group including rear wheels; (5) steering group for controlling the direction of the car and including front wheels and axle; (6) frame upon which all other groups except wheels are hung. The body makes a seventh group, but strictly speaking it is not mechanical.

Q. How many sub-groups are there pertaining to the engine?

A. According to their functions, the parts and accessories of the engine may be subdivided into 10 groups: (1) cylinders, pistons, connecting rods, crankshaft, and other basic parts; (2) carburetion sub-group through which the mixture is supplied which enables the engine to run; (3) valve group through which the mixture is allowed to enter and leave the cylinders at the correct time; (4) exhausting system through which the burned gases are led away from the motor; (5) ignition system by means of which the mixture in the cylinders is ignited at the proper time; (6) cooling system by means of which the temperature of the motor is kept down to a point at which it can operate safely and continuously; (7) lubrication sub-group by means of which the rotating, or rubbing, parts are kept lubricated so as to run without friction or heat; (8) starting sub-group by means of which the motor is started; (9) lighting sub-group through which the car is lighted, not strictly an engine part but closely allied with starting and ignition, and because of its drive from the engine and general location of its parts on it, it is classed as an engine sub-group; (10) flywheel sub-group. The last is really a single unit but its size, weight, shape, location, attachment, and other points are becoming so important as to warrant separate consideration.

Q. Why is it necessary to consider each of these separately?

A. Because their functions all differ. The very things which make each group best fitted to its work make it more widely different from each of the others. Some groups are so very different as to warrant separate consideration, almost as extended as the balance of the motor group, as, for instance, ignition, starting, and lighting, which naturally group together.

Q. What are the most popular cylinder forms?

A. Automobile engine cylinders are mainly of the following forms: (1) cast in pairs; (2) cast in block; (3) cast in threes, in the case of six-cylinder motors. The last is really a modification of the first.

Q. What are the advantages of each of these?

A. The cast-in-pairs form can be removed by one man and replaced by two, if it is broken, cracked, or damaged; replacement is less expensive; the casting is less complicated, consequently there is less waste in the foundry; they are easier to machine, store, ship, handle; they also have other advantages. All these apply to the cast-in-threes modification. The cast-in-block form makes a more simple looking engine, a shorter and more compact one, and renders alignment and spacing more accurate and permanent. Furthermore, all water, inlet, exhaust, and other connections may be cast integral, which is not possible with the cast-in-pairs or cast-in-threes forms. Similarly, the crankcase may be cast integral if desired.

Q. How is the weight of reciprocating parts lessened?

A. In the case of pistons, this may be done in one of three ways: (1) the form, shape, size, and material may remain unchanged, while the walls are machined thinner, or ribs are eliminated; (2) the material may be changed to a steel which can be machined thinner and smaller everywhere, thus saving a material amount; or (3) the material may be changed to an aluminum alloy which is lighter throughout, is strong to stand machining very thin in some places, and is so ribbed as to stand casting very thin in others. The first assumes that cast iron is retained; the second calls for a high quality of forged steel and is most expensive, so that it is used only on racing cars or cars of unusually high prices. The last is fast becoming the general method.

Q. What is the modern tendency in piston rings?

A. The experiences of aircraft engines and those in racing cars have taught that two well-made and well-fitted rings are sufficient. This is being applied rapidly to all motor-car engines by the removal of the extra and superfluous rings. Many motors had this number previously with an oil ring at the bottom, but it has been found that the removal of this makes little difference.

Q. Is there a noticeable tendency toward simplicity in connecting-rod constructions?

A. Yes, the same as in pistons and rings, toward simplification and lightening of the weight, with the removal of all superfluous parts. Two bolts are becoming the standard for the big end. The H-section machined all over is almost universal, smaller sections being used than formerly. Pressed-in wrist-pin bearings of comparatively thin walls are being used and a better class of material generally, which allows lighter weight and smaller sizes for equal or greater strength. Lubrication scoops are being machined-in in the forms of holds, and a simple projecting lip instead of former brass tubes, which were added.

Q. What is the accepted type of connecting-rod big-end bearing?

A. The split, or two-piece, form with a shell or backing of bronze and a facing, or wearing surface, of babbitt with oil holes drilled through and the interior surfaces oil-grooved to and from these to distribute the oil evenly.

Q. Why is this the accepted form?

A. The bronze backing or shell gives the desired stiffness and permanence, also machines well and resists overheating well. The babbitt facing, when worn, is easily replaced by any repair man, and it will melt out in case of lubrication neglect so little harm is done, yet when well-fitted it gives a fine bearing surface. The system of drilling and grooving supplies a film of oil at all times. These materials and this arrangement supply an almost ideal combination when well-made and fitted, hence their wide acceptance.

Q. What difference is noted in V-type engine bearings?

A. When the two rods of a V-type engine act upon a single pin, the arrangement of the bearings must be such that one must be notched out, or divided, to make room for the second, or else the exterior of the first must be formed as a bearing surface for the second. In the former case, the one bearing is practically in four parts; in the latter, the exterior of the inner bearing becomes as important as its interior surface, since it acts as the bearing pin for the outer rod.

Q. Name two general forms of crankshaft today.

A. The single-plane type and the multi-plane type. In the former, as used on four- and eight-cylinder engines, all pins, bearings, and webs are in one plane. In the latter, as used on six- and twelve-cylinder engines, the pins are in three planes set at an angle of 120 degrees with each other.

Q. How many different forms of four-cylinder shafts are there?

A. There are but three radically different forms of four-cylinder crankshafts, depending upon the bearings. These are: (1) The shaft in which there is a bearing on each side of each application of power, or five bearings in all; (2) the form in which there is a bearing at each end and one in the middle, or three bearings in all; (3) the form in which there are no center bearings, but only the two end bearings. The first is used on the highest-priced four-cylinder cars, because it is expensive of itself and has a similar influence on other parts, notably bearings, crankcase, etc. The second is in wide use; being the most popular form. The last is used only when extreme compactness is desired. There is an odd form of shaft in which four bearings are used, but only one maker ever used it.

Q. What is the difference in the average of six-cylinder crankshafts?

A. Six-cylinder crankshafts differ about the same as fours, according to the number of bearings. There are the same number of different forms as follows: (1) with seven bearings, or one on each side of each application of power; (2) with four bearings, or one at each end and one between each pair of cylinders; (3) with three bearings, one at each end and one in the middle, used only with block-cast cylinders.

Q. What can you say of eight-cylinder crankshafts?

A. These vary the same as fours in general, the eight-cylinder motor having a four-cylinder shaft with perhaps slightly longer pins and of slightly larger diameter throughout.

Q. How do twelve-cylinder shafts vary?

A. They are the same as six-cylinder shafts, with the same variations as to bearings; in fact, all twelves have six-cylinder shafts with slightly longer and larger pins.

Q. Does counterbalancing effect the shaft?

A. No, except in outward appearance. The counterbalanced shaft is just the same as the shaft without counterbalancing masses.

The general type is the same, also the number of bearings. This applies to fours, sixes, eights, twelves, or to any form.

Q. What are shims, and for what are they used?

A. Shims are very thin pieces of metal placed between the two halves of bearing caps for the purpose of giving a quick, simple, easy adjustment when the bearing wears. In theory, this works as follows: When a bearing has worn down $\frac{2}{1000}$ inch, the cap is unscrewed and removed, and shims of a thickness of $\frac{2}{1000}$ inch are taken out on each side. Then the cap is replaced and tightened, and the bearing is as good as new. In actual practice, the removal of the shims creates a shape of bearing which is not an exact circle, so that some slight scraping with very little wear, is necessary, as illustrated above, and a great deal of rescraping and refitting (in addition to shim removal) with greater wear.

Q. For what is a crankcase used?

A. The crankcase is used to support the cylinders and the crankshaft; to act as a housing to keep out dust and dirt and as a retainer and reservoir to hold the oil in.

Q. What is its general shape?

A. Generally, crankcases are either of the box shape or of the round, or barrel, type. The first named is generally split horizontally along the crankshaft center line; has a flat top and bottom, with vertical sides; has the bearings supported in the top half only, the bottom acting simply as an oil pan. The second form is generally in one piece with removable ends in which two of the shaft bearings are located; has a rounded bottom in which the oil is held; has a flat top but rounded sides.

Q. Of what material is the crankcase constructed generally?

A. Aluminum and aluminum alloys are most widely used, although there are a number of motors with cast iron, some with a cast-iron upper half and a pressed-steel or aluminum lower half, and a few of bronze. The latter is expensive and is losing ground. Pressed steel is suitable only for quantity production, while cast iron is losing ground except in those up-to-date designs in which the upper half of the case is combined with the cylinder block.

Q. How are crankcases supported on the frames?

A. The most general method on pleasure cars is the casting of arms, generally four, integral with the crankcase, these extending out to and resting upon the frame, to and through which they are fastened. Generally, too, a thin web is cast between the front and the rear arm on each side, extending out horizontally from the sides of the case to the frame. This serves the double purpose of replacing the underpan and of acting as a stiffener for both arms and case. On a few cars and on quite a few trucks, a pivoted cross-arm is used at the front and a bolt cross-arm at the rear (or *vice versa*), these being forged members. In this way a three-point support is obtained, which yields as the frame is twisted or raised unequally.

Q. What is the gear cover and what are its functions?

A. It is the removable cover at the front end of the engine, which covers and protects the camshaft and other gears or silent-chain drives. In addition to keeping out dust and dirt from these, it minimizes the unavoidable noises which they make and retains the lubricant. It is generally a light aluminum shell held on by a dozen or less bolts.

Q. What is the general method of lifting an engine out of the frame?

A. By a rope or a chain sling, hoisted from above by a chain hoist, block and tackle, overhead crane, or movable floor crane. The latter are of recent introduction but have the advantage over the overhead form that they can be rolled around the garage or repair shop to any needed point, while the overhead form is useful only under its track or runway. In addition, they can be put into use more quickly on a rush job, take up little room, and cost no more than the overhead built-in form.

Q. How are engine stands useful?

A. They hold the engine in a convenient place and at a reasonable working height. They hold it firmly so that pressure can be exerted if necessary or hammering can be done. Moreover, if rightly constructed, they allow rotating the engine to do work upon the sides or bottom. In these and other ways they save much time and trouble, hasten the work, and thus cut the cost. In addition, their convenience allows of doing better work.

Q. Is there any best method of removing carbon from cylinders?

A. The method depends upon the design and the construction of the motor, the quantity and the hardness of the carbon and its location in the cylinder, and, in part, upon the facilities which the shop possesses. The best method varies with almost every case.

Q. What is the most rapid method?

A. Probably burning out with oxygen is the quickest method, when the shop possesses an oxygen-burning outfit. The spark plugs are removed and their holes plugged, one or more valve caps are removed to allow working, the gas is turned on and lighted, when the workman can do a cylinder thoroughly in three or four minutes. This means that the entire process of doing an engine will not take over twenty-five to thirty minutes. Any other process will take twice as long as this.

PACKARD CARBURETOR USED ON "TWIN SIXES"
Courtesy of Packard Motor Car Company, Detroit, Michigan

GASOLINE AUTOMOBILES

PART II

ENGINE-GROUP ELEMENTS—(Continued)

CARBURETORS AND CARBURETION

Function of the Carburetor. As has been pointed out in the general outline of the motor car, the first and most important thing in the engine cycle is to get the fuel into the cylinders. This is done through the medium of the carburetion system, the principal unit in which is the carburetor. The function of this is to convert a liquid (gasoline) into gas (gasoline vapor) measure this, and add to it the right quantity of air to give proper and complete combustion. If this be not done, power is lost, either through the use of too much or too little air. In the latter case, not all the fuel is vaporized, hence some of it is wasted.

This sounds like a simple proposition, yet its very simplicity has been the undoing of many automobile experts. The vaporizer becomes more and more complex each year, constant additions and changes are being made in the other parts of the system, and in other ways the carburetion system shows a constant change. Despite all this, few fundamental laws have been found to be in error, and few new ones have been discovered or developed.

Effect of Heavier Fuels. For some years past there has been under way a subtle change in the character of the fuel—the gasoline used for the propulsion of automobiles. The small production and the increasing demand have combined to render almost unpurchasable, except at high prices and then from large dealers, the lighter and more volatile gasolines of some years ago. In the place of them there have been quietly introduced much heavier petroleum distillates, which evaporate less readily—though they are actually of higher value in terms of power units. This condition has compelled several changes in the carburetor problem.

In addition to the foregoing, in some parts of the world there have been serious efforts made to utilize in automobile motors alcohol and benzene (not benzine), which, with proper provision for their carburetion, constitute excellent fuels.

The most important of the changes dictated by this development in the fuel situation is the now general practice of heating the float chambers of carburetors, either by water from the circulating system or by exhaust gases. An alternative scheme is that of drawing of the air for the carburetor from a point adjacent to the exhaust piping, so that this air is sufficiently warmed to readily take up the gasoline necessary to constitute a proper explosive mixture.

Jacketed Manifolds. A subsequent and very successful method of handling the heavier fuels is that of jacketing the upper portion of the inlet manifold, and the circulating of the hot water in the cylinder-cooling system through this. By having this jacket close to the point where the gaseous mixture enters the cylinder, any remaining particles of liquid fuel are vaporized before entering the cylinders. In a few instances, the same effect is obtained by incorporating the carburetor in the cylinder water-jacket casting. In still others, where the carburetor is placed on one side and the inlet valves on the other, there is a cored inlet passage through the cylinder block between the cylinders which heats the mixture, with the same result as stated above.

Fuel Injection. Systems of fuel feeding by direct injection of minute quantities of the combustible liquid into the cylinders or into the intake piping have been advocated or experimented with for many years, and have found very successful application in stationary and flight engineering, though as yet not one of these sytems has successfully competed with the carburetor in automobile service, where the conditions of power variation are such that fuel injection has not seemed readily applicable.

Nevertheless, there are many engineers who adhere to the view that sooner or later fuel injection will supplant present systems of carburetion, and progress made recently with aviation motors of fuel-injection types may seem in some measure to justify this view.

Despite the success of this system on aeroplane and stationary engines—notably on the Antoinette and the Diesel, respectively—there is not, to the writer's knowledge, a single American motor-car manufacturer now using or experimenting with fuel injection. A few years ago a motor car brought out in the Middle West used it, but this was short-lived. Since then, nothing has been done.

More Valves vs. Forced Induction. The present-day tendency toward the use of many valves, four per cylinder, seems to indicate a necessity for getting more gas into the cylinders in order to get more power and speed from the same size of motor. This would seem to lead back to the subject, agitated a few years ago and dropped for lack of interest, of the need for forced induction. This will introduce a greater quantity of gas into the cylinders without resorting to the complications and trouble-breeding possibilities of four valves per cylinder. It differs widely from fuel injection, consisting in its simplest form of a special form of fan or blower to drive the vaporized fuel into the cylinders.

Classification of Carburetors. Carburetors, as a whole, may be divided into three classes: the surface form, in which the air passing over the surface of the fuel picks up some of it, mixes with it, and produces an explosive vapor; the ebullition, or filtering, type, in which air is forced through a body of fuel from below, absorbing small particles so that when it reaches the top and is drawn off, it is suitable for use in the cylinders; and the float-feed, or spraying, type, under which head nearly all modern devices come. The others have gone out of use, as fuels today are too heavy for them to be practicable.

The original float-feed carburetor consisted of one part besides the fuel pipe, float chamber, and passage to cylinder, which made it remarkable for its simplicity. It had no adjustments, nor was there any way of securing an even and continuous flow of fuel or of air, except as the engine suction produced these. The need for these qualities brought out, one by one, the modifications of the original; and through continuous modifications and recombinations of these, all the modern devices have been developed.

Defects in the Original Are Not Found in Modern Types. The original carburetor had no adjustment; the opening in the casting measured the amount of air, while the size of the nozzle measured the amount of the fuel and the fineness of the spray. There was no means of regrinding the float valve, and thus no way of assuring an even and continuous flow of fuel. The modern adjuncts of the original Maybach device consist of remedies for these defects, and, in addition, a proper means of balancing and adjusting the float.

To pick out a modern carburetor at random, take the one shown in Fig. 81. Like its ancestor, it has a gasoline chamber into which

Fig. 81. Stromberg Model "L" Carburetor
Courtesy Stromberg Carburetor Company, Chicago

the fuel is admitted by the action of a float, when it first passes through a strainer. From the float chamber the liquid passes up to and through the spraying nozzle. The weight of the float is so calculated that the level in the final nozzle is just 1 millimeter (0.04 inch) below the top. This insures that there will always be fuel there for the air suction to draw off. As the physical action of changing a substance from a liquid to a gas is usually accompanied by the absorption of heat, it is advisable to supply a reasonable amount of this, and thus assist the change of form. In the older Maybach, this was inadvertently done by placing the whole apparatus in close contact with the hot cylinder. In the modern carburetor, placed some distance from the heated portions of the engine, this additional heat is supplied by the jacket water. An alternate scheme is to pre-heat the air supply by a special pipe from the exhaust manifold.

From this mixing chamber the mixture of air and gasoline vapor passes upward into a secondary mixing chamber. This communicates with the inlet pipe through the medium of the throttle valve. The auxiliary air supply, when used, has access into the secondary chamber through the auxiliary air valve. This comes into action on very high speeds when the engine is pulling very strongly. At this time the proportion of gasoline to air is likely to be too large, so the auxiliary opens, admits more air, and thus dilutes the mixture.

Throttle Valves. *Butterfly Type.* Whatever the nature of the mixture in the carburetor, it is admitted to the cylinder by the throttle valve, which may take the form known as the butterfly. This is a flat piece of sheet metal, preferably brass, attached to a suitable shaft with an operating lever on the external end.

Piston Type. Besides the butterfly type there are fully as many of the piston type. The sliding form is a cylindrical ring or shell of metal, which is free to slide in a corresponding cylindrical chamber. In the walls of the latter are a number of apertures or ports which the longitudinal movement of the piston either uncovers or covers as the case may be. Sometimes, to facilitate this action, the sides of the piston are grooved or notched, but this does not alter the principle of sliding a cylinder within another cylinder to cover or uncover certain ports in the cylinder walls.

In addition to the sliding piston, there is the rotating piston, working in practically the same manner, that is, its rotation connects openings in the piston walls with the interior of the vaporizing chamber on one side and with the inlet manifold on the other, the amount of the opening depending upon the distance the piston is rotated.

Needle Valves. Needle valves—or spray nozzles as they are sometimes called because of the function they perform—constitute an important part of every carburetor, or liquid-vaporizing device. It might be thought that so long as there is a hole by which the fuel can enter the vaporizing chamber that is sufficient; yet such is far from the case. In addition to the function of an entering hole, the needle has the additional duty of breaking the fuel up into a fine spray or mist, the particles of which are easily picked up by the inrushing air, and as easily converted into a vapor. Therefore, that shape, form, or arrangement which will divide the entering liquid up into the finest particles will be the most efficient. The difference of opinion on this latter point has produced the large number of shapes of nozzle and needle which are now in use.

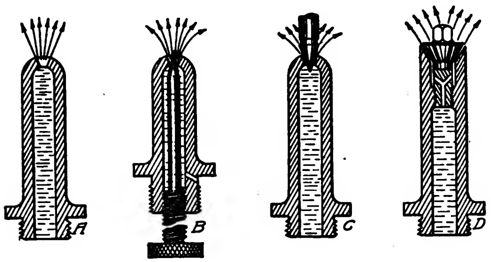


Fig. 82. The Four Usual Shapes of Gasoline Needle Valves and Spray Nozzles

Simple Vertical Tube. In general, practically all these can be divided into four groups, illustrated in Fig. 82. The one at *A* is a simple round vertical tube with an opening in the top, through which the liquid may pass out. It does not alter the type if the sides of the opening converge, diverge, or are straight, but it will influence the resulting spray somewhat. Of the twelve makes shown with this type, practically all indicate the opening as straight, but this may be due to the small size of the drawing which does not make the taper apparent.

Internal Needle Type. Type *B*, Fig. 82, is similar to the first, except that an adjustable pointed needle is added on the inside. This occupies most of the center space, forcing the liquid to pass out in a smaller circular sheet or stream than would be the case with Type *A*, considering equal-sized holes. In addition, the fact that the internal needle valve may be raised or lowered allows this stream to vary greatly, both as to quantity of fuel flowing, and the extent to which it is spread out. When the needle is down very low, only its point enters the hole, so that practically the full area of the latter is available, the central needle influencing the column of fuel passing out only to make it hollow in the center.

With the needle raised to nearly its maximum height, however, the point projects clear through, and the needle shaft almost fills the lower part of the hole. This reduces the flow to a very fine hollow column of spray, as the shape of the needle and of the lower edge of the hole is such as to force it inward and then outward so that as it leaves the top of the hole it is diverging widely. Thus, the effect of the addition of the needle is to allow the use of much smaller quantities of liquid with the same-sized hole, of diffusing it more widely, and of making it adjustable to varying needs. Despite all its advantages, only three of the carburetors and vaporizers shown use this type; and of these, one is a combination of this with *A*.

External Needle Type. The third type shown at *C*, Fig. 82, is an inversion of *B* in that the needle is made external and descends from above into the hole in the nozzle. In this form, the shape of the needle point produces the desired diffusion and spraying effect, which accounts for its popularity. Of the models shown herewith, nine are of this kind, one being a modified combination of this form and *A*.

External Sectional Needle Type. The fourth form, shown at *D*, is like *C*, except that instead of a needle resting upon the upper surface of the hole and allowing a continuous hollow stream of fuel to flow, a series of holes break up the column into a number of very much smaller columns, each with its own opening. In this form the central member may be movable or not, while the holes may be set at any angle. Of the examples of this form shown in this article, three in all, every one has the holes placed horizontally instead of inclined to a vertical, as shown in Fig. 82. Of these, two show a combination of *B* and *D*. This is an effective combination.

Floats. Another feature of the earlier forms of carburetors, which was soon found to be in need of a change, was the arrangement of the float. In Maybach's original vaporizer, there was no means of balancing the float; consequently, there was no way of preventing wrenching and breaking of the needle-valve spindle. As this disarranged the gasoline supply, it made a change very important;

and this problem received early attention. There was also the necessity for reliable devices to regulate the supply of air and of gasoline spray from the nozzle, either by original adjustment, by means of a governor, or by effecting a constant variation by hand to meet constantly varying conditions of engine demands.

These additions to the original form caused some trouble. The ordinary way of managing the balancing of the float, while it may be the cause of trouble at times, is a very simple one. The float is of exceeding lightness, whether made of cork or metal. With the inflow of gasoline in liquid form this float rises, and in so doing it strikes against a pair of small pivoted levers near the top of the float chamber. The other ends of the pivoted levers rest upon a form of shifting collar on the needle-valve stem. So, when the float rises above a certain level, it automatically shuts off the flow of gasoline by pressing against the pivoted levers, which, in turn, act against the stem and press it down until the flow is cut off. The float will stay up until the suction of the engine has lowered the gasoline level so that the dropping of the float releases the levers which raise the needle valve off its seat. The gasoline flow is thus automatically regulated by this balanced-float arrangement.

ADJUSTMENT OF AIR AND GASOLINE SUPPLY

Methods of Handling Fuel Spray. Probably no one detail of the whole list of carburetor parts has caused, and still does cause, more difference of opinion than the source of and adjustment of the air supply, and its companion, the adjustment of the gasoline spray. The latter drew attention long before the former; in fact, the former is more of a modern appliance. The fuel spray was investigated long ago; for the gasoline spray had no adjustment, but the size and the location of the level of the nozzle were fixed. The spray itself, however, received special treatment. It was projected against a conical spray deflector which served to break up the column into finer and more diffused particles. In this way, greater vaporizing action was gained.

Water-Jacketing. Longuemare was among the first to use a water jacket around the vaporizing chamber. The conversion of a liquid into a gas is an endothermic reaction and requires heat for its completion. If this is not supplied by external means, it will be extracted from surrounding objects. This accounts for the frost which gathers on the outside of the mixing chambers of carburetors which do not have a water jacket or other source of heat supply. The heat is abstracted from the air so rapidly that the moisture in the air is frozen, appearing as frost on the outside of the carburetor.

Auxiliary Air Valve. The auxiliary air valve has always caused discussion, its opponents claiming that it means extra parts, and therefore more adjustments and more sources of trouble; while those favoring it say that without some additional means of this sort for diluting the mixture at high speeds, it is impossible to run the engine fast, as high speed will then mean an over-rich charge. Be that as it may, the fact remains that the weight of opinion lies with the auxiliary valve.

Necessity with Heavy Fuels. Practically all the more modern vaporizers use an auxiliary air valve, as this is a partial necessity with the heavier fuels. That is, it has been found that the heavier fuels require more air to vaporize them than can be supplied by the primary air inlet. Moreover, these heavy fuels require considerable additional heat in order to vaporize, and the auxiliary air inlet has been made the vehicle for conveying this. As will be explained in detail later on, this is generally connected with the exhaust manifold in such a way that the air entering through it is heated to a high temperature. Adding this after the fuel has been split up by the spraying nozzle and the primary air has proved very successful.

Usual Forms of Auxiliary Air-Inlet Valve. The auxiliary air inlet usually consists of a simple valve, opening inward, held in its place by a spring of a certain known tension. The strength of the spring is carefully determined so that at the proper moment—when the motor requires more air in proportion to the amount of gasoline used—the valve will open just enough to allow the required amount of air to enter. It will be seen that the time and the amount of opening will be controlled by the speed of the engine, i.e., by the amount of suction produced by the movement of the piston in the cylinder. Of course, as the engine speeds up, there is a greater piston displacement to be filled per minute, and therefore it is necessary to supply a greater amount of mixture. Upon changing speed suddenly from, say, 500 revolutions to 900 or 1000, the carburetor which does not have this device will *not* give a uniform mixture immediately; in fact, it might require a new adjustment of the gasoline flow in order to supply the right amount of fuel. What the auxiliary air inlet actually does, then, is to control automatically, above a certain point, the amount of air admitted, thereby always maintaining a homogeneous mixture. In order to prevent any chattering of the valve or rapid changes in the air supply, a diaphragm or a dashpot is sometimes used in connection with the valve.

As a substitute for an auxiliary air valve, a number of makers have tried the use of steel balls, resting in holes about two-thirds the diameter of the ball. By varying the size and weight of the balls, a truly progressive action is obtained, for light suction lifts the light balls, and strong suction all balls.

Venturi-Tube Mixing Chamber. Like every other carburetor part, the spraying action and the shape or size of the chamber in which it takes place have been the subject of much debate. Originally, the chamber took any convenient shape and varied all the way from a perfectly plain cylindrical shape to an equally perfect square, with all the possible variations in between. A few years ago, however, scientists began to look into the vaporizing and equally important measuring action of carburetors, with the result that a new shape came into use, which was based upon a scientific principle.

This is the principle of the Venturi meter used for measuring the flow of water, and from its use the tube, or chamber, having this shape has come to be known as a Venturi tube. In form, this consists of two cone-shaped tubes diverging in opposite directions from a common point, which in the water meter is the *point of measurement* and in the carburetor is the *point of location* of the spray nozzle. The principle is that if these two frustrums of cones are of the proper shape, i.e., include the proper angle and are correctly set with relation to one another, the flow of air and gas will be in correct proportions to each other at all speeds, assuming first that the air enters at the bottom of the tube having the greater angle.

As a proof of the soundness of the principle of this type of vaporizing chamber, it might be said that the majority of carburetors in use today have it incorporated in one form or another. Many make the upper tube conical for a very short distance, beyond which it assumes a cylindrical form. In the true Venturi shape, the usual angle at the bottom is 30 degrees, while that at the top is 5 degrees.

In water meters the contracted area is made one-ninth that of the pipe. This same relation, although not exact, holds in the case of the carburetor. Since the area varies as the square of the diameter, this is equivalent to saying that the diameter of the contraction should be one-third the diameter of the full-sized pipe.

Double-Nozzle Type. A distinctive design of two connections leading into the vaporization chamber is the Zenith (French) carburetor, a diagrammatic sketch being shown in Fig. 83. This is but a modification, in a way, of the Venturi plan, for the latter shape is actually used for the vaporizing chamber. The new idea consists in leading into this mixing chamber, two tubes. Of these, one is the ordinary spray nozzle and does not differ from that used on hundreds

Fig. 83. Zenith Carburetor, Model "O"
Courtesy of Zenith Carburetor Company, Detroit, Michigan

of other devices. The second, however, is very different. While it leads into the same mixing chamber, it does so through the medium of a secondary chamber, or standpipe, to which the suction of the engine has access. If this suction is strong, more gasoline is drawn into the secondary chamber, from which it may enter the spraying zone.

The ordinary nozzle is of an exact size and, consequently, can pass only a certain amount of fuel, always at the same speed. With the additional nozzle, this does not hold; and being of large diameter (comparatively), the flow through it depends wholly upon the engine suction, which varies at all speeds, often at the same speed upon different occasions.

Use of By-Pass. This matter of two standpipes has a parallel in the use of a by-pass, so-called, around the usual mixing chamber. On some carburetors this is made so as to allow easy starting, the idea being that when suction is applied to the carburetor by cranking, with the throttle closed, practically pure gasoline vapor will be drawn through the by-pass. This will start the engine after which, as the throttle is opened gradually, its movement cuts off the by-pass, until at medium speeds it is out of use entirely. The same thing applies to the use of a secondary tube or standpipe for low-speed running.

A by-pass of a separate nature is made use of for starting and priming purposes; this consists of a small separate tank of gasoline attached to the dashboard under the hood, with a valve running through to the driver's side for turning on the supply. This is connected into the inlet manifold above the carburetor by means of a special pipe tapped into the manifold. When it is desired to start the motor, it is primed with this device by simply turning on the supply. Some gasoline flows into the manifold, and after a few seconds it vaporizes. The motor is than cranked over sharply, and a start is almost certain. This has the advantage of simplicity, accessibility, and low cost. In addition, it is economical of time as compared with lifting the hood to prime each cylinder separately.

Nature of New Developments. *Horizontal Carburetor Outlets.* Among the newest carburetor features are some which have worked themselves out naturally, and others which have been forced by changes in engine design, in fuel quality, etc. Thus the tendency toward block motors, and with it the tendency toward neat lines and simplicity, has brought forth a general simplification, or elimination of inlet pipes, and a fairly wide use of horizontal carburetor outlets. The latter has affected carburetors by requiring a shorter and more compact instrument, with a side outlet and a vaporizing arrangement which will produce tolerably complete vaporization in a comparatively short distance. To a certain extent, this horizontal-carburetor tendency has modified existing practice in nozzles, Venturi tubes, interior areas and arrangements, etc.

Effect of Heavier Fuels. The growing realization by carburetor manufacturers that the increased use of heavier fuels is inevitable has brought forth much worthy effort in the way of vaporizing them. This has temporarily set aside the kerosene and other heavy-fuel vaporizers. However, as the fuel is bound to become heavier and heavier, on account of the excessive demands for gasoline, it is only a question of a year or so before kerosene and distillate vaporizers will be agitated again.

Effect of Vacuum Feeds. The wide use of vacuum feeding devices, combined with the tendency mentioned above to clean and simplify, has caused a much higher mounting of carburetors. This has always been desirable, but hitherto it has not been possible. The vacuum feed for the gasoline supply has made this change possible, while the cleaning process and simplification actually forced it.

Effect of Motor Changes. The high-speed form of motor now so generally being adopted has had a big influence, as have also the multi-cylinder forms, both creating a demand for greater acceleration. Similarly, starting devices have forced the use of a carburetor modification by which instant starting is possible. These requirements have called for new designs, smaller and lighter parts, more nearly complete automatic actions to uncover large air ports, as well as other improvements.

Double Carburetors for Multi-Cylinder Motors. While many eight- and twelve-cylinder motors have but a larger-sized plain carburetor, the better forms have a double device, each half supplying a group of cylinders, and the halves are entirely separate and distinct from the other, except for a common fuel-supply pipe. Each set of cylinders has its own suction-actuated nozzle and its own independent nozzle. This form has shown its worth in actual use, having been very successful in aeroplane work on eight-cylinder and twelve-cylinder motors, and also on a number of the better eight- and twelve-cylinder motor cars.

Multiple-Nozzle Carburetors. Another development brought about by this demand for rapid acceleration, coupled with great maximum capacity, has been the swing toward multiple nozzles. As has been pointed out on previous pages, there are a number of carburetors now with two nozzles.

Stromberg Carburetors. Fig. 81 shows a cross-section of the Stromberg Model "L." Except that Model "LB," which is shown in Fig. 84, has a horizontal outlet which necessitates the air entering from the top and downward, instead of the side and upward, these two are almost identical, and the general instructions which follow will cover both. In general, all the Stromberg carburetors are of the so-called plain tube type, that is, the air and gasoline openings are plain tubes and thus fixed in size. This construction automatically meters the fuel by the suction of air velocity past the jets, and in addition does away with the auxiliary air valve, all the air supply being taken in through a single pipe which is heated. Thus, the entire air supply is heated, this making for more efficient operation with the present heavier fuels.

The Model "M" is a vertical, and "MB" horizontal form which are similar to the "L" and "LB" models except that they are made without the economizer attachment. This alters their outward appearance, cross sections, and eliminates one adjustment. That is, the "L" and "LB" have three adjustments, high, low, and economizer, while the "M" and "MB" have but two adjustments, high and low. To make these points plain in the subsequent adjustment instructions, Model "MB" is shown in Fig. 85.

General Instructions. The high speed is controlled by the knurled nut "A," which locates the position of the needle "E," past whose point all the gasoline is taken at all speeds. Turning nut "A" to the right or clockwise raises the needle "E" and gives more fuel; turning it to the left or counterclockwise gives less fuel on the "L" and "LB" models. On the "M" and "MB" the instructions are the same except that turning to the left or counterclockwise gives more fuel and to the right less.

If an entirely new setting becomes necessary, put the economizer "L" in the fifth notch (farthest from the float chamber)

Fig. 84. Stromberg Model "LB" Horizontal Type Carburetor
Courtesy Stromberg Carburetor Company, Chicago

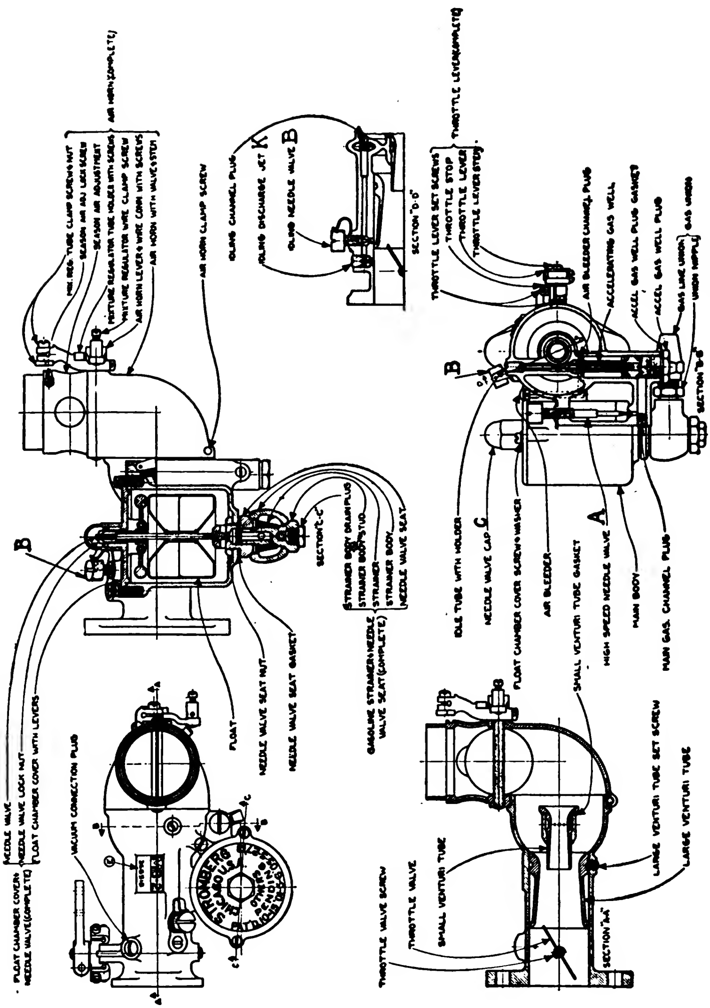


Fig. 85. Stromberg Model "MB" Horizontal Type Carburetor
Courtesy Stromberg Carburetor Company, Chicago

as an indicator, then turn the nut "A" to the left until the needle "E" reaches its seat as shown by the nut not moving when the throttle is opened and closed. When the needle "E" is in its seat it can be felt to stick slightly when nut "A" is lifted with the fingers. Find the adjustment of "A" where it just begins to move with the throttle opening, then give it 24 notches to the right or clockwise. In this turning the notches can be felt. Then move the economizer pointer "L" back to the zero (0) notch, toward the float chamber which will give a rich adjustment. Warm the motor thoroughly, then thin down the mixture by turning "A" counterclockwise until the motor shows the best power with a quick opening of the throttle. This will be the desired adjustment.

The low speed adjustment is made by means of the adjusting screw "B," which controls the jet "K." The latter passes the gasoline in above the throttle and the movement of "B" provides the necessary air dilution. Screwing "B" in clockwise gives more fuel on all models; outward, less. The best adjustment is usually ½ to 3 turns outward from a seated position. This, it should be noted, is only an idling adjustment and does not affect the mixture above a car speed of 8 miles per hour. When the motor is idling properly, there should be a steady hiss in the carburetor; if there is a leak anywhere, or one cylinder leaks, or if the adjustment is entirely too rich, the hissing sound will be unsteady. The adjustment process should be continued until a steady hissing sound is produced, for best all-around results.

As pointed out previously, Models "L" and "LB," Figs. 81 and 84, have an additional adjustment called the economizer. This tends to the use of a leaner mixture, that is, economy of fuel, hence its name. To give this desired result, high speed needle "E" and nut "A" are raised slightly, the amount of movement being regulated by the pointer "L." After making the high speed adjustment for best power with "L" in the zero (0) notch, as described previously, place the throttle lever on the steering wheel in a position giving about 20 m.p.h. road speed. Then move the pointer "L" clockwise or away from the float chamber, slowly and one notch at a time, until the motor begins to slow down. At this point turn back one notch, that is, the adjustment should be one notch before the point of slowing down.

The amount of this economizer action depends upon the quality of fuel, which differs in different parts of the country, and also varies with the temperature. Thus, in the Middle West the best economizer adjustment will be the third or fourth notch, usually. With Pennsylvania gasolines and throughout the South, the second notch will prove the best adjustment, while on the Pacific Coast no economizer action will be necessary unless distillate is used. Fewer notches of economizer action will be needed in summer than in winter.

Model "LS." A sectional view of the Stromberg Model "LS" carburetor is shown in Fig. 85a. It is of the plain-tube type because, having no air valve or metering needles, both the air passage and the gasoline jet are of fixed size for all engine speeds. It has several interesting features, such as a gasoline feed above the throttle with idling adjustment, an accelerating well, which gives an extra supply of fuel the moment the throttle is opened, and an economizer, which permits the carburetor to operate on a very lean and economical mixture at the closed-throttle, or average driving, position. This economizer automatically shifts to the richer setting when the full power of the motor is called for and operates on the thinner setting when maximum power from the motor is unnecessary.

Fig. 85a. Stromberg Carburetor, Model "LS"

Adjustments. The idling mixture is controlled by the turning of the idle adjustment screw *A*. This regulates the amount of air; screwing it in gives a richer mixture, and screwing it out a leaner one. Turn screw *A* out, anti-clockwise, until the motor slows down. Then turn in, or clockwise, notch by notch until the motor runs at its greatest speed without missing or "loping." When the motor is idling properly, there should be a steady hiss in the carburetor. If there is a weak cylinder or a manifold leak, the hiss may be unsteady and the motor is likely to miss if this unsteady hiss is allowed to continue.

After adjusting the low speed, if the motor runs too fast, the throttle stop screw *M* should be turned to the left, or counter-clockwise, until the motor runs at the desired speed. If, however, the motor idles too slowly and stops, the screw *M* should be turned to the right, or clockwise, until the proper speed is reached. Before adjusting the screw *M*, it will be necessary to loosen the lock screw *O*.

The high-speed adjustment is regulated by the high-speed needle *B*. This needle regulates the opening through which the fuel flows to the jet. Turning *B* to the left, or counter-clockwise, gives more gasoline; turning it to the right, or clockwise, gives less gasoline. In order to make the proper high-speed adjustment, the spark lever should be advanced. Set the throttle lever on the steering wheel at a position that will give about 25 miles an hour car speed on a smooth road. Then adjust the high-speed needle to the minimum opening that will give the greatest engine speed for that throttle opening. This will give a good average adjustment, although two or three notches lean will give best economy for continuous driving, or touring; two or three notches rich may be best for short runs in cold weather, when the motor is not operating at the proper temperature. To secure greater economy as thin a mixture as possible should be used.

To prevent the wrong high-speed adjustment from giving a harmful rich mixture, the gasoline nozzle reducer is inserted beyond the high-speed needle in the base of the discharge jet above the plug *K*. To secure a richer mixture the reducer placed in the carburetor at the factory will permit about 20 per cent more gas to pass than may be needed. The economizer device *D* operates to automatically thin out the mixture at speeds from 10 to 45 miles per hour.

In all cases adjustments should be made when the motor is warm and the motometer shows a temperature higher than 140 degrees.

This carburetor is manufactured in sizes suitable for both the vertical and horizontal style. It is now used on a large number of truck and pleasure car manufacturers, as it is simple and has a very wide range of adjustment. There is a dirt trap in this carburetor which collects dirt and sediment, thereby preventing this dirt from clogging up the nozzles and causing the motor to miss. This strainer is provided in practically all modern carburetors. The float is adjusted at the factory and should not be changed only in rare instances.

Zenith Carburetors. The Zenith Model "O" carburetor, shown in Fig. 83, enjoys wide use in this country because of its simplicity. It has fewer ordinary adjustments than any other carburetor This is so constructed that but one adjustment, that for slow speed, is provided. However, its makers realize that sometimes changes and adjustments are necessary to secure proper results. They provide for these by the removal of three internal parts and their replacement with simpler parts, but with different working orifices, or holes.

Zenith Adjustments. The three parts mentioned are: choke tube, main jet, and compensator. In Fig. 83, the choke tube is marked X. This is really an air nozzle of such a stream-line shape (approximating the Venturi) as to allow the maximum flow of air without eddies and with the least resistance. When the pick-up, or acceleration, is defective and slow-speed running is not smooth, the choke tube is too large. In this case, it will be found that a larger compensator I does not better the situation. Then a smaller choke tube is needed. This is held in place by a screw X_1 in the choke itself with a lock washer to prevent its jarring loose. To remove the choke, the butterfly T must first be removed. In the horizontal types, the body is in two pieces, which are held together by an assembling nut. When this is removed and the two pieces taken apart (the bowl from the barrel), the choke can easily be slipped out of the barrel. When the motor will not take a full charge, that is, when it cannot, with the throttle fully opened, this indicates the need for a larger choke tube. It will be noted that although the pick-up is good, the car will not make all the speed of which it is capable. In this case, take out the choke tube X, as explained above, and replace with a larger one.

Changing the Main Jet. The main jet *G*, Fig. 83, shows its influence mostly at high speeds. When running at high speed on a level road, if the indications show a rich mixture, irregular running, characteristic smell of over-rich mixture from the exhaust, firing in the muffler, sooting up of the spark plugs, and low mileage, the main jet is too large and should be replaced by a smaller one. On the other hand, when running at high speed, if the indications are that the mixture is too lean, if the car will not attain its maximum speed, if there is occasional back firing at high speed, then the main jet is too small and should be replaced by a larger one. In respect to back firing, however, care should be used, as this is more often due to large air leaks in the intake or valves or to defects in the gasoline line.

To Replace Main Jet. When it is necessary to change the main jet *G*, Fig. 83, to a larger or smaller size, the lower plug *L* is removed first. This has a square head and is removed with a wrench. Then the main jet is unscrewed from below by means of a screwdriver, a notch being cut into its lower part for this purpose. In reassembling care should be taken to see that the fiber joint packing is on the jet and that the jet is screwed up far enough to compress this. Otherwise gasoline may leak around the threads. But one fiber washer should be used. Then the lower plug *L* is replaced, and this also must be screwed up tight.

Changing the Compensator. The third change which can be made is in the compensator *I*, Fig. 83. The opening in this supplies the fuel to the secondary well and, if too large or too small, will have a corresponding influence upon the running of the car. The makers call attention to the fact that its influence is most marked at low speeds and suggest that when this is suspected, the car should be tried out on a hill, regular but long, and of such a slope that the motor will labor rather hard to make it on high gear. Under such a test, if the indications are of too rich a mixture, that is, the same as for a rich mixture at high speed on the level, as previously explained, the compensator is too large, and must be replaced with a smaller one. If the indications are of a lean mixture, with the motor liable to miss and give a jerky action, the compensator is too small and must be replaced with a larger one. This is easily removed in the same manner as the main jet *G*, by removing the bottom plug beneath it and then removing *I* with a screwdriver, through the medium of slots for this purpose in its lower surface. In connection with this last method of adjustment, the makers recommend that the workman should start with the setting provided, then proceed to determine first the main jet, then the compensator, then the choke. In a sense, this method makes double work, for any change in the choke calls for a corresponding change in the main jet, but it gives superior results.

Slow-Speed Adjustment. The one adjustment in the Zenith device which is really an adjustment and not a change is that for slow speed. This is preferably made on the garage floor, with the motor properly warmed up. When this has been done and it has been throttled down to idling speed, any irregularity, such as the lack of ability to throttle down to a really slow speed (say 350 or less r.p.m.), calls for a change in the adjustment. When the throttle *T*, Fig. 83, is nearly closed, there is considerable suction at the edge, and the tube *J* in the top of the secondary well *P* terminates in a hole *A* near the edge of the butterfly at which gasoline is picked up. If the motor will not throttle down as slowly as it should, the supply of gasoline can be reduced by means of the external milled screw *O*. When this is turned in, the air entrance *N* is restricted, and consequently a richer mixture is drawn in. When it is unscrewed, or turned out, a larger air opening is uncovered, and consequently a leaner mixture is drawn in.

In this connection, many factors other than the correct slow-speed adjustment of the carburetor may prevent good idling. Some of these are: too light a flywheel, too much spark advance, and air leaks created by (1) poor gaskets, (2) loose valve stems, (3) pitted or scored valves, (4) leaky valve caps, (5) spark or valve plugs, (6) leaky priming cups, and others. Obviously, if any of these faults exist, no amount of adjustment of the slow-speed device on the carburetor will give good idling.

Horizontal Type Adjustments and Changes. Everything that has been said thus far applies equally well to the horizontal type shown in Fig. 86, except for the adjustment of the idling jet. In this form, the idling jet P_2 is supported by the knurled nut *O* which governs the air opening for this jet, and replaces the horizontal milled screw *O*. If a leaner mixture is desired, this is turned to the right, or clockwise; this lowers the jet and increases the size of the available air passage. For a rich mixture it is turned the other way, or counter-clockwise, reducing the air opening.

Float Removal. In both models, it will be noted that the float cover is held on by the spring catch. This is lifted by means of its handle, and swung around out of the way. The float cover can then be lifted readily by means of the knurled edge. When this is removed it should be lifted up straight. The float is then exposed

Fig. 86. Zenith Carburetor, Model "HP"
Courtesy of Zenith Carburetor Company, Detroit, Michigan

and can be removed easily with a piece of wire bent at the end or with a match inserted in the center hole.

Model "T4." One of the latest developments of the Zenith Carburetor Company is the Model "T4" carburetor, which is similar in principle to the other Zenith products, the main difference being in the refinements and adjusting features. A sectional view of this carburetor is shown in Fig. 87.

Operation. The gasoline from the tank enters the strainer body *D*, passes through filter screw *D1* and enters the float chamber bowl through the needle-valve seat *S*. As soon as the fuel reaches a predetermined height—shown by the horizontal level line—in the bowl, the float automatically rises, which forces the needle down by lifting the needle arms *B*. The gasoline is then fed from this bowl through the nozzles in different quantities, which are always in relation to the speed of the engine.

Adjustments. The sizes of the nozzles have been determined at the factory and should not be changed. The only adjustment which might be useful is the idling adjustment. When the butterfly throttle valve *T* is nearly closed and the motor is turned off, a strong suction is produced at the edge of the butterfly where the idling is located. Under this condition, little or no fuel is supplied at the main jet *G* or cap jet *H*. Gasoline from compensating jet *I* flows into the atmospheric well *W*, the suction then lifting it through idling jet *P*, which has a calibrated measuring hole at its upper end. From this point, it is carried into its idling port *J*, where it is mixed with the air measured past the conical end of the idling jet. It then passes through the idling hole into the carburetor manifold and to the motor. Idling tube *J* is screwed into the bottom of the barrel and its position is thus fixed. Idling adjusting tube *P1*, which is permanently assembled to idling jet *P*, screws into the idling tube and is screwed up or down to secure the proper adjustment for idling the motor.

Fig. 87. Zenith Carburetor Model "T4"

Screwing down increases the air passage left between the conical upper end of idling jet *P* and the flared-out lower end of idling tube *J*, thus admitting more air and thinning the mixture. Screwing up reduces the air passage and thus enriches the mixture. The adjustment is locked by the idling spring *P2*, which engages the knurled surface of the idling adjustment *2*. As the throttle is opened, the idling jet ceases to function and the gas vapor is supplied through the main jet *H* as in other previous Zenith models. The choke *Q1* is supplied for easy starting. This choke cuts off the air supply and is operated from the dash. *Y1* is a revolving air shutter which controls the hot or cold air supplied to the carburetor.

As the adjustment is changed, a difference in the idling should be noticed. If the motor begins to run evenly or speeds up, it shows that the mixture becomes right in proportion, but that there is too much of it. This is remedied by changing the butterfly throttle position slightly, closing it by screwing out the stop screw which regulates the closed position for idling. Care should be taken to have the butterfly held firmly against this stop at all times when idling the motor. The single thing which is radically different and must be remembered in this connection is that multi-cylinder engines have very light flywheels and reciprocating parts, so the motor is extremely sensitive at low speeds to unequal conditions of ignition, compression, and air leaks. This makes it more necessary than with a plain four- or six-cylinder form to have the motor in the best possible condition before changing the carburetor idling adjustment.

The Zenith Model "L" is a refinement of Model "O," just described, but all adjustments are made in the way described for "O."

Carburetors on Ford Cars. On the Model "T" Ford car, there are two very simple forms of carburetor used. They are very much alike in general design and construction, but they are made by different firms. The form shown in Fig. 89 is the Model "G" Holley, while the other form, shown in Fig. 88, is the Kingston. Both forms have been used in about equal quantities by the Ford Company from 1909 to date.

In the Kingston (Fig. 88), "A" is the fuel connection, "B" the air valve, "C" the low speed tube, "D" the spray nozzle, "E" the choke throttle, "G" the drain cock, "H" the lever operating the choke throttle, "J" the needle valve, and "K" the needle valve binder nut. To adjust, warm up the motor, retard the spark fully, open the throttle five or six notches on the steering post quadrant, then loosen the binder nut "K" so the needle valve "J" turns easily. Turn this valve down with the dash adjustment, until it seats lightly but do not force it. Then turn back away from the seat one complete turn. Let motor run a little while, then make the final adjustment. Close the throttle until the motor runs at idling speed, which can be controlled by adjusting the stop screw in the throttle lever. Adjust the needle valve "J" towards its seat slowly until the motor begins to lose speed. Stop and adjust the needle valve away from its seat very slowly until the motor attains its best and most positive speed. Close the throttle until the motor runs slowly, then pull it open

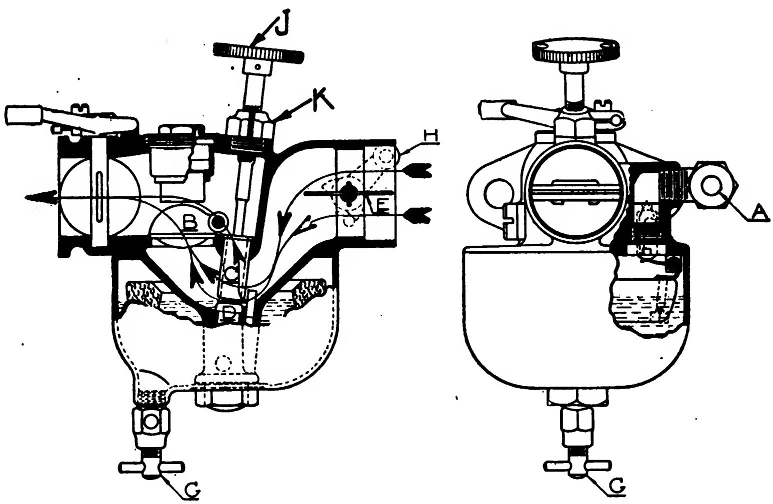


Fig. 88. Drawings Showing Construction of Kingston Model "L2" Carburetor
Courtesy Byrne, Kingston and Company, Kokomo, Indiana

quickly. The motor should respond strongly. If sluggish, a further adjustment may be necessary. Tighten the binder nut.

In the Holley, *A* is the thumbscrew with an extension to the clutch, by means of which the needle valve *B* is raised or lowered. The lower end of this projects down into the spray nozzle *C*, where fuel enters from the float chamber *D*, reaching it through the gasoline intake *E*. To draw off sediment and water use the cock *F*.

From the nozzle, the fuel passes up through the strangling tube *G*, where it is met by the entering air from the air inlet *H*, which has been deflected downward and toward the center of this circular space so as to pick up the spray of fuel at the nozzle and carry it upward in the strangling tube. Then it passes into the mixing tube *N*, thence out to the motor via the mixture outlet *I*. In this, its quantity is governed by the throttle, the lever of which may be seen at *J*. In the air intake, there is a throttle plate *K*, which deflects a large part of the entering air so that it passes to the right (straight in) and is added to the mixture in the mixer chamber. This forms the auxiliary air valve. The position of this plate, governed by the auxiliary throttle lever *L*, determines the quantity of both the primary and auxiliary air, since by its position it splits the entering air into two parts, one of which becomes the primary air, and the other the auxiliary air. For low speeds and idling, the low-speed tube *M* carries the very rich mixture up direct to the mixing chamber and thus into the engine.

Ford Adjustment. This Holley model, like the Kingston, has but one adjustment. The needle valve *B*, which has a projecting knurled head *A* for turning it, has a conical point *C* which seats into the fuel opening. If this is seated, no gasoline can enter, but as it is screwed out or up an opening is created and increased, which allows fuel to flow. The amount of this determines the amount of mixture entering the cylinder combustion chambers. Consequently, the primary adjustment with this screw is that of the fuel flow. Air enters through the opening *H*, passes the throttle *K*, and then mixes with the fuel spray, diluting it and carrying it up into the cylinders. The amount of the air is governed by the air lever *L*, its position

Fig. 89. Section of Holley Carburetor for Ford Cars
Courtesy of Holley Brothers Company, Detroit Michigan

being adjusted at the factory. The adjustments as recommended by the Ford Motor Company are as follows:

Initial Adjustment. The usual method of regulating the carburetor is to start the motor, advance the throttle lever (on the steering wheel) to about the sixth notch, with the spark lever (also on the steering wheel) retarded to about the fourth notch. The flow of gasoline should now be cut off by screwing the needle valve down (to the right) until the engine begins to misfire; then gradually increase the gasoline feed by opening the needle valve until the motor picks up and reaches its highest speed and until no trace of black smoke comes from the exhaust. Having determined the point where the motor runs at its maximum speed, the adjustment should not be changed except as indicated below. For average results, a lean mixture will give better results than a rich one.

Fig. 90. Dash Adjustment of Ford Carburetor
Courtesy of Ford Motor Company, Detroit, Michigan

Dash Adjustment. The gasoline adjustment is placed on the dash, Fig. 90, the milled head shown being fastened to a long rod whose lower end is attached to the needle valve head *A*, Fig. 89. Any movement of the milled head moves the needle valve and gives more or less gasoline. After the car has been worked in so that it runs satisfactorily, a file mark should be made on the face of this milled head to indicate the point at which the engine runs most satisfactorily. This is indicated by Fig. 90, in which *A* shows the milled headed rod projecting through the dash, and *B* the mark for satisfactory normal running. In cold weather, it will probably be found necessary to turn the finger wheel one-quarter turn to the left, or counter-clockwise, as shown at *C*, particularly in starting a cold engine. This movement increases the amount of gasoline and makes the mixture richer. In warm weather, gasoline vaporizes more readily, and it will be found advisable to give the milled head a one-quarter turn to the right, or clockwise, about as shown at *D*. This admits less gasoline and gives a leaner mixture. This last adjustment is particularly advisable when taking long rides at high speed for it increases the mileage per gallon of fuel.

Other Ford Models. While the foregoing describes the carburetors used by the Ford Motor Company, there have been many different carburetors developed by other companies intended to

Fig. 91. End View of the Hudson and Essex Carburetor

replace the ones just described and supposedly giving better results. Practically every large carburetor company has a so-called Ford model, while many firms build only carburetors for Fords.

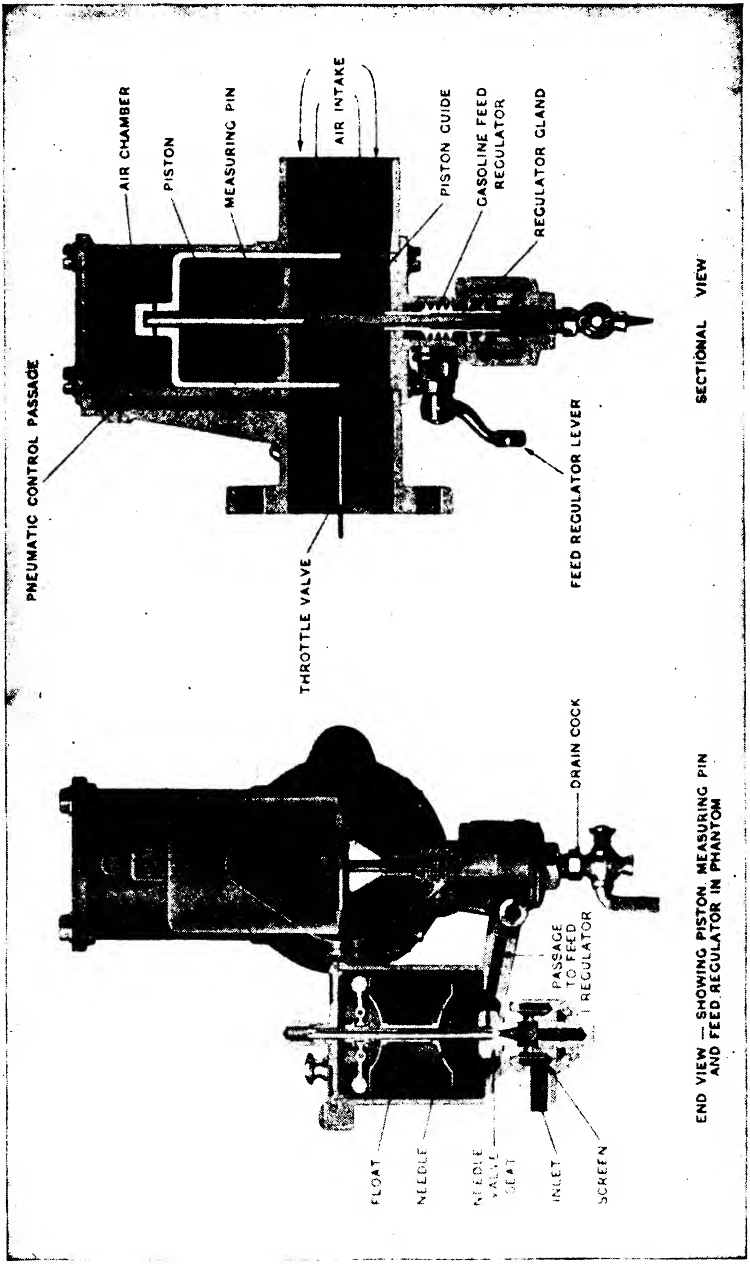


Fig. 92. Front and Side View of the Hudson and Essex Carburetor

From which it may be argued backwards that the results obtained with the cars as sold are not always entirely satisfactory. A few of these carburetors will be described although lack of space prevents a description of many of them.

Carburetors on Hudson and Essex Cars. The carburetors used on the Hudson and the Essex are identical in principle but a little different in detail construction. The gasoline level, Fig. 91, is somewhat lower than the top of the gasoline feed regulator. This regulator, which is adjustable from the dash, determines the amount of gasoline fed at a given altitude or temperature. For high altitudes where the pressure of the air is lower than at sea level, less gasoline is needed, and the sleeve is moved upward.

Principle of Operation. When the throttle is open, the air is drawn out of the air chamber, Fig. 92, through the pneumatic control passage, thus creating a vacuum in the air chamber which allows the piston to be lifted up. As the measuring pin is connected to the piston, it will also be lifted and will expose a deeper portion of the tapered slot on this pin, thus increasing the amount of gasoline as the air is increased. The piston also acts as the air cutoff and returns to its position slowly after the throttle has been closed.

This action is necessary as a greater amount of air must be provided with the greater amount of gasoline in order to obtain the same ratio in the result of mixture. A peculiar air intake construction is provided on both the Hudson and Essex carburetor, and the inquisitive mechanic often wonders why this construction is used. This air inlet is made in the form of an inverted funnel, having the large end toward the carburetor. A butterfly valve is located at the small end to shut off the air side when it is necessary to supply the motor with a rich mixture in starting. This style of motor inlet manifold was not used on the first Hudson cars, and it was found that a miss was constantly present when the motor was in operation. While this noise was not detrimental, it was rather annoying, and the Hudson people found that if the air inlet was constructed in the form of an inverted funnel that this undesirable miss would be done away with, the manifold acting as a muffler just as the muffler that is attached to the exhaust of the motor, so that the noise resulting from the escaping gases may be deadened.

Other Holley Carburetors. As has been stated, the carburetor illustrated in Fig. 89 and just described is a Holley Model "G". This firm also markets a Model "K", which is very similar to the "G", as will be noted in Fig. 93. The biggest differences between these models are: the vertical outlet in place of a horizontal; and the placing of the needle valve at the bottom because of this. In this latter figure, fuel enters by the gasoline pipe through the strainer *A*, past the float valve *B*, into the float chamber *D*, the level being regulated by the movements of the cork float *C*. From there, it passes through the opening *F* into the nozzle well *E*, through the hole *H* past the needle to a level in its cup-shaped upper end which just submerges the bottom of a small tube *J*, with its outlet at the edge of the throttle disc *K*. When the engine is cranked with the throttle nearly closed an energetic flow of air past this point draws liquid fuel which is atomized upon its exit from the small opening at the throttle edge.

Fig. 93. Holley Curburetor, Model "K"
Courtesy of Holley Brothers Company, Detroit, Michigan

As the engine rotates, considerable air is forced to move through the conical passage outside of the strangling tube *L*. The shape of the passage around the lower end of this is such that the entering air attains its highest velocity, and thus lowest pressure, near the upper end of the standpipe *M*. Consequently, there is a difference in pressure between the top and bottom of this pipe, and the air flows downward through the series of holes *N*. At the bottom it turns sharply upward, picks up the fuel spray there and passes into the main vaporizing chamber above *O*, and thence past the opened throttle into the inlet manifold at *P*.

Adjustment. As will have been noted, there is but one adjustment, that provided by the movement of the needle valve *I*. When this is screwed to the right, or clockwise, the valve moves upward and reduces the size of the fuel opening. When turned backward to the left, or counter-clockwise, it increases the opening and admits more fuel. The effect of these changes in its setting are claimed by the maker to be manifest equally over the whole range of the motor. According to the maker, this desirable feature is the result of utilizing in the nozzle action the pressure drop due to velocity of flow rather

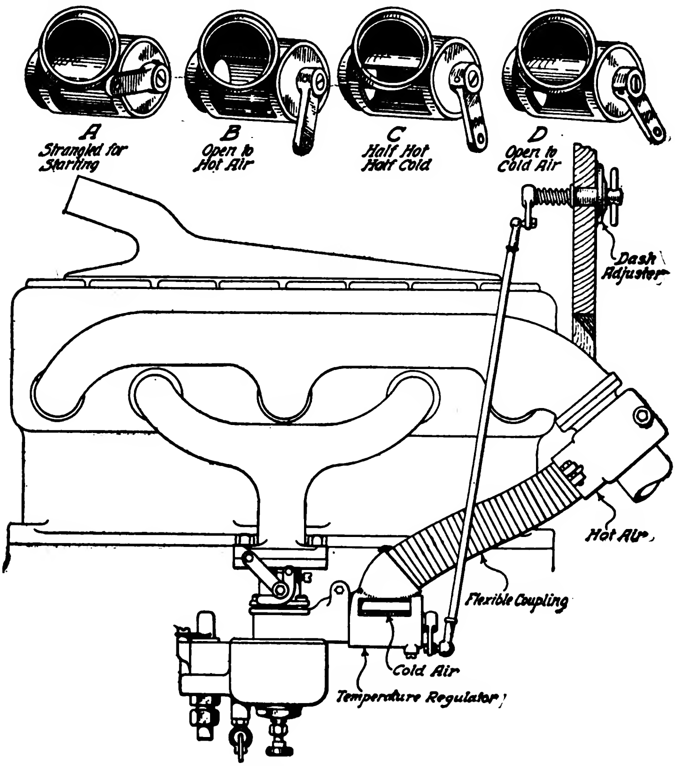


Fig. 94. Holley Temperature Regulator Attached to Carburetor

than the pressure drop causing the air to flow. Other Holley models, for motorcycles and small cars, are smaller in size, and need not be described here.

Temperature Regulator. This firm recommends a temperature regulator for use with its own and other carburetors. This is particularly important now, with the scarcity of fuel, its consequent low quality, and its high price. It is admitted by all that the heat is necessary in cold months, but that it is less necessary, although advisable, in warm months. This necessitates a means of varying it. There is no better source of heat than the handy exhaust pipe where heat is going to waste, so the Holley device, as illustrated in Fig. 94, utilizes the exhaust pipe as a source of heat and leads the same to the carburetor through a flexible tube with a regulating valve at the lower, or carburetor end. This is regulated by a simple rod connection with a small handle which projects through the dash and has a dial behind it. This can also be used as a strangling valve to assist starting, as shown above at *A*, for hot-air supply in winter, as at *B*, for half cold air in the spring and fall months, and for all cold air throughout the summer months.

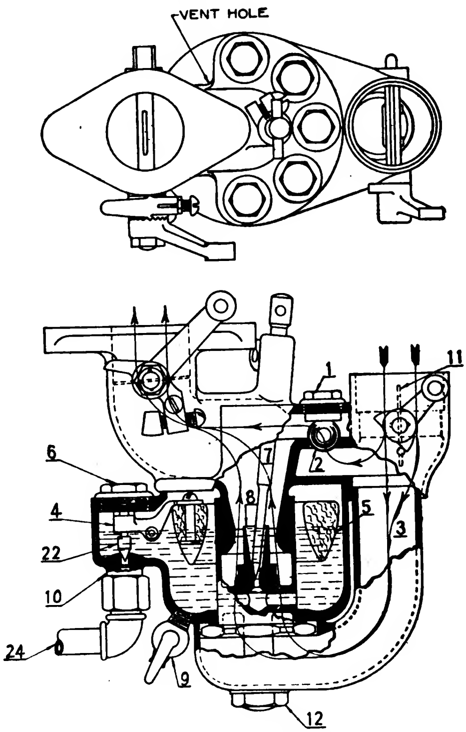


Fig. 95. **Plan and Section of Kingston Enclosed Carburetor**
Courtesy of Byrne, Kingston and Company, Kokomo, Indiana

Kingston Carburetors. *Enclosed Type.* The Kingston enclosed type, as shown in Fig. 95, differs from the type previously shown in that the auxiliary air valves in the form of various sizes of steel balls are used. These are normally seated, but they are lifted from their seats by increased suction. The primary air valve is not radically different from the former model, but the passage of the air is vertical rather than at an angle. When the suction lifts the ball valves, more air is admitted. This joins the partially vaporized mixture at the top of the vaporizing chamber and completes the vaporization and dilution before passing the throttle valve on its way to the inlet manifold. Like the model previously shown, it has the cup-shaped needle recess, so that when the motor is shut off, a pool of fuel collects there; this makes starting easy, for this fuel is drawn directly in, almost without dilution.

Adjustments. If the float is found to be too high or too low, it can be adjusted readily by bending the float lever to which it is attached. The only other adjustments are: the setting of the throttle which governs the lowest speed, this being accomplished by the screw shown on the throttle-lever arm projection at the left; and the setting of the needle valve for satisfactory high speeds. This is accomplished by unscrewing the cap to which the needle is attached and allowing more fuel to flow. Continue until the highest speed is reached and passed, then turn back until the maximum speed is reached.

Fig. 96. Part Section of Kingston Dual Form of Carburetor
Courtesy of Byrne, Kingston and Company, Kokomo, Indiana

Kingston Dual Form. This form, as shown in Fig. 96, is really two of the enclosed models, just described, attached to a common outlet and with a single throttle valve. It is intended for use with heavy fuels; one side is connected up for gasoline, which is used in starting and for exceptionally slow speeds long continued, while the other side is set for heavy fuel, such as kerosene, distillate, etc., and is used as soon as the engine running on gasoline has heated up sufficiently. It will be noted that one-half of this device is fitted with a water valve, which is placed on the heavy fuel side. It is a gravity valve seated by its own weight at low speeds and lifted progressively at higher speeds until wide open. In continuous running on heavy fuels, it has been found that after a certain time the engine begins to pound, but that if cooling water be introduced with the mixture, the engine will run cooler, and this pound will disappear. To remedy this is the function of the water valve.

Adjustments. Adjustments and repairs for this model will be exactly the same as with the previously described enclosed model, since it is simply two of these joined together. As has been stated, the added water valve works automatically.

Kingston Model "L." The last Kingston model shown, that of Fig. 97, is very similar to the Ford model, except that it is formed with a vertical outlet, and the air valve *B* added in the vaporizing chamber so formed. This is hinged at the side so as to be swung upward by the suction of the motor, thus uncovering a larger and larger orifice. It is weighted and acts automatically. It will be noted also that the shape of the nozzle has been altered slightly, that on the Ford model being perfectly straight. Near its lower end, it passes through the low-speed tube *C*, which has a series of holes around the bottom and an annular space around the body of the needle. Through this space the fuel and a very little air are drawn for starting, as, at that low suction, the valve *B* would be entirely seated.

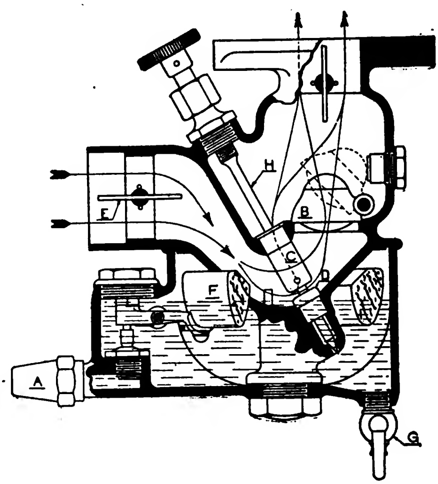


Fig. 97. Section of Kingston Model "L" Carburetor
Courtesy of Byrne, Kingston and Company, Kokomo, Indiana

Adjustments. After retarding the spark, opening the throttle, loosening the needle, and starting the motor, let it run at a fair speed long enough to warm up. Then adjust the needle valve. Close the throttle by adjusting the stop screw in the throttle lever until the motor runs at the desired idling speed. Adjust the needle valve towards the seat slowly until the motor begins to lose speed, which indicates a weak mixture. Now adjust the needle valve away from its seat until the motor attains its best and most positive speed. This should complete the adjustment. Close the throttle and let the motor idle, then jerk it open rapidly. The motor should respond readily. If it does not respond, a slight further adjustment may be necessary. When the adjustment has been made, lock it. Float troubles may be remedied in the same way as for the enclosed model.

Master Carburetor. The Master is called a carburetor without an adjustment. It was originally developed in Los Angeles for the purpose of using the heavy oil, called distillate, which is available there. This, as shown in Fig. 98, is a design of remarkable individuality. Except for the float chamber, it does not resemble any other carburetor. In design it consists of a float chamber to which the fuel enters from below through a round pan-like screen which filters it. From the float chamber the fuel passes through another cylinder-like screen which filters it again. Then it passes to one end of a long fuel passage, from which lead a series of vertical passages, each ending in a nozzle. These passages discharge the fuel into a cylindrical throttle chamber within which is placed a rotary throttle valve. This has a peculiar spiral-shaped edge, so that one tube—the end one shown on the right-hand edge slightly separated from the others—alone communicates with the vaporizing space. This is the starting and idling tube, or, nozzle. As the throttle is revolved, the spiral edge brings the other tubes into play, one at a time, until the whole number is engaged. When the throttle is revolved to the full opening, its central portion, as shown in the left-hand figure, is seen to be somewhat restricted at the center and flared at the ends to produce a slightly modified Venturi shape. The passage above the throttle leading to the inlet manifold, and the shape of the passage below it through which the air enters, both contribute to this effect.

The air enters from the right, Fig. 98, and the shape of this passage, to match the general shape of the carburetor, is low but wide. This has led to the development of a variable method of furnishing the air; for a division in the end of the passage allows of having all cold air, half cold and half hot, or all hot, as desired. For the heavy fuel conditions under which the device was developed, the all-hot air arrangement was used. Except in the hot summer months this would be most desirable, but there are conditions under which the semi-hot air arrangement would be best.

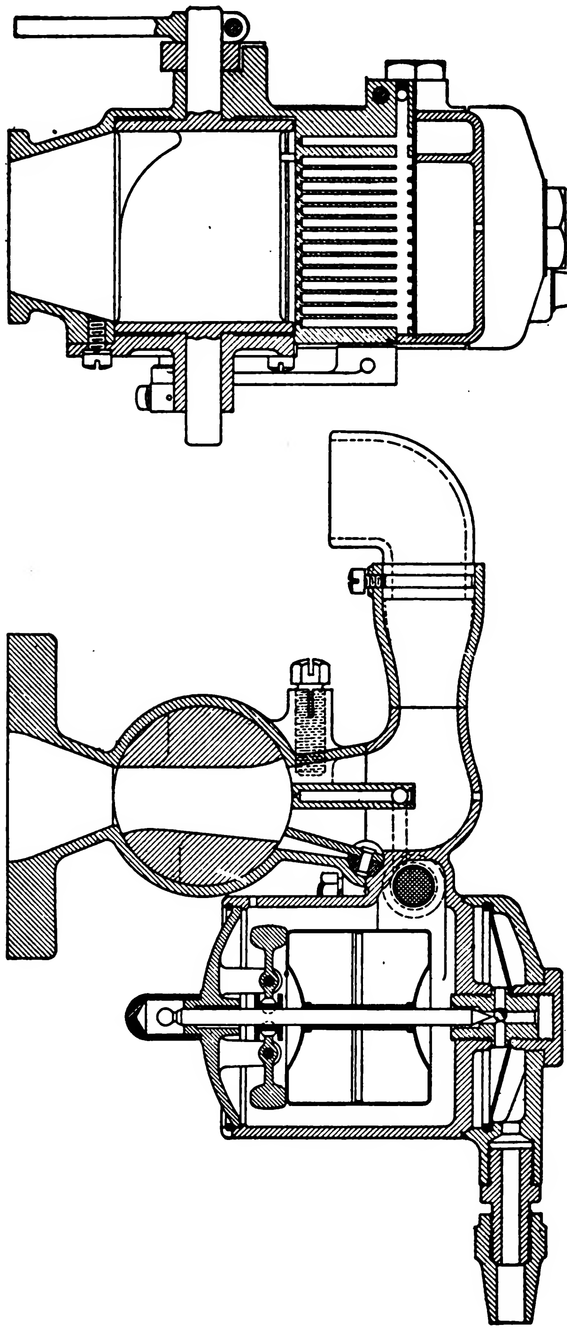


Fig. 98. Section through the Master Carburetor, Which Is a Multiple-Nozzle Form and Handles Heavy Fuels Well
Courtesy of Master Carburetor Company, Detroit, Michigan

Adjustment. While it is said not to have any adjustment, there is a variation which corresponds to the adjustment in many carburetors. This is the air damper, which is a long, rigid, flat plate extending across the incoming air passage parallel to the distributor and is connected by means of a Bowden wire mechanism to an operating lever on the steering post in the position where the usual carburetor adjustment is located. When this is moved, the air damper is swung over toward, or away from, the distributor. This movement restricts or increases the air passage at the jets. When the damper is moved so as to restrict the passage of air, its velocity is increased, and the greater suction carries up more fuel from the jets, and thereby produces a richer mixture. On the other hand, when the damper is moved to enlarge the area, there is less suction; consequently less fuel is drawn up, and the mixture is leaner. In the sense that the operator can change nozzles or modify the maximum or minimum amount of air or fuel entering the carburetor, this device has no adjustments. The nozzles cannot be changed in any way, and the amount of air can be varied only in a wholesale way, i.e., by changing from lean to rich through the whole range between these two. This device has been used four years as regular equipment on Moreland trucks which are built to use distillate selling at 6 cents a gallon, in barrel lots. This fuel has a specific gravity of 51 at 60° F.

When made for Ford cars, this device has only 11 nozzles. On the larger sizes from 14 to 19 are employed. The use of this device, with its vertical opening, necessitates a special inlet manifold to replace that on the Ford which provides for a horizontal carburetor outlet.

Miller Racing Carburetor. A carburetting device very similar to the Master is that shown in Fig. 99, this being the Miller carburetor. Proof of its efficiency is shown by its very wide use on the highest powered engines, such as the King-Bugatti 16-cylinder aeronautic engine, the Duesenberg line of racing and airplane engines, and on the majority of recent racing cars.

As will be noted in the figure (this showing the carburetor as used on the King-Bugatti 400-horsepower engine), a number of screwed-in jets are used, in the case of this particular engine, the number being seven, while the number of carburetors used was four, one for each four cylinders. In ordinary racing practice one or two of the seven-jet carburetors are used.

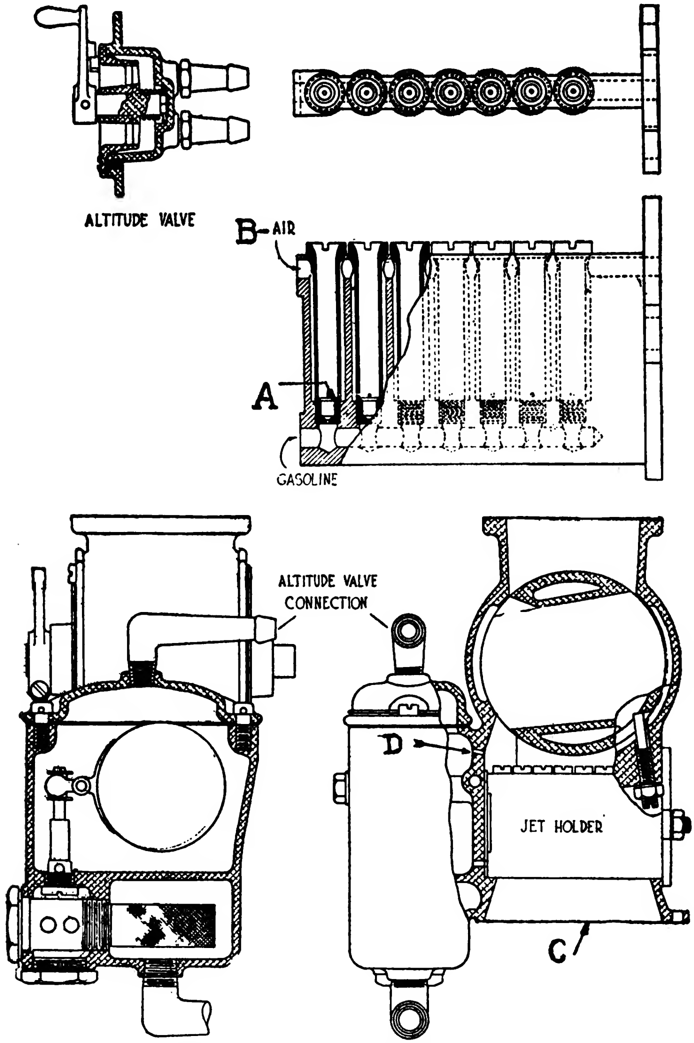


Fig. 99. Miller Multi-Jet Carburetor and Altitude Valve Details
Courtesy H. A. Miller Manufacturing Company, Los Angeles, California

As the general view and detail indicate, gasoline is drawn into each one of the jets through the small hole in the bottom of the threaded end, mixing with a certain amount of air sucked in through the four small holes at *A* drilled in the barrel of the jet just above the threaded portion. This air is taken from the outside through the upper $\frac{3}{16}$-inch hole *B* in the jet holder, and passes down around the outside of the jet to the four small holes mentioned. The major portion of the air enters the carburetor through the lower end *C* of the Venturi, which is 3 inches in diameter, passes up around the jet bar holder, combining above this with the rich mixture from the seven jets to form the proper mixture for combustion.

This particular instrument being for airplane use, an altitude adjustment is necessary, and the details of this are shown in the illustration. It operates by turning the lever, and has two openings in its seat which when open register with similar holes in the cover giving the free passages to the atmosphere. The float chamber is in direct connection with the Venturi through the drilled hole *D* $\frac{5}{64}$ inch in diameter, this being well above the fuel level. When the altitude control valve is opened, by this means, the vacuum in the float chamber is decreased, thus increasing the flow of fuel through the jets.

Like the Master, this has no adjustment, changes in performance being produced by replacing the jets with different ones.

Webber Automatic Carburetor. The Webber carburetor has been produced to meet the need for a very finely and carefully made instrument. It is an instrument of precision and is priced accordingly. Two models are made, namely, Model "C," which has a vertical outlet and water jacket; and Model "E," which has a horizontal outlet and no water jacket and is therefore smaller and more compact. With these exceptions, the two are very similar in construction, as well as in adjustment. For this reason only the Model "C" will be shown. This will be seen in Fig. 100, which shows a longitudinal section along the center line of the two chambers. It will be noted that this device has a concentric float *37* in which the spray nozzle *35* is located. The needle point *32* is controlled through the needle-point lever *13* which works down onto it from above. The nozzle is placed in the center of the modified Venturi chamber *7*, the top outlet of which consists of a series of 10 tapered holes. As the fuel mixed with the hot air entering through the air horn *9* reaches the vaporizing chamber, the auxiliary air enters from the side. Because of the shape of the cylindrical vaporizing chamber

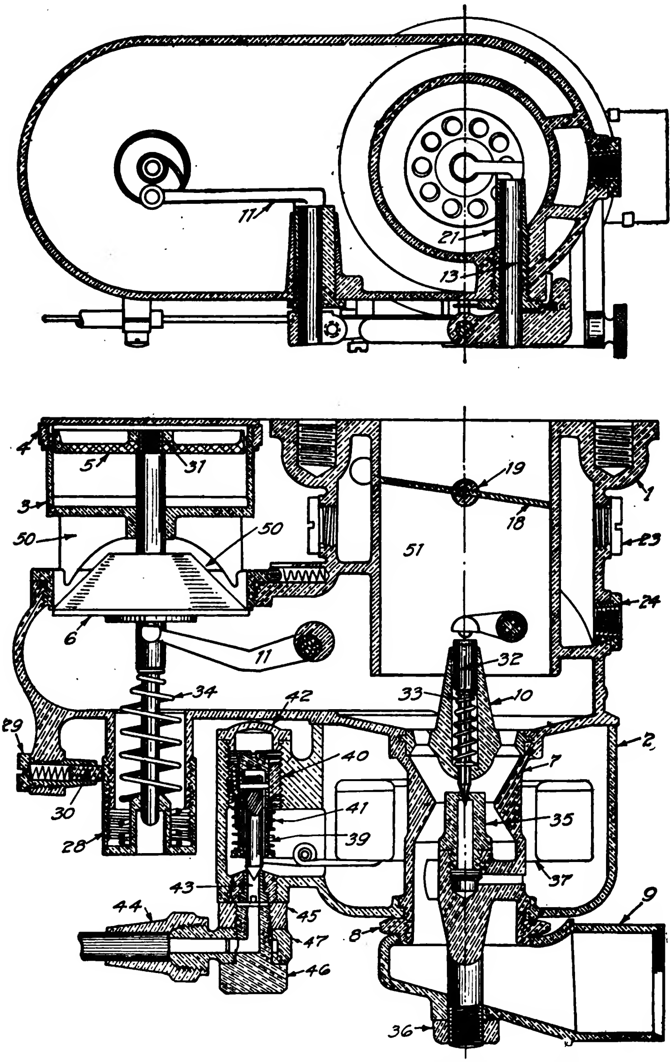


Fig. 100. Section through Webber Automatic Carburetor
Courtesy of Webber Manufacturing Company, Boston, Massachusetts

51 and the distance which this chamber extends downward, the auxiliary air is forced to turn at right angles and also to pass through a restricted area, thus giving it an increased velocity where it picks up the partly vaporized fuel. In this upper cylindrical vaporizing chamber *51* the throttle valve *18* of the simple butterfly type is located.

The auxiliary air enters through the holes *50* below the dashpot chamber *3* in which the piston *5* is located. This is attached to the upper end of the auxiliary air-valve stem, its lower part having a conical extended shape so as to spread out the air. The dashpot prevents fluttering while the downward movement of the air valve is resisted by the spring *34*. The tension of the spring is adjustable

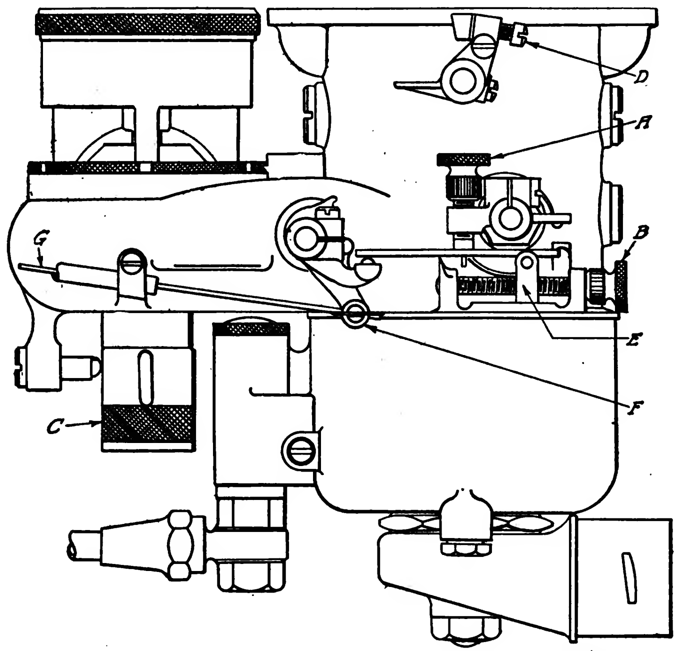


Fig. 101. External View of Webber Carburetor, Showing Adjustments

by means of the milled thimble *28* and the locking plunger *30*. The air-valve lever *11* is interconnected with the needle-valve lever *13*, so that any movement which increases the air opening automatically increases the fuel flow also, and *vice versa*.

Adjusting the Webber. There are two adjustments, aside from the setting of the air valve and the determination of the proper needle valve and its correctly proportioned spring. These are for low speed, or idling, and for high speed, or maximum power. Assuming that the carburetor has been installed correctly and the fuel turned on, the makers recommend turning the air-valve adjusting-spring thimble *C*, Fig. 101, up or down until the air valve upon being pressed down and released returns lightly but positively to its seat. Next turn the low-speed adjusting screw *A* down (right handed, or clockwise) as far as it will go without resistance, then turn it up, or back, about three-fourths turn. Turn the high-speed adjusting screw *B* to the right or left until the fulcrum block *E* is approximately in the center of its travel. Be sure that when the lever of the steering-post control (handle operating Bowden wire) is moved down to the lean position, the lever *F* on the carburetor is pressed forward firmly against its stop.

Low-Speed Adjustment. Move the lever of the steering control to the rich position, open the throttle about one-quarter, then start the motor. Now move the lever on the steering-column control down to the lean position and allow the motor to run idle until thoroughly warmed up. If it does not idle properly, turn the low-speed adjusting screw *A* up or down until it runs smoothly with the throttle closed against the stop screw *D*. The latter, after being adjusted properly, should be fastened by setting up the clamp screw provided for this purpose. This adjustment is for idling only.

High-Speed Adjustment. The high-speed adjustment is made by turning the screw *B* to the left or right. This moves the fulcrum block *E* in or out; moving it in gives less gasoline at high speed, and moving it out gives more gasoline at high speed. This adjustment can be made with the motor standing and continued until what seems to be the best position is reached; but the final high-speed adjustment should be made on a long hill. On this, start up at the bottom at about 20 miles per hour, open the throttle wide, and note the speed at the top. Now go down the hill. After moving the fulcrum block *E* out about $\frac{1}{16}$ inch, try the hill a second time, starting from the bottom at the same speed as before and noting particularly the speed which results at the top. If this shows a gain, move the fulcrum block out another $\frac{1}{16}$ inch and try again. If it shows a loss, move the fulcrum block in and then try the hill. Continue until the maximum speed at the top of the hill is obtained, then lock the adjustment. This means but a few trips up and down the hill and results in a setting which is permanent and gives maximum power at all times. This adjustment is for maximum power only and has no effect upon the idling adjustment made previously. Be careful also not to pass the point of maximum power; as this point means maximum speed, flexibility, and acceleration..

Starting Adjustment. The makers claim that it is unnecessary when the proper adjustments have been made to wait for the motor to warm up before starting away; simply move the steering-column control to the rich position, start the motor, and drive off, then, as the motor warms up, move this control lever down toward the lean position, running normally with this as far down toward lean as it will go.

Fig. 102. Section of Rayfield Carburetor, Model "G"
Courtesy of Findeisen and Kropf Manufacturing Company, Chicago

Except that some of these adjusting screws are located differently, the adjustment of the Model "E" is the same as that of Model "C", as is also that of the Model "E H" a modification of the "E" adapted particularly to the Hupmobile.

Rayfield Carburetor. The Rayfield carburetor, Model "G", as shown in Fig. 102, is of the double-needle type, with three air-inlet openings and an eccentric float chamber. The latter is shown at the left, with fuel entering from below through a strainer. Communicating directly with this float chamber is the passage in which the low-speed nozzle (marked spray nozzle) is situated; this consists of a hollow member with the actual needle point coming down vertically from outside and above, similar to *C*, Fig. 82. Communicating with the float chamber is a passage, or well, through which fuel flows across to the bottom of the high-speed well. In this passage is located a hollow metering-pin nozzle; and in the upper part of it is the metering pin. The upper end, through which the fuel flows, is located in one end of the elongated vaporizing chamber, while the upper automatic air valve has access to the top of it and furnishes the air supply.

At the other end of the vaporizing chamber the idling needle is located, and directly beyond it is the constant air opening, a simple round hole communicating with the atmosphere. This end is short and close to the central portion of the chamber, which is approximately cylindrical. The lower air valve is at the bottom, while the vertical connection to the inlet manifold and the butterfly throttle are at the top. The lower air valve and the upper automatic air valve are linked together so as to operate simultaneously. The movement of the upper automatic air valve downward actuates the metering pin, moving it downward; this tends to allow fuel to flow out around the pin. At the same time, the stem of this valve is connected at the bottom with a piston working in the dashpot which is filled with fuel, so that any sudden tendency for the air valve to open is checked by this dashpot. At the same time, this piston communicates with the hollow metering-pin nozzle, so that the downward movement of the piston forces an extra supply of fuel into the nozzle and enriches the mixture. Thus, the opening of the throttle automatically produces a rich mixture for starting, as the slow movement of the air valve in opening against the drag of the dashpot causes a relatively stronger suction on the nozzles. This arrangement eliminates the necessity for an air-valve adjustment, that is, an adjustment which owner or repair man is supposed to use. As a matter of fact the carburetor is made with an adjusting ring, which, after setting at the factory, is locked by means of a set screw and is not supposed to be touched.

Adjustments. Referring to Fig. 103, there are but two simple adjustments on the Rayfield; both are made by means of external milled head screws. Before making any adjustments, be sure there are no obstructions in the gasoline line, that all manifold connections are tight and free from air leaks, that valves and ignition are correctly timed, and that there is good compression and a hot spark in all cylinders. These carburetors are generally fitted with dash control.

Always adjust the carburetor with this dash control down. The low-speed adjustment should be made first. To make this, close the throttle and let the dash control down, then close the nozzle needle by turning the low-speed adjustment, Fig. 103, to the left until the block *U* leaves contact with the cam *M* slightly. Then turn to the right about three full turns. Start the motor and allow it to run until warmed up, then push the dash control all the way down, retard the spark, close the throttle until the motor runs slowly without stopping. Now make the final adjustment by turning the low-speed screw to the left until the motor slows down. Next, turn to the right,

Fig. 103. External View of Rayfield Carburetor, Model "G", Showing Adjustments

one notch at a time, until the motor idles smoothly. If the motor does not throttle low enough, turn the stop-arm screw on the main throttle-valve shaft to the left until the motor does run at the minimum speed desired.

High-Speed Adjustment. Advance the spark about one-quarter with the motor running, then open the throttle quickly. Should the motor back-fire, it indicates a lean mixture. Correct this by turning the high-speed adjusting screw, Fig. 103, to the right, about one notch at a time, until the throttle can be opened quickly without back-firing. If loading, or choking, is experienced when the motor is running under heavy load with the throttle wide open, it indicates too rich a mixture. This can be overcome by turning the high-speed adjustment to the left. Adjustments made for high speed will not affect low speed. Low-speed adjustments must not be used to get a correct mixture at high speed. Both adjustments are positively locked.

Changing Nozzles. "Never, under any circumstances, change nozzles in the Models "G" and "L" carburetor," say the manufacturers. Neither should the float level be changed, as they say this is correctly set at the factory and should not be touched. For use with a pressure system, two pounds pressure is advised. The plugs *S*, *Y*, and *X*

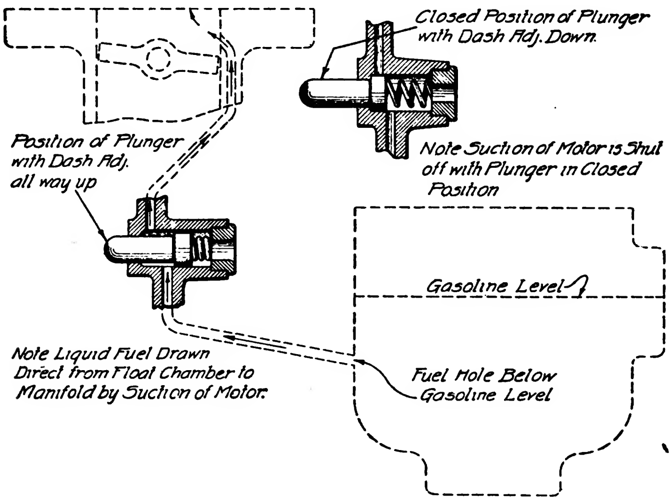


Fig. 104. Sketch of Starting Primer Attached to Model "N" Rayfield Carburetor

are for cleaning and draining purposes. In the bottom of the float chamber there is a strainer trap, which can be cleaned by shutting off the gasoline supply and removing the nut *S*. The dashpot is drained by opening the drain cock *X;* it is advisable to do this occasionally to remove any sediment that may have accumulated there. The float chamber should also be drained occasionally by removing the plug *Y*. When this is replaced, it should be tightened very carefully; and when the strainer trap is removed and cleaned, care should be taken in replacing it to put the gaskets back in place as well as to tighten the nut adequately.

The Model "L" is the same as Model "G" without the water jacket. It is adjusted in the same manner, and all that has been said above on the subject of adjusting the "G" applies with equal force to the "L".

Adjusting Model "M". The Rayfield firm makes another model, known as Model "M", which is similar to the Model "L", except that it has a side, or horizontal, outlet. It has the same two adjustments, made in the same way, but the shape of the carburetor locates these in a different place. The low-speed adjusting screw is on the extreme top of the carburetor, and the high-speed adjusting screw is also on the top, but it is made accessible by removing the hot-air elbow from the main air valve. This model is fitted with a starting primer incorporated in the device itself and operated through the medium of a dash lever. In the sketch, Fig. 104, which is self-explanatory, the construction and operation of this are shown. When pressure feed is used, not more than one pound is recommended for Model "M". When the starting primer is to be attached, the following method should be used: Locate the position on the dash desired for the push button and drill a $\frac{5}{8}$-inch hole at the proper angle. Attach the adjustment and run the tubing to the bracket on the carburetor, avoiding sharp bends. Cut off the tubing so it will extend beyond the bracket not more than $\frac{1}{4}$ inch. Remove the temporary wire from the carburetor, insert the tubing and secure permanently by tightening the clamp screw. Run the dash adjustment wire through the hole in the binding post on the eccentric lever. Then, with the push button down, place the eccentric arm in position so that the line on the eccentric just comes in contact with the adjusting screw. Tighten the screw in the binding post, cut off the surplus wire, and, without changing the position of the push button, make the carburetor adjustment, as previously described.

Ball and Ball Carburetor. The Ball and Ball device has been developed by Frank H. and Frederick O. Ball and is named after them, but it is manufactured and sold by the Penberthy Injector Company. In all its forms, as used on a number of different cars, whether single or double, horizontal or vertical, it is a two-stage instrument. These two stages are called the primary and the secondary. As shown in Fig. 105, the primary stage corresponds to the usual simple air-valve carburetor. This consists of nozzle, or jet, *3*, located in the fixed air passage, or Venturi, *2*. In the passage above this, it receives its air for complete vaporization from the valve *4*. Some air is, of course, admitted around the nozzle *3* below the Venturi *2*, otherwise the fuel would not be drawn up. This nozzle receives its fuel from the float chamber *14*, which is supplied through a strainer in the usual manner from the gasoline pipe *13*. The connection from the float chamber to the jet extends first to the well *16*, thence across the horizontal passage *17*, from which the nozzle *3* draws its supply.

Now, to this simple carburetor add another which consists of the nozzle *6* and of the air supply *5*, which is normally closed by the

Fig. 105. Section through Ball and Ball Two-Stage Carburetor
Courtesy of Penberthy Injector Company, Detroit, Michigan

butterfly throttle *7*; this latter, when closed by a spring, covers the top of the jet *6* so that it cannot function. It is obvious that the primary stage is constructed for low speed, idling, and for the lower range of driving, and is very economical. As this lower range covers perhaps 85 to 90 per cent of ordinary driving, this would be a desirable feature.

As the drawing shows, the opening of the second throttle valve *7* allows additional air to enter and, at the same time, uncovers the second jet *6*, so that this starts to function by drawing its gasoline from the same horizontal passage *17* as does the primary jet. If this throttle be connected up to the other throttle in such a way that, when approaching the maximum opening of the main throttle, the secondary throttle begins to open, we have, in effect, two carburetors, one working over the lower range, which gives good idling and splendid economy, and another high-speed and high-power device adding its total effect to that of the primary. The two contradictory and opposed qualities of highest power and highest economy are thus produced by what is, in effect, a double carburetor. This, with variations for various sizes and types of cars, constitutes the Ball and Ball device, shown in section in Fig. 105.

Pick-Up Device. This carburetor has a pick-up device which produces remarkable acceleration. This consists of the plunger *8* having a smaller sized upper end *9*. It is loosely fitted in the chamber *15*, the bottom of which communicates with the float chamber, and is thus kept full of gasoline. At the top, a small hole *10* communicates with the manifold above the throttle, while *11* is an opening to the atmosphere, and *12* is an opening to the mixing chamber. When the throttle is nearly closed, the vacuum in the manifold raises the plunger, and the space below it fills with gasoline. In this position it is ready to act. When the throttle is opened suddenly, the vacuum is broken, and the plunger drops of its own weight, forcing the gasoline up where it is swept into the mixing chamber by the air entering through the passages *11* and *12*. This is repeated as often as the throttle is suddenly opened from a nearly closed position.

Adjustments. The primary stage must be adjusted as a whole to give the best idling and slow speeds; this consists of the adjustment of the air-valve spring, the arrangement of the hot-air passage leading to it, or, if these prove insufficient, the changing of the primary nozzle. The last change is opposed by the makers.

Beyond this, the only adjustment possible lies in the hot-air choke valve which can be moved or altered from the dash to give more or less hot air. The partial closing of this valve makes starting easier and helps the running of the motor until it gets warmed up, but in normal running its manipulation has little effect. In going farther than this, the only possibility lies in altering the design by varying the connection between the two throttles, so the second stage cuts in sooner or later, but this might impair the usefulness of the instrument. The same is true if the secondary nozzle is changed. The device, then, is really lacking in adjustments in the ordinary sense, except for the initial setting of the primary-stage air valve.

Newcomb Carburetor. The Newcomb carburetor is made by the Holtzer-Cabot Electric Company and is a constant vacuum type having a single nozzle and an eccentric float chamber. It is a high-grade instrument and is used only on the highest-priced cars. As

Fig. 106. Section through Newcomb Carburetor
Courtesy of Holtzer-Cabot Electric Company, Boston, Massachusetts

shown in Fig. 106, the hot-water-jacketed vaporizing chamber will be noted at the left. In the center of it is the hollow plunger *69*, which works up and down in the plunger chamber *68*. The top portion of the plunger has the needle holder *73* held in place by the lock nut *74*. The hollow plunger *69* surrounds a tube at the top of which the fuel nozzle *72* is located. The fuel controlling needle *71* is fixed in the needle holder *73* and projects through this nozzle down into the central fuel well. This is connected by a horizontal passage at the bottom to the lower part of the float chamber, seen at the right, which is of normal, or usual, construction, except for the regulating cap *77* on the top of the central opening above the float needle *85*.

Around the bottom edge of the plunger *69* a large number of holes of small size are drilled, and these are arranged to register with an equal number of relatively narrow air slots cut in the bottom of the plunger chamber walls. These distribute the fuel after it has passed up the central well, issued from the nozzle, and been drawn within the plunger. The plunger when at rest is seated on the collar *70*, which is threaded into the bottom of the plunger chamber and is used as a means of adjustment, as will be explained later. This collar is so set as to raise the plunger slightly, thus opening the fuel nozzle without uncovering the air slots in the plunger chamber. In this way, the fuel port is given a lead with respect to the air ports, so that a rich mixture is delivered when the plunger is raised a little, as in starting or idling.

When air is drawn through the carburetor by the motor suction, the plunger lifts in proportion to the amount of air entering. This lifts the needle and, at the same time, releases the exact amount of fuel needed to charge the entering air correctly and thoroughly. The higher the plunger is lifted, the greater the air and fuel openings. The effective areas of these air and fuel ports are so proportioned as to be correct at all positions. The slots in the plunger chamber walls being small, the jets of air coming through them have a high velocity, so that the fuel is atomized as it issues at these points. Any unatomized or unvaporized fuel is thrown against the heated walls of the vaporizing chamber, which are made greatest in area in this region. This produces a dry gas and high fuel economy. The gas passes around the outside of the plunger chamber, through the main throttle valve, and thence goes into the inlet manifold.

Starting Device. The small pipe shown at *101* is a starting device and consists of a pipe connection from the lower part of the float chamber into the gas outlet passage above the throttle valve. When about to start, the throttle is thrown over to a position in which the opening of this pipe is included in the manifold above it. It is then susceptible to the partial vacuum existing there, and pure fuel in a very fine spray is drawn directly into the manifold. Under normal running conditions, its operation is negligible.

The Dashpot. This device has a solid head to the plunger *69* and also to the plunger chamber *68* in which it works. Between the two there is a considerable space, and, as the plunger is a fairly close fit in the chamber, this acts as a dashpot and retards the speed of the plunger when the motor is accelerating, or when the throttle is opened suddenly. By retarding the speed of the plunger, a richer mixture is obtained at the precise time when it is needed, in fact, demanded, by the motor. And yet when the plunger rises and stops rising, the mixture again becomes normal. This arrangement, therefore, does not need an extra rich setting in order to obtain good acceleration, for the engine can run on a lean mixture with a rapid pick-up.

Mixture Indicating Pointer. The top of the float chamber carries a name plate *88* on which a graduated arc varying from *1* to *9* is etched; the *1* end being marked poor, and the *9* end rich, as shown in Fig. 107. On the top center of the float chamber is a regulating cap *77*, Fig. 106; attached to the top of it is the regulating pointer *78*, which traverses the arc shown and in this way indicates the quality of the mixture being formed with that setting. This pointer, shown as straight, but having two bends, from a horizontal to a vertical and back to a horizontal at the scale, has a small hole at one end to which a dashboard controlling lever can be attached, thus a quick and easy adjustment can be obtained. This pointer, which carries with it the regulating cap *77*, Fig. 106, adjusts the degree of vacuum above the gasoline in the float chamber and this holds back or partially restrains the flow of fuel to the nozzle. When turned to poor, the vacuum is increased, and the flow of fuel is reduced, giving a weaker, or leaner, mixture. When turned to rich, the vacuum is reduced so the fuel flow is increased and results in a richer mixture. This effect is felt throughout the range of throttle opening and thus throughout the speed range. It is used also to compensate for changes in temperature, altitude, and varying fuel densities. This vacuum arrangement replaces the usual change of area of the fuel opening in other carburetors.

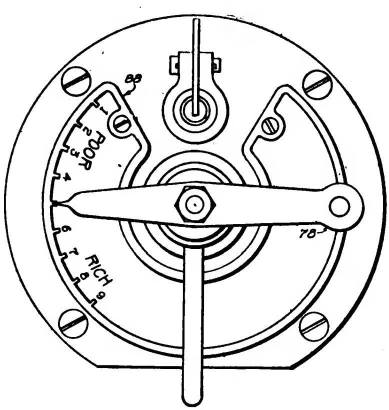


Fig. 107. Sketch of Regulating Pointer on Newcomb Carburetor

Adjustments. There are but two adjustments: the load-carrying adjustment controlled by the pointer *78* and cap *77* just described; and the idling adjustment controlled by the regulating collar *70*, mentioned previously, and shown in Fig. 106. Contrary to the usual method, the load-carrying adjustment is made first, and the low-speed, or idling, adjustment is made last. To make the load-carrying adjustment, set the throttle in the special starting position as described, turn the regulating pointer to the rich position on the dial, then screw the slow-speed ring, or regulating collar, *70* as far up as it will go. This is the rich position of the ring for starting only. Flood the carburetor by means of the tickler *94* until gasoline appears on top of the float chamber. Then start the motor and immediately move the throttle to a running position, otherwise the motor will stall.

With the motor running normally, move the regulating pointer *78* to about 5 on the dial; this gives an average setting, but different points should be tried and the poor-mixture, or lean-mixture, side should be favored always. To obtain the best setting, move the pointer half a point at a time, and try out the setting each time on the road. When the best setting has been found for some one condition of motor speed and load, the mixture will be found correct under all conditions except idling.

Idling and Low-Speed Adjustment. Now that the load-carrying adjustment has been made, the ring *70* which adjusts the mixture for idling should be unscrewed to weaken the mixture until the motor throttles evenly, without loading or popping when accelerated. Possibly the best combination of slow running and quick smooth acceleration may call for a slightly richer mixture than that on which the motor idles best and slowest. After this setting has been made, to see if the ring is screwed up too far and is giving a richer mixture than is necessary, move the regulating pointer *78* slowly from the No. 5 point toward poor. If the motor speeds up, the mixture is too rich, and the ring *70* should be unscrewed until the motor idles correctly with the pointer in the position found to be correct for the load-carrying mixture. After the correct idling position has been found, all variations for atmosphere, temperature, and fuel conditions should be made by changing the pointer only.

Newcomb Air-heated Model. In addition to Model "B" just shown and described, the Newcomb is made in an air-heated form shown in Fig. 108. This is known as Model "E," and differs from Model "B" mainly in the method of heating (air instead of water), the slow speed adjustment, and the arrangement of the high speed adjustment.

In place of the adjusting ring *70* which raises or lowers the plunger in Model "B," spray nozzle is raised or lowered by means of an adjusting thumb nut at the bottom of the carburetor and outside. This is seen at the bottom of Fig. 108, which shows also how this nozzle would be withdrawn from the metering needle or raised to it by such movement. The high speed adjust-

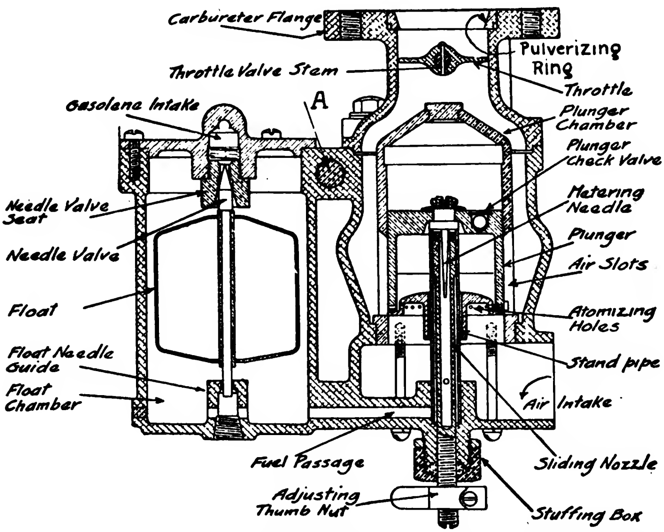


Fig. 108. Section through Newcomb Model "E" Air-Heated Type Carburetor
Courtesy Holtzer-Cabot Electric Company, Boston, Massachusetts

ment is much the same in principle, but instead of the pointer on top of the float chamber a lever hung in a vertical plane works upon a pin "A" between the float chamber and body, this by its position governing the amount of vacuum above the fuel, and thus, its flow. The starting device is similar to the pipe *101*, Fig. 106, but the fuel is broken up by the knurled edge of a pulverizing ring in the throat above the throttle, the knurling doing the actual work of pulverization.

Marvel Carburetor. The Marvel carburetor, Model "E," shown in section in Fig. 109, is notable for using the exhaust gases directly for heating the vaporizing chamber, as well as for pre-heating the air used for vaporizing the fuel. The latter is common enough, but in the usual case where heating is thought necessary, hot water from the motor's water-circulating system is used. Another novelty in this design is the inclined hinged form of air valve set across the lower part of the vaporizing chamber. The float chamber *A* is eccentric to the central vaporizing chamber *B*, but is set very close to it, so the ends of the cylindrical float *C* have to be cut off for clearance.

Fig. 109. Section through Marvel Carburetor, Model "E"
Courtesy of Marvel Carburetor Company, Flint, Michigan

Fuel enters from below. It enters the gasoline passage from above, as this is horizontal. The primary, or low-speed, nozzle *D*, which is adjustable, takes off from this about midway of its length, and the high-speed nozzle *E* from the end. The former operates within a Venturi tube which is supplied with air from below. Above this, the chamber broadens out through the zone in which the high-speed nozzle contributes, but above that it narrows down again before meeting the outlet, the last few inches having exhaust heat applied around it.

These exhaust gases pass downward through an external cylindrical passage and, after warming the Venturi and primary nozzle region, escape tó the atmosphere. This gas is obtained by tapping into the exhaust manifold within a few inches of the last cylinder outlet (4 inches are recommended). As the motor demand rises beyond the ability of the primary nozzle, the inclined air valve is drawn toward the vertical position, and, as soon as it leaves the cylinder wall, the high-speed nozzle is uncovered and starts to contribute. The air is supplied from the same air inlet, but it rises more directly. A throttle is placed in the air inlet to facilitate starting; closing this cuts off the air, so that a richer mixture is supplied. There is a damper, or throttle, *F* in the exhaust gas-inlet passage. It is interconnected with the main throttle *G* in such a way that it is opened when the latter is closed and closed when the latter is opened. The idea is to furnish a great quantity of heat when the throttle is nearly closed, and to gradually diminish the supply as the throttle is opened and the motor warms up.

Adjustments. There are two adjustments: the gasoline adjustment *H*, so-called by the maker, and the air adjustment *I*. The gasoline adjustment operates the primary nozzle. These preliminary adjustments can be made on the instrument as received by closing the gasoline needle valve *H* by turning it gently to the right until seated, then opening it by turning to the left $\frac{3}{4}$ turn. The air-adjusting screw *I* should be turned until the end of the screw is about even with the edge of the spring ratchet *J* provided to hold it when set. After starting, close the throttle to produce a moderate speed. Then close the gasoline needle *H* a very little at a time until the motor runs smoothly. Allow the motor to get thoroughly warmed up, though, before making the final adjustment.

Next, adjust the air valve. Turn the adjusting screw *I* to the left to back it out and release the air spring about one-eighth of a turn at a time until the motor begins to slow down. This indicates that the screw is too loose, so turn back slowly, one-eighth of a turn at a time, until it runs smoothly again. Next, advance the spark two-thirds of its travel and open the throttle quickly. The motor should speed up promptly and quickly. If it hesitates or pops back a little more gasoline should be released at the needle valve *H* by turning it to the left a very little at a time. It may also be necessary to tighten the air screw *I* a little more. Now, wait for the motor to settle down to this new adjustment, then open the throttle again quickly. Continue this sudden throttle opening and subsequent adjustment until the point is reached where the motor will respond in a satisfactory manner to a sudden throttle opening. The highest economy is obtained by turning the air screw to the left and the gasoline needle *H* to the right, closing it as nearly as possible and still obtain the desired results.

Fuel Supply. When the carburetor is fed by gravity, the bottom of the bowl should be at least eight inches below the bottom of the gasoline tank. When it is fed by pressure, one pound is sufficient, and two pounds should never be exceeded.

The Marvel Carburetor Company also makes a Model "N", designed for Ford cars to which it can be attached without change of manifold, levers, or other fittings. It is built on the same general plan as the Model "E" previously illustrated and described.

Schebler Carburetors. The Schebler carburetor is one of the simplest complete carburetors made. In general, all Scheblers have a concentric float; a single needle valve, the position of which can be adjusted to suit varying needs; and an auxiliary air valve which is also adjustable. In all these models, too, there is a primary air orifice of unvarying section. In the later models, the needle valve, or metering pin, as it is more correctly called, is interconnected with the air valve so that operation of the latter varies the former. Many models are made and all are still in use, but space forbids description of more than four: the widely used "L"; its successor, the "R"; and the latest form, the "A," made with vertical outlet and horizontal air inlet, much like the Zenith "L," which it resembles.

Adjustment of Model "L." It will be noted in Model "L," shown in Fig. 110, that the needle valve sets at an angle in the mixing chamber. The upper expansion of this chamber forms the vaporizing chamber of long rectangular shape with rounded ends and has the auxiliary air valve located at the other end of it. The vaporized mixture passes upward, by the throttle, and into the manifold. To adjust this model, turn the screw *A* down to make sure the air valve seats firmly, then close the needle valve by turning the adjusting screw *B* to the right until it stops; but do not apply pressure. Then turn it to the left four or five complete turns and prime, or flush, the carburetor by means of the priming lever *C*, holding this up about five seconds. Open the throttle one-third and start the motor, then close the throttle slightly and retard the spark. Next, adjust the throttle-lever screw *F* and needle-valve adjusting screw *B* until the motor runs at the desired speed, smoothly and evenly on all cylinders. Then make the high-speed adjustment on the dials *D* and *E*. Turn the pointer on the dial *D* from *1* toward *3*, about half way. Advance the spark and open the throttle so the roller on the track running below the dials is in line with the first dial. If the motor back-fires, turn the indicator a little more toward *3*, or, if the mixture is too rich, turn the indicator back toward *1* until it runs properly. Now open

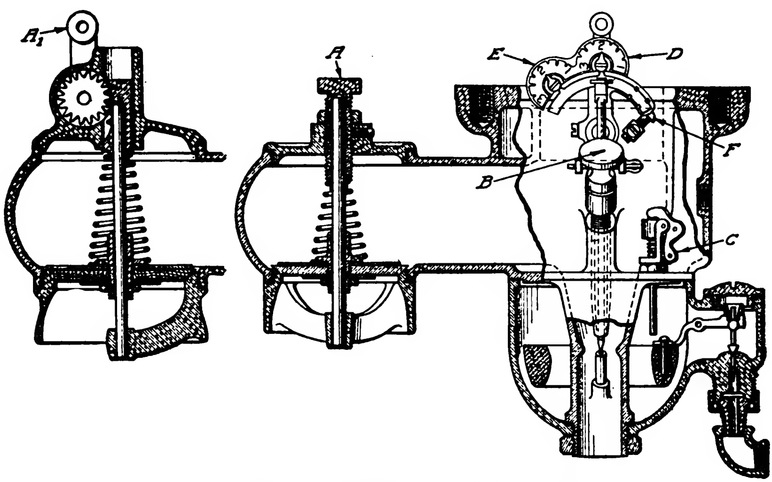


Fig. 110. Section through Schebler Carburetor, Model "L"
Courtesy of Wheeler and Schebler Company, Indianapolis, Indiana

the throttle wide and make the adjustment on dial *E* for the high speed in the manner just completed on *D* for intermediate. As lean a mixture as the motor will stand is advised.

This model is also made with a dash-control air valve, as shown separately at the left of Fig. 110. Otherwise the carburetor and adjustment are exactly the same, except that where the directions previously given above have read *A*, those dealing with the dashboard connection should read A_1. As will be noted, the movement of this lever rotates a small gear which engages with a rack formed in the air-valve stem, so that movement of the lever gives the same result as turning the screw *A*.

Adjustment of Model "R". Model "R", as Fig. 111. shows, is very similar, the most noticeable change being the vertical setting of the needle valve (here marked *E*). Its movement is adjusted by an internal lever connected to the air-valve cap *A*. The air inlet group has been raised to correspond with the longer Venturi, and its main opening is on top, with the adjusting screw *F* on the bottom. To adjust this model, see that lever *B* is attached to the steering-column control or dash control in such a way that the boss *D* is against the stop *C* when the lever on the steering column or dash registers lean, or air. This is the proper running position. To adjust, turn the air-valve cap *A* clockwise, or to the right, until it stops, then turn to the left, or counter-clockwise, one full turn. Open the throttle one-eighth to one-quarter, start the motor, let it warm up, then turn the air-valve cap *A* to left, or counter-clockwise, until the engine hits perfectly. Advance the spark three-quarters, and if the engine back-fires on quick acceleration, turn the adjusting screw *F* up until acceleration is satisfactory. This increases the tension on the air-valve spring. Turning the air-valve cap to the right, or clockwise, lifts the needle valve *E* out of the nozzle and enriches the mixture. Turning it counter-clockwise lowers it and makes the mixture lean. When the motor is cold or the car has been standing, move the steering-column or dash-control lever toward the gas, or rich, position. This lifts the needle *E* out of the nozzle and makes a rich mixture for starting. As the motor warms up, move the lever back toward the air, position to obtain the best running position

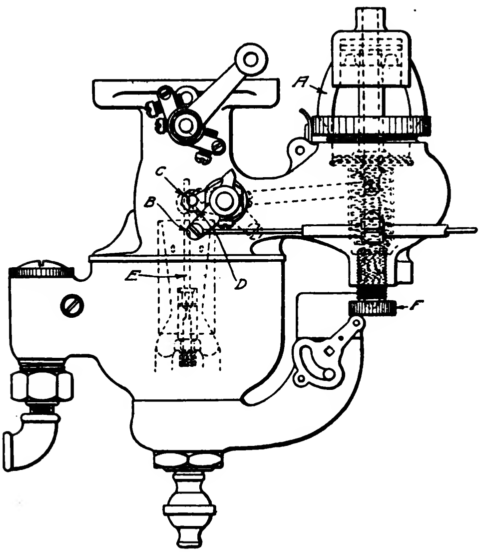


Fig. 111. Schebler Carburetor, Model "R"
Courtesy of Wheeler and Schebler, Indianapolis, Indiana

Adjustments of Model "A." The newest form, Model "A," is made in both the vertical and horizontal forms. Only the former will be illustrated here, this being shown in Fig. 112, which presents a vertical section. This is built around the principle of the "Pitot" tube, utilizing the differential head created by an up-stream and down-stream pitot tube to control the fuel delivery into the Venturi-shaped vaporizing chamber, to which the air has access from below. This arrangement gives a fuel flow exactly proportioned and controlled by the air. In the figure, *E* indicates the up-stream opening and *F* the down-stream nozzle of this arrangement, with air entering at the lower left through the passage there, which is controlled by the starting shutter *C*. The high speed adjustment is simple, and is made through the needle

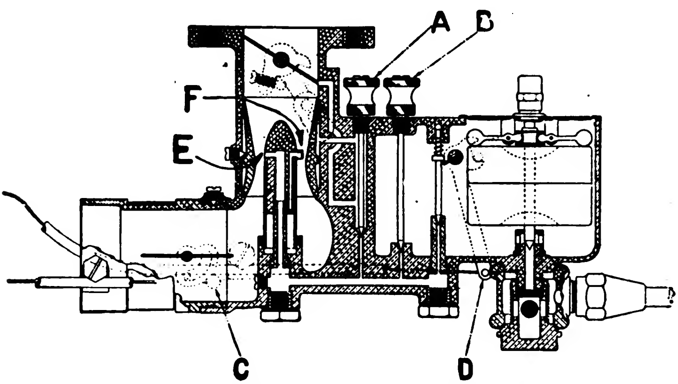


Fig. 112. Schebler Model "A" Carburetor, a Single Tube Device
Courtesy Wheeler and Schebler Company, Indianapolis, Indiana

B. The low speed or idling device delivers fuel and air at the low edge of the throttle disc in its closed position, this being adjusted through needle *A* and the passages in the body of the carburetor, shown adjacent to *A*.

Adjustment of Model "A." With the lever *D* set to give a rich mixture, and air choker *C* set to cut off all the air, both fuel nozzles *A* and *B* are opened 3 or 4 complete turns from the closed or seated position. Open throttle, start motor and let it warm up. Then with warming-up lever *D* fully retarded adjust *A* to correct mixture for idling. Open throttle ¼ and adjust high speed mixture with needle *B*.

Stewart Carburetor. The predominating feature of the Stewart Model "25" is the automatic metering valve by which the air admitted measures the gasoline used. This valve, which is the only moving part, is drawn upward by the suction of the motor and comes back down onto its seat through its own weight when the suction is lessened. In Fig. 113, the complete carburetor with the throttle open is shown at the right, and the vaporizing chamber only and with throttle closed is shown at the left; the float chamber is the same in both cases. Gasoline flows in through the strainer to the float chamber, thence to the dashpot, filling this and continuing to rise to a point about on a line with the top of the tapered metering pin, which corresponds to the usual needle valve.

With the engine at rest, as shown by the left-hand figure, the upper end of the metering valve, which has a conical lower surface,

Fig. 113. Sections Showing Construction of Stewart Carburetor
Courtesy of Detroit Lubricator Company, Detroit, Michigan

rests upon the valve seat, thus closing the main air passage. Its lower end extends down into the gasoline in the dashpot. Through its center is an opening, known as the aspirating tube, into the lower end of which extends (from below) the tapered metering pin. As soon as the motor starts, or is turned over, so that a partial vacuum is created in the mixing chamber, the metering valve is lifted to admit air past the valve seat, as shown in the right-hand part of the figure. This vacuum is also communicated to the fuel chamber through the aspirating tube, drawing gasoline through it and up the central passage; the latter is expanded in diameter near the top and is then flared out to a large size at the point where the air entering through the vertical holes in the metering valve meets the gasoline and picks it up. The purpose of this flare is to spread the fuel out into a thin film, which the high velocity primary air picks up readily in minute particles, producing thorough atomization. The high velocity of the air is due to the constant vacuum, this vacuum being determined by the weight of the valve which is always the same. Obviously, atomization is equally good at all speeds.

Starting. This arrangement also makes for easy starting, but this is further facilitated by means of a dash control, which is attached to the metering pin in such a way that, when the plunger (on the dash) is pulled out, the metering pin is lowered away from the metering valve above. This permits more gasoline to be drawn up through the aspirating tube and results in a richer mixture. The dashpot arrangement prevents rapid fluctuations and also makes the metering valve slower to respond than the fuel valve; in this way it produces a gasoline lead over the air which gives good acceleration.

Fig. 114. Exterior of Stewart Carburetor, Showing Adjustments
Courtesy of Detroit Lubricator Company, Detroit, Michigan

The higher the metering valve lifts in response to engine suction, the greater will be the opening around the metering pin, which permits more gasoline to be drawn up; therefore, as the suction varies and the metering valve moves up and down, the volume of air and amount of gasoline must always increase or decrease in the right ratio, automatically giving the right proportions in the mixture at all speeds.

Adjustment. The Stewart has but one adjustment. This consists of the lowering or raising of the tapered metering pin, thereby increasing or decreasing the relative amount of gasoline admitted to the mixing chamber in response to the movement of the metering valve. This movement is produced by the rotation of the small gear *A*, which engages with a rack on the lower end of the tapered metering pin. This gear is rotated by means of a flexible-wire (Bowden) connection to the dash control. The limit of this motion, as well as the normal position of the gear, is governed by the setting of the adjusting, or stop, screw *B*, shown in the external view, Fig. 114.

This screw can be turned either way; turning it to the right lowers the position of the metering pin, admitting more gasoline; and turning it to the left raises it so that less fuel is admitted. A wider range of adjustment than this stop screw affords can be had by releasing the Clamp *C* of the pinion-shaft lever *D* and moving it around to a new position on the shaft. This adjustment, however, is not recommended except for expert repair men.

With the motor idling the adjustment should be made by moving the screw up and down, that is, out and in until the motor runs smoothly. This adjustment must be made with the dash control pushed all the way in. When this simple adjustment is made correctly, the device is practically automatic from that time on. A stop screw *E* on the throttle lever is movable and affords the equivalent of a limited adjustment, for it can be set to give a smaller and smaller opening and thus slower and slower idling. It also has an influence on the maximum opening which influences the highest speed.

Johnson Carburetor. The Johnson carburetor, of which a section through Model "D" is shown in Fig. 115, is one of the newer designs to be placed on the market. It is a simple form, with a concentric type of float chamber *A*, above which is a simple cylindrical mixing chamber *B* containing the air-regulating device. It is surrounded by a hot-air jacket *C*, which warms the mixing chamber and furnishes the primary air supply. This is composed of the strangle tube *D* and air controlling sleeve *E*, with a lift plate *F* suspended from this sleeve in the strangle tube.

Operation. Gasoline enters the float chamber from above, in the usual way. It enters the spray nozzle through the cross-hole *G*, then rises inside this and passes the tip of the needle *H*, where it continues out through the nozzle point into the lower part of the mixing chamber. The fuel issues as a fine spray into the strangle tube *D*, which is conical in shape. In the mixing chamber is a sliding brass sleeve *E,* which moves up and down according to the engine suction and carries the lift plate *F* which is just above the outlet from the spraying nozzle. Warm air enters the air inlet *I* and finds its way around the chamber *C,* some of it reaching the passage *J* below the lift plate and strangle tube. Here it picks up the fuel from the nozzle and impinges it against the lift plate to break it up into finer particles. In addition, the rising air and fuel raise the plate and with it the sleeve *E,* allowing more air to enter around the bottom of the sleeve. By this arrangement, the current of air is divided and forms both the primary and the auxiliary currents. The latter current is varied to suit the engine demands by the rising and falling of the sleeve. This movement of the sleeve automatically proportions the air and gas to the demand, for, in rising, the lift plate is drawn away from the nozzle tip, and more fuel is allowed to flow out.

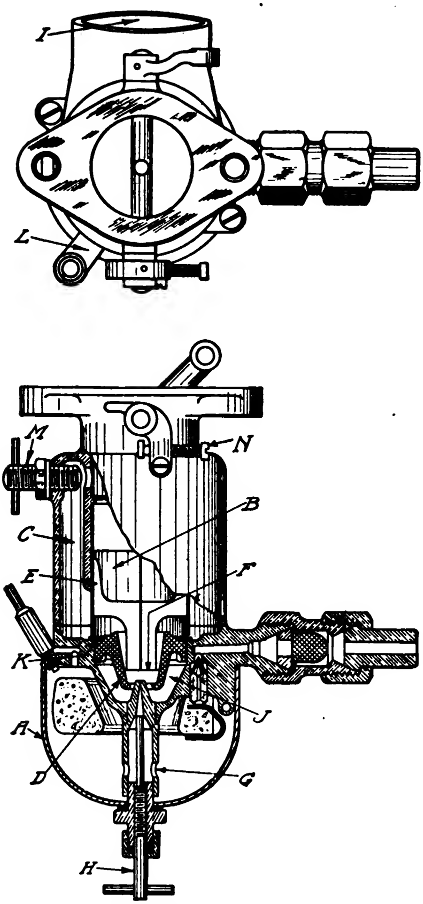


Fig. 115. Top View and Section of Johnson Carburetor, Model "D"

On top of the strangle tube rests a flat choker plate *K,* which is capable of being turned around. There are holes in this to correspond with the holes in the strangle tube through which the primary air passes down to the lower side. In rising again, it picks up the fuel spray. A lever *L* extends through the outside of the carburetor and is connected up to the dash control. This lever controls the choker plate which can be moved around to cover or uncover the air holes and give more or less primary air as the device needs it. Thus, the low-speed screw *M*, the needle valve, and the stop screw *N* on the throttle shaft constitute the adjustments.

Adjusting the Johnson. The function of the low-speed screw is to admit or to cut off the small amount of air supply to the upper part of the mixing chamber as the motor demands; this screw is to be adjusted only with a closed throttle, retarded spark, and the motor idling. The motor should be hot. This is an idling adjustment, designed to supply additional air through the opening *O*, the need for which is caused by the sleeve *E* being in its bottom position and thus cutting off the supply, which is available later when the sleeve has risen and in so doing has formed the annular air passage.

The spray needle *H*, adjusted by the external handle, takes care of all other throttle positions and speeds by admitting more or less fuel. To adjust it, turn the low-speed screw and spray needle to their seats and set the throttle-lever stop screw to approximate the correct closed position. Open the spray needle one and one-half turns. Start the motor, and when it has warmed up, place the spark lever in the fully retarded position; then open the throttle quickly, and if the motor does not back-fire, the mixture is slightly rich and the spray needle should be closed by turning to the right about one-eighth of a turn. Again open the throttle quickly and repeat until the motor does back-fire; this will determine a lean mixture. Open the needle slightly to correct the mixture, which will give the correct adjustment on high and intermediate speed. Adjust the throttle stop screw until the desired idling speed, or about 240 r.p.m., is secured. If the motor does not fire continuously and run smoothly, the low-speed mixture is too rich and is corrected by backing out the low-speed screw *M* until sufficient air is admitted for smooth even firing. Then lock it with the lock nut. If this last adjustment has increased the speed of the motor, restore the idling speed by unscrewing the throttle stop screw *N* slightly. If necessary, reset the low-speed screw, as both of these have to be adjusted in combination.

Dash Control. This controls the choker plate, which acts as a choke to the nozzle by reducing the supply of primary air. After the motor has been warmed up, this should be in the wide-open position. The position for a cold motor, approximating the closed position, will be determined by experience. It is recommended that the motor be choked, that is, the dash control set in the closed position, when stopping. This provides a rich charge for starting. As will be seen from this, the choker plate, with its dash control, is primarily a starting device.

Other Models. This carburetor is made in other models, notably a small one for the Ford car; the essential difference in this being the location of the low-speed screw on top, as it has a horizontal outlet on one side and the warm air inlet on the other. Another large size for eight-cylinder models has a special accelerating device consisting of a fuel plunger operated from the throttle. Still another model is a fixed-needle type in which the nozzle is calibrated for the motor. The adjustment is practically the same for all these.

Carter Carburetor. The Carter carburetor is a multiple-jet device in which, at slow or idling speed, but one jet is furnishing fuel, while at extreme high speed eighteen are operating. These are not jets in the sense that the ordinary carburetor has separate vertical or horizontal jets, as in the Master carburetor, for instance, but they consist of a series of holes set spirally around a central standpipe of fairly large diameter. The action of the device is such that only one is working at low speed, while at high speed the great suction is drawing the fuel up so high in the standpipe that it is issuing from the entire group of 18 holes.

Fig. 116. Section of Carter Multiple-Jet Carburetor
Courtesy of Carter Carburetor Company, St. Louis, Missouri

A vertical section through the center of this carburetor is shown in Fig. 116. As will be noted, the bottom of this rests in a tube, or open standpipe, which communicates with the float chamber and is kept filled to the float level with fuel. Just at the top of this tube is the main air inlet. The air enters around the sides of the standpipe and rises vertically along it. Around the upper part of the standpipe is a flaring conical tube, the top of which is closed by a damper. Air enters here and is drawn downward, its amount being controlled by the damper. At the left will be seen the supplementary air valve, a third source of air; this air is also drawn downward, and the amount is adjustable. From this it can be seen that the primary air and the fuel from the first few jets come upward, while the secondary air and the fuel from the additional jets go downward, and that the supplementary air rushes in at an angle where these two meet at the bottom of the U-shaped vaporizing chamber. This produces a constant state of turbulence around the standpipe, which facilitates breaking up and vaporizing the fuel. The fuel passes a butterfly throttle in its passage to the inlet manifold.

For easy starting, a tube (marked anti-strangling tube in the cut) is by-passed around the vaporizing chamber, taking its fuel directly from the well at the left of the float chamber and furnishing it directly into the outlet pipe above the throttle. In starting and idling on the lowest jet, or hole, of the standpipe, the fuel is drawn almost directly from the float chamber. For this reason an unusually accurate float arrangement is necessary, and this is provided by the metal ball float and the needle arrangement with its ball and spring shock absorber. The latter eliminates any possibility of jamming and gives accurate control of the fuel level. The action of the device is very simple, the engine suction drawing the fuel higher and higher in the standpipe as the suction increases, while the same suction draws open the intermediate air valve as soon as the required supply exceeds the capacity of the main air intake. The high-speed air inlet, operated by the damper, is thrown into action from the steering post or dash at the will of the operator.

Adjusting the Carter. By reference to Fig. 116, the adjusting will be made plain. First set the high-speed adjustment with the lever in a vertical position; then turn the knurled button marked low-speed adjustment down, or to the right as far as it will go; next back it off and turn it to the left three-quarters of a turn. Turn the knurled valve ring marked intermediate-speed adjustment to the point where the valve seats lightly, then turn the valve down, or to the right, from eight to ten notches to increase the spring tension. Pull the easy-starting lever, connected with the dash, forward to the position shown in Fig. 119, advance the spark a very little, close the throttle, and start the engine.

Through the medium of the anti-strangling tube, this will furnish rich mixture (almost pure fuel) to the inlet manifold and result in instantaneous starting. Immediately reverse the easy-starting lever which controls the flow of fuel and open the main throttle slightly. By means of the two screws AA on either side of the throttle lever, set the throttle valve where it gives the desired engine speed when idling. Move the low-speed adjustment to the left, one notch at a time, until the engine slows down, noting each setting. Now move it in the opposite direction, one notch at a time, until the engine again slows down. Then move the adjustment to a point midway between the two, and the low-speed setting will have been finally fixed. This should not be changed on account of weather or temperature variations.

Set the throttle about one-third open and turn the intermediate adjustment to the left until the engine slows down. Move to the right until a similar decrease in speed is noted, then set midway between the two. This adjustment, when once properly made, should not be changed for weather or temperature changes. After this adjustment has been made, connect the high-speed adjusting lever to the dash or steering-post control so that in the center of its movement the lever on the carburetor is vertical. Drive the car over a level road at about 20 miles an hour, then move the control lever to the point where the engine gives the best results at this speed. At low temperatures, or when the engine is cold, this control should be moved toward the closed position, so as to cut off air and make a richer mixture. At high temperatures and with a warm engine, the best results are obtained with the control wide open. This is the only adjustment which should be varied for weather or temperature variations.

Newer Carter Models. In addition, this company has two newer models, "H" and "L," the principal difference being in the outlets, "H" having a vertical and "L" a horizontal outlet. The former is shown in Fig. 117, which shows both a vertical section and end view. It will be noted that the fuel passes through a strainer into the float chamber, then entering below passes through the high speed jet if the throttle is open and through the small hole in it, and thence through the low speed jet, up the vertical fuel passage, and part passes out into the vaporizing chamber, while part continues on up into the inlet manifold above or beyond the throttle. The action of these two jets is evident from their construction and this description.

Adjustment of Carter "H" and "L" Models. The adjustment of these two models is similar, this being controlled ordinarily by setting the throw of the throttle lever in the proper position for idle engine speed. This is done by means of an adjusting screw,

Fig. 117. Carter Model "H" Carburetor with Vertical Outlet
Courtesy Carter Carburetor Company, St. Louis, Missouri

which is provided with a lock screw to hold it when adjusted. This lever should be so set that with steering wheel quadrant lever and accelerator closed, engine will turn over at normal idling speed of 250 to 300 r.p.m. Model "L" has an additional idling adjustment, consisting of a small screw which controls the amount of fuel passing out into the manifold beyond the throttle. The only other normal adjustment is the connection of the dash control wire to the carburetor choker lever; shortening this will cause the air shutter to close more tightly, lengthening it, not as tightly.

Carter Truck Carburetor. A Carter carburetor especially designed for truck use is made with extra large bearings for the working parts. The throttle and choke shaft are larger than those employed in common practice, and the bearings for these shafts are longer. Bronze bushings are used on the throttle shaft where the wear is greatest; if these bearings become worn, however, they may be replaced. The upper part of the float is reinforced, which

Fig. 118. Model "M" Carter Carburetor

List of Parts—Description: 1, body; 2, throttle valve; 3, throttle shaft; 4, throttle lever; 7, choker valve; 11, idle well tube; 12, fuel metering jet; 13, choker shaft; 14, choker lever; 17, needle; 20, main jet and float needle seat plug gasket; 21, float; 22, float lever; 24, float lever pin; 25, float needle seat plug; 29A, strainer cap; 30, strainer gauze; 30A, idle adjustment screw; 37, gasoline connection; 48, float needle adjusting collar; 49, float cover dust cap; 50, float cover; 51, drain plug; 52, strainer trap screw; 53, idle well plug; 54, jet body plug; 55, nozzle assembly; 59, idle adjustment screw lock nut; 60, wire clamp; 60A, lower lever; 61, idle adjustment screw body; 63, idle well plug gasket.

eliminates the wearing of holes, for the float is in continuous contact with the float weights. It will be noted that the idling adjusting screw and lock nut are shown in detail in the upper half of Fig. 118.

A sectional view of this carburetor is shown in Fig. 118. This is a standard, plain-tube carburetor, idling through the by-pass at the throttle and having but one main gasoline passage, through which a metered supply of fuel is admitted to the main nozzle from the float chamber.

The main nozzle is of the air-bleed type, composed of a combination of passages and ports which admit both air and fuel to the mixing chamber. This nozzle, being entirely self-contained, is automatic in action, supplying the proper mixture at all speeds.

There is but one main nonadjustable supply jet, although this jet can be changed to a different sized jet when it becomes necessary to make another adjustment.

Tillotson Carburetor. In a general way the Tillotson carburetor resembles a long U-shaped tube laid upon its side, with the air entering the upper branch, passing around the curve and out to the motor at the end of the lower branch. In the latter near the delivery end, are placed the two jets, first the secondary, next the primary. A pair of flexible reeds are arranged within the passage in such a way that they entirely enclose and shut off the secondary when they are closed, but do not interfere with the primary. The reeds are opened by the suction of the engine, so

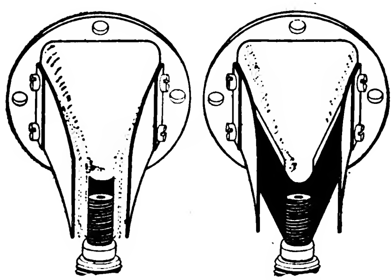


Fig. 119. Tillotson Model "C" Carburetor, Showing Steel Reeds
Courtesy Tillotson Manufacturing Company, Toledo, Ohio

that the primary nozzle furnishes fuel at all engine speeds but is the *only* one in operation at the slower speeds, and is the only one that is adjustable. The secondary nozzle gives the added fuel for high engine speeds and is in operation at these higher speeds only.

Not all the Tillotson models have this exact shape, many being more of an L shape. The float chamber location varies with the different models in some being below the U (or L) tube, in others at one side.

Adjustment of the Tillotson Carburetor. As has been stated the primary nozzle only is adjustable. The company recommends that this be done with unusual care, and very slowly. With the motor running and well warmed up, turn the adjusting handle up to the right until the motor commences to slow down from lack of fuel, then turn it back about one-eighth of a turn. Avoid getting the mixture too rich. Fig. 119 shows Model "C" 85-6 in partial section and the reed action.

Pierce-Arrow Carburetor. This carburetor utilizes a little different principle in the introduction of auxiliary air from most other carburetors as the air passes through reeds in somewhat the same manner as in the Tillotson carburetor. Fig. 120 shows the construction of this carburetor. The gasoline level should be $\frac{5}{16}$ inch below the top of the spray nozzle *K*. The opening of the spray nozzle is regulated by a valve *H* when the throttle is practically closed. The air entering the carburetor at *R* is thoroughly mixed with gasoline regulated by the nozzle *S*. The amount of mixture entering the cylinder is regulated by the adjusting screw *E*, which is really a throttle for the small passage *R*. The three auxiliary air reed valves are closed. As the throttle *B* opens, the suction is greater through *R* than through the main passage for a short period and then becomes the same in both. As the motor speeds up, the light, intermediate, and heavy reeds open in succession, admitting more air. In setting the reeds, the distance between the reed valves and the supplementary springs should be $\frac{1}{8}$ inch for the light reed and $\frac{5}{32}$ inch for the intermediate and heavy reeds. There is a supplementary spray nozzle *L*, provided with the adjustment needle valve *J*. This spray nozzle comes into action when the motor is operating at high speeds and the reed valves are open.

Adjustments. Disconnect the throttle rod from the lever and close the main throttle *B* tight by backing off on screw *C*. Adjust this screw until it touches the lever *A*. Then screw in from $\frac{1}{2}$ to $\frac{3}{4}$ of a turn more and turn lock nut *B*. Connect the throttle rod, adjusting the length so that the throttle just begins to open. Turn idle screw *E* into the shoulder until the head of the screw seats, then back out about $1\frac{1}{2}$ turns. Loosen screw *F* on lever *G* and turn needle *H* to the left until it is seated, then turn to the

Fig. 120. Pierce-Arrow Carburetor

right to open $\frac{3}{4}$ of a turn. Start the motor by priming and allow it to run until warm—run on battery with the lever advanced $\frac{1}{2}$ inch on the quadrant—and then open the throttle so that a motor speed of 20 to 30 miles per hour is obtained. Next adjust needle *H* until the motor runs best, set lever *G* at right angles to center line, and tighten screw *F*. Set the regulator on the steering column in center, put the wire in lever *G*, and tighten screw *I*. This should give equal travel to each side of center. Loosen the high-speed screw on high-speed needle *J* and, with the finger, screw down until closed, and then turn back or up from $\frac{3}{8}$ to $\frac{5}{8}$ of a turn. The car should then be tested on the road and should not be adjusted to run slower than 5 or 6 miles. Always keep throttle screw *E* closed as much as possible. If the car works best at a speed of 20 to 30 miles per hour with the regulator in center adjustment on needle *H*, it can be considered O.K. If it will run better at 50 miles with the regulator at the heavy position, the high-speed needle must be open more; the reverse is true if it runs better with the regulator on the light side. If properly adjusted, the motor should run the entire range of speed with the regulator in one position. No change is necessary except to take care of climatic conditions.

Packard Carburetor. The carburetor used on the Packard twin-six (twelve-cylinder) cars is shown in section in Fig. 123. The inlet manifold, or rather the pipe which leads in both directions to the manifold proper, is seen at the top at *A*. It will be noted that this is water-jacketed, the water space being at the top. The float arrangement is of the usual type, with a metal float which supplies fuel to a small well *B* at the base of the single-spray tube *C*. This has a flared end located in the center of the Venturi. When the air from the air horn *D* passes the air shutter *E*, it picks up the fuel and carries it up into the vaporizing chamber *F*. The primary air shutter is normally open but not in use. It is operated by a hand wheel on the control board which also operates the auxiliary air valve *G*. By turning this clear over to the position marked choke, the air intake is closed, and a rich mixture is drawn in for starting. After that, the hand wheel should be set back toward the position marked AIR which opens the air intake.

The auxiliary air valve is controlled by the springs *H* and *I*. These are adjusted so that the valve opens very slightly at low speed, but more and more as the speed, and consequently the suction, increases. The air enters around the outside of the Venturi, communicating with the mixture only above the top of the latter where the real vaporizing chamber commences. The tension of the springs

Fig. 123. Section through Packard Twin-Six Carburetor
Courtesy of Packard Motor Car Company, Detroit, Michigan

is varied by means of the adjusting nuts at the top and by the adjusting cams *J*. The cams are connected up to the air-valve hand wheel which is turned toward gas to provide a richer mixture and toward air for a leaner mixture. If the wheel is turned too far toward air, spitting back may result; and if it is turned too far toward gas, the result may be irregular running and overheating. The throttle *K* is of the butterfly type and regulates the quantity of mixture allowed to pass out, not its quality. An adjustable stop holds this valve open slightly and allows a small amount of mixture to pass, even when the hand throttle is entirely closed. This minimum amount is for slowest running, or idling, only. To increase it, loosen the check nut *L* and screw the stop *M* forward. To decrease the minimum speed, screw the stop backward.

Adjustments. Aside from those described previously, the Packard Company advises against making any adjustments as it prefers to have this done by its own men, who have had extended experience in adjusting the motor and carburetor combinations.

Packard Fuelizer. The Packard fuelizer is an auxiliary carburetor operated by motor suction. This fuelizer, Fig. 123a, is connected to a combustion chamber located on the intake manifold, the combustion chamber having an ordinary spark plug, igniting the incoming gas, which is under atmospheric pressure. As this carbureted gas burns, the products of combustion, which are composed of hot gases, mix through small openings with the cold incoming gas vapor from the carburetor as shown in Fig. 123b. This heat thoroughly vaporizes the mixture, making it dry—it does not condense and does not pass the piston rings into the crankcase. The fuelizer also does away with a great deal of carbon on account of better vaporization and of better fuel combustion.

With the fuelizer installed and in proper operating condition, it is possible, even in cold weather, to operate the car with the choke set in normal position after the motor has been running for from twenty to thirty seconds. The acceleration, or pick-up, of the car is thus greatly improved. On account of the fuel being thoroughly vaporized, better combustion takes place, carbon formation is practically eliminated, and a great deal of spark-plug trouble is overcome. Gasoline economy is not effected to a very great extent, although in cold weather a little more mileage is obtained.

On the twin six, three sparks per revolution of the engine are used at the fuelizer plug. There are two methods of obtaining the spark. On new cars, an auxiliary breaker is provided operating from the same cam which works the main breakers, this breaker being supplied with its own condenser and resistance. An additional spark coil located on the dash receives current from the ignition current in the same manner as the standard ignition coils.

Fig. 124a. An Outside and Cross Sectional View of the Packard Fuelizer Used on the 1920 Packard Twin-Six

A somewhat simpler construction applied to cars in service consists of the same coil, the primary of which is wired in series with the primary of one of the main coils, Fig. 123c. The extra resistance and self-induction of the extra coil in series do not perceptibly have any effect on the regular ignition at engine speeds under 2600 r.p.m.

Special Suggestions and Precautions. If the inspection glass is dirty, it should be cleaned through the spark-plug opening instead

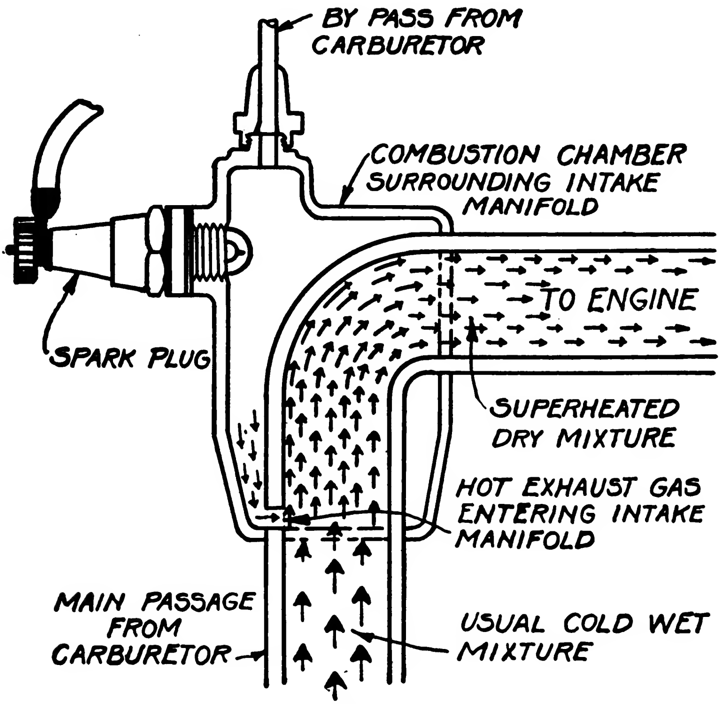


Fig. 124b. Simple Illustration Showing the Principle of the Packard Fuelizer

of removing the glass from the container. If the nut is removed, air leaks may be caused in replacing, as the nut may be drawn up too tight, which will cause the glass to break when at running temperature. If the glass becomes sooted rapidly, it is a sign that the mixture is too rich; this should be corrected by raising the vaporizer choke and inserting a gasket. The glass may foul up if oil or some other substance is mixed with the gasoline.

If there is no gas passing through the burner, the spark appears purple and stringy. This is due to some obstruction which prevents the gasoline vapor from reaching the burner. The entire vaporizer equipment may be easily removed.

To check the gasoline level and to make sure that the gasoline is reaching the vaporizer in proper condition, it is simply

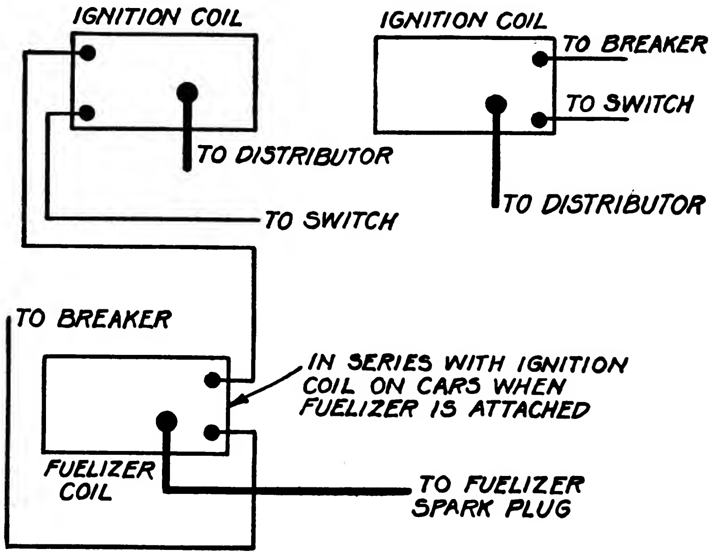


Fig. 124c. Wiring Connections of the Packard Fuelizer When Installed After the Car Leaves the Factory

necessary to remove the vaporizer and measure the distance from the top of the float chamber down to the gasoline level while the motor is running. This dimension should be $1\frac{7}{16}$ inches.

Cadillac Carburetor. A section through the latest Cadillac carburetor, which is a very simple device, is shown in Fig. 124. Fuel enters through the pipe *A* at the bottom, passing on to the well *B*, and thence to the float chamber, through the vertical pipe *C* and the float valve *D*, which are operated by the float *E*. This float is concentric and is hinged on one side of the float chamber. Below the float chamber is another chamber, or well, *F* which is supplied from it. Through the opening in the side of the nozzle *G*, this well in turn supplies fuel to the nozzle *H*, the fuel being drawn out at the top into the Venturi chamber *I*. At the left will be seen the air valve *J* as well as the scoop of shield *K*, which assists in drawing in the required volume of air. This air reaches the passage *L*, whence a portion is drawn downward around the outside of the Venturi *I*, through the passage *M*, and around the bottom of the tube, then upward. There it mixes with the fuel spray, vaporizes it, and carries it up into the main vaporizing chamber *N*, where additional air comes in from *L*,

Fig. 124. Section through Cadillac Carburetor Used on Models 53, 55 and 57
Courtesy of Cadillac Motor Car Company, Detroit, Michigan

and the mixture passes on up, through the throttle valve *O*, into the inlet manifold.

On a lever *P* attached to the throttle valve shaft is hung the connecting rod *Q*, by means of which it is attached at its lower end to the piston *R*. This works up and down in the chamber *S*. Its lower portion, or well, *T* is full of fuel and communicates through passage *U* with the well *F* and the nozzle *H*. When the throttle is opened, the plunger is forced into the gasoline in the carburetor bowl, and fuel is thus forced through the hole *G* up to the nozzle *H*. When the throttle is opened quickly, this acts to supply the needed fuel. When the throttle is opened slowly, the plunger has practically no effect. This plunger has an influence on starting, as will be explained.

Adjustments. Carburetors are factory set and should need no adjustment ordinarily, but for different atmospheric conditions a slight change in the air-valve spring may be needed. In the exterior view, Fig. 125, this is altered by turning the screw *V*. In case the carburetor really needs adjustment, proceed as follows: Open the throttle lever on the steering wheel about two inches, place the spark in the driving range and start the motor; run it until the water jacket on the intake pipe is hot; then move the spark lever to the extreme left on the sector and the throttle lever to a position which leaves the throttle slightly open, and adjust the air-valve screw *V* to a point which produces the highest engine speed. Turning this screw clockwise increases the proportion of gasoline to air in the mixture, that is, makes it richer; while turning it counter-clockwise decreases the proportion of gasoline, that is, makes it leaner.

Close the throttle by moving it to the extreme left on the sector, and adjust the throttle stop screw *W* to a point which causes the engine to run at a speed of about 300 r.p.m. The spark lever should be at the extreme left when this adjustment is made. With the spark and throttle levers in this same position, adjust the air valve screw *V* again to the highest motor speed. Open the throttle until the shutter attached to the right-hand end of the throttle shaft just covers the slot in the carburetor body (the other side of the carburetor is not shown in either view). Then adjust the screw *X* to the point which produces the highest engine speed or to a point where the engine slows down slightly from a lean mixture. This screw also works clockwise to give a richer mixture and counter-clockwise for a leaner one. During very cold weather, it will be found advisable to turn this screw farther in a clockwise direction to give a slightly richer mixture.

The rod *Q* from throttle arm *P* to the fuel plunger is adjusted closely at the factory and should need no change unless the carburetor is disassembled. When reassembling, the rod should be adjusted so that its upper end is flush with the upper face of the arm *P*. When the carburetor has been used for a long time, there may be slight wear at the point of the inlet or where the float needle *D*, Fig. 121, rests on its seat. If this should occur, the height of the fuel in the carburetor bowl will rise. To determine whether the float is set properly, remove the carburetor from the engine and the bowl from the carburetor. Then measure the distance from the upper surface of the float to the metal surface above it, as indicated at *Y* to *Z*. This is measured best with the carburetor inverted and should be exactly $\frac{1}{2}$ inch. If more, or less, the setting may be corrected by slightly bending the arm to which the float is attached.

Starting. In cold weather, when the engine will not start immediately, it is not advisable to continue cranking the engine over and over. Instead, open and close the throttle rather quickly once or twice, no more, with the throttle lever on the steering wheel or foot accelerator. This action raises and lowers the throttle pump attached to the throttle-shaft arm, as previously explained, thus raising the level of the fuel in the float chamber so that it is more easily drawn up. If pumped more than once or twice, too much fuel will be forced up, and this is just as bad as too little.

Oxygen-Adding Devices. There are now upon the market a number of devices for assisting carburetion by furnishing an additional source of oxygen. These are not carburetors in themselves, in that they do not handle any fuel, consequently they must be used in addition to some standard carburetor, furnished with fuel in the regular way. The desired result is obtained in a number of different ways, as for instance the direct injection of water, which the heat of combustion is supposed to break up into its components hydrogen and oxygen. The hydrogen is a fuel itself, and the oxygen assists the vaporized gasoline fuel to burn better and more completely. Steam is but a variation of this, the exhaust heat being used to create this from water furnished by a special tank. When equipped with valves to control water passage or steam emission, these constitute the only adjustment.

KEROSENE AND HEAVY FUEL CARBURETORS

Need for Heavy Fuel Carburetors. As has been mentioned several times previously, and explained elsewhere in detail, the lighter, more volatile grades of gasoline are not available in sufficient quantities to supply the present demand. Consequently, the fuel now carries a considerable quantity of what was formerly sold as kerosene and also under other names. At that, the fuel sold is still much lighter than kerosene—of which tremendous quantities are available—as well as other heavy fuels, notably benzol in England, where kerosene is called paraffin. To develop a carburetor which would handle these cheaper but heavier and more available fuels has been the aim of many inventors and a vexing problem for carburetor manufacturers.

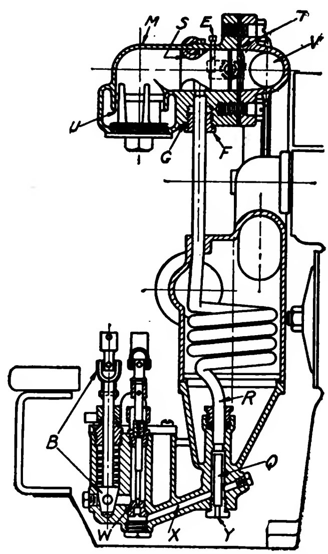


Fig. 126. Section through the Holley Kerosene Carburetor

Holley Type. A firm, the Holley Company, which has devoted much time and study to this problem, has developed the device shown in Fig. 125. While this is not offered as perfect, even by its maker, who is still working on this problem, it has been found to do these things: cut the fuel cost over 50 per cent; increase the power 5 to 8 per cent; save almost one-half of the engine lubricant; give less spark-plug trouble and less carbonizing; and give a greater mileage to the gallon. It also has these deficiencies: requires the use of gasoline for starting; and necessitates a material reduction in compression pressures.

This device as shown in Fig. 126 has two float chambers, one for gasoline used in starting, the other for the kerosene or heavier fuel. The shifter valve *B* determines which fuel flows to the adjusting needle valve *W* and through a jet where a minute quantity of the total air needed in the form of an air blast atomizes it. Then it is carried up through the tube *R* situated in the exhaust manifold and heated by it. Then it enters the main mixing chamber *M*, where the main air supply enters through *U*, this opening being governed by the suction of the motor and the throttle valve opening. From here it is drawn in through the intake manifold *V* in the usual way.

Adjustment Holley Kerosene Device. In general, the motor is always started on gasoline, which is used purely for starting and warming up the motor, when the change over to kerosene is made. The adjustments should be made on the basis of kerosene, even though it seems somewhat rich when running on gasoline. Set screw *E*, which limits the throw of the throttle lever, should be adjusted so the motor runs at proper idling speed when the hand throttle lever is in the closed position.

Holley All-Fuel Carburetor. Another Holley device is intended for the use of all kinds of fuel, heavier than our so-called gasoline. This is shown in Fig. 127, which presents a sectional view and explains all the parts as well as the operation. It consists of a simple spraying device with an air valve which sprays the heavy fuel, adds a very small amount of air to it, and then forces this mixture through a vapor tube, consisting of coils of thin-walled pipe surrounding the exhaust pipe. The exhaust heats the walls enough to completely vaporize any fuel that will evaporate below 600° F. This heater, rich, dry gas mixture is then returned to the main body of the carburetor where additional cold air is admitted to convert it into a perfectly combustible mixture. It then passes through the throttle and inlet manifold to the engine. Like the Holley kerosene carburetor just described, this starts on gasoline, and is switched to the heavier fuel as soon as the motor is well warmed up and the exhaust heat begins to be available.

Aside from the usual throttle and air valve limit stops, there really is but one adjustment.

Adjusting the All-Fuel Carburetor. The principal adjustment on this device is the idling. The figure shows this near the bottom, it consisting of a valve with a milled outside head which controls the inflow of air. Sufficient air is drawn past this for idling and it lifts to admit more air for higher motor speeds. The valve is regulated so that in its lowest position just enough air passes to give a satisfactory idling speed. An arrow on the

Fig. 127. Section Showing Construction of All-Fuel Carburetor
Courtesy Holley Brothers Company, Detroit, Michigan

top indicates this. When the valve is entirely closed, as indicated by the arrow, the air is practically shut off and the mixture is richest.

The air intake is fitted with a choke throttle and the tightness of closing this can be regulated by a stop screw. Similarly, the main throttle can be regulated by means of a stop screw, to vary its tightness in the closed position. The only other changes or adjustments would be to change the atomizer for one with different sized jet holes at *Y* and *Z* as well as the primary air inlet.

Foreign Kerosene Carburetors. A large number of firms in different parts of the world have worked on this problem of kerosene vaporization. In Germany, the following have done so, and in solving this each has been obliged to develop his own vaporizer: Daimler; Swiderski; Maurer; Adler; Sleipner (boats mostly); Deutz; Banki; Neckarsulmer (motorcycle); Koerting (fuel injection); Kämper; Diesel (fuel injection); Capitaine (boats mostly); Gardner; Dufaux (Swiss motorcycle); and others. Space prevents a description of these, the list being given simply to show that kerosene as a fuel has attracted wide attention.

In France the same is true; the Aster device, for instance, having been so very successful that it is now made under license in both England and Germany.

In England the Binks, with two jets, is designed to use 20 per cent gasoline and 80 per cent kerosene after starting. The Hamilton Bi-fuel has two float chambers, two nozzles, and other duplicate features. This is designed for a 44 gasoline (petrol) and 56 kerosene (paraffin) mixture; on such a mixture, a test of a bus engine showed equal (rated) power at 890 r.p.m.; 1 horsepower more at 1050; almost 3 more at 1275; and at its highest speed 1375 r.p.m., 3 horsepower more, maximum output. The Kellaway has two fuel leads, but these use a common jet. The Morris uses forced feed with a constant air pressure of 4 pounds per square inch on the fuel tank; this is supposed to minimize variations in fuel flow, and thus, as pointed out in the description of the Browne, minimize variations in the output. The Southey ignites part of the fuel to create heat with which to vaporize the balance, delivering to the cylinders a fixed gas which is heated. The Edwards has been described. In the Notax the fuel spray, as it enters the vaporizing chamber, is forced to strike the lower hot surface of the exhaust-gas passage, which not only encircles the chamber but has a passage right through the middle of it. In the G. C. (English and American), the vaporizer complete replaces both carburetor and muffler. It is constructed to utilize all the heat in the exhaust gases for vaporizing the kerosene, which then is led up to the engine, and auxiliary air added just before it enters the manifold. This has a separate small gasoline carburetor for starting and a special float chamber for the kerosene. In America, the Knox employs an arrangement in which a gasoline by-pass around the entire carburetor is used for starting, while the exhaust heating concerns the fuel at the bottom of the device only. The Secor type is used on the Rumely tractors. The Hart-Parr Tractor Company and a number of other builders of tractor, marine, and stationary engines have been more or less successful in vaporizing kerosene so as to use it advantageously.

Master Carburetor. The Master device, previously shown and described, was designed primarily for the extra heavy fuels, or the residuum in the distilling process called distillate, which is heavier than kerosene and has heretofore been considered a waste product. The Master has utilized this successfully in actual service for more than four years. In addition, it will handle kerosene, alcohol, and other heavy fuels, as well as mixtures of all these with one another and with gasoline.

Like the Master, the Miller also previously described as a gasoline device, was designed originally for the extra heavy fuels of the coast, so that it must be considered as a heavy fuel carburetor. This is partly true of the "H and N," which was designed originally for heavy fuels, the present form embodying the most successful details of the heavy-fuel device.

Bennett Carburetor. The Bennett device, Type "C" which is shown in section in Fig. 128, is intended for kerosene, alcohol, distillates, or other heavy fuels, but by a simple change of the adjustments it can be used for gasoline. For alcohol, however, the makers provide a special float, the carburetor remaining the same otherwise. It has two needle valves: one projecting downward from the top of the device *A*, called the slow-speed needle; and the other, projecting upward from the bottom *B*, called the high-speed needle. The primary air for both enters at *C*, passes around the exhaust heating pipe *D*, and enters from below. It rises around the lower needle and fuel passage into the chamber *E*, where the fuel is picked up and carried up into the main vaporizing chamber *F*. From here it passes up into the passage *G*, where additional air comes in from the air valve *H*, after passing the air throttle *I*. This dilutes the mixture and completes vaporization, and the mixture passes the main throttle *J* into the manifold, or engine.

The fuel enters the float chamber *K*, in which the float is indicated, and passes from this through the horizontal opening *L* to the needles. As there is hot air in the passage just below the opening, and exhaust gases in the passage just above it, it is subjected to a considerable warming effect. In the center at the bottom, a recess forms a dashpot for the lower end of the shaft *M*, which is connected to the air valve *H* at its upper end; this prevents rapid fluctuation, or fluttering, of this valve when there is a sudden opening of the throttle after running at slow speed. The extra suction created by the sudden opening of the throttle tends to jerk the auxiliary air

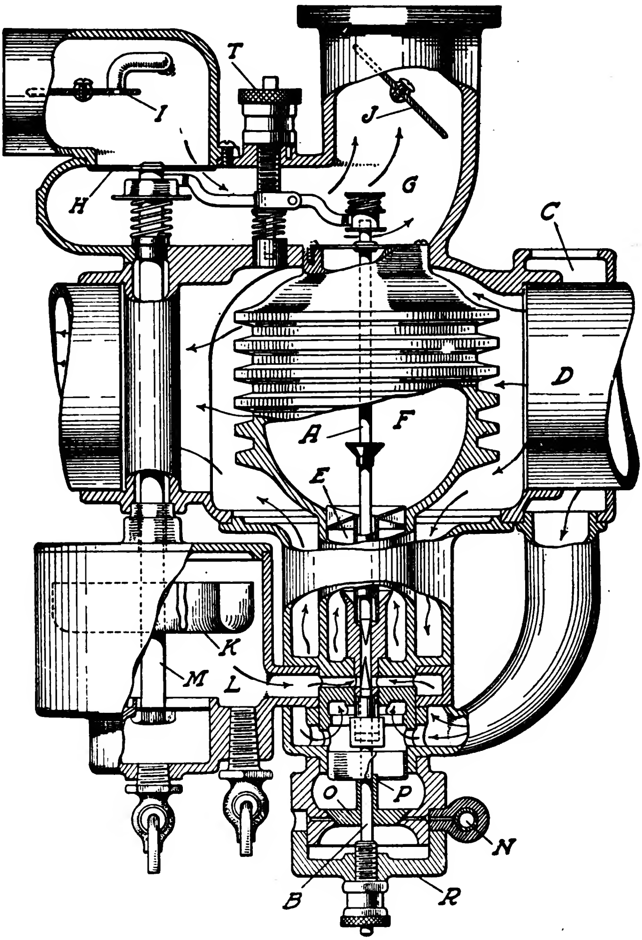


Fig. 128. Section through Bennett Double-Jet Kerosene Carburetor
Courtesy of Wilcox-Bennett Carburetor Company, Minneapolis, Minnesota

valve open quickly to its maximum area. Another feature of the device is the feeding of small quantities of hot water from the motor circulating system through the pipe *N;* this has an adjustable valve (not shown) connected to the dash. The water is sprayed in through the medium of the valve *O* attached to the bottom of the small dash-pot and the plunger *P* which surrounds the bottom of the high-speed needle *B*. An additional feature of the device is an air cleaner *Q*, which is shown at the left in the diagram, Fig. 129. Its function is to clean all dust out of the entering air when the carburetor is used on a tractor or other unit which must work in the midst of considerable dust. As this dust is known to filter slowly but surely through the carburetor and, in time, reach the pistons, valves, rings, and bearings, where it does considerable damage, the utility of this simple auxiliary device, which has no moving parts, is evident.

Installation. Whenever it is possible to use the air cleaner, install the carburetor with the hood of the air intake facing away from

Fig. 129. Diagram Showing Method of Connecting and Adjusting Bennett Carburetor

the fan so as to prevent dirt from being blown into it. Connect the exhaust manifold to the carburetor, using the three-way valve or damper in such a way that the amount of gas can be regulated. Whenever possible the exhaust connection should enter the larger end, because the cored passage for heating the primary air is there. Screw an elbow in at the other end, and, if required, a short piece of pipe, to carry the used exhaust gases away from the carburetor. Connect the water jet near the bottom with the water jacket or a small auxiliary water tank. This water jet and its regulating needle can be moved to any desired position by means of the large nut *R*. The needle is connected to the dash so as to be operated by the driver. Two fuel tanks are needed, one for gasoline to be used for starting, and the other for kerosene to be used in regular running; they should be connected to the float chamber at the bottom by means of a three-way valve or a siamesed pipe, with a shut-off cock in each line above the T-connection.

Adjustment. There are but two adjustments, so-called: the high-speed fuel needle for full load; and the slow-speed fuel needle for slow speeds and idling. Both are made by knurled nuts, which are turned clockwise to close and counter-clockwise to open. In the process of adjusting, close the exhaust damper *S*, so as to throw the exhaust gases through the carburetor and furnish the needed heat. Then close the air-choke valve *I*, to make a rich mixture for starting purposes. Before turning on the gasoline, open the high-speed needle *B* about two turns. Then start the motor and immediately open the air choke valve *I*. If it fires unevenly after running a little while, close the slow-speed needle *A* by turning the knurled nut *T* to the right, one notch at a time, until the motor fires and runs evenly when throttled down to the slowest speed. If the motor hesitates and stops when the air choke valve is opened, open the slow-speed adjustment, one notch at a time, until the point is reached at which the motor will just run and fire evenly when throttled down.

Regulate the high-speed needle until the motor will respond when the throttle is opened quickly, by speeding it up to its maximum number of revolutions without missing. If the motor misses when the throttle is jerked open, close the needle slowly, one notch at a time, until the missing ceases and the motor responds to the quick opening smoothly. On the other hand, if the motor back-fires when the throttle is suddenly opened wide, open the needle slowly until it will speed up without missing or popping back. As soon as motor and carburetor have become thoroughly heated, turn on the kerosene and shut off the gasoline.

Kerosene Modified Adjustments. The use of the kerosene may change the adjustments slightly. Thus the slow-speed needle adjustment may have to be opened one or two notches more for kerosene than for gasoline. Similarly, the high-speed needle adjustment will have to be opened two or three notches more. If the motor becomes so hot when running on kerosene that pre-ignition occurs—and this is likely because the whole device is designed to use the maximum possible amount of heat—the water-needle connection to the operator should be opened. This pre-ignition can be detected as a sharp metallic knock in the cylinder. Only enough water should be used to stop the knock; the carburetor should not be flooded with it. The cap at the bottom, or inlet, of the air cleaner Q should be kept tight. The air cleaner should be emptied once a day, but it should not be removed while the engine is running.

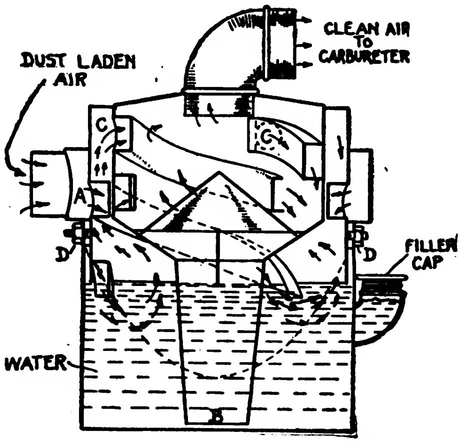


Fig. 130. Bennett Air Washer, Indicating Operation
Courtesy Wilcox-Bennett Company, Minneapolis, Minnesota

Bennett Air Washer. The wider use of tractors and also of cars and trucks in the country, over dusty roads, and in the dust-laden fields which are being plowed, harrowed or otherwise worked, has forced the use of devices for removing the dust from the entering air. The device indicated at Q is one of these and is shown in detail in Fig. 130. Its interior consists of a series of spiral passages. The air enters one of these at A and is forced to pass through the water. Then it passes upward and out along the other spirals C, C. The air is doubly purified, first by passing through the water, second in the removal of dirt by centrifugal action.

Fig. 131. **Parrett Air Cleaner for Removing Dust and Dirt**
Courtesy Ross-Wortham Company, Chicago

Parrett Air Cleaner. A similar device working on a different principle is the Parrett air cleaner shown in Fig. 131. Air enters at the top and is drawn downward through the central tube, the lower part of which is flared out and is supported on a metal float smaller than the bottom of the bell. The air passes between the two, through a very narrow opening, at high velocity. Large air bubbles can not form, and because of the high velocity all heavy dust particles are thrown directly into the water. The rising purified air and moisture are separated by a series of baffle plates so the air finally passing to the carburetor is completely cleaned of dirt or dust.

Deppé Gas Generator. Although not called a carburetor by its maker, the Deppé gas generator replaces the ordinary carburetor for the purpose of vaporizing kerosene. In appearance and in sectional drawing, as shown in Fig. 132, it is not unlike an ordinary carburetor with an extra-special somewhat globular chamber above it, and below it the ordinary inlet manifold, which is exhaust heated. Some of the things claimed for it, when it is attached to ordinary cars with no change except in the vaporizer, are: perfect gas at all speeds; superior acceleration; no loading; increased high speed; lower slow speed on high gear; much greater fuel efficiency expressed in miles per gallon; handles all ordinary hydrocarbon liquids—gasoline,

Fig. 132. Section of Deppé Gas Generator, Showing Construction
Courtesy of W. P. Deppé, New York City

kerosene, naphtha, etc., and mixtures of these; fixed metering adjustment which is not affected by altitude, temperature, or location; easy starting; less vibration of engine; and others.

In Fig. 132, the fuel enters the float chamber *A* from below and passes through a horizontal passage *B* from which the two nozzles lead upward. The low-speed nozzle *C* draws its heated air through the primary intake *D* and mingles with this in the modified Venturi *E*. When the engine demands more fuel, it is supplied by the high-speed nozzle *F*, which gets its air from the auxiliary air valve *G;* this air and fuel mixture combine with the other in the chamber *H*, just above the Venturi and just below the center-opening throttle *I*. Up to this point it is not radically different from the average two-jet carburetor with the auxiliary air valve.

However, in the chamber just above this a mechanical atomizer, or rotating mixer on ball bearings *J*, is inserted. The idea is to combine the air and fuel particles more intimately through the rotation of this mixer within the zone of vaporization. The actual vaporizing chamber *K* is next above this. It is an annular passage around the highly heated exhaust gas chamber *L*, but inside of the outer exhaust chamber. This insures the absolute completion of the gasification started in other chambers, so that the mixture passing into the gasification chamber *M* at the top and thence into the inlet manifolds and cylinders is sure to be a pure dry gas.

Starting. To assist in starting, the primary-air passage is fitted with a choke valve of the butterfly type, which closes off this passage entirely so as to produce a rich mixture. Across the middle of the lower vaporizing chamber *H*, an electric resistance wire or heating coil is strung. The coil is connected to the starting battery. The connection is made so that the current passes through this heating coil as soon as it is turned on. This supplies the cold carburetor with the equivalent of the exhaust gas heat, which is available shortly after the engine has been started.

Adjustments. As will be seen from the illustration, the low-speed nozzle and air opening are fixed, the only possible adjustment, setting, or change being in the alteration of the nozzle or in the quantity of primary air admitted. The high-speed nozzle is fixed similarly so that it cannot be adjusted, the high-speed air valve *G* furnishing the only adjustment. The adjustment of this is very simple;

with the engine running, advance the spark pretty well to the limit, open the throttle lever to its maximum, and then vary the position of the nut *N* which governs the tension of the spring *O* to the point where the maximum speed of rotation is obtained. This setting should be checked against actual high-speed running on the road, as there is usually a difference between the best road high-speed setting and the best engine-speed setting, with the car standing on the garage floor.

Ensign Heavy Fuel Carburetors. A section through a new device recently perfected on the Pacific Coast, the Ensign carburetor, is shown in Fig. 132 A, while Fig. 132 B is a horizontal section of the vortex mixing chamber which forms an important part of this. This device was designed to handle heavy fuels, but that shown in Fig. 132 A can be used for gasoline. As the figure shows the fuel enters a float chamber, thence into the bottom of a standpipe *H*, within which a suction tube *A* is set with its top opening slightly above the fuel level so that fuel must be drawn up by the air suction. This air enters at *B* and passing around the vortex, of which Fig. 132 B shows a better view, acquires a high velocity. Thus a considerable suction is exerted on the fuel which passes out through holes *D* into the whirling air stream, which vaporizes it. Should any fuel moisture remain the centrifugal action of the air stream throws it against the walls whence it drips down through holes *J* into the mixture which passes through the narrowed throat *K*, thence makes a sharp bend to a horizontal direction, and another to a vertical flow entering the inlet pipe *V* on its way past the throttle *M* to the cylinders. The nature of this vortex chamber thins the mixture as it is produced at *D*, and with increasing demands, and thus increasing air velocity, continues to thin it, so the vortex chamber automatically delivers a thinner and thinner mixture as the engine speeds up.

Adjusting the Ensign Type G. This model has two adjustments, air at *A* and fuel at *G*. Screw both of these clockwise to a closed position; then open *G* one and a half turns, and *A* one-fourth turn for four-cylinder motors, one-eighth turn for six or more cylinders. Start the motor and warm it up. Open the throttle to high speed and use *G* as a needle valve, adjusting to get the highest motor speed. Then refine this by adjusting *A*, one notch at a time. To start cold, open throttle *M* to slightly more than an idling position, and pull primer *Y* heavily before cranking.

Ensign Fuel Converter. This company's Model "N" device is intended to handle the very heaviest fuels, up to a dry boiling point of 600° F. It consists of three elements, the carburetor proper, the gas producer and the temperature regulator. Fig. 132 C shows that the first is almost identical with the carburetor shown in Fig. 132 A. To this is added the gas producer which consists of the fire screen *U* to which the heavy unvaporized fuel flows, the combustion chamber *Q* and the sparking element *A* which ignites it. This heats up screen *U* and the plate *C* below it so that these subsequently vaporize a larger portion of the fuel, and less of it passes down into chamber *Q* to be ignited and thus vaporized. That is, this part of the device is self-regulating as to temperature. The idling temperature is controlled by thermostat capsule *N*, operating temperature control plug *M*. This is half full of alcohol, and its chamber is provided with means for circulating the hot mixture. As the mixture approaches 210° F. the capsule pushes the plug outward and closes the port *O* reducing the draft and thus controlling the temperature.

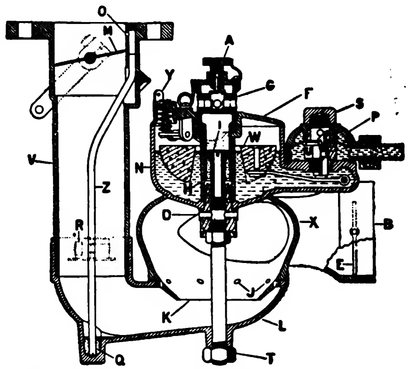


Fig. 132 A. Ensign Carburetor, Model "G"
Courtesy Ensign Carburetor Company, Los Angeles, California

Fig. 132 B. Horizontal Section of Ensign Carburetor Showing Vortex Mixing Chamber

Fig. 132 C. Section through Ensign Fuel Converter

Adjustment of Ensign Fuel Converter. Adjustment of this device is the same as the carburetor previously described, except for starting and with the addition of the spark plug care. In starting *G* is opened 1 turn, then *E* is filled with gasoline to fill the fire bowl up to the overflow *F*. If motor and converter are hot, prime very little; if motor has stopped but a few minutes, prime with *Y* on top of the flat bowl and start directly on the heavy fuel. With spark retarded adjust *G* to maximum engine speed. After engine has been running some time check this adjustment.

CARBURETOR TROUBLES AND REMEDIES

Engine Should Start on the First Turn. In starting a car or any engine, whether located in a car or not, everything should be inspected so as to know if all is right before attempting a start. With the novice, this is somewhat of a task, but to the old hand it is so much of a routine task that he does it unconsciously. If all conditions are right, the carburetor is primed and the engine will start on the first turn of the crank. If it does not do so, there is a source of trouble which must be remedied first, and it is useless to continue cranking. The trouble may lie in the fuel system itself, but exterior to the vaporizer, or it may be in the ignition apparatus. It is well in a case of this sort to start with the gasoline tank and follow the fuel through each step until it apparently reaches the combustion chamber in the form of a properly proportioned mixture of gasoline and air.

To start with the tank—is there enough fuel in it not only for starting purposes, but enough to allow of making the proposed trip? This is readily ascertained by unscrewing the filler cap and inserting a measuring stick. For the purpose a graduated rule is good, but not necessary; any stick or small branch of a tree will answer, or, lacking all these, a piece of wire can be used.

Having verified the presence of fuel, the next question is: Does it reach the vaporizer as it should? Nearly all carburetors have a drain cock at the lowest point. Open this, and if fuel flows out in a steady stream, you may be sure that the pipe from the tank up to this point is not clogged.

In either case, if there is no sign of gasoline when the tank contains plenty, it is apparent that the feed pipe is clogged. To remedy this, the method of procedure is as follows: Shut off the cock below the tank so that none of the previous liquid can escape, then drain off the carburetor and pipe into a handy pail. Next, open the union below the cock in the feed line and the one at the other end of the same pipe. At both places look fŏr obstruction. Then clean the pipe out thoroughly, using flowing water, a piece of wire, or other means which are available at the time.

Gasoline Strainer a Source of Trouble. If you find nothing here, look in the strainer of the carburetor to make sure that the flow is not stopped there by the accumulation of dirt and grit, filtered out of the fuel. The strainer should be cleaned often, but, like many other dirty jobs, it is postponed from time to time.

Should this source of trouble prove "not guilty" the carburetor itself becomes an object of suspicion. Is the float jammed down upon its seat, or are there obstructions which prevent the flow of fluid? Is the float punctured, or has one of the soldered joints, if a metal one, opened, or is it fuel-soaked, if cork?

Bent Needle Valve-Stem. To attend to this sort of trouble, disconnect the priming arrangement, take the cover off the float chamber (it usually is screwed on with a right-hand thread) and take the float out. An examination of the float, Fig. 133, will disclose whether it is at fault in any of the above-mentioned ways, all of which are comparatively easy to fix. If the float was jammed down, perhaps by priming, the act of taking it out will loosen it, provided that the stem of the float is not bent, and the needle valve or its seat is not injured. If the seat is scored, it should be ground-in just like any other valve, using oil and fine emery. A fuel-soaked cork should be thrown away if another is at hand to replace it, but if not, the cork float should be moved in its position on the stem so that it sets higher in the liquid. In other words, move the cork up sufficiently to compensate for its loss of buoyancy.

Fig. 133. Bent Needle Valve

In case of a punctured metal float or of loose solder, the only real remedy in either case is to resolder. It usually happens that a soldering outfit is not available out on the road, and some form of makeshift will be necessary in order to reach a place where one may be had. If the puncture is on the bottom, it is sometimes possible to accomplish this by inverting the float so that the hole comes at the top where the gasoline seldom reaches it. If the flow be reduced to make sure that the float will not fill up, it is possible to reach a place where a soldering iron may be procured.

A remedy which might be tried in an extreme case of this sort is to fill the float to make it heavy, so that it will have a tendency to sink. Then take a spring of small diameter, cut off a short piece and place it in the float chamber so that it opposes the sinking action of the now heavy float. By carefully determining the length and the strength of this spring, the same action is obtained as if the float were working all right. If the entrance of the liquid fuel is such that the sinking of the heavy float tends to close rather than open the gasoline inlet, the spring would have to be on the bottom and fairly strong so as to oppose the action of gravity. But if the float works downward to open the gasoline passage, the spring will be at the bottom and very weak being there simply to prevent an excessive flow.

Throttle Loose on Shaft. Now the carburetor trouble has been reduced to a minimum. The remaining troubles might be centered in a clogged spraying nozzle. But this nozzle is readily removed, and with it the trouble, if that be the offending member. If the spray is proven O. K., the throttle is ready for attention. If of the butterfly type, it may have become loose on its shaft, or, what is the same thing, the operating lever may be loose. In either case the shape and weight are such that it would swing into such a position as to cut off the entrance of gas to the inlet pipe and thus to the cylinder. If the throttle is of the circular sliding or piston form, it may not be connected to the throttle rod, but is stuck in such a position as to prevent the passage of gas. This sometimes happens when running, and then, apparently, closing the throttle does not stop the engine. The writer had this happen to him once at a time when it was absolutely necessary to stop. The only way that trouble was averted was by the instantaneous closing of the switch and the hasty application of the brakes.

The last hope of finding trouble in the carburetor system rests with the inlet pipe. If the source of the trouble is not found elsewhere, take this off in search of misplaced waste or similar substances. The size of the pipe is such that anything in it large enough to cause trouble may be instantly seen and removed. The only exception to this is a small hole in the inlet-pipe casting, which, if clogged even with a grain of sand or other material, will not only cause trouble with the mixture at all times, but will also be very hard to find, particularly if it happens to be of very small diameter.

The valve, or cock, controlling the flow of liquid from the tank should be examined frequently and care be taken to keep it in good shape. It must act hard and must be tight, so that no gasoline flows when it is supposed to be shut off. If this valve does not act hard it is likely to jiggle shut during a long run and stop the engine by shutting off the gas supply from the tank. A method of fixing it—which, in general, is not to be recommended—is to open the cock and then hammer the handle so as to jam it tight against the seat, but in the open position. This makeshift will answer until a place is reached where the taper seat can be reground or tightened in place, if that is what it needs. In case the driver does not wish to do this, and the cock is of the two-way type—open when the handle is parallel to the axis of the pipe—it may be tied in the open position by passing a cord around the cock and pipe.

Carburetor Adjustment. In adjusting the carburetor the worker should remember that the correct proportion varies from 11 to 14 parts of air to 1 of gasoline vapor. It is not always possible to measure the two in just this way, but the adjustment is provided for in the carburetor. The tendency in carburetor construction is toward simplification and fewer adjustments. In making carburetor adjustments, always remember to make them with the motor hot. A good plan is not to make any adjustments of this kind until after the motor has been running for an hour.

Tool for Carburetor Nozzles. Many carburetor nozzles are made with a screwdriver slot to facilitate their removal. It will soon be found, however, that the screwdriver is not so easy to use on these as a home-made tool. One useful form consists of a bar of $\frac{1}{4}$-inch steel-bar stock bent into the form of an L, the short end being flattened down into a screwdriver thickness and hardened.

Starving at High Speeds. Many times, a motorist will experience the phenomenon known as starving at high speeds, that is, his motor will give better power and run faster with the throttle partly closed than when wide open. This happens when the auxiliary air valve does not open sufficiently to admit the large quantity of air needed at the widest throttle opening. The mixture, therefore, becomes too rich, and the motor starves. The auxiliary air valve usually has an outside spring, the tension of which is controlled by a milled nut, also on the outside. Then, when it is desired to make a change in the mixture, the nut is turned, altering the tension of the spring and thus altering the lift of the air valve; in this way the proper amount of air is admitted. To admit more air, the nut is backed off in order to weaken the tension and thus allow the air valve to open wider. To admit less air, the spring tension must be increased so that the air valve cannot open quite so far or stay open so long.

Adjustments for Heating Water and Air Supply. On a large number of carburetors there are two more adjustments: those for heating the water and those for heating the air. The general run of carburetors are now water-jacketed to help vaporize the heavy fuels; during warm weather this may supply too much heat. For this reason, a cock is generally fitted to the hot-water line, which will allow partial as well as total closure.

Similarly, hot air is supplied to almost all carburetors to vaporize the heavy fuels more quickly, a necessity if rapid acceleration, quick getaways, and other present-day demands are satisfied. In order to vary the hot air according to the weather or to cut it off entirely, some kind of a shutter is provided which can be locked in any position. When the days begin to grow warm late in the spring, the shutter is partly closed; during the heat of mid-summer, it is closed completely, and sometimes the connection with the exhaust manifold for heating the air is entirely removed from the car; when the temperatures begin to go down, the shutter is opened again, and in cold weather it is entirely open, and as much heat as possible is supplied the carburetor.

Adjustment of the Nozzle. *Nozzle Too High.* A rather common trouble is failure to start readily. One puzzled driver described his case as follows:

The engine starts hard, necessitates priming, and the primer must be held down for a long time. When this is done, it will start and run for a short distance, when it will stop and the same proceeding must be repeated. On taking the carburetor apart, everything was clean and apparently all right.

If you are ever bothered in this way, you may be sure, granting that the spark is good, that the trouble lies in the fuel system. From the description of the trouble, it appears as if conditions were such as to starve the engine, although this was doubtless done unconsciously. This action is due to the fact that the gasoline level has been lowered so far that the suction of the engine does not draw up sufficient fuel for running. The fact that you have to prime to start and then prime to keep going, even this priming failing to work sometimes, would seem to prove that the engine is not getting enough fuel. The trouble is that the spray nozzle has been raised too high, so that the gasoline level is four or five times as far below the nozzle as it should be. The engine suction must raise the gasoline this distance before

Fig. 134. Section of Carburetor Showing Variation of Nozzle Level. First Figure, Correct; Second, Too Low—Engine Will Flood; Third, Too High—Engine Will Starve

any of the fuel will get into the cylinder, and if the distance exceeds the height to which the suction can raise the fuel, none will pass over. In a case of this sort, priming only helps temporarily.

Cleaning the Carburetor. Cleaning the carburetor, then, should be done very carefully, until one becomes quite familiar with it and with the influence which movement of the various parts will have. In Fig. 135, a foreign carburetor partly taken down shows how the top part of the float chamber should be removed in order not to damage the delicate needle point at the bottom of the float by which the latter governs the fuel supply. The cover should be loosened and then lifted straight up until clear of all remaining parts. With the cover off, the float may readily be removed in the same way, the only care being in starting it. As the amount, or length, of the needle point within the tapered seat is small, the float need be raised but a small amount.

Pre-Heating the Air. One thing that gives a lot of trouble is the heavier fuel now supplied. It can be used successfully only by adding heat, the application of which may take one of two forms: a water or exhaust-gas jacket around the carburetor or an arrangement pre-heating the air supply. The former cannot be added, but the latter can very easily. This is done by running to the inlet for the carburetor a flexible metal pipe from a collector fastened to the exhaust manifold. This tubing can be obtained at any well-equipped automobile supply house, as can also the various fittings for the exhaust pipes. In some cases, these firms carry the carburetor hot-air attachments also, but, if not, the

Fig. 137. Method of Adding a Hot-Air Connection to Improve Carburetion

maker of the carburetor can supply them at low prices. By the use of this attachment, the air drawn in through the carburetor passes around the very hot exhaust pipe, hence it is heated a great deal.

With the present grade of fuel, it is necessary to supply a great deal of extra heat in order to properly vaporize the fuel, especially during the winter months. It is sometimes advisable to remove the hot air pipe during the summer, as there is danger of too much heat.

Practically all late-model cars are equipped with a carburetor having a hot-water jacket and a special pipe for leading heated air to the carburetor. In Fig. 138 is an English example of this, showing the carburetor connections on the four-cylinder Belsize. The pipe at the left is the inlet manifold and the one at the right, the hot-air pipe from exhaust manifold down to air inlet. In all cases this hot-air connection is made as short as possible.

Causes of Misfiring. There are a number of vexatious things to make the novice and prospective driver peevish. Chief among these is the trouble known as misfiring. This may be described as a failure of the mixture to fire in any one cylinder. It is usually due to ignition, so that the term, as used now, means a failure to fire a charge due to an electrical cause. However, there are many common misfires which are due equally as much to a failure in the fuel-supply system, so that the latter meaning attached to the word is a misnomer.

Among the causes which contribute to misfiring may be mentioned ignition troubles, such as short-circuit in wires, exhausted battery, pitted or improperly adjusted vibrators of the coil, sooty or cracked plugs, loose connections or switch, dirty timer or commutator, punctured condenser, moisture in coil, wet wires or cables, water on distributing plate, dirt or wear on contacts in distributor, or dirt or wear in timer.

Then, there are the misfires due in part or wholly to the fuel or carburetion system. These may be grouped or listed as follows:

Carburetion and Fuel. Faulty mixture, sediment, or water in the carburetor, clogged gasoline strainer, leaky float, clogged spraying nozzle, bent float-valve spindle, stale gasoline, partial stoppage of fuel-supply pipe, hole or obstruction in intake pipe or manifold—these are not all the things that might happen, but are the principal ones which the writer's experience has suggested as most likely to occur to cars in general.

Foremost among the several difficulties which may be called common misfires is the lack of a proper mixture. A rich mixture containing a relatively large proportion of gasoline in proportion to air is never desirable, inasmuch as it deposits considerable soot upon the piston, cylinder walls, and valves, and is, moreover, a waste of fuel. The motor will seldom run well on a very rich mixture, and the carburetor should be so adjusted that no more gasoline is fed to the mixing chamber than is sufficient for the motor to develop its full power. The exact mixture may be found by experiment.

A very rich mixture will cause misfiring; the motor will have a tendency to choke at other than high speeds and is likely to overheat. A lean or too thin mixture will, on the other hand, lower the efficiency of the motor, giving it a marked tendency to miss at high speeds, and is also accompanied by a popping sound in the carburetor. In this case, the needle valve should be adjusted to admit more gasoline, or, if due to an excessive supply of air, the auxiliary air valve should be adjusted to admit less air.

Bent Float Spindle. A bent float spindle will cause missing in one or more cylinders. The float spindle may become bent or it may become jammed into its seat by too vigorous priming. This may be discovered by unscrewing the cover and lifting out the float. Considerable care should be taken in straightening out a bent spindle, and the metal should be placed upon a block of hard wood, another block interposed, and the spindle gently tapped with a hammer.

Leaky Float. A leaking metal float or a fuel-logged cork will cause missing, owing to its uncertain and erratic action. A cork float should be thoroughly dried out and then given a couple of coats of shellac to prevent it from absorbing the gasoline. As a new float is not at all expensive, the driver will probably find it more convenient to put in a new one. A metal float must be soldered when it leaks. As the copper is thin and easily damaged, only a very little solder need be used. Precaution should be taken to keep the hot soldering bit away from the metal.

A clogged gasoline strainer is often the cause of trouble, and this is about the first thing that the autoist should examine when the misfiring is apparently in the fuel-supply system. The brass gauze strainer should be frequently taken out and cleaned of any dirt that may have been filtered out of the gasoline.

Obstructed Spraying Nozzle. Owing to the small needle-like opening in the spraying jet, it is not uncommon for a particle of grit to lodge in the orifice and partially stop the flow of gasoline. The obstruction will not always interfere with starting, but as soon as the motor speeds up, the amount of gasoline sucked through the nozzle will not be sufficient for the motor at higher speeds, and it will soon begin to misfire until the motor slows down to first speed. A leak in the intake manifold will cause misfiring and is often mistaken for ignition trouble. The cause may be due to loosening up of the bolts.

Summary of Gasoline System Troubles

Carburetors should be among the last things to change in case of trouble. A black smoke from the exhaust will indicate too rich a mixture. Too thin a mixture may cause back-firing through the carburetor.

Flooding of Carburetor. This may be due to the failure of the needle valve to seat properly, which may be corrected by grinding the valve; or to a punctured float which must be removed and the hole carefully soldered. It may also be due to the spraying nozzle being so adjusted that the opening is below the gasoline level. To remedy, raise the nozzle by easy steps until the correct level is obtained.

Filling of Gasoline Tank. This should never be done by lamp or lantern light.

Leaks in Gasoline Line. These must be repaired as soon as discovered. They may result in fire, destroying the car and endangering the lives of its occupants.

Filler Cap. The filler cap should uncover an opening in which is a strainer of gauze wire which should not be taken out, or, if broken, it should be replaced promptly. As an additional protection against small foreign particles getting into the gasoline system a funnel with a chamois skin through which the gasoline may be poured should be used.

Grade of Gasoline. For ordinary use, gasoline from 56 to 68 degrees test is most satisfactory. The former, called also stove gasoline, is the only kind obtainable now.

Obstruction in Needle Valve in Carburetor. In searching for a clogged gasoline line, it is well to unscrew the needle of the needle valve and then blow through the valve. This will remove particles of dirt that may be there.

INLET MANIFOLD DESIGN AND CONSTRUCTION

Changes in Manifold with Engine Developments. Notwithstanding the marked attention paid to minor details of design in the last three or four years, manufacturers have had no greater problem than that of vaporizing the fuel properly, quickly, and efficiently; this has led to considerable attention being given to inlet-manifold design. In the beginning, the inlet was a plain straight piece of

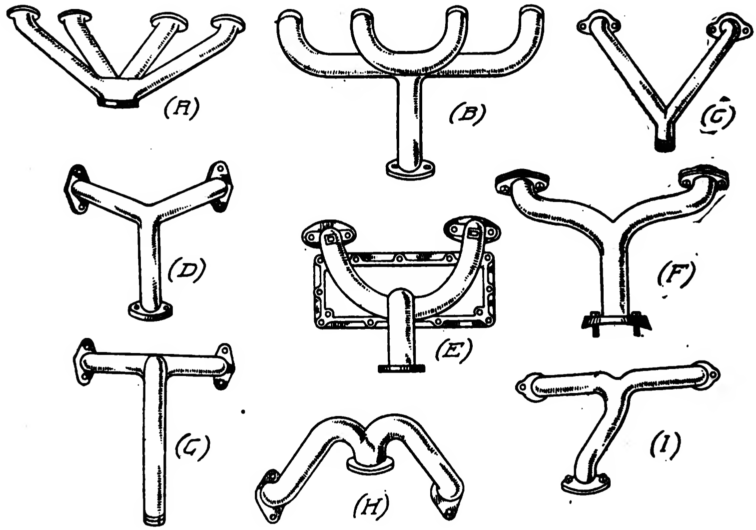


Fig. 139. Different Types of Inlet Manifolds for Four-Cylinder Engines
Courtesy of N. W. Henley Publishing Company, New York City

Fig. 140. Exterior of Studebaker Six Motor, Showing Particular Form of Inlet Manifold
Courtesy of Studebaker Corporation, Detroit, Michigan

tubing from what corresponded to the carburetor to the hole in the cylinder leading to the combustion chamber via the inlet valve. With the development of the four-cylinder motor, the majority of these were cast in pairs, and the pipe assumed a plain or modified Y-shape. Even at that, there was considerable chance for variety, as will be noted in the nine different forms shown in Fig. 139.

Changes from Fours to Sixes. With the coming into popularity of the six-cylinder form of motor, the inlet manifold received renewed attention; for now there were more variables, and it was a question of the best combination of them. One solution of this, as seen on a medium sized block six, is illustrated in Fig. 140. Here, the distance which the fuel must travel to the two central cylinders (cylinders *3* and *4*) is so much less than the distance which the gases must travel to either *1* and *2* at the front or *5* and *6* at the rear that there was the possibility of these four cylinders being somewhat starved. To compensate for this, the central part of the manifold where the three pipes to the cylinders join that from the carburetor was made much larger, with the idea of providing a well, or reservoir, for gaseous mixture large enough so the two central cylinders could not use all its contents.

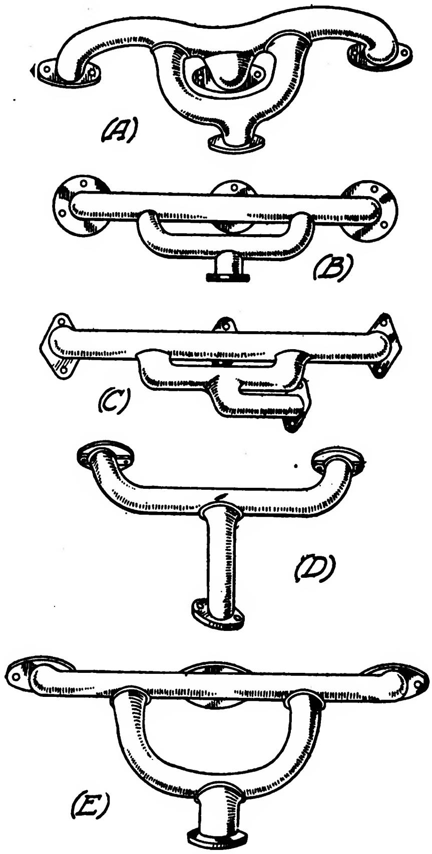


Fig. 141. Variety of Inlet Manifolds Used on Six-Cylinder Engines
Courtesy of N. W. Henley Publishing Company, New York City

The majority of designers, however, preferred to make the distance for the gases the same in each case, which led to some of the shapes seen in Fig. 141. Here it will be noted that a central loop is used to make these distances come out equal in all but one case; in that, the cylinders are cast in threes with a single inlet for each group.

Changes for Eights and Twelves. The coming of the V-type motors, both eights and twelves, has had another influence; for they came at the time when fuel was getting heavier and heavier. Designers were beginning to recognize the difficulty of vaporizing all the heavy fuel before it reached the cylinders, and, to assist in this, they began utilizing the manifold. Consequently, the majority, if not all, the eight- and twelve-cylinder engines have manifolds of the

Fig. 142. View of National Twelve-Cylinder Motor from Above, Showing Inlet Manifold
Courtesy of National Motor Vehicle Company, Indianapolis, Indiana

loop type shown in Fig. 142. The unusual diameter of this is due to the water jacket around it; the water inlet is seen at *A* and the outlet to the carburetor water jacket at *B*. In this form, the unusual height is due to two things: the necessity of getting the carburetor between it and the cylinders, yet not too close for accessibility; and of having a sufficient volume to act as a storage reservoir, since each side of this (each half of the loop) serves six cylinders (four in the case of the eight-cylinder engine). This is a typical eight- and twelve-cylinder manifold, except that many of them have a pair of pet cocks let into it for priming or cylinder testing purposes.

Heating the Charge. The method of heating the charge has taken a number of forms. In a simple four-cylinder motor of the

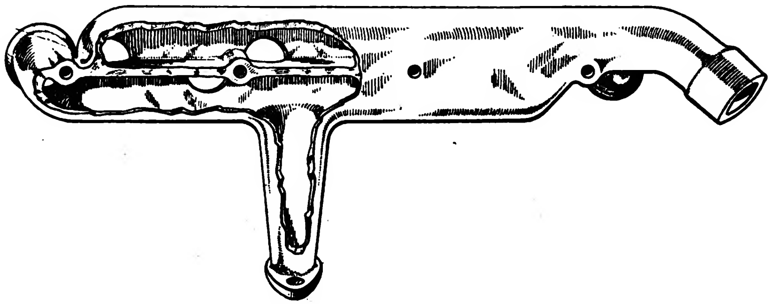


Fig. 143. Type of Combination Inlet and Exhaust Manifold Which Improves Vaporization

L-head type, like the Ford, it has been possible to develop a combination inlet and exhaust manifold (a single casting which would replace both of the former manifolds) which would give the heating effect desired in the inlet portion. Fig. 143 shows one way in which this is done and shows the central plate, or rib, between the two manifolds, which is heated to a high temperature by the exhaust gases, and thus

Fig. 144. Form of Water-Jacketed Inlet Manifold Used on Marmon Motor
Courtesy of Nordyke & Marmon Company, Indianapolis, Indiana

has a large influence on the final vaporization of the inflowing gases on the other side of it. It is claimed for this form that it will save from 25 to 40 per cent of the fuel used, and, even though this claim is not borne out in all cases, the fact that there is a saving shows that this is a correct method. Many of the more modern motors are not only incorporating this as a method of saving fuel and increasing the motor's efficiency, but also of reducing the number of parts in the machine, the opportunities for trouble, and possibly of reducing weight.

Another way in which the ordinary four- and six-cylinder inlet manifold has been altered is by the addition of the water jacket, previously mentioned. A typical example of this is seen in Fig. 144, which shows a water-jacketed inlet manifold on a six-cylinder motor, although the water-pipe connections are not visible.

Changes in Construction of Manifold. In addition to the design, the construction of inlet manifolds has been of marked influence. Thus a manifold of aluminum, iron, or other cast metal is usually quite different from what a manifold for the same engine would be if made from copper or steel tubing. In addition to the limitations of the process of production, there would be the changes which the surface produced would have. Thus, a casting would have a more or less rough surface, while a drawn tube would be perfectly smooth. This allows the use of a slightly smaller diameter and more abrupt bends with the latter than with the former. Similarly, the fastening means have had an influence. On a number of block-cast motors, the manifolds have been cast integral with the cylinders, thus taking further advantage of the heat generated within the motor, for fuel vaporizing purposes. It is for this type of motor that the horizontal-outlet type of carburetor has been developed. In this type the volume of vaporizing space beyond the spray nozzle is at a minimum, that is, they have been designed simply to mix the fuel spray and air, while the highly heated inlet passages do the actual vaporizing.

Hot Spots in Manifolds. A later trend in inlet manifold has to do with easier vaporization of the heavier fuels of today. Due to the high boiling point an external source of heat has been found necessary in this, and one of the ways in which this has been done is by means of the "hot-spot" manifold. To explain this simply, the inlet manifold is so constructed that a portion of it consisting of solid metal is in constant contact with the exhaust manifold so that in continuous running this solid metal in the intake manifold becomes heated, perhaps to a high degree. Furthermore, this "hot-spot" is so located in the inlet passages that all fuel must pass over it before passing to the cylinders, that is the last thing before passing in. A sharp bend in the inlet passage at this point does it, with the result that any unvaporized particles remaining in the fuel gas at this point are thrown against this highly heated spot and vaporized there, instead of being carried into the cylinders as liquid particles, as would be the case without this heated spot. One of these using the Stromberg "L" car-

Fig. 144 A. Chalmers Hot-Spot Inlet Manifold
Courtesy Automotive Industries, New York

buretor is that of the Chalmers, shown in Fig. 144 A, said to produce more power, greater economy, and more rapid acceleration.

Another similar arrangement is used on the Hinkley truck engine as shown in Fig. 144 B. This engine is really a modification of the Class B Government engine and resembles it very closely. As will be noted in the drawing, this arrangement is very similar to the Chalmers, the exhaust and inlet being slightly different to facilitate easy and quick removal and replacement.

As has been stated frequently, much heavy fuel is available on the Pacific Coast and at low prices, so out there considerable effort has been expended on using these cheaper but heavier fuels. A modification of the hot-spot arrangement, designed to be used on Ford cars is shown in sketch form in Fig. 144 C. Here the hot

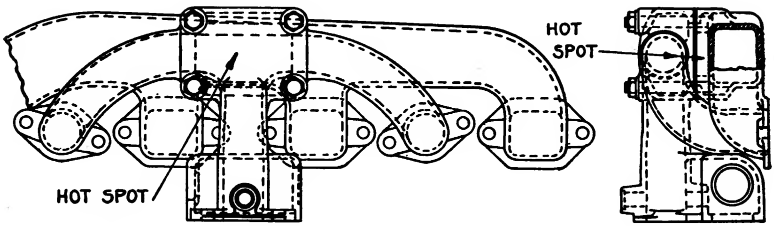


Fig. 144 B. Hot Spot Manifold Arrangement on Hinkley Truck Engine
Courtesy Hinkley Motors Corporation, Detroit, Michigan

spot projecting into the exhaust manifold is not alone made very large but the outer or heating surface is increased by the addition of fins similar to an air-cooled engine. This adds metal to heat up and hold the heat, which is what the heavier fuels like distillate must have. In addition, as will be noted, the carburetor is so constructed as to spray all the fuel oil directly into the interior of this highly heated mass of metal, the gasified parts coming down into the intake manifold. This heated mass of metal is thus the entire dependence for vaporization in this case, the actual carburetor part of the device having been eliminated. It would seem that this carries the hot-spot or hot surface plan almost too far,

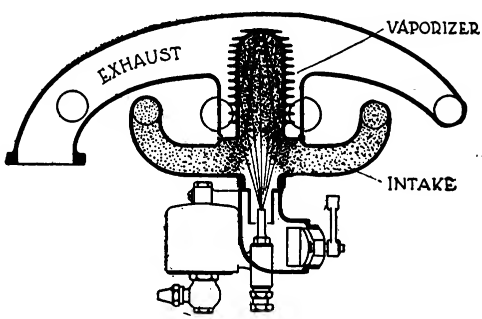


Fig. 144 C. Far-Western Carburetor Which Is All Hot Spot

its original intention having been for use as an auxiliary solely, the hot surface vaporizing only those heavy globules of the liquid which the spraying and atomizing and air mixing did not or could not break up and vaporize. In short it was intended originally only as a clean-up device, following and wholly dependent upon the carburetor. The device in Fig. 144 C aims to make the hot surface become hot surface, vaporizer and clean-up device all in one.

Another version of the heated manifold surface is shown in Fig. 144 D, the manifolds of the Velie tractor. Here the first part of the inlet manifold is highly heated by constructing the two manifolds as one, the inlet consisting of a straight vertical passage through the center of the exhaust passages, just as the detail at the left shows. This would give the high heat necessary for the original vaporization or cracking up of all the fuel, but to insure continuation of this condition, that is, to prevent any of the mixture condensing out into liquid again, the second portion

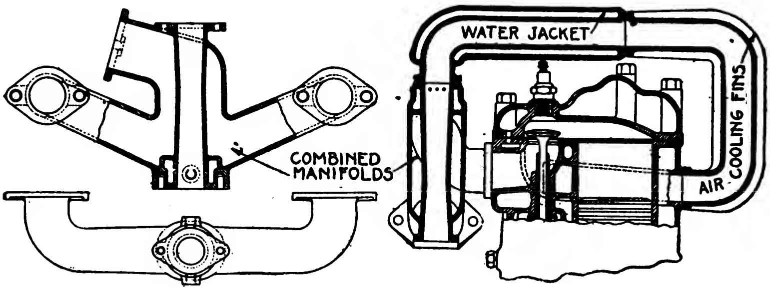


Fig. 144 D. Combined Inlet and Exhaust Manifold of Velie Tractor
Courtesy Velie Motors Corporation, Moline, Illinois

across the top of the cylinders is water cooled. In this condition, the gas would be too hot to enter the cylinders, hence it is cooled by means of air-cooling fins or ribs along the last portion of its length. As a permanent gas has been produced by the previous steps, this carries with it small possibility of any condensation.

The real flaw in the hot surface method is that it is of no help whatever in starting, since it does not begin to work until after the engine has run for some time, and heated up. And poor starting is really more drawback than running on heavier fuels.

Inlet Manifold Troubles. The principal inlet manifold troubles are air leaks, which dilute the mixture beyond the carburetor, making it and its many elaborate adjustments more or less useless. These leaks may be due to leaks around joints, connections, or gaskets or to porous castings. If the inlet manifold is of copper or steel tubing, the idea of a leak can be dismissed, but, otherwise, a porous pipe can be discovered at idling speeds by squirting gasoline upon the suspected surface of the manifold and noting if the motor speeds up. If it does, this is a sign that some of the gasoline has been drawn through the holes in the manifold, enriching the mixture.

The leaks around joints, connections, or gaskets can be found in much the same way. When the leak is found, the joint should be tightened if possible, or a new gasket should be put in, or both. In the case of the porous manifold casting, it can be painted with a fairly heavy paint while hot so that the pores of the metal are well opened. Then, after this has dried in thoroughly, another coat will probably finish the job. If this does not prove to be the case, special cement for filling porous castings can be purchased and applied; or, best of all, if the case is a bad one, an entirely new manifold should be put in.

FUEL SUPPLY

For storage of the fuel required for the propulsion of a car and for feeding the fuel to the carburetor, many different systems are in use.

Tank Placing. In automobiles, the gasoline tanks are generally placed under the front or rear seats, or under the frame at the rear. In many types of runabouts and roadsters, the tank is placed above the frame at the rear.

Fuel Feeding. When the tank is at the rear, or when it is under the front or rear seat, no special provision is necessary, under ordinary circumstances, to insure a positive flow of the liquid fuel to the carburetor.

Gravity. With the tanks placed high, the gasoline can be depended upon to run down to the float chamber by gravity. In mountainous districts it is sometimes found, in climbing very steep hills, that the angle becomes such that the fuel will not flow, especially when the tanks are under or back of the rear seat, or when they are nearly empty.

A means of getting around this difficulty is to place an auxiliary tank of one or two gallons capacity on the front of the dashboard, behind the engine and under the bonnet, and run a pipe direct from it to the carburetor. When the car is in a level position, this auxiliary tank fills automatically from the main tank, but a simple valve prevents the contents of the auxiliary tank from running back when the machine is tilted up. In this way a sufficient supply for 15 or 20 miles running is placed in a position to reach the carburetor under any possible road condition.

Air Pressure. With the tanks placed low, whether under the frame or above it, it is necessary to feed the fuel to the carburetor by more positive means than gravity. One of the commonest systems involves pumping a low air pressure into the tank above the fuel, so that this pressure forces the liquid out regardless of the relative heights of tank and carburetor. Ordinarily, a small hand pump is sufficient to provide such air pressure, though in modern automobiles equipped with compressed-air starting devices, or compressed-air tanks for filling the tires, provisions can be readily made for supplying the tanks with air from these sources for the purpose of feeding the fuel.

Exhaust Pressure. A system that is much used for providing pressure in the fuel tanks, though not so highly regarded as in the past, is to tap the exhaust piping and to take from the connection a pipe line that permits the entry of a certain amount of the exhaust gases into the fuel tank. A simple automatic valve controls the pressure and shuts off the admission of gas when the pressure rises above the very low maximum required. In a system of this character there is no possible danger of fire, not only because the exhaust gas is very quickly cooled in passing through a length of small piping, but also because the contents of a gasoline tank is ordinarily not ignitiable, because of the lack of any air to support the combustion.

Fig. 145. Section through the Stewart Vacuum Gasoline Feed Device

Sooting up of the automatic valve is the commonest trouble with this system.

New Vacuum Feed Device. The many troubles incident to the use of the rear tank location with pressure feed have brought about the production of a new device, which is called the Stewart vacuum feed. This is a small compact circular unit, which is placed on the dash under the hood for use with a rear tank and, when so used, eliminates the pressure feed. A sectional drawing of this is shown in Fig. 145. It may be described as follows: There are three connections at the top, one to the gasoline tank, one to the intake manifold, and one to the air vent. Through the medium of the intake-manifold connection, the motor suction is communicated to the tank, for that is what the device amounts to. This produces a vacuum and opens the valve connecting with the gasoline tank. That, as well as the connecting-pipe line, being air tight, gasoline is drawn in to fill the vacuum, flowing into the upper chamber with which the gasoline tank communicates.

This has a valve connection to the lower chamber, operated by means of a float; it, in turn, is controlled by the intake manifold suction, through the medium of the system of levers. By it the lower chamber is kept filled to a fairly high level, whence feed to the carburetor is by gravity. This method thus does away with all the troubles of the pressure system, at the same time allowing the accessible and advantageous rear-tank location. It is placed as high as possible on the inside of the dash under the hood, hence there is never any trouble with the gravity feed even on the steepest hill. In one test, this vacuum-feed device increased the mileage of the car per gallon of fuel by more than 22 per cent.

Stromberg Fuel Pump. The Stromberg Fuel Pump operates on the pulsating principle. It consists of a pulsator and pump connected by a tube. The pulsator is a part of the engine and consists of a cylinder and reciprocating piston. There are no ports or valves and this pulsator is driven from the camshaft and is lubricated by the emulsion from the crankcase. The fuel pump is placed in the main line between the tank and the carburetor. This pump consists of a float chamber, an inlet chamber which is also a sediment trap, and an outlet chamber, which is also an air-cushion chamber. The inlet chamber is connected to the float chamber through a gravity valve, and, in turn, the float chamber is connected to the outlet chamber by a similar valve, which is closed by a spring. This construction is shown in Fig. 146.

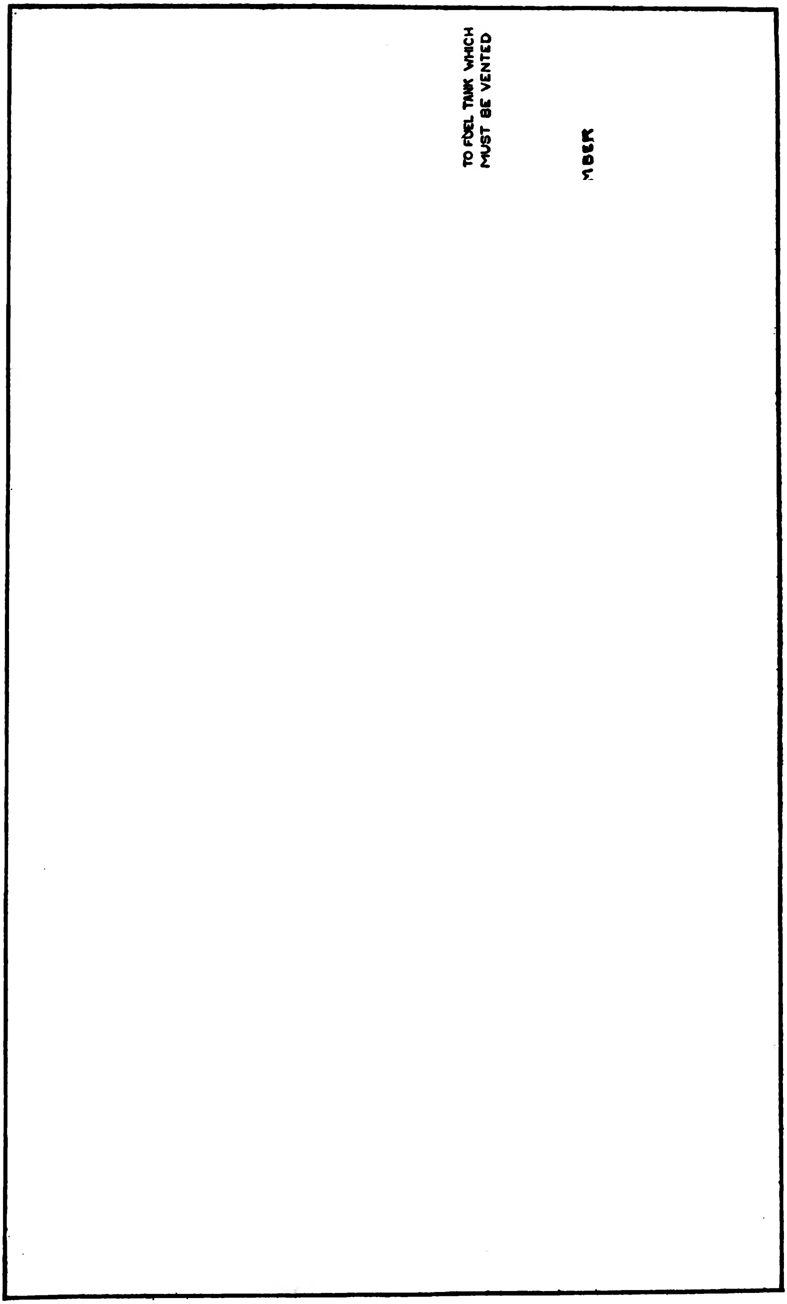


Fig. 146. Sectional View of the Stromberg Fuel Pump System

Connections. As a guard against breakage and to allow alterations in the relative positions of different parts, due either to the straining of the machine while it is in use or to a change of adjustments when it is disassembled or reassembled, loops or coils in the soft brass or copper pipe line are of great advantage.

Stop cocks close to the tanks are an excellent safeguard against fire, since they permit the shutting off of the fuel supply in the case of any breaks in the line. Such safeguards should always be provided.

With reference to the pressure system of fuel feed, there is hardly any limit to the precautions which must be taken to avoid leaks. The smallest leak puts the system out of commission as soon as the pressure leaks down to a point where the fuel will not rise to the carburetor. When this occurs, the engine cannot be operated until the leak is found and fixed. To avoid leaks, many drivers go over all joints frequently and likewise replace all old packing. In addition, they wipe the joints with soap to prevent leakage and then cover them on the outside with tire tape or similar flexible material which can be wound on in such a way as to stay permanently. The rapid adoption of the Stewart device, since it was brought out in 1914, shows better than anything else how troublesome was the pressure-feed system. Statistics for 1914 cars showed that in 237 different models, 109 had the gravity tank under the seat, and 31 in the cowl, this making 140 with gravity feed, leaving 97 with the rear-pressure tank location. Similar statistics for 1915 show 52 per cent in favor of the rear tank location, while 1916 shows almost 66 per cent with rear location, and 34 per cent vacuum fed.

Reserve Tanks. To guard against the annoying mishap of having the gasoline give out while an automobile is in use, perhaps remote from any source of supply, many cars are now provided with reserve tanks which hold back one or two gallons of gasoline. This reserve cannot be used except when it is fed into the system through the deliberate intent of the operator.

In its simplest and one of its best forms, a reserve tank takes the shape of a partitioned-off portion of the main tank, into which the gasoline automatically flows through an opening at the top when the tank is filled. It cannot pass to the carburetor until a special valve in the bottom is opened and the fuel allowed to flow back into the main tank.

A later and even more simple provision is the use for the gasoline tank of a three-way outlet cock which has a fairly long extension up into the tank. The extension tube is open at the top and has a hole near the bottom of the tank which communicates through a branch tube with the third way of the cock. When the outlet cock is set for normal flow, the fuel feeds until the level reaches the top of the extension; at that point it stops flowing. This is the warning to the driver that his fuel is low. Then all he has to do is to turn the outlet cock to the other position, thus allowing the fuel to feed from the bottom hole of the extension tube. The remainder of the fuel, that is, the amount represented by the difference in level between the top and bottom of the extension tube, will carry the car to the next fuel station.

Fuel Gages. The development of depth and quantity indicators has received much attention in the last few years, with the result that practically all new cars have some form of gage on, or in, the fuel system. On rear-pressure tanks, it is usually located on the tank, so the driver must go to the rear of the car to see how much fuel he has left, but on cowl tanks or those located under the seat, it is possible to have the gage set on the instrument board or the dash, as the case may be, so that it is in plain sight. Practically all the gages give indications in gallons and fractions, so that with the gasoline gage and odometer in front of him, and knowing how many miles he averages to the gallon of fuel, no driver need worry about having gas. He can readily figure ahead and keep sufficient on hand for his needs. A device has been produced to give dashboard indication of rear-tank capacities, but this is so complicated and expensive that it is little used.

FUEL SYSTEM TROUBLES AND REPAIRS

Failure of Fuel to Flow from Full Gravity Tank. Many times the fuel will not flow from a gravity tank which is full. This may be because the air holes in the filler have been stopped up so that no air can enter. By cleaning out the holes, if there are any, drilling some if there are not, or by loosening the filler, this can be remedied. For this reason, it is well not to use a gasket or washer on a gravity tank. On a pressure tank, just the reverse situation exists, and it is advisable to use a rubber or leather washer at the filler cap.

Fuel Line Obstructed. Many times an obstruction in the fuel line will be found at a very low point or sharp bend, where dirt in the fuel has gradually collected until there was enough to cut off the flow. A good way out of such a difficulty is to close connections at the tank and at the carburetor, take the entire fuel line off and blow it out with compressed air. This will clean it thoroughly.

Lock on Fuel Line. The garage or repair man can insert a very efficient lock on any car by putting into the fuel line at a convenient point a shut-off cock which works with a removable key. These are readily obtained, and any good workman can install one in a couple of hours. Many owners of cars would be glad of an efficient lock and would be willing to pay well for one. This one has the advantage of being simple, cheap, and effective.

SUMMARY OF CARBURETOR INSTRUCTIONS

Q. What is a carburetor?

A. A carburetor is a device for vaporizing liquid fuels, and for adding to them, when vaporized, the proper amount of air for immediate and complete combustion.

Q. How many types of carburetors are there?

A. Three: the surface form, now out of date; the filtering type, no longer used, except on one or two English cars; and the spraying type, to which all modern devices belong. The first was useful only with the very light and extremely volatile fuels of ten and twenty years ago.

Q. What are the essential units of a spraying type of carburetor?

A. The essential parts of a spraying type of carburetor are: a float chamber with a float arranged to regulate the level of the inflowing fuel; a needle and nozzle, or spraying device, which should preferably be adjustable; an air opening, which may be variable or not, which may be in multiple form or not, which may have automatic valves to regulate its size or not; and a throttle valve to control the quantity of mixture passed into the cylinders. As an important auxiliary, the needle, nozzle, or spraying device, whatever its form, should be placed in a special vaporizing chamber, of a size and shape to give the best results.

Q. Do all these appear in all modern carburetors?

A. Practically all, in one form or another, and also a considerable number of additional parts. Thus many carburetors have two or more nozzles, or spraying devices; quite a few have two air openings, one of which is controlled by an automatic valve, some have three air openings; many, in fact most, of the modern devices have a method of heating the vaporizing chamber, or the space immediately above or below it, so as to facilitate complete vaporization, as well as to quicken the action; some have air valves in the form of steel balls; others have pistons and dash pots to eliminate sudden movements or changes in operation; many have auxiliary devices intended to give a special starting mixture; practically all have removable strainers for cleaning the fuel, some having two different forms of strainer.

Q. What is the generally accepted form of needle valve, or spraying nozzle?

A. There is no one accepted form, although the majority of carburetors have spraying nozzles, or needle valves, which come into one of four classifications. These are: the hollow nozzle with an opening at the top, slightly smaller in inside diameter than in outside, so that the spray of fuel is opened out in a fan-like form; the same form with an internal needle having a long tapered point and screwing up into it from below, this giving a means of adjustment which the plain hole does not; the same plain tube and hole, with an external needle having a tapered point and screwing down into it from above (in this, the body of the needle divides the spray of fuel); and the form of hollow nozzle in which the fuel is forced to flow outward through a series of holes, then upward to an outlet which consists either of an additional series of holes or a very fine annular ring. Either form gives the same result, a very fine and somewhat extended spray of fuel. The last form is sometimes modified to the extent that this annular ring of fuel, where it emerges into the vaporizing chamber, is as much as 3 or 4 inches in diameter.

Q. What is the purpose of the auxiliary air valve?

A. To supply additional or auxiliary air at the higher and highest speeds. Without this, the heavy suction of high speeds or hard pulling is very likely to produce too rich a mixture, that is, a mixture with too much fuel and too little air.

Q. Is there any disadvantage in this?

A. Yes. It has been found by experience that a motor will not operate well or give its extreme power or greatest speed on a rich mixture. Rather, at its highest output, the mixture should tend toward leanness.

Q. How does the auxiliary air valve remedy this?

A. By adding air when the motor suction gets strong enough to open the auxiliary air valve, the amount added being in direct proportion to the strength of the suction.

Q. What other disadvantage is there in over rich mixtures for high speeds?

A. An over rich mixture at high speeds shows a noticeable lack of economy, as at these speeds a great amount of gas is being used, and, if too rich, the gasoline fuel is being used up very rapidly. The makers of practically any carburetor equipped with an auxiliary air valve will guarantee a saving of 20 per cent in fuel consumption when it replaces a carburetor which has no auxiliary air valve.

Q. Why are some carburetors water-jacketed?

A. The conversion of a liquid like gasoline into a vapor is a chemical action which needs heat to complete it. If no heat is supplied, it will be taken from surrounding objects, or else the vaporization will not be completed. This abstraction of heat from the surroundings can be noticed in unjacketed carburetors in the form of frost or snow forming on the outside of the vaporizing chamber. The water-jacketed carburetor has the hot water of the engine system circulated through it to supply the needed heat, and thus assist and complete the vaporizing of the fuel.

Q. Why are some carburetors supplied with hot air?

A. This is done for the same reason. The pre-heated air is supplied to vaporize the fuel, instead of using cold air and supplying heat from other sources. In principle, it is practically the same as the other.

Q. When hot air is supplied, how is this heated?

A. Generally a stove, or a hollow member around the heated exhaust pipe, is connected by metal tubing to the air inlet of the carburetor; in this way all of the air drawn in is forced to pass around the exhaust pipe, which heats it. This is not always the case, some makers using air sucked in from around the heated cylinders. Still others use an exhaust jacket on the carburetor, and draw the cold air supply in around this, so that it is heated.

Q. What difference does the fuel make in this heating method?

A. On the heavier fuels, such as kerosene, alcohol, distillate, and mixtures of these with gasoline, a great quantity of heat is necessary, as these heavier fuels are more difficult to vaporize and are also slower to start vaporizing. This means an extra supply of heat at starting time, and more than the usual supply at all times. It works out, in the direct use of exhaust gases, through a small pipe tapped into the exhaust manifold, thus giving the highest available temperature. This is used through the carburetor jackets, but, in addition, the air supply to vaporize the fuel is heated. Another vaporizer of heavy fuels, which has been quite successful, places heavy metal weights inside the carburetor in the upper part of the vaporizing chamber and then forces the exhaust gases through hollow passages in these. In this way, the weights are heated up, and this heat is transmitted to the gas and air; the size and nature of the metal gives an equable supply of heat, regardless of the exhaust gases.

Q. What is the throttle valve?

A. A valve placed in the pipe between carburetor and cylinders to vary (or throttle) the quantity of mixture flowing to the latter. This is generally connected to the throttle lever on the steering wheel, and to the accelerator pedal. General practice in driving, after the initial stages of learning, is to set the hand throttle at some medium point, and thereafter to vary the speed of the motor by means of the foot.

Q. What is the general form of this throttle valve?

A. The butterfly throttle is used more than any other form, although the piston valve is considerably used. The butterfly is the simplest form possible, consisting of a thin circular disc the size of the interior diameter of the inlet pipe, fastened at the middle to a round shaft which extends across the pipe, and has a lever fastened on the outside extension. When this lever is turned so that the disc lies at right angles to the pipe, the passage will be shut off; when it is turned up parallel to the pipe, the passage will be wide open, for the disc is so thin as to offer practically no resistance to the gases. The piston type of throttle may be arranged so as to rotate or to slide. When it rotates, it is generally constructed with holes in its walls which register with the opening in the pipe, according to its position. When it slides, these holes are generally continuous at one end, this being moved along so as to register with the opening in the pipe. Another type of throttle is the swinging, or flap valve. This is so shaped as to swing from side to side, closing the passage entirely in one position, and leaving it entirely open in another.

Q. What is a Venturi tube?

A. This is the essential principle of the inner member of the Venturi meter, invented for measuring the flow of water. It consists of two cone-shaped tubes diverging in opposite directions, with the proper relation of angles to one another and to the diameter of the smallest point, or meeting point, of the two tubes. The larger angle should be at the bottom, or entering end for the gases; the nozzle, or needle, should be just at or just below the smallest diameter; and the gases should flow through from end to end, that is, air in at one end, gas in at the middle, mixture out at the other end. In the true Venturi tube, the bottom angle is 30 degrees, the top angle 5 degrees.

Q. When more than one nozzle is used, how are they connected?

A. In practically all multiple-nozzle forms, the arrangement is such that the second (and later) nozzles are brought into action by increased demand from the engine, that is, automatically. In one case, a flap valve covers the second nozzle; but, as the suction increases this is drawn up and the nozzle is uncovered; having its own air supply, the nozzle begins to function as soon as it is uncovered, the amount of gas supplied by it depending upon the extent to which it is uncovered by the suction. In another, the first nozzle passes a fixed amount of fuel, as the engine demands rise; this suction is communicated to the second nozzle and the fuel standpipe from which it draws; it is put into action, but varies its supply always according to demand. The combination of fixed and variable nozzles gives reasonably good vaporization at all possible speeds and under all variations of conditions.

Q. What is a horizontal-outlet carburetor?

A. The first carburetors were all connected to the engine cylinders through the intermediary of an inlet manifold. The latter connected up to the cylinder horizontal face at a number of points, and was carried down to a single flange for the carburetor connection. While the surface of this flange was horizontal, the outlet on the carburetor, that is, the passage to this, was vertical. Consequently, carburetors made to fit this arrangement are said to have vertical outlets. With the principle of block casting, it is usual to incorporate the inlet manifold in the cylinder casting and have a single carburetor opening and place for attaching, this being a vertical face. As the face, or carburetor flange, is at right angles to the body of the carburetor outlets, this brought about a horizontal outlet. A carburetor with this form of outlet, and intended to bolt directly upon the cylinder casting in the manner just described, is called a horizontal-outlet carburetor or a horizontal carburetor.

Q. What is a double carburetor?

A. A double carburetor is one made for a V-type of motor in which a common float chamber supplies fuel to two separate and distinct groups of vaporizing chamber, fuel nozzle and needle, air inlet, etc., each half supplying one of the blocks of cylinders. That is to say, it is a double carburetor, or two carburetors, if that is easier to understand, each one of which supplies one-half of the engine's cylinders, but has nothing to do with the other half. It has been found that better results can be obtained in this way than in any other.

Q. What has been the effect of vacuum feeds?

A. The principal effect has been to raise the carburetor. Formerly, the carburetor had to be set low so the fuel could flow to it, and even when pressure became general, the carburetors were still set very low. Now, with auxiliary tank feeding, it is possible to raise the carburetor from two to six inches, and practically all designers have taken advantage of this. It makes the carburetor easier to adjust, easier to prime when priming is necessary, less likely to be stopped or clogged by road dirt or water, because it is farther away from the road and better protected, also, the car can go through deeper water without stopping. Another effect has been to produce a steadier and more even flow of fuel at all times and under all circumstances. In one way, this gave better power, in another, it benefited by giving better economy.

Q. What is the vacuum feed?

A. It is an auxiliary gasoline tank which draws the fuel from the main gasoline tank at the rear of the chassis (or elsewhere). It does this and maintains itself filled automatically, the vacuum being used to raise the fuel from the main tank to the auxiliary, which is usually about a foot higher. The tank can be placed anywhere, but the two usual mountings are on the inside of the bonnet, either on the engine or on the dash.

Q. What other methods are there of fuel supply?

A. The original method was by gravity, from a tank under the front seat. This necessitated having the carburetor so low that the fuel would flow to it on the steepest hill. The substitute for this was pressure, but this necessitated much apparatus, and the system had to be kept air tight or it was useless. In this form an air pump forced air through a regulator into the air-tight tank, this pressure forcing the fuel out and to the carburetor.

Q. How does the Stromberg fuel pump differ from the Stewart vacuum feed?

A. The Stromberg fuel pump operates on the pulsating principle, this pulsating being produced by a small pump, while the Stewart vacuum feed operates on the vacuum principle, the fuel being lifted by means of a vacuum created in the intake manifold. The Stromberg fuel pump draws a supply into an auxiliary float chamber, from which it is forced into the float chamber of the carburetor by the action of the pulsator.

Q. What is the Packard fuelizer?

A. The Packard fuelizer is an instrument which produces heat by means of a small gas torch. This heat goes into the intake manifold, vaporizing the mixture.

Q. When no fuel flows, yet the tank is filled, what is the trouble?

A. If the tank is full and no fuel flows, there must be an obstruction in the line somewhere. Try the gasoline pipe line first for a bend or kink. If none is found, try the carburetor connection. Failing that, remove the strainer and inspect it. Then look into the float and float chamber, float valve and outlet to vaporizing chamber. Some one of these is sure to be at fault.

Q. How can a punctured float be managed, so as to get home?

A. Let the float sink, but oppose this sinking by means of a spring, carefully cut to the right length to give the same effect as if the float were O. K. This will carry the car to the nearest repair shop, or lacking that, will take it home. A punctured metal float can readily be soldered, but should be dried out very carefully first, this being done primarily to make sure there is no more gasoline inside, nor any vapor to condense.

Study Questions for Home Work

1. What are the general rules for adjusting Stromberg carburetors, Models L, LB, M and MB? If an entirely new setting is necessary on Model MB, what is the correct procedure?

2. What is the purpose of the economizer adjustment on the Stromberg Model L?

3. Tell how the main jet is replaced on the Zenith.

4. A car equipped with a Zenith Model O carburetor does not accelerate well and slow speed running is not smooth. What is the trouble? What is the remedy when this car will not develop full speed?

5. Give the method of making a slow-speed adjustment on the Ford car.

6. Describe the construction of the Master carburetor throttle.

7. Explain the action of the air damper on the Master carburetor.

8. How is the Miller carburetor adjusted for altitude?

9. Mention in detail the process of starting adjustment of the Webber.

10. How many adjustments has the Rayfield? Describe them.

11. What is the mixture-indicating pointer on the Newcomb? What are its advantages?

12. How would you adjust a new Schebler Model "L"?

13. What is the predominating feature of the Stewart carburetor?

14. How is the Johnson carburetor adjusted?

15. What are the salient features of the Packard carburetor?

16. Describe the adjustment of the Cadillac, (a) low speed, (b) starting, (c) high speed.

17. Select and describe the working of a heavy fuel carburetor.

18. Describe in detail the workings of the Carter auxiliary tank.

19. It is desired to burn distillate in a truck. What carburetor would you select?

20. What is the difference between an oxygen-adding device and a regular carburetor?

21. Describe the construction of the Bennett air washer and of the Parrett air cleaner. Where are such devices necessary?

22. Describe the construction and operation of the Toquet atomizer.

23. Describe the construction and operation of the Ensign fuel converter. How is alcohol used in this instrument?

24. How is vaporization obtained in the "Nitro?" How many adjustments are possible?

25. What is the purpose of the flexible reeds in the Tillotson carburetor? How are they operated?

26. How is a mechanical subdivision of the fuel obtained in the Shakespeare carburetor? How is this carburetor adjusted?

27. Trace the fuel through the Holley "all fuel" carburetor.

Sectional View of the LaFayette Eight-Cylinder Motor Showing the Valves Set at an Angle to the Cylinders

GASOLINE AUTOMOBILES

PART III

ENGINE-GROUP ELEMENTS (Continued)

VALVES AND THEIR MECHANISM

Importance of Valves. Probably the most important thing about a four-cycle gasoline engine is the valve, or, more correctly, are the valves, for the usual number is two per cylinder. The opening and closing of these control the functions of the engine; for if the valve does not open and allow a charge of gas to enter, how can the piston compress, and the ignition system fire, a charge? Similarly, if the exhaust valve is not opened and the burned gases allowed to escape, they will mingle with and dilute the fresh, incoming charge, possibly to the extent of making the latter into a non-combustible gas. This is purposely stated in this way because both methods mentioned have been utilized for governing the engine speed, although not to any great extent in automobile work.

Summary of Valve Features. In the valves and valve mechanisms of modern gasoline engines there have been and are impending more interesting changes than seem in prospect in any other portion of the mechanism of the modern automobile. Particularly is this the case with reference to the present tendency to discard the poppet valve with its many objectionable features. Even where there is no tendency toward the use of a sleeve-valve or slide-valve form of motor, much experimenting has been done with increasing the number and changing the position of the valves.

Poppet Valves. Though the very first internal-combustion engines ever made were operated with slide valves, the poppet valve was introduced very early in the history of this art, and has reigned supreme in practically all types of gas and gasoline engines.

The chief advantage of the poppet valve is its capacity for continuous operation at excessively high temperatures, but since the cooling of engines has progressed to the status of high reliability, this advantage is of less importance than formerly. And the disadvantages of poppet valves—the small openings that they afford, the noisy and hammering action they involve, their tendency to leak and in other ways give out, and the necessity for frequently regrinding them—are objections so serious that it is no wonder the prospect of their elimination is so widely welcomed.

About the only recent improvement that has been made in poppet valves is in the quality of material used in them. Many valves now used have cast-iron and nickel heads, which offer a maximum resistance to warping from the heat to which they are subjected. These are fitted with carbon-steel stems, which are superior in their wearing qualities. More use has been made recently of tungsten as a material for valves. Steel containing this is even harder than nickel steel, and experiments have shown that it does not warp as much. In practice, the objection found to cast-iron heads was that the fastenings to the carbon-steel stem were not sufficiently strong to withstand the constant pulling and pushing to which a valve was subjected. As a result they separated, causing trouble.

In the operation of poppet valves, the cams become an important factor. These are the parts which, in revolving, raise the valves so that they open at the proper time. In addition, the cams are so shaped as to hold the valves open for just the right length of time and allow them to close, through the medium of the valve-spring pressure, at the proper point in the cycle. The importance of this can be seen, if we consider that opening the slightest fraction of a second too late will reduce the amount of the charge very much, and thus lessen the power developed by the motor.

Enclosures. The use of casings to enclose the valve stems, springs, and push rods, so as to keep these elements from exposure to dirt, and at the same time silence, in a large degree, the noise they make, is also becoming usual.

Many excellent examples of this may be seen in modern motors. The whole side of the motor where the valve mechanism is located is covered with a long removable plate, keeping in noise and lubricant and keeping out dirt. Usually, however, on a six-cylinder motor the valve enclosure is made in two parts, one half enclosing the mechanism of the valves in the first three cylinders, the other half, those in the last three. This is, of course, the preferred construction on those six-cylinder engines which have the cylinders cast in threes, instead of in a block, as the one referred to. On some motors where this construction has not found favor, the designers have followed the plan of enclosing the individual valve mechanisms. While more expensive, this method is equally as efficient. On the other hand, it adds to the parts, and the whole modern tendency has been to reduce the number of parts.

Sleeve Valves. This type of valve, while not at all new, has only within the past few years come into considerable prominence, chiefly as a result of the truly remarkable performances of the Knight motor, which is equipped with the most advanced examples of this type of valve.

Contrary to past opinion, it has been conclusively demonstrated that sleeve valves do not, to any perceptible degree, increase the tendency of a motor to overheat, nor do they wear at any very measurable rate. They afford, moreover, in the best constructions, a much higher thermal and mechanical efficiency than it is possible to secure from the average poppet-valve motor, this improvement being due to the better-shaped combustion chamber that can be used and the greater areas of valve opening, which facilitate the ingress and egress of the charges.

Another advantage in favor of the sleeve valve is that its timing is permanent and unchangeable and does not alter materially with wear. Not the least of the merits of the sleeve valve is found in the fact that it lends itself to positive operation by eccentric mechanisms, which are in every way greatly superior to the non-positive cam mechanisms universally used to actuate poppet valves.

A very good example of this latest type of Knight motor is illustrated in Fig. 149, showing the intake side of the Moline-Knight four-cylinder motor.

Sliding Valves. Sliding valves of other than the sleeve type, embracing a considerable variety of piston valves and valves similar to those employed in steam engines, have not found as much favor with designers of automobile engines as have other types herein referred to.

One exception is the successful use of a "split-ring" valve sliding up and down in the cylinder head just above the piston, which has found successful application in a few motors recently built by the Renault Company, of France.

Rotating Valves. A number of engines with rotating valves have been built from time to time, but none of these seem to have survived the test of time, for not one which was in evidence two years ago is being made now. A case in point is the Speedwell car with the Mead rotating-valve motor. The motor was excellent but is no longer made.

Half-Time Shafts. For the actuation of the valve mechanism of any four-cycle motor, it is necessary to have a shaft (or in the case

Fig. 149. Intake Side of Moline-Knight 50-Horsepower Motor
Courtesy of Moline Automobile Company, East Moline, Illinois

of rotary valves, to run the valve itself as a shaft) turning at one-half the speed of the crankshaft through a two-to-one gear ratio.

Ordinarily the half-time shaft is the camshaft, but in motors of the Knight type it is, of course, an eccentric shaft. Camshafts, particularly, call for good workmanship and high-grade materials, as well as sound design, since the constant pounding of the valve stems or push rods on the cams is a prolific source of trouble, if anything but the soundest of sound construction be employed.

The most important recent innovation in this detail of automobile mechanism is the driving of half-time shafts by silent chains in place of the long-used gearing of spur and helical type. By this improvement the noise of the gears is eliminated.

A typical silent-chain installation, driving half-time shaft and other shafts as well, is seen in Fig. 150, which presents the King eight-

Fig. 150. Front of King Eight with Cover Removed to Show Use of Silent Chain
Courtesy of King Motor Car Company, Detroit, Michigan

cylinder motor with the chain cover removed. These occupy the compartment formerly called the gear case, or gear cover, when all driving was done by gears. Here it will be noted that there are two sprockets on the crankshaft; one driving the camshaft through the medium of a third sprocket which serves a double purpose, as a chain tightener and as a drive for the pressure oil pump; while the other sprocket, through a second silent chain, drives the electric generator at the right, no tightener being needed as the generator can be moved sufficiently to care for this.

In the Cadillac motor, shown in Fig. 2, Part I, a pair of gears is used, one driving the camshaft from the crankshaft, while the other drives the auxiliary shaft from the camshaft. In the American form of Knight sliding sleeve-valve motors, shown in Fig. 149, a pair of silent chains is used for the eccentric shaft on one side and the electric generator on the other. These are driven from a pair of sprockets set side by side on an extension of the crankshaft.

A point that should be brought out in connection with silent-chain camshaft driving is that the use of the chain allows the shafts to be placed anywhere desired and thus, to a certain extent, frees the designer from the former restriction of a two-to-one reduction ratio in the gears, which rather fixed the size and, consequently, the position of the gears. This restriction had an influence also upon cylinder design, as the center of the camshaft fixed the center of all the valves, that is, their distance from the center line of the motor.

DETAILS OF POPPET-VALVE GEARS

Cams

Function. Granting the necessity for proper means to regulate the inflow and outgo of the charge and consequent products of combustion, as exemplified by the valves, the next most important part is the one which controls the movement of the valve, and is, therefore, essential to the success of the latter. This is what is known as a cam and in the usual case amounts to an extension of, or projection from, the so-called camshaft. In as much as the valve functions only come into play upon every other stroke of the crankshaft, this camshaft is gear-driven from the crankshaft, so as to rotate at half the speed of the latter. This is very simply effected by having the cam gear twice as large as the crankshaft gear. As the same valve is never used for both the inlet and the exhaust, so the cams are seldom made to do more than the one thing, namely, operate one set of the valves. From this has grown the custom of referring to them according to the function of the valve which they operate—inlet cam, exhaust cam, etc.

In laying out or designing a set of cams for a gasoline engine, such as is used on an automobile, it is first necessary to decide

TABLE I

Valve Timing of a Number of American Cars

upon the exact cycle upon which to operate the engine. By this is meant the exact length of time, as referred to the stroke, in which the valve action will take place. Upon this subject, designers all over the world differ, and no wonder, as this cycle can but be judged by results, for it is impossible to watch it as it operates. Deductions differ, therefore, as to what happens and, consequently, as to the effect of various angles of beginning and ending the valve actions.

Valve Timing. Table I shows the valve setting of a number of standard 1920 cars of American manufacture. From this table it may be seen that the time of opening the exhaust valve has a range of from 35 degrees on the Maxwell to 71 degrees on the Stutz. The valve opens much earlier on the Stutz, so that plenty of time will be allowed to get rid of the burnt gases, as this motor operates at a fairly high rate of speed. The general average of the opening of this valve, however, is about 50 degrees before lower dead center. On the Mercer the valve opens at 70 degrees for the same reason as on the Stutz. The closing of the exhaust valve varies between 10 degrees before dead center on the Dorris and 25 degrees after dead center on the Franklin. This is considered a very wide range for the closing of the exhaust valve—much wider than in former practice. The Cadillac closes its exhaust valve at upper dead center. The Maxwell does likewise, while the others have this valve closing at an average of about 10 degrees past upper dead center.

The opening of the inlet valve also has a very wide range. The Franklin inlet opens 5 degrees before upper dead center, while the Chandler opens its intake valve 18 degrees 16 minutes after upper dead center. Both the Cadillac and the Chalmers open the intake valve at upper dead center. The King eight also has this opening. The average intake opening of the other motors is about 12 degrees past upper dead center. There are a few motors that have the positive timing; that is, the inlet opens at the same time that the exhaust closes. Examples will be found on the Stutz, National, Chevrolet, and Cadillac.

The closing of the inlet valve varies between 35 degrees and 57 degrees past lower dead center; 35 degrees is a very common position of this valve, while a few cars have their inlet valve closing at or above 50 degrees, such as the Stutz, National, Mercer, Franklin, Chalmers, Willys-Knight, Cameron, and Chevrolet. The closing of this inlet valve is made late on these models as the speed of the motor is generally high and this timing will allow a greater volumetric efficiency, which naturally increases the possible power output of the motor.

The late valve timing of the foreign motors is not available at this time. The earliest exhaust opening of the 1908 French cars was on the Mutel, the valve opening at 62 degrees before lower dead center. Referring to Table I, it will be noted that the earliest exhaust opening of the late American cars is on the Stutz, the valve opening at 71 degrees before lower dead center, while the average opening of the late American cars is 50 degrees before lower dead center, and the average opening of the exhaust in the 1908 French cars was 46 degrees and 20 minutes before lower dead center. This setting is similar. The inlet valve of the Unic (French) opens 40 degrees after lower dead center, while the inlet of the Peugeot closes 58 degrees past lower dead center. This closing position is rather extreme, although the Stutz inlet valve closes at 57 degrees past lower dead center, comparing very favorably with the Peugeot car.

The late American motors operate at a higher rate of speed than in the early part of the industry and it has, therefore, been necessary to use a valve timing that would allow a greater amount of gas to be taken in and expelled in order to obtain a satisfactory volumetric efficiency. Foreign motors have been built with a small bore and a long stroke, producing a very high speed for years. This accounts for the rather fast valve timing of these cars. The present tendency is toward small higher speed motors, as they are more economical to operate.

Timing Any Motor. Many automobile mechanics believe that gas engines cannot be timed unless the exact timing for the particular motor is known. This is true to a certain extent; yet it does not hold good throughout as the engine can be set at an average setting and give good results. The pitch of the timing gears is generally coarse enough to allow only one proper setting. When this position is almost reached the teeth of the camshaft gear, which mesh between the two correct teeth on the crankshaft gear, will be so close to the correct setting that less than the width of one tooth will be between that setting and the exact valve position.

The average setting taken from 146 cars, which include a number of prominent 1920 types, is: intake opens 10 degrees past upper dead center; intake closes 43 degrees past lower dead center; exhaust opens 50 degrees before upper dead center; exhaust closes 8 degrees after upper dead center. It will be noticed that the intake opens about 2 degrees after the exhaust valve has closed.

If the motor is of L-head construction, it will be necessary to follow only one mark, either that of the intake opening or of the exhaust closing. The other settings will naturally take care of themselves. In any case, however, the valves should be timed by the intake opening or the exhaust closing, as these two points vary the least.

Typical Valve Actions. Figs. 151 and 152 illustrate the complete valve action very well; the former, that of the Locomobile Company of America, Bridgeport, Connecticut, showing the form in which the cam works against a roller in the bottom of the push rod. This works upward in the push-rod guide and has a dirt excluding arrangement at the top. The top of the push rod bears against the bottom of the valve stem with an adjustable hardened screw forming the contact. The valve is held down on its seat in the cylinder by means of a strong spring, which the upward movement of the push rod opposes. The valve is guided in and has its bearing in the valve guide, which is made long to give large bearing surface. As the Locomobile motor is of the T-head type, the exhaust and inlet valves are on opposite sides of the cylinders and are operated by separate camshafts. The valve mechanism is completely enclosed.

The second figure shows the valve action used on Haynes cars, made by the Haynes Automobile Company, Kokomo, Indiana. The difference is in the elimination of the roller at the bottom of the push rod which forms the point of contact with the cam. In this form, a flat hardened surface makes the push rod more simple and reduces the number of parts. It has been said against this form that the cam scrapes across the push-rod face and thus wears it, but in actual use it has been found that the push rod rotates and in this way the wear is distributed over the whole flat face, which in this construction can be made much larger than can the face of the roller. The push rods are of the "mushroom" type and are

Fig. 151. Complete Valve Motion with Roller Push Rod
Courtesy of Locomobile Company of America, Bridgeport, Connecticut

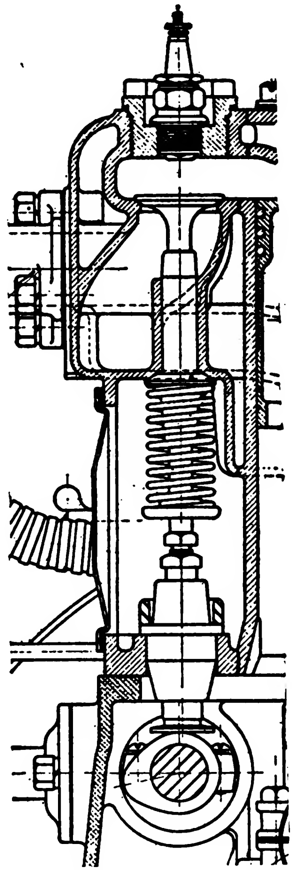


Fig. 152. Complete Valve Motion without Roller in Push Rod
Courtesy of Haynes Automobile Company, Kokomo, Indiana

made of nickel steel. The push-rod adjustments are completely enclosed but may be readily reached without disturbing any other unit. They may be removed and replaced without removing the valve springs or valves.

Neither of these systems is in decided favor, designers being about equally divided between them.

The construction and operation of the cam mechanism is the same whether used in connection with an exhaust or an inlet valve; as the same line of reasoning and the same method of procedure, in both cases, would lead to the same results.

It has many times been tried and still more often urged that the straight surface of the side of the cam is not conducive to the best results, because of the fact that when the first straight portion of the cam surface strikes the cam roller it does so with so much force that it tends to wear the latter in that direction. As for the receding face, it has been urged that the ordinary closing of the valve is too slow and that the straight surface can be altered so as to allow of speeding up the downward movement of the valve. This idea works out into a curve; the back of the surface is hollowed out so that as soon as the cam roller passes the center it drops vertically, owing to the tension of the spring. This method has been tried, but without success.

Fig. 153. Power Curve of an American Engine with Superior Cams and Balancing

What Good Modern Practice Shows. A more modern way, which is fast becoming universal, is to use straight sides for the cams and take advantage of rapid closing in another way, the benefits of which more than offset the benefits of the old way and have no corresponding disadvantages. In the ordinary automobile engine running at 1000 revolutions per minute, the gases are traveling into the cylinder at the rate of 5000 to 6000 feet per minute, and traveling out at from 7000 to 10,000 feet per minute. At this tremendous speed, the gas inertia is very high, and experiments go to show that the gases by means of this inertia will continue to force their way into the cylinder even against the return motion of the piston. So it is now common practice to hold the inlet valve open about 30 degrees on the upstroke of the piston, which results in a much larger piston charge. The same practice is carried out with the exhaust, but as the pressure is higher, so large an angle is not necessary. These actions take place on the back—flat side—of the cam surface and have given to the high-speed automobile engine a larger charge and a more complete scavenging effect, resulting in more power and speed from the same size of cylinder.

As proof of this statement, the power curve of an engine of but 3½-inch diameter of cylinder is shown in Fig. 153. This size of six-cylinder engine would be rated by any formula at about 29 horsepower at the maximum speed, and a commercially obtainable type in this size would doubtless be guaranteed to deliver between 20 and 25 horsepower. This engine, which is not built for racing purposes, displays a power curve which continuously rises; a speed at which it would turn downward has not been obtainable in the tests. This curve shows also that the maximum power obtained was over 80, which is nearly three times the power of the ordinary engine of this same size. This result is ascribable to superior valves and superior attention to the valve angles as governed by the cams.

Number of Valves per Cylinder. *Three Valves per Cylinder.* When it was stated that but two valves per cylinder were ordinarily used, with one cam for each, the majority case was spoken of. But, as it is a fact that there are other cases which differ from this, it would not be fair to close the subject without mentioning them. The most prominent advocate of air cooling in this country and the world, the H. H. Franklin Manufacturing Company, used three valves, and consequently three cams, per cylinder. These three were the ordinary inlet; the usual exhaust; and the additional auxiliary exhaust. By re-designing later, this complication was avoided and the third valve eliminated.

The Wisconsin Motor Company has developed another motor with four valves per cylinder and, after a notable racing success, has placed it upon the market. Any maker desiring to do so, may purchase this and incorporate it in his chassis. This emphasizes the distance which the sixteen-valve four-cylinder motor has progressed in the space of a year or so. A section through this motor, both side elevation and end view, showing all the details of the construction, is shown in Fig. 154. The exhaust of the Stutz motor is given in Fig. 155.

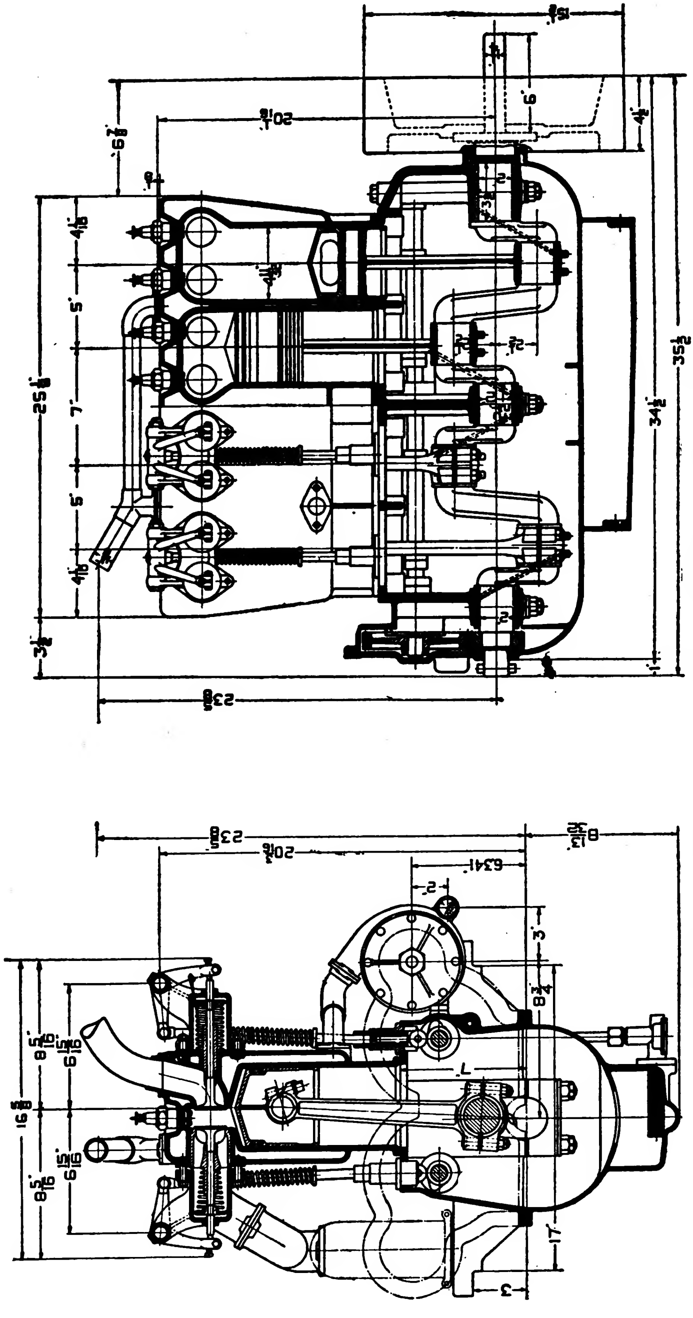


Fig. 154. Sections through Wisconsin Sixteen-Valve Motor—Side and End Views
Courtesy of Wisconsin Motor Company, Milwaukee, Wisconsin

Four Valves per Cylinder. The very latest practice in the way of multiple valves is the use of four valves per cylinder—two inlets and two exhausts. There are a number of reasons why this construction is a good one. The area through which the gases enter and leave the cylinders is made greater, thus giving the same or greater supply of gas more quickly and a better scavenging effect.

The volumetric efficiency of the cylinder is greatly increased in this way, giving more power and speed from the same size of cylinders—so much more as to give a four-cylinder engine with

Fig. 155. Exhaust Side of the 1920 Stutz Sixteen-Valve Motor

sixteen valves as great a flexibility as that of a six-cylinder with but twelve valves. Another big advantage claimed for the smaller lighter valves of this construction is that very much lighter valve springs can be used. This advantage was discovered by using sixteen valves on a four-cylinder racing engine where the compression and other pressures were enormous. The valve springs for the ordinary eight-valve engine had to be very stiff and, consequently, gave much cam trouble. The stiff springs dug out the sides of the cams very rapidly and also failed rapidly themselves.

With the lighter springs which can be used with sixteen valves, these troubles are eliminated.

In the 23 cars starting in the 1920 Indianapolis Derby, 13 were of the four-cylinder forms and the remaining 10 were seven-cylinder cars. The four-cylinder cars had sixteen valves with exception of 3, these having twenty valves. The eights were constructed with all cylinders in line and four valves to each cylinder. In the sixteen-valve motor developed by the Stutz Motor Car Company, the engine has the outward appearance of any other T-head form, for the use of double the usual number of valves does not change the exterior at all.

Fig. 156. Carburetor Side of the Monroe Racing Type Engine. (Winner of the 1920 Indianapolis Race)

In the majority of V-type motors, both eights and twelves, the valves are in side pockets; the cylinders are of the L-type, and thus there is no radical innovation except the inclined push rods and valve systems. In a few of these motors, however, a follower is used between the cams and the push rods because of some other structural reasons.

When any kind of a cam follower differing from the usual direct-lift push rod is used, this may or may not affect the shape of the cam. Usually it does not, so that the shape does not have to be taken into account. Ordinarily these followers are used to prevent side thrust on the push-rod guide, the follower itself taking all the thrust and being so designed as to be readily removable or adjustable, to take care of this. In cases where this does not obtain, the object usually sought is the removal of noise. The two objects may be combined, as in the case shown in Fig. 158. This represents an enlarged view of the cam mechanism of the famous one-cylinder French car, Peugeot. It will be clear that the action is that of one cam operating both the exhaust and the inlet valves through the medium of a pair of levers, upon which the cam works alternately.

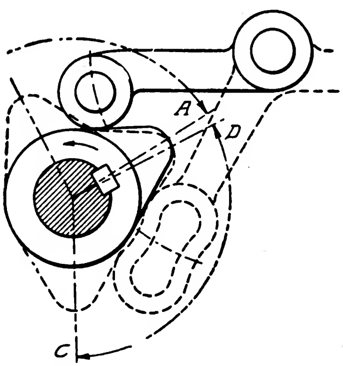


Fig. 158. Cam Mechanism of Peugeot Single-Cylinder Engine

A cam follower of somewhat different form, but one achieving the same results, will be noted in the Cadillac eight-cylinder motor, shown in Fig. 164, where attention has been called to these, and also in the Chalmers six-cylinder motor with overhead valves, shown in Fig. 156.

Difficulties in Making Cams. There was a time when the production of a good, accurate camshaft was a big job in any machine shop, well-equipped or otherwise, and represented the expenditure of much money in jigs, tools, and fixtures. Now, however, the machine-tool builder has come to the rescue of the automobile manufacturer, and special tools have made the work easy. So it was with the production of the shaft with integral cams; this used to be a big

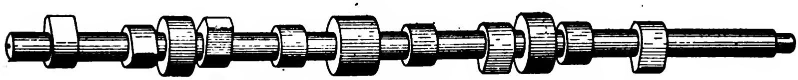


Fig. 159. Cams Integral with Shaft—Milling Machine Job

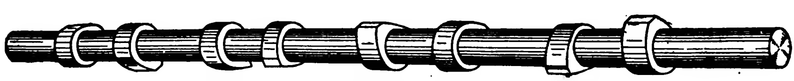


Fig. 160. Another Camshaft with Integral Cams

undertaking, but today special machinery has made it an easy matter. The illustrations, Figs. 159 and 160, show some of the product of a cam milling machine. This is now the favored way of putting out engines, for the integral cams and shaft have the advantage of much lower first cost and, with proper hardening, will last fully as long as those made by mounting the separate cams directly on the shaft.

Grinding Increases Accuracy. An even later improvement in the way of a machine for producing cams on an integral shaft is the grinding machine which has been developed for this purpose. This works to what is called a master camshaft, that is, a larger size of shaft which has been very accurately finished. This master shaft is placed in the grinding machine, the construction of which is such that the grinding wheel follows the contour of the very accurate master shaft and produces a duplicate of it, only reduced in size, a reducing motion being used between master shaft and grinder-wheel shaft.

The result of this arrangement is a machine which is almost human in its action, for it moves outward for the high points on the cams and inward for the low spots on the shaft. Moreover, it has the further advantage that all shafts turned out are absolutely alike and thus accurately interchangeable. It allows also of another arrangement of the work, the drop forging of the shafts within a few thousandths of an inch in size; the surface of skin is easily ground off in one operation, then the hardening is done, and the final grinding to size is quickly accomplished. In this way, the shafts may be produced more cheaply than was formerly the case and have, in addition, the merits brought out above, namely, greater accuracy, superior interchangeability, and quicker production.

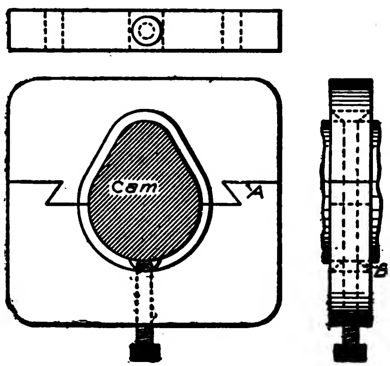


Fig. 161. Useful Form of Gage for Separate Cams

The same process is applicable to, and is used for, other parts of the modern motor car; thus crankshafts are ground, pump and magneto shafts are finished by grinding, and many other applications of this process are utilized. The process can be extended indefinitely, the only drawback being that a master shaft is very expensive.

Old Way Required More Accurate Inspection. With the old method of making the cams and shaft separate, the amount of inspection work was very great and represented a large total expense in the cost of the car. Thus, it was necessary to prove up every cam separately, as well as every shaft, and, later, the cams and shaft assembled. One of the forms of gages used for inspecting cams is shown in Fig. 161. It is in two pieces, dovetailed together. This allows of the testing of many shapes of cam with but one base piece and a number of upper, or profile, pieces equal to the number of different cams to be tested. To test, the cam is slipped into the opening, and if small, the set screw forces it up into the formed part of the gage, showing its deficiencies; while if large, it will not enter the form.

Valve Timing

This increase of speed without material alteration in the engine is what every repair man aims to get when he goes over the timing of the motor. Valve timing has been called an art, but it is not; it is only the application of common sense and the known valve diagram to the motor in an attempt to get the best all-around results. These, as might be expected, are a compromise, and that repair man does the best timing, who realizes this and, instead of attempting the impossible, simply produces the most desirable all-around compromise.

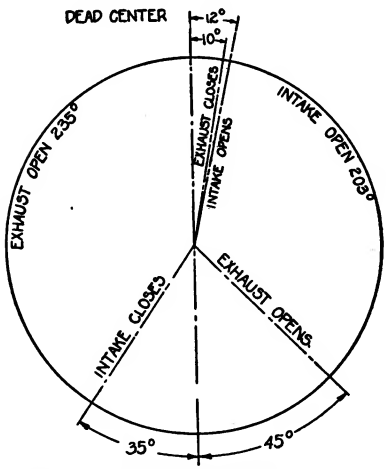


Fig. 162. Overland Four Valve Timing

Flywheel Markings. Nearly all motors now have the timing marked upon the rim or face of the flywheel, so that it is unnecessary to bother with the crankshaft and pistons. This has been found by experience to be the best and handiest way, for the flywheel is generally accessible without removing many other parts. The same is true with the valves. This is not the case with pistons and crankshaft; moreover, with these it is difficult to determine the exact upper and lower dead centers, and still more difficult to work to angles.

To use these settings marked on the flywheel, a stationary pointer on the upper surface of the crankcase hangs over the flywheel surface as closely as possible and indicates the reading. The flywheel is turned by hand or by means of the crank at the front of the engine until a mark or the desired mark is brought up to the pointer. Thus, the cylinders are marked from front to back always, that nearest the radiator being 1, the next 2, then 3, and the last, in the case of a four-cylinder motor, 4. In a six-cylinder motor the method is the same with the addition of two cylinders, the one nearest the dash being, of course, 6. The flywheel sometimes has the positions marked on its surface, as well as the valve operations. Referring to Fig. 162, this shows the valve-timing diagram of the Overland Four, 1920 model. Notice in this that none of the valve operations begin or end on a dead center point so that even if the centers are marked on the flywheel (as they are in this case) this is of little benefit except as will be pointed out. The marks on the flywheel are as follows, this showing also what they indicate. In referring to these it will be remembered that on a four-cylinder crankshaft the first and fourth crankpins are up (or down) together, while the second and third are down (or up) together:

1-4 UP	Means that pistons in cylinders 1 and 4 are in their uppermost position, or at upper dead center.
2-3 UP	Means that pistons in cylinders 2 and 3 are in their uppermost position, or at upper dead center.
1-4 I-O	Means that inlet valve of cylinder 1 or 4 (not both) opens.
1-4 I-C	Means inlet valve of cylinder 1 or 4 closes.
1-4 E-O	Means exhaust valve of cylinder 1 or 4 opens.
1-4 E-C	Means exhaust valve of cylinder 1 or 4 closes.
2-3 I-O	Means inlet of cylinder 2 or 3 opens.
2-3 I-C	Means inlet of cylinder 2 or 3 closes.
2-3 E-O	Means exhaust of cylinder 2 or 3 opens.
2-3 E-C	Means exhaust of cylinder 2 or 3 closes.

The firing order of the cylinders is 1- 3- 4- 2. To apply this knowledge, open the pet cocks so the motor will turn over easily; selecting cylinder 1 to start with, turn the flywheel until the mark 1-4 UP comes to the pointer at the top. Now continue turning to the left (at the rear end) about an inch more when the mark 1-4 I-O will be seen. Bring this slowly up to the pointer, when the inlet valve should just begin to open. This can be noted by feeling the stem, or by placing a wire upon the top of the valve and noting when it begins to be pushed upward by the valve movement. If this should happen in cylinder 4 instead of 1, turn the flywheel one complete revolution, bringing the same point to the top. If this is entirely correct, the flywheel can be turned in the same direction about 5 to 6 inches more than half a turn, when the mark 1-4 I-C will appear. Turn slowly until it reaches the pointer, when the valve in cylinder 1 should be completely closed. This can be determined again by feeling of the valve stem which should come down to its lowest position, or by the wire on the top of the valve. At this point the valve-tappet clearance comes in. When the valve tappet has reached its lowest point, and the valve has been allowed to seat, the tappet should go down slightly farther than the valve, leaving a very small space between the two. This is the clearance and it varies in normal engines from .002 inch to .012 inch. In the motor which is being described it is .012 inch. The closest approximation to this is an ordinary visiting card, which is about .012 inch thick; when a motor is handled which has less, very much less, this can be approximated by means of cigarette papers which are very close to .003 inch thick. These are used in the absence of precise metal thickness gages, or feelers, as they are called.

Valve-Stem Clearance. This clearance is necessary to compensate for the expansion of the valve stem when it becomes highly heated during the operation of the engine; the tappet or push rod does not become heated, consequently it does not expand. Practically all motors are made with an adjustment here in the form of a screw with a hexagon head which is hardened where it strikes the valve stem or it is recessed out for a piece of hard fiber to deaden the noise, Fig. 151, and the fiber is locked in the desired position by means of a lock nut. If the clearance is less than the required amount or greater so that the motor is very noisy, the lock nut is loosened, and the screw gradually turned upward until it just begins to grip the visiting card. This should be done very carefully, for if the clearance is made too small, the valve will not seat fully when the motor is hot and the valve has expanded; on the other hand, if the clearance is made too large, the push rod will come up against the valve end each time with a bang, and eight of these repeated a thousand times a minute make a great deal of disagreeable and useless noise. In the modern motor, the cams are made an integral part of the camshaft. If the driving gear for the camshaft is in its right place, and the camshaft bearings are all in good shape, this push rod adjustment is the only valve adjustment possible. If the timing is not correct, that is, if none of the valve operations correspond with the marks on the flywheel and the maker's instructions, then the cam gear has been misplaced.

Exhaust-Valve Setting. The same procedure is followed through for the exhaust valve of the same cylinder, continuing past the 1-4 UP mark to the mark 1-4 E-O. At this point the exhaust valve of cylinder 1 should just begin to open. Then continue around to the

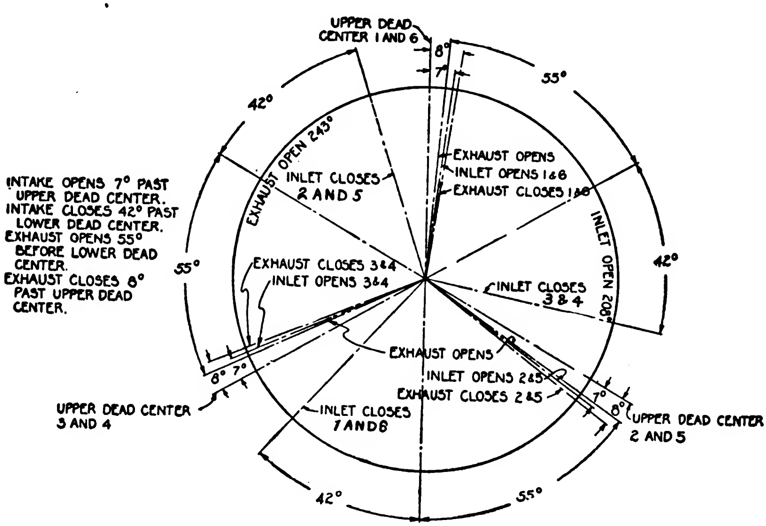


Fig. 163. Valve Timing Diagram for Hudson Super-Six Motor, Showing All Cylinders

1-4 E-C point where the exhaust valve of cylinder 1 is just completing its downward, or closing, movement. If there should be any need for adjustment here, as described previously, this should be made before proceeding to the other cylinders. It should be stated that many makers give the exhaust-valve stems slightly greater clearance than the inlets, on the assumption that they work with hotter gases, are subjected to more heat, and should therefore expand more. The make being described has the same clearance for both valves; .004-inch clearance on the intake and .005 to .006-inch on the exhaust are recommended.

Relation of Settings in Each Cylinder. Now, having checked up and adjusted both valves for cylinder 1, follow through the same process for cylinder 4, and, after that, of cylinder 2, then 3. The diagram, Fig. 162, shows but the cycle in each cylinder, while the description above simply listed the markings to be found on the flywheel, so the additional diagram, Fig. 163, is given to show the relation of these marks to one another. This diagram refers to a different motor, a Hudson Super-Six model, and the timing is indicated on the face, but the repair man will understand that this is done simply for convenience, and that these marks are actually found on the rim. So, too, the lines drawn down to the center are simply shown for convenience in indicating the angles and do not appear on the flywheel.

Fig. 164. Section through Cadillac Eight, Showing Camshaft and Valve Mechanism
Courtesy of Cadillac Motor Car Company, Detroit, Michigan

In this a different timing will be noted, in that the inlet opens later and closes earlier, while the exhaust opens earlier and closes earlier.

System Applies to All Types of Motors. As has been stated previously, discussed, and shown in Table I, there is now, and always has been, a wide divergence among designers on the subject of valve timing, so that the repair man must look for a different setting with each different make, and often a different setting with each different model of the same make. All that can be used for all cars is the general method. The general method, however, is applicable whether the valves are all on one side (L-head cylinders), half on each side (T-head cylinders), all in the head or half on one side and the other half in the head, in short, regardless of the valve position. Similarly with regard to numbers, the method holds good regardless of the number of valves per cylinder. Moreover, it applies regardless of the number and arrangement of the cylinders, as it is just as good for eights and twelves as for the four described. On V-type motors there is a close relation between the opposing cylinders, right-hand No. 1 and left-hand No. 1, and this must be taken into account. In some motors there is a cam for each valve, in which case no trouble would ensue; but in others there are but eight cams for the sixteen valves (of an eight-cylinder motor). This type of shaft will influence the timing diagram, and in setting, the repair man will have to concern himself with the same cam for two different valves—

Fig. 165. Cadillac Camshaft, Cam Followers, and Covers Removed from Motor

one in a cylinder of the right-hand group and one in a cylinder of the left-hand group.

This statement will be more plain perhaps if reference is made to Fig. 164, which shows a section through the Cadillac eight for 1917, and indicates how the one cam operates two valves through the hinged rocker arms *A* on the left-hand cylinder and *B* on the right for the right-hand cylinder. By comparison, see also Fig. 165, which shows the plate *C* in Fig. 164 removed and turned upside down, with the camshaft and rockers complete. Not all eights and twelves are like this, nor do all have a single camshaft set in the middle of the V; on the contrary, one well-known twelve-cylinder motor, the National, has the valves on the outside of the two groups of cylinders, and thus has two camshafts. In such a case, the timing method just described would be followed through for all the cylinders on one block, then the same system would be followed through on the other side of the engine, one cylinder after another, on that block.

Repairing Poppet Valves and Valve Parts

The interest of the repair man in all these valve-motion parts is quite different from that of the designer, for he cares not so much how they are made as how they are taken out, repaired, and put back, when accident or wear make this work necessary. To the repair man suitable tools for doing this kind of work are also of interest, particularly those for reaching inaccessible parts or for doing things which without the tools could not be done.

Curing a Noisy Tappet. Valve springs and the valves themselves, either at the seat end or at the tappet end, give the most trouble. For example, when the clearance between the end of the tappet and the end of the valve (usually from .003 to .008 inch) is too great, a metallic click results. Often this noise from the tappet is mistaken for a motor knock; but the skilled repair man has little trouble in finding and remedying it, for, even if he cannot measure in thousandths of an inch, he knows, for instance, that the ordinary cigarette paper is about .003 inch in thickness, and from this he can estimate .003, .006, or .009 inch. Ordinary thin wrapping paper is well known to be about .005 inch; with this alone, or in combination with cigarette papers, he can obtain .005, .008, .010, and .011 inch, practically all the variation he is likely to need.

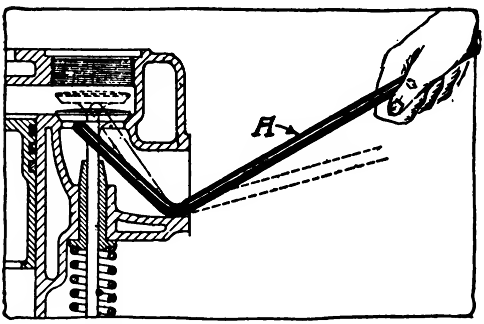


Fig. 166. Bent Tool Which Facilitates Removal of Stuck Valves

Removing Valve. Getting the valve out frequently gives much trouble; the valve is often found frozen to its seat or to the stem gummed in its guide. A tool to meet this difficulty is a plain bar or round iron about ¼ inch in diameter, Fig. 166, with one end, for a distance of perhaps 2 or 2½ inches, bent up at an angle of about 120 degrees. To use the tool, insert the short bent end in the exhaust or the inlet opening, according to which valve is stuck, until the end touches the under side of the valve head, then lower the outer end until the bottom of the bent part or point at which the bend occurs rests against solid metal. The outer end can now be pressed down, and, with the inner end acting as a lever, the valve can be pressed off its seat and out very quickly.

To make this clearer, the rod, Fig. 166, is indicated at *A*, while the dotted line shows how it is pressed down and the valve forced out. The garage man can elaborate upon the tool when making it for himself by using square stock; it has the inner end forked so as to bear on each side of the valve. The form pointed out above is the simplest, cheapest, and easiest to make.

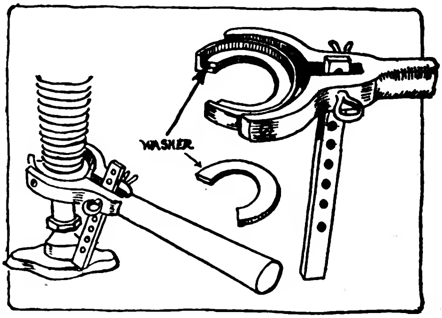


Fig. 167. Easily Made Tool for Removing Valve Spring

Removing Valve Spring. Taking out the valve spring is frequently difficult for various reasons; perhaps the springs are very stiff, or they may have rusted to the valve cups at the bottom, or the design may not allow room enough to work, etc. At any rate the removal is difficult, and a tool which will help in this and which is simple and cheap, is in demand. Many motor cylinders are cast with a slight projection, or shelf, opposite the valve-spring positions, so that one only needs a tool that will encircle the lower end of the valve spring and rest upon this ledge and give an outer leverage.

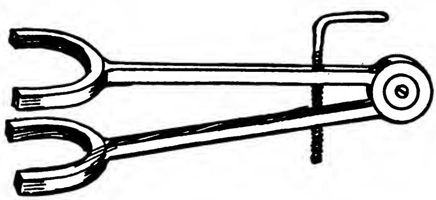


Fig. 168. Type of Valve-Spring Tool Which Leaves the Hands Free

Types of Valve Removers. In working on cylinders that do not have this cast projection, a tool like that shown in Fig. 167 is useful. It consists of a yoke for encircling the lower end of valve spring and cup, with a long outer arm for prying, and a slot into which a drilled bar is set. This bar is placed in various positions according to the kind of motor which is being worked on; when removing a valve-spring key, the lower end of the bar rests upon the crankcase upper surface, or upon the push-rod upper surface if that is extended. After slipping the grooved yoke under the spring cup, a simple pressure on the outer end raises the valve so the key can be withdrawn. Then the removal of the tool allows the valve spring to drop down, and the valve is free.

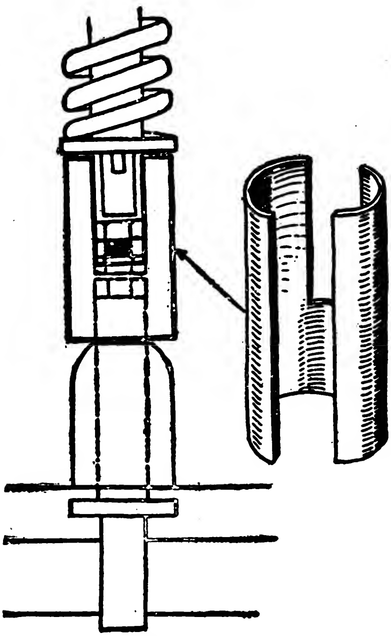


Fig. 169. Substitute for a Valve Spring Remover Which Pushes Spring away as Motor is Turned

The valve spring may be removed in two other ways by the use of the two tools shown in Figs. 168 and 169. In the former, the idea is to compress the spring only, no other part being touched. This tool, once set, will continue to hold the spring compressed, leaving the hands free—a decided advantage over the tool shown in Fig. 167. This device consists, as the illustration shows, of a pair of arms with forked inner ends and with outer ends joined by a pin. A bent-handled screw draws the ends together or separates them, according to which way it is turned.

The simplest tool of all is the one shown in Fig. 169. It is a formed piece of stiff sheet metal which is set into place when the valve is open, and when the valve is closed by turning the motor, the sheet-metal piece holds the spring up in its compressed position.

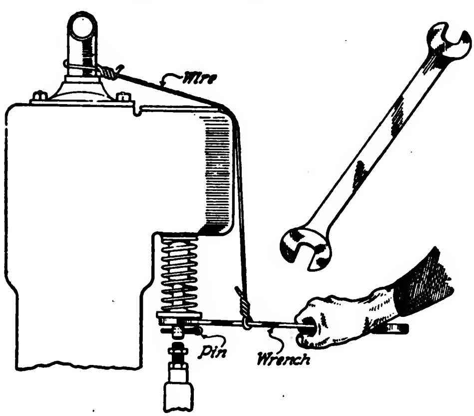


Fig. 170. Method of Compressing Valve Spring without Special Tool
Courtesy of "Motor World"

There are almost as many different valve and valve-spring removers as there are different cars or different motors. However, the simple makeshift shown in Fig. 170 is worthy of mention. Lacking a form of valve- or spring-removing tool, this repair man simply supported a plain double-ended wrench by means of a wire attached to the water pipe on top of the motor; adjusting the length of it so that the end of the wrench would just slip under the valve key, he was able to remove the pin, which freed the spring and thus the valve. Practically the same thing was evolved by another repair man who took a wrench of this type and drilled a hole through the center of the handle which was first twisted through a right angle. Then he bent a piece of stout wire into the form of a hook, one end through the wrench, the other over some projection on the engine. With the hook removed, the wrench was not radically different from any other and could be used as freely; with the hook in, he had a simple valve-spring removing tool.

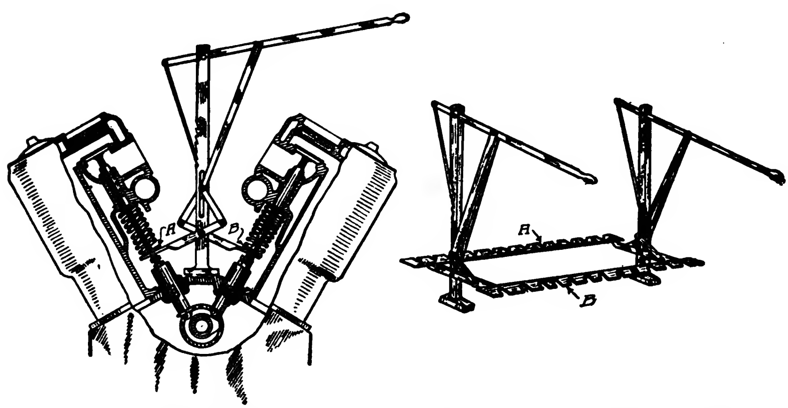


Fig. 171. Method of Compressing All Twenty-Four Packard Valve Springs at Once
Courtesy of "Motor World"

Twelve-Cylinder Valve Remover. One of the objections raised to the twelve-cylinder motor is the trouble of removing and grinding all the valves. The Philadelphia Branch of the Packard Company has overcome this disadvantage by constructing the special tool shown in Fig. 171. This lifts the whole 24 valves at once. It consists of the central stand, which rests on the flat top of the crankcase, having a long arm and connected levers at the bottom to work the spring compressors. These, as will be seen at *A* and *B*, are really the special feature of the outfit, as they are specially constructed to fit around the valves in sets of 12 each. A ratchet holds the device locked, so that after it is applied and fitted to all the valves, they can be forced up and locked; then the matter of valve removal, regrinding, and replacement can be handled for the whole 24. At its conclusion, the rigging can be unlocked and all 24 valves freed at once.

Holding Valve Springs Compressed. Many times there is a need for holding the spring in its compressed form, as, for instance, when the valve is removed with the positive certainty that it will be replaced within four or five minutes. In such a case a clamp which will hold it in compression is very useful, for it saves both time and work. These may be made to the form shown in Fig. 172 in a few minutes' time, for they consist simply of a pair of sheet-metal strips with the ends bent over to form a very wide U-shape. A pair of these is made for each separate make of valve spring, because of the varying lengths, but they are so easily and quickly made that this is no disadvantage.

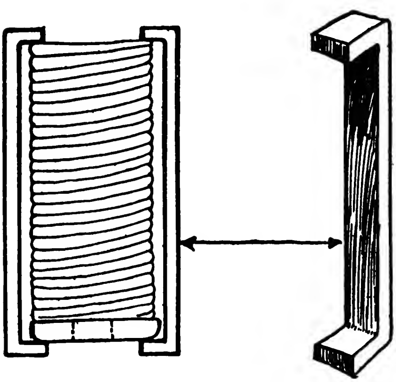


Fig. 172. Spring Clamp, Which Is Easily Made and Saves Much Work and Trouble

In many shops, after getting in the habit of making these clamps, the workmen take this way of replacing the spring in preference to all others. After removal of the valve, the spring may be compressed in a vise and a pair of the clamps put on. Then when the valve is ready to go back in, the spring is as easy to handle as any other part. This is especially true when replacing the spring retainer and its lock.

Stretching and Tempering Valve Springs. Many times when valve springs become weakened, they can be stretched to their former length, so that their original strength is restored. This can be done by removing them and stretching each individual coil, taking care to do it as evenly as possible. When well stretched, it is advisable to leave the coils that way for several days. This method will not, of course, restore the strength permanently; it is at best a makeshift, for in the course of a few thousand miles the springs will be as bad as before.

Sometimes weakened valve springs may be renewed by retempering, on the theory that the original temper was not good or they would not have broken down in use. The tempering is done by heating to a blood-red color and quenching in whale oil. If this is not successful, new springs are advised.

Adjusting Tension of Valves. Unless all the valves on a motor agree, it will run irregularly, that is, all the exhausts must be of the same tension, and all the inlets must agree among themselves, though not necessarily with the exhausts. Many times irregular running of this kind, called galloping, is more difficult to trace and remove than missing or some other form of more serious trouble, and it is fully as annoying to the owner as missing would be.

To be certain of finding this trouble, the repair man should have a means of testing the strength of springs; a simple device for this purpose is shown in Fig. 173. As will be seen, this consists of sheet-metal strips and connecting rods of light stock, with a hook at the top for a spring balance and a connection at the bottom to a pivoted hand lever for compressing the spring. By means of the center rod at *R* and the thumb screw at the bottom, the exact pressure required to compress the spring to a certain size may be determined. Suppose the spring should compress from 4 inches to $3\frac{1}{2}$ inches under 50 pounds. By compressing it in the center portion of the device, so that the distance between the two adjacent strips of metal indicated by *S* is just $3\frac{1}{2}$ inches, the spring balance should show just 50 pounds. If it shows any less, the spring is too weak and should be discarded; if it shows any more, it is stronger than normal—which is desirable if all the other springs on the same engine are also stronger.

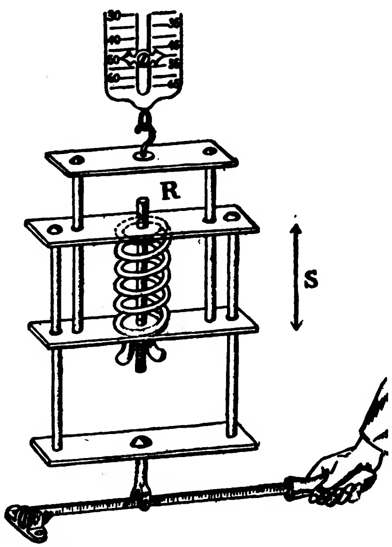


Fig. 173. Simple Rigging for Testing Valve-Spring Pressure and Strength

If only a quick comparison of four springs is desired, the device can be made without the bottom lever, as the setting of *S* at a definite figure—say to a template of exact length—would call for a certain reading of the scale of the spring balance.

Cutting Valve-Key Slots. Cutting valve-key slots in valve stems is another mean job which the repair man frequently meets. He runs across this in repairing old cars for which he has to make new valves; and at other times for other repairs. The best plan is to make a simple jig which will hold, guide, and measure all these things at once, as all are important. Such a jig is shown in Fig. 174. It consists of a piece of round or other bar stock, in which a central longitudinal hole is drilled to fit the valve stem, one end being threaded for a set screw. Near the other end of the jig, three holes, of such a diameter as to correspond with the width of key slot desired, are drilled in from the side. These are so placed that the length from the top of the upper hole to the bottom of the lower gives the length of key seat desired. Opposite the three drilled holes and at right angles to them, another hole is drilled and tapped for a set screw.

Fig. 174. Cheap Jig for Slotting Valve Stems

To use the device, slip the valve in place and set the bottom screw of the jig so as to bring the three drilled holes at the correct height for the location of the key seat. Then the three holes are drilled, and the valve is moved upward so that the space between the holes is opposite a guide hole, and two more holes are drilled to take out the metal between. The five holes will give a fairly clean slot, which needs a little cleaning out with a file before using.

Grinding the Valves. The new driver must learn when to grind his valves, that is, how often, and he must also learn to do the work properly. There is no hard and fast rule which can be given aside from grinding when it is necessary. A careful driver may get four to five thousand miles out of his valves with one grinding, while another may get only one or two thousand miles with the selfsame car and engine. There are many factors which enter into the life of a valve seat, and, in the frequency of grinding, all of these have to be taken into account. Some of these are: imperfect cooling of the seats; too strong springs, which cause hammering and thus wear out the seats prematurely; over-lubricating, which causes spitting and sooting, both of which reduce the active life of the valve seat.

Another cause for frequent grinding is contributory negligence on the part of the driver. He does not examine them as often as he should, and the result is failure to discover something in the way of soot or dust caught in between the valve and seat, which is being gradually pressed into the seat.

Regrinding Process. When either the valve head or seat has become worn or pitted, it must be reground as follows: Secure a small amount of flour of emery, the finer the better, and mix this into a thin paste using cylinder oil, or graphite, or both. Loosen the valve, disconnect all attachments, remove the valve cap above, and free the valve in a vertical direction. Now lift it out, place a daub of the emery paste on the seat, and replace the valve. With a large screwdriver

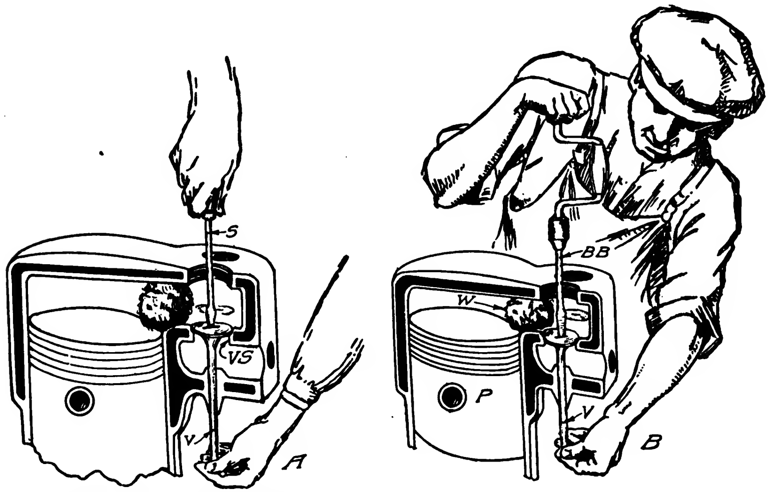


Fig. 175. Two methods of Grinding-In Valves: (*A*) by Hand, Using a Screwdriver; (*B*) with Brace, Screwdriver and Bit

press the valve firmly in place, at the same time rotating it about one-fourth of a turn to the right and then the same amount to the left.

This is shown in Fig. 175-*A*, in which *S* is the screwdriver, *V* the valve, and *VS* the valve seat. Note how the right hand presses down on the screwdriver and turns it at the same time. While this is being done, the left hand should be held right below the valve stem with one finger just touching it. After moving back and forth about eight or ten times, lift the valve off its seat with the finger, turn it through a quarter-turn, and drop it back into place. Then repeat the grinding until the whole circle has been covered several times. Then remove the valve and clean off both moving member and seat with gasoline. Mark the seat on the valve with a slight touch of Prussian blue, replace the valve, and twirl it around several times so as to distribute the color. Remove the valve without touching the seat portion on it or in the cylinder, and examine both. If the grinding process has been complete and accurate, the color will have been distributed in a continuous band of equal width all around the surface. If not continuous, or not of equal width all around, the task is but partially completed and must be continued until the full streak results. On the first attempt at this rather delicate piece of work, it is well to call in an expert repair man to examine and pass upon the job.

In Fig. 175B the same process is shown, but a brace, screw-driver, and bit are used in place of the slower screwdriver. This method would hardly be advocated for an amateur attempting his first job of valve grinding, but as soon as some proficiency has been attained, it is the best, quickest, and most thorough method.

There are, of course, a number of tools now on the market for grinding valves; some of these are constructed in such a manner as to do all the work, namely, the partial turn and reverse on the grinding stroke, then the lift and partial revolution, then dropping the valve down on the seat again, and repeat. The use of one of these tools reduces the act of valve grinding to a matter of knowing how to apply the emery and when and how to stop.

Noisy Valves. Sometimes the valves get very noisy and bother the driver a great deal in this way, that is, the wear in the valve-operating system becomes so considerable as to make a noise every time a valve is opened or closed. With the engine running at slow speeds, each one of these is heard as a separate small noise and not much is thought of it, but when the motor is speeded up, the noises all increase and become continuous and very noticeable. This may be remedied by taking up the valve tappets which usually are made adjustable for this purpose. They should be taken up until there is but a few thousandths of an inch between the valve tappet and the lower end of the valve stem. A good way to measure this is to adjust until one thickness of tissue paper will just pass between the two; then there is approximately 0.003 inch between them.

The clearance between the end of the valve stems varies a great deal in different motors. This depends mainly upon the cam clearance, the length of the valve stems and the cooling of the stems. A variable thickness gauge may be had from any supply house.

Troubles with Inlet Valve. The inlet valve is often the seat of the trouble, and missing here is generally caused by a weak or broken spring, a bent stem, or a carbonized valve. If the valve spring has lost its temper and broken down, the tension will be insufficient to properly hold the valve on its seat, and the gas will partially escape and so cause missing. The insertion of an iron washer or two will increase the tension of the defective spring and serve as a temporary road repair. A broken spring may be similarly repaired by placing a washer between the broken ends. A bent valve stem should be taken out and carefully straightened by laying it upon a billet of wood with another block interposed between it and the hammer. Only a very little force is needed, and the stem should be repeatedly tried until it slides freely in its guide.

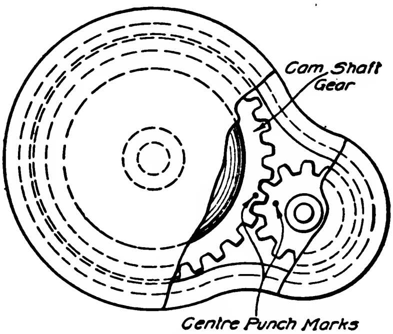


Fig. 178. Marking Timing Gears Is a Simple Job and Saves Much Time and Trouble

Valve Timing Gears. As has been stated, the camshaft is generally gear-driven from a crankshaft by a pair of two-to-one reduction gears; these are simple spur gears with straight or spiral teeth. As the one gear is keyed to the crankshaft and the other to the camshaft, it is highly important that these two gears be meshed in an exact manner. If one of them is out as little as one tooth, the difference in the running of the engine will be very marked. The timing previously mentioned under the head of Valve Timing will not be obtained; either all operations will occur later than the valve timing diagram and instructions call for, or else all these will be earlier. In either case, there will be a loss of speed and power, accompanied by noise, and the engine will not throttle down or speed.

To avoid this difficulty for the repair man, all gears are set and marked correctly at the factory. The marking is done in several ways. One is by lines cut on the gears when correctly meshed, so that if the gears are correctly meshed later, the part of a line on one gear will be a prolongation of the part on the other. Another way is to use center punch marks, one mark between the teeth on one and on the tooth meshing with these on the other. Then, if a second place has to be marked, two prick-punch marks are used in a similar manner, and if a third is marked, three punch marks. A third method is the use of numbers, the first pair marked being numbered *1* on each gear at the point of meshing, the second pair marked *2* on each, etc.

For the second method, all that is necessary is a prick punch and hammer, used in the manner shown in Fig. 178. When there are but

Fig. 179. Method of Marking Timing Gears by Means of Numbers

two gears, as in the case shown, it is easy to make one hole between two teeth on one gear and another which lines up with it and as close to it as possible on the other gear. Where there are three, four, or more gears, the usual practice is to make the first and third with two prick-punch marks on each, the others with three, four, etc.

For the third method, or the use of numbers, see the set of gears shown in Fig. 179. This figure is that of the engine whose timing was described and shown in Fig. 162. It has four gears; from right to left they are camshaft gear, crankshaft gear, idler gear, and magneto gear. As will be noted, the crankshaft gear meshes with two others, so it must be marked in two places, *1* where it meshes with the camshaft gear and *2* where it meshes with the idler. A moment's thought will show, however, that it could never be replaced in the wrong manner, since it is marked only on the outside face, its *1* and *2* figures show where it matches a *1* mark on one gear and a *2* mark on another.

Chain Drive for Camshafts. The silent chain has gained much popularity for camshaft and accessory drives in the last two years for a number of reasons. It saves the use of idler gears in such cases as

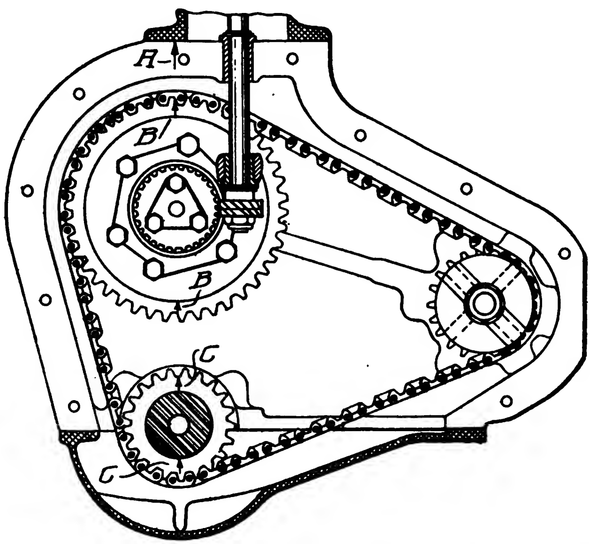


Fig. 180. Silent-Chain Drive for Packard Twelve, Showing Method of Marking

that just illustrated and described; it allows the placing of the camshaft and other shafts anywhere desired (at least in so far as the gear is concerned); it is more quiet than the gear drive in the prescribed position which the two-to-one reduction necessitates; it is less expensive to construct and apply, and it weighs slightly less. The teeth on the silent-chain gearing are called sprocket teeth, while those on the two-to-one reduction are called gear teeth.

In the silent-chain drive for camshaft and accessories, which is shown in Fig. 180, it will be noted that there is a line scribed vertically across both gears and the crankcase, with prick-punch marks on the case at *A*, on the camshaft sprocket at *BB*, and on the crankshaft sprocket at *CC*. This makes its correct adjustment easy. A straightedge is laid across the case marks, the crankshaft sprocket turned to this line, and the chain put in place but not joined; finally the camshaft sprocket is turned to the line, the chain moved to hold it in this position, and its ends joined. By this method, there would be two possible positions for the camshaft sprocket, as compared with the crankshaft sprocket and line on the case. These could readily be distinguished as correct and incorrect as soon as the chain is applied and the engine given a couple of turns. If incorrect, it is simply a matter of lining them up again by opening the chain, turning the camshaft gear through 180 degrees, putting the chain back on and joining its ends a second time.

Other Parts of Valve System. There are a number of other parts in the valve group whose names and functions should be explained, for these are of interest to both the owner and the repair man. The repair man should know what work they do in order to be able to repair them successfully. Fig. 181 shows an overhead-valve system in which the camshaft is in the usual place in the crankcase; long push rods are used with rocker arms, or levers, at the top. This is mentioned because many, in fact the majority of, motors with overhead valves have an overhead camshaft like the Chalmers, Fig. 156.

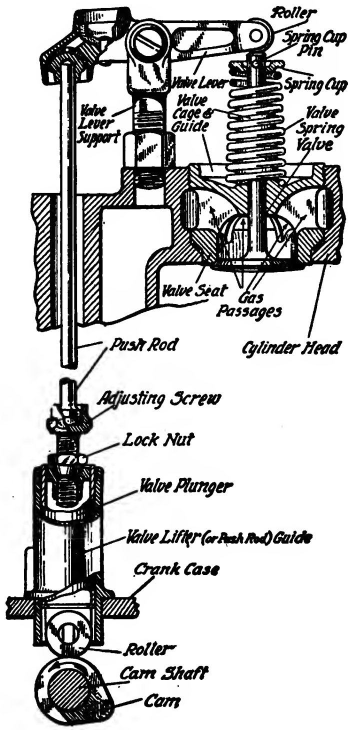


Fig. 181. Typical Overhead-Valve Layout, Showing Complete Mechanism

In this figure the various parts are named. The rotation of the *camshaft* brings the *cam* around so that it lifts the *roller* and *plunger* which has the *adjusting screw* and its *lock nut* at the top. The top of the roller bears against the bottom of the *push rod*, and the upper end of the push rod operates the *valve rocker lever* which is held in the support. At the other end of the valve rocker lever a *roller* presses against the top end of the *valve stem* and pushes it down from off the *valve seat* against the pressure of the *spring*, the upper end of which is held by the *cup* and *cup pin* and the lower end rests upon the upper surface of the *valve cage*. The latter is made so that its central upward extension also forms the *valve guide*. The valve cage is screwed down into the *cylinder head* with packing to make a gas-tight joint. It carries the *valve seat* and is cored out for the *gas passages* through which the gas enters (or leaves).

When the valve in pockets is substituted for the long push rod, in either the L-head or in the T-head cylinder, the construction is about the same as if the upper right-hand valve group were lifted bodily, turned upside down, and placed so that the upper end of the valve stem, upon which the roller rests, comes into contact with the adjusting screw. In that case, the valve lifter would be called the push rod, and the valve cage would become a part of the cylinder with an integral or, in some cases, a removable valve guide.

Fig. 182. Method of Holding Two Push Rods with Yoke and Single Central Nut

Push Rods and Guides. As can be seen from Fig. 181 and the explanation accompanying it, the push rod and its guide, or lifter and guide, become important. The shape of the cam is such that it deals the roller and lower end of the push rod, or lifter which holds it, a fairly heavy blow sideways each time it comes against it. If the roller and rod are not a perfect fit, something will yield each time, and the roller will wear oval in a short time. The movement and noise will increase rapidly and soon become very objectionable. The only remedy is replacement. These guides are held in place in one of two ways; either individually by means of a pair of bolts or in pairs by means of a yoke and a single central bolt and nut of large diameter. The Locomobile, Fig. 151, shows the former method; the Haynes, Fig. 152, the latter method. These, however, are end views which do not bring out the point as clearly as Fig. 182. Here the arrow points to the nut midway between the two push rods, which holds down the yoke that rests upon shoulders on the push rods and holds them in place. From a repair man's point of view, the latter construction is better, for the push rods can be removed and replaced much more easily and quickly.

Valve Cage Repairs. When the valves are in overhead cages, it is highly important that they fit tightly in the cylinder head; they must be ground in as carefully and as tightly as the valves are ground into their seats. Where a shop handles a good many motors of the overhead-valve type, it is desirable to make a rig to do the grinding easily. One of these rigs is shown in Fig. 183. It consists of a shaft and handle with lock nuts for the valve cages used on Buick cars. On these cars, it is in two parts; the cage proper, and the locking member which screws into the cylinder. Obviously the cage is the one to be ground in. The rig shown slides in the central opening, that is, fits in the valve guide, and has a lock nut top and bottom to fasten it tightly. When fitted into place firmly, the right-angle bend in the rig gives a handle by means of which the cage can be lifted in and out and, what is more important, rotated on its seat. When the cage is prepared, the seat is given a little oil and emery or oil and powdered glass or prepared valve grinding composition, the cage is set in place and ground in the same as a valve, that is, with one-third to one-half rotations in one position, then lift, move around, and repeat in the new position, continuing this until the whole surface of the cage in the cylinder has been covered twice. This should result in a good seat.

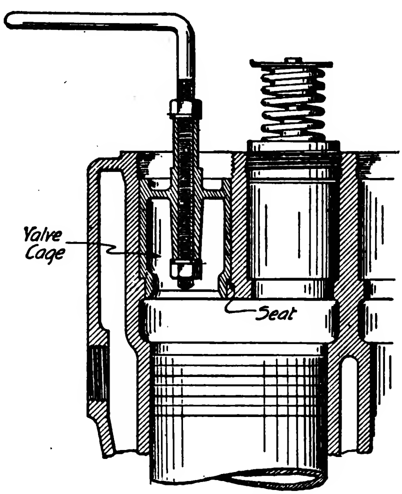


Fig. 183. Simple Fixture for Grinding-In Overhead Valve Cages
Courtesy of "Motor World"

When the valves in an overhead motor need grinding, the valve and cage are taken out completely and held in an inverted position in a vise or other clamp, and the valve ground in to the seat in the cage in the regular way. It is said this can be done very rapidly and well by chucking the valve stem, as it projects from the cage, in a lathe rotating at a very slow speed, and operating the cage by hand, that is, slide the cage back, apply grinding compound, then move the cage up to the rotating valve and hold it with the hand while the valve is turning with the lathe. In holding it thus, the pressure endwise should be very light.

Fig. 184. Method of Curing Valve-Guide Leak Quickly and Cheaply

Valve Guides. The valve stem must be a tight fit in the guide, otherwise air will leak through into the combustion chamber and dilute the mixture, or the compression will leak out, or both. Any valve leak will affect the running of the motor, so it should be stopped at once. Two methods of temporarily remedying small leaks are shown in Figs. 184 and 185. A simple leather washer with a small hole through the center, which fits tightly over the valve stem, is pressed up around the outside of the guides, as shown in Fig. 184. This simple repair was very effective, and the leather washers lasted an astonishingly long time. The other method, Fig. 185, shows practically the same result arrived at differently. In this case, old spark-plug shells, with considerable recesses in the center part, were turned down so as to fit around the bottom of the guides. These recesses were packed with felt or other available packing, care being taken to pack the recesses tightly. Then the whole thing was held up in place by a lighter spring put inside the main valve spring. By adding a few drops of oil to the packing now and then to keep it soft, it lasts almost indefinitely.

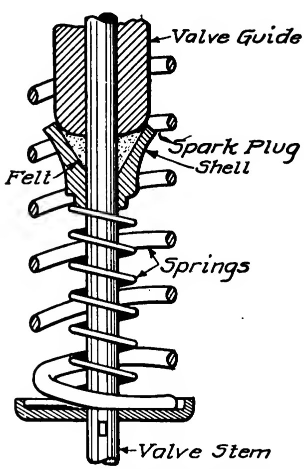


Fig. 185. Remedy for Leaky Valve-Stem Guide, Using Old Spark Plug and Felt

The valve-guide hole in the cylinder is generally made as long as possible, both to give a straight and true hold on the valve stem and thus maintain its straightness in spite of the heat, and to give a long wearing surface. This length and the need for accuracy throughout makes the valve-guide hole an awkward surface to repair. When worn beyond any hope of simple repair, it is best to ream it out and press in a bronze bushing so that the valves can still be used. An excellent tool for this purpose, developed for Dodge motors but which is usable for almost any motor, is shown in Fig. 186. This consists of a high threaded bushing which is clamped to two diagonal cylinder studs. The thread inside the bushing is very fine. A long tube, with the lower end bored out to take a standard reamer, is screwed into it. The top is squared and a handle is made to fit it. When the handle is turned, the tube is gradually screwed down into the cylinder, carrying the reamer slowly but truly down through the valve guide. This rigging is simple, easily made, and gives accurate results. When the valve-guide hole is reamed, the bushing can be turned up and pressed in with any form of shop press.

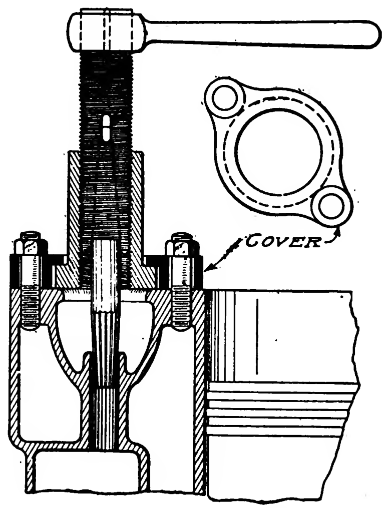


Fig. 186. Rigging for Reaming Out Valve-Stem Guide Holes
Courtesy of "Motor World"

Valve Caps. The plug which fits into the top opening in the cylinder through which the valve is put in place and removed is called the valve cap. Sometimes it has external hexagonal sides so it can be easily removed, but more often it has an internal hexagon, or internal ribs. The latter form can be removed most easily by constructing a special tool, consisting of a cylindrical member, with a bottom diameter slightly larger than the opening in the valve cap, with four (or more) teeth, or projections, set into the bottom of this to match the ribs inside the cap. A central hole is drilled for a bolt with spark-plug threads at the bottom. To use the member, remove the spark plug, set the device in place, slip the central bolt in and screw it down into the plug to hold the whole thing in place, then apply a wrench to its upper square surface and remove the valve, cap and all.

It can be laid aside just as removed, and when the work is concluded, the whole thing can be screwed back in, the central screw loosened, and the rig removed from the cap.

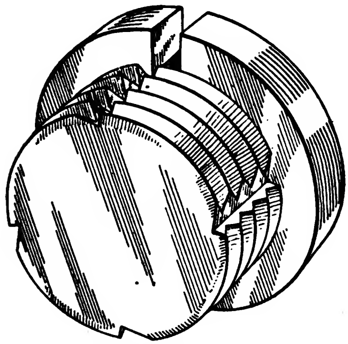


Fig. 187. Reamer for Clearing Out Threads of Valve Cap
Courtesy of "Motor World"

Sometimes the threads in the cylinder into which the valve cap screws become dirty, slightly cut up, or marred so that the cap does not screw in or out readily. By taking an old valve cap of the same motor and same threads and fluting these in a milling machine, as indicated in Fig. 187, a neat tap can be made which will clean out the threads in a jiffy. It is simple, effective, and cheap.

Cleaning Camshaft Gears. On the majority of engines, the camshaft and other gears or the silent chain which replaces them, are lubricated automatically by the running of the engine as they are by-passed in on the engine lubricating system. This is an excellent feature, but it leads to neglect. These gears or sprockets are sure to wear, and the metal worn off remains in the case. Moreover, dust and the impurities of the oil are bound to get in. The foreign matter has a cutting action on gears, chains, or bearings, so the gear case should be cleaned out frequently. This is done best by thoroughly flushing out the case and the gears, or sprockets and chains, as the case may be, with kerosene. After using the kerosene, use gasoline along with the kerosene to clear away any remaining dirt or oil. After applying the gasoline, wait long enough for it to evaporate before replacing the parts. while it might be considered extravagant to use both, it really is economical of time.

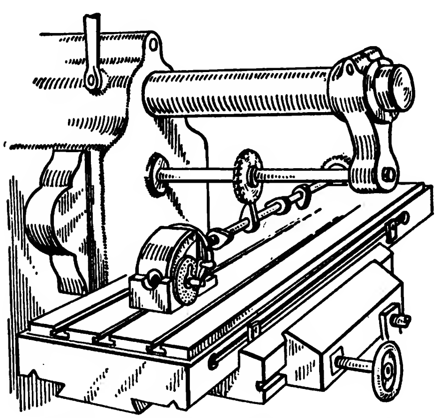


Fig. 188. Checking up Camshaft in Milling Machine

Twisted Camshafts. With the present form of camshaft having the cams forged integral, troubles and irregularities between one cylinder and another, which the repair man finds difficult to trace or run down, sometimes develop in the running of the engine. A fairly light camshaft will sometimes become twisted, usually right at a cam where the stress is. When trouble of this kind is indicated, the camshaft should be removed and tested. A good way to do this is to place the shaft in the milling machine with the index head set so that one revolution of the shaft can be divided into four equal parts. Place a thin disc in the arbor, then mount the shaft and bring it up to the disc. Choose one of the cams and set the disc to the exact center of the point of it. Then, by turning the shaft a quarter-turn each time, the other cams can be tested with their relation to this one. Sometimes a difference of $\frac{1}{8}$ inch will be found in this way. The lay-out for this is seen in Fig. 188.

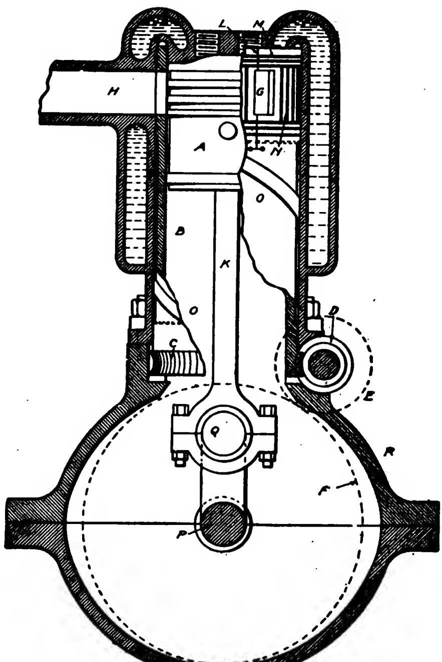


Fig. 189. Section through Ledru (French) Camless Engine. The Rotary Gear-Driven Sleeve Displaces All Cams

DETAILS OF SLIDING-SLEEVE VALVES

A method of avoiding cams, and with them all cam troubles, is the use of a sliding sleeve in place of a valve, slots in the sleeve corresponding to the usual valve openings, both as to area and timing. The sleeves may be operated by means of eccentrics by various lever motions, or by a direct drive by means of agear mounted on a separate shaft.

Gear Control. An example of the application of a worm and gear for this purpose to a French two-cycle engine is shown in

Fig. 189, although there is nothing in its construction which would prevent its use on the more usual four-cycle engine.

In this figure, *P* is the usual crankshaft, *Q* the large end of the connecting rod *K*, while *A* is the piston and *R* the crankcase, no one of these differing from those in other engines. On the crankshaft there is a large gear *F*, which drives a smaller gear *E*, located on a longitudinal shaft above and outside of the crankcase. On this shaft is located a worm gear *D*, which meshes with a worm *C* formed integral with the sleeve surrounding the piston *B*. Aside from this worm gear, the sleeve is perfectly cylindrical, being open at both ends. It is placed outside of the piston, between that and the cylinder walls. At its upper end, it has a number of ports, or slots, cut through it, which are correctly located vertically to register, or coincide, with the port openings in the cylinder wall when the sleeve is rotated. One of these is seen at *H;* the exhaust, while 90 degrees around from it, and hence invisible in this figure, is a similar port for the inlet. As the crankshaft rotates, the side shaft carrying the worm is constrained to turn also. This turns the worm which rotates the worm wheel on the sleeve. In this way, the openings in the sleeve are brought around to the proper openings in the cylinder, and the combustion chamber is supplied with fresh gas, the burned gases being carried away at the correct time in the cycle of operations.

With a motor of this sort, the greatest question is that of lubrication. The manner in which it is effected in this case is by means of the large wide spiral grooves shown at *OO* and the smaller circular grooves at the upper end *M*. Another method which renders this problem more easy of solution is by the machining of the sleeve; during this operation much metal is cut away along the sides so that the sleeve does not bear against the cylinder walls along its whole length but only for a short length at the top and a still shorter length at the bottom.

Knight Sleeve Valves. In the last few years, tremendous progress has been made here and abroad with the Knight motor, named after its Chicago inventor. In many important factories this valve has displaced the poppet valve. In a regular four-cylinder four-cycle engine, the valves consist of a pair of concentric sleeves, the openings in the two sleeves performing the requisite functions of valves in the proper order. These sleeves, as Fig. 190 shows, are actuated from a regular camshaft—running at half the crankshaft speed and driven by a silent chain—by means of a series of eccentrics and connecting rods. In the figure, *A* is the inner and longer sleeve and carries the groove or projection *C* at its lower end. The collar actuating the sleeve is fixed around and into it. This collar is

Fig. 190. Willys-Knight Engine in Which Eccentrics and Sliding Sleeves Replace Cams and Valves

attached to the eccentric rod *E*, which is driven by the eccentric shaft shown. The collar *D* performs a similar function for the outer sleeve *B*.

At the upper ends of both sleeves, slots *G* are cut through. These slots are so sized and located as to be brought into correct

TABLE II

Royal Automobile Club's Committee Report on Knight Engine

Motor horsepower—R. A. C.	38.4		22.85
Bore and stroke	124 by 130		96 by 130
Minimum horsepower allowed	50.8		35.3
Speed on bench test	1200 r.p.m.		1400 r.p.m.
Car weight on track	3805 lb.		3332.5 lb.
Car weight on road	4085 lb.		3612.5 lb.
Duration of bench test	134 hours 15 min.		132 hours 58 min.
Penalized stops	None		None
Non-penalized stops	Five—116 min.		Two—17 min.
Light load periods	19 min.		41 min.
Average horsepower	54.3		38.83
Final bench test	5 hours 15 min.		5 hours 2 min.
Penalized stops	None		None
Light load periods	15 min.		1 min.
Average horsepower	57.25		38.96
Mileage on track	1930.5		1914.1
Mileage on road	229		229
Total time on track	45 hours 32 min.		45 hours 42 min.
Average track speed	42.4 m. p. h.		41.8 m. p. h.
Fuel per brake horsepower per hour	First bench test	.679 pt.	.739 pt.
		.613 lb.	.668 lb.
	Final bench test	.599 pt.	.749 pt.
		.541 lb.	.677 lb.
Car miles per gallon	On track	20.57	22.44
	On road	19.48	19.48
Ton miles per gallon	On track	34.94	33.37
	On road	35.97	31.19

relation to one another and to the cylinder ports and the exhaust at *II* and inlet at *I*, in the course of the stroke.

It might be thought that the sliding sleeves would eat up more power in internal friction than would be gained, but a very severe and especially thorough test of an engine of this type, made by the Royal Automobile Club of England, an unbiased body, proved that for its size the power output was greater than that of many engines of the regulation type. Moreover, the amount of lubricating oil was small.

The results of the test are shown in Table II. After the test was concluded, both the sleeves, Fig. 191, were found to show still the original marks of the lathe tool. This proved conclusively that the principle of this type was right, for the tests were equivalent to an ordinary season's running.

The slots which serve as valve ports are at *G*, Fig. 191. The longer sleeve *A* is the inner one. At the bases of the sleeves are the collars and pins *D* by which the connecting rods are attached.

The surfaces of the valves are grooved at *J* to produce proper distribution of oil.

The Knight type of motor has been adopted by a number of well-known firms in America, such as the Stearns, Willys, F. R. P., Brewster, and Moline Companies. These engines are noted for their silent running and for their efficiency. The Moline-Knight motor was subjected to a severe continuous-run test of 337 hours, under the auspices of the A. C. A. authorities, in January, 1914. During this time the motor developed an average of 38.3 brake horse-

Fig. 191. Sleeves Which Replaced Valves on Knight Engine, after 137-Hour Bench Test and 2200 Miles on the Road

power. During the 337th hour the throttle was opened, the motor developed a higher speed and a brake horsepower of 53. After the test, the motor parts showed no particular evidence of wear. The test gives abundant evidence of the endurance and reliability of the sleeve-valve type of motor and of the sterling qualities of the product of the American automobile manufacturers.

In addition to the four-cylinder forms just mentioned, the Knight type of motor is also made as a six, and, more recently, as a V-type eight. In these forms, the basic principle of sliding sleeves and their method of operation and timing is not changed.

Originally, the Knight motor was installed only in the highest-class cars. The firms in Europe which took it up ranked among the very first—notably the Daimler, Panhard, Minerva, etc.—but in this country it has made little progress among the better cars. It is now assuming the rank of a low- and medium-priced motor, being available for about $1000, and as an eight, for approximately $2000.

Timing the Willys-Knight. While the connection between the Knight motor sleeves and eccentric rods, and between the rods and the eccentric shaft, is more or less permanent, there is the possibility of the shaft being bent or twisted during running or dismounting. The repair man should know how the motor is timed, in order to correct any faults. As will be noted in the timing diagram shown in Fig. 192, this is not radically different from the poppet-valve type. The inlet opens at 15 degrees past the upper center and closes 50 degrees past the lower center, a total opening of 215 degrees. The exhaust opens 50 degrees before the lower center and closes 8 degrees past the upper center, a total opening of 238 degrees.

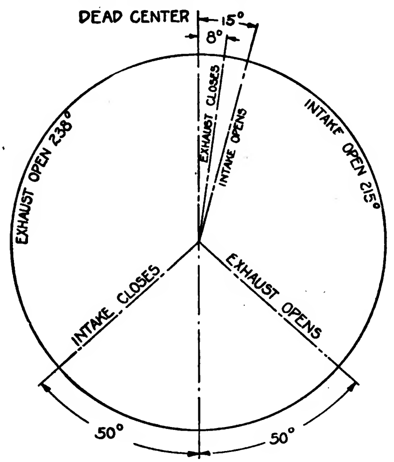


Fig. 192. Valve Timing 1920 Willys-Knight

The various positions are clearly shown in Fig. 193, and make the action of the motor much more clear than the simple timing diagram. The figures, reading from the left, are as follows: *1* shows the inlet just beginning to open; the inner sleeve is coming up, and the outer sleeve is going down, so the port opening is increasing in area with unusual rapidity. At *2* the inlet is fully open; the inner sleeve is coming up, but the outer has reached the bottom of its travel; the two ports are fully open and register exactly with one another and with the opening in the cylinder. At *3* the inlet has just closed, the inner sleeve is still coming up, while the outer sleeve has come up a considerable distance. A slightly further upward movement of both inner and outer sleeves shows the motor in *4*, the top of the compression stroke, with all ports closed. This is the point of explosion. In *5* the exhaust

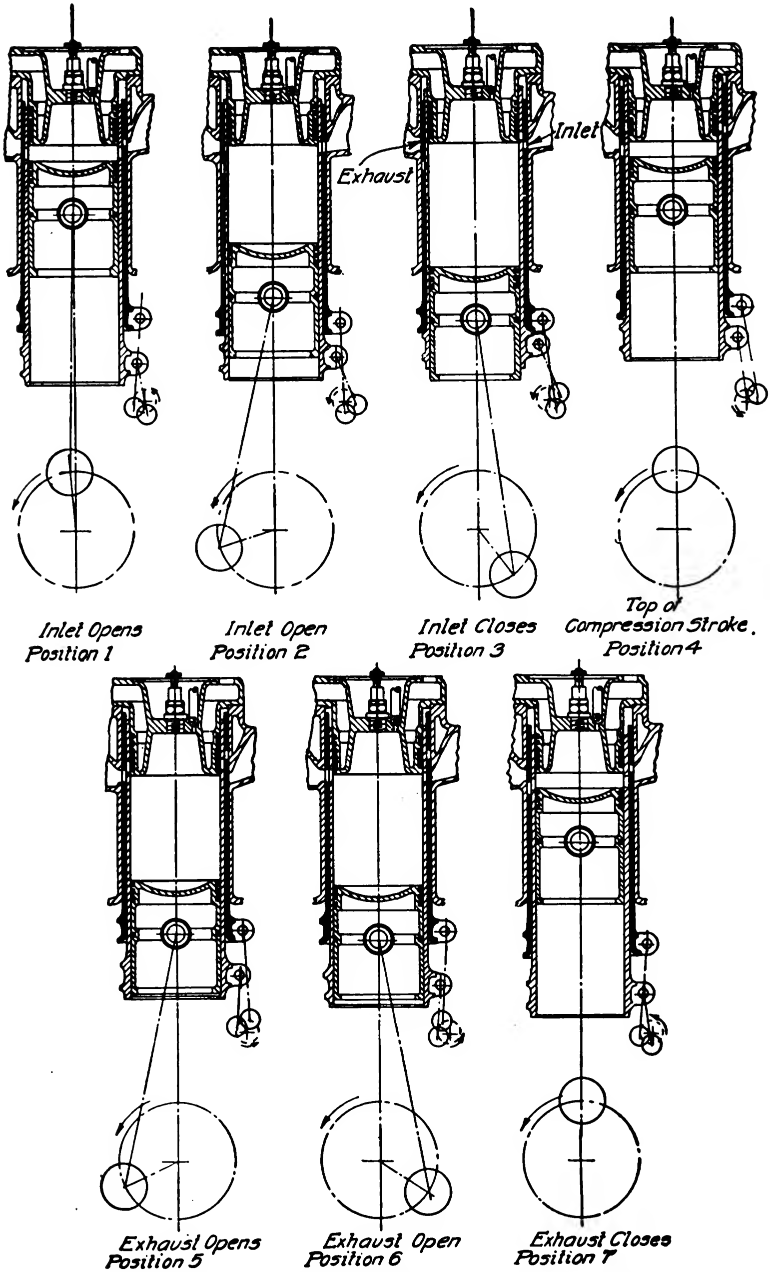


Fig. 193. Various Stages in Cycle of Knight Sliding-Sleeve Motor

is beginning to open, the inner sleeve has reached the top of its movement and started down, while the outer is almost at the top. At *6* the exhaust port is fully open, the slots register exactly with each other and with the cylinder outlet, both sleeves are traveling down, the outer having reached and passed its highest point. At *7* the exhaust has just closed, the inner sleeve has reached its bottom position and is about to start up, while the outer sleeve is close to the bottom. The cycle of inlet, compression, explosion, and exhaust has now been completed and is about to start over. Note that position *7* is almost exactly like position *1*, but a slight additional movement of the sleeves is needed to produce the latter.

The eccentric rods are very similar to connecting rods, as will be noted by referring back to Fig. 191. Here *E* is the eccentric rod operating the inner sleeve *C*, while *D* is the eccentric rod which operates the outer sleeve *B*. As will be seen, these have an upper end exactly like a piston, or wrist pin, except that no bushing is provided. At the lower end, it will be noted that the fastening and arrangement is just like the big end of a connecting rod. It should be cared for, adjusted, and tightened in just the same way to get the best results.

DETAILS OF ROTATING VALVES

Successful Operation Requires Two Valves. In addition to rotating and reciprocating sleeves and reciprocating valves, the rotating valve has been tried, in common with any number of other devices intended to supplant the ordinary poppet valve. This arrangement on a multi-cylinder motor consisted of a single valve for all the cylinders, which extends along the top or side of the cylinder head and is driven by shaft, chain, or otherwise, at one end. Naturally, this necessitated having the ports cut very accurately in the exterior of the valve, or rather the sleeve—as it usually assumed the form of a hollow shell—for not alone did it act as inlet and exhaust manifold but also as the timing device. This multiplicity of functions seems to have been its undoing, for the latest types using valves of this form have no longer one shell as at first but a pair, one for the exhaust valves and one for the inlet valves. In the latter shape these have been more successful, but not sufficiently so to bring them into competition with the poppet and Knight sleeve-valve forms.

Roberts Rotary Valve. A motor—a two-cycle motor, by the way—which has been very successful in motor-boat and aeroplane

Fig. 194. Roberts Two-Cycle Motor with Rotating Crankcase Valve
Courtesy of E. W. Roberts, Sandusky, Ohio

work, although it is not used for motor cars, is the Roberts, shown in Fig. 194, with the valve in Fig. 195. This valve is for the inlet ports only and is located inside the crankcase, while the cylinders

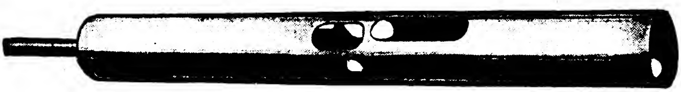


Fig. 195. Rotating Inlet Valve of Roberts Two-Cycle Motor

exhaust freely into the open air, the exhaust issuing directly from the cylinders.

EXHAUST SYSTEM

Importance of Handling Exhaust Gases Properly. In all that has been said previously on the subject of valves no mention has been made of a specific form of valve, everything applying equally to the inlet or the exhaust type. Under the subject of carburetors, the inlet manifold has been considered in detail. So far, nothing has been said of the exhaust gases and the method of handling them. Generally speaking, the matter of handling exhaust gases in the past has been done with the smallest possible amount of time, trouble, and thought. They had to be gotten rid of, so it was done as easily and quickly as possible. As engines got larger and larger, and as speeds increased, there was more and more gas to handle. The growing cry for a quiet or a noiseless car necessitated giving the problem more thought, for the simple application of a muffler did not entirely eliminate the noise. As fuels grew heavier, heat was required to assist in the process of vaporizing. In order to apply heat, many designers began to see possible uses for some of the gas pouring out at the rear end of the car. Today, the handling of the exhaust gases is probably being given as much thought as any part or unit on the entire car.

Forms of Exhaust Manifolds. Ordinarily the exhaust gases emerge from the cylinders into the exhaust manifold. This is gen-

Fig. 196. View of National Twelve-Cylinder Motor, Showing Particularly Exhaust Manifold
Courtesy of National Motor Vehicle Company, Indianapolis, Indiana

erally a cast-iron member of fairly large size held in position by bolts. At its rear end, which is round, it is threaded or flanged for the attachment of the exhaust pipe. This is shown rather well in the National engine in Fig. 196. Although this is a twelve-cylinder motor, it has the outside valves, so the exhaust manifold is located there. It is a typical cast-iron manifold, differing from the ordinary manifold only in having the outlet at the center instead of the rear end. Six bolts hold it in place; four on the upper edge, and two on the lower. Its interior structure is evidently the same throughout, and no special

Fig. 197. Section through Peerless Eight, Showing Ribbed Exhaust Manifold
Courtesy of Peerless Motor Car and Truck Corporation, Cleveland, Ohio

provision has been made for reducing gas friction. It has no attachments of any kind.

Many exhaust manifolds have been cast integral with the cylinder block; this method is quite popular among small car makers, as it is used as much to save the expense of machining and fitting and to reduce the weight and number of parts as for any other reasons. In the larger sizes it probably never will become popular, because of the difficult core work in the foundry which makes cylinder-casting cost prohibitive, and thus more than offsets any other saving.

A number of manifolds have been cast with cooling fins, or flanges, on the outside, the effect being to reduce the exhaust heat immediately by dissipation; a secondary idea is that of making the casting stiffer and stronger and less liable to loss by breakage. A flanged manifold

Fig. 198. Three-Quarter Rear View of Cadillac Motor in Chassis, Showing Exhaust Manifold and Pipes in Duplicate

is shown in Fig. 197, which illustrates the Peerless eight-cylinder motor; the exhaust manifold is marked at *A* and *B*. The section taken at *A* shows the full exterior size; the boss, through which a holding bolt passes, is seen in elevation. At *B*, however, the section is taken through a pair of bolts, so the section appears smaller than it actually is.

In the usual eight- and twelve-cylinder motor and in some sixes, a pair of manifolds, each with its own exhaust pipe and muffler, are used. It has been found by experience that the tremendous volume

Fig. 199. Cadillac Chassis from Above, Showing Double System of Exhausting with Twin Mufflers

of gas to be handled, the speed at which it had to be handled, and the necessity for silence called for a separate exhausting system for each group of cylinders. These were problems, aside from the fact that it was more simple structurally to handle the exhaust in two manifolds. A double-manifold construction is shown in the Cadillac, Fig. 198, which is a view of the rear end of the engine. The two manifolds for the two sides can be seen readily; also the two separate exhaust pipes, wrapped with asbestos where they pass the dash and other wooden parts. A further view of this car is shown in Fig. 199, the chassis from above, in which the two separate systems can be followed back to the mufflers just forward of the rear axle on either side.

Muffler. The purpose of the muffler is to reduce the pressure of the gases by expansion to a point where they will emerge into the atmosphere without noise. This is generally done by providing a number of concentric chambers; the gas is allowed to expand from the first passage into the much larger second one, then into the still larger third one, and so on, to the final and largest passage, which is connected to the pipe leading out into the atmosphere. This is not as simple as it sounds, for, if it is not well and wisely done, there will be back pressure which will reduce the power and speed of the engine, cause heating troubles, and may possibly cause the motor to stop.

The process of spraying water into the muffler has been tried, but on account of its first cost and lack of positive beneficial results, it has been abandoned. The actual construction of the muffler, however, takes a number of different forms. A number of forms are shown in Fig. 200. Baffle plates are used in the form at *A*, the gases being forced by them to expand from one chamber to the next so all the speed and pressure is dissipated before the outlet is reached. In the form shown at *B*, the gases are allowed immediate and sudden expansion from a comparatively small pipe into a large chamber. A series of annular chambers of large diameter but small depth forms the basis of *C;* the gas enters each of these chambers from the center through small holes, thence exhausting outwards, each chamber having an outlet around its circumference. In the form at *D*, the gases enter the central small pipe, escape through holes at its far end, which is blocked off, into the first concentric chamber where they travel to the front end where holes allow it to pass out into the second concentric chamber and out into the atmosphere. This is a widely used

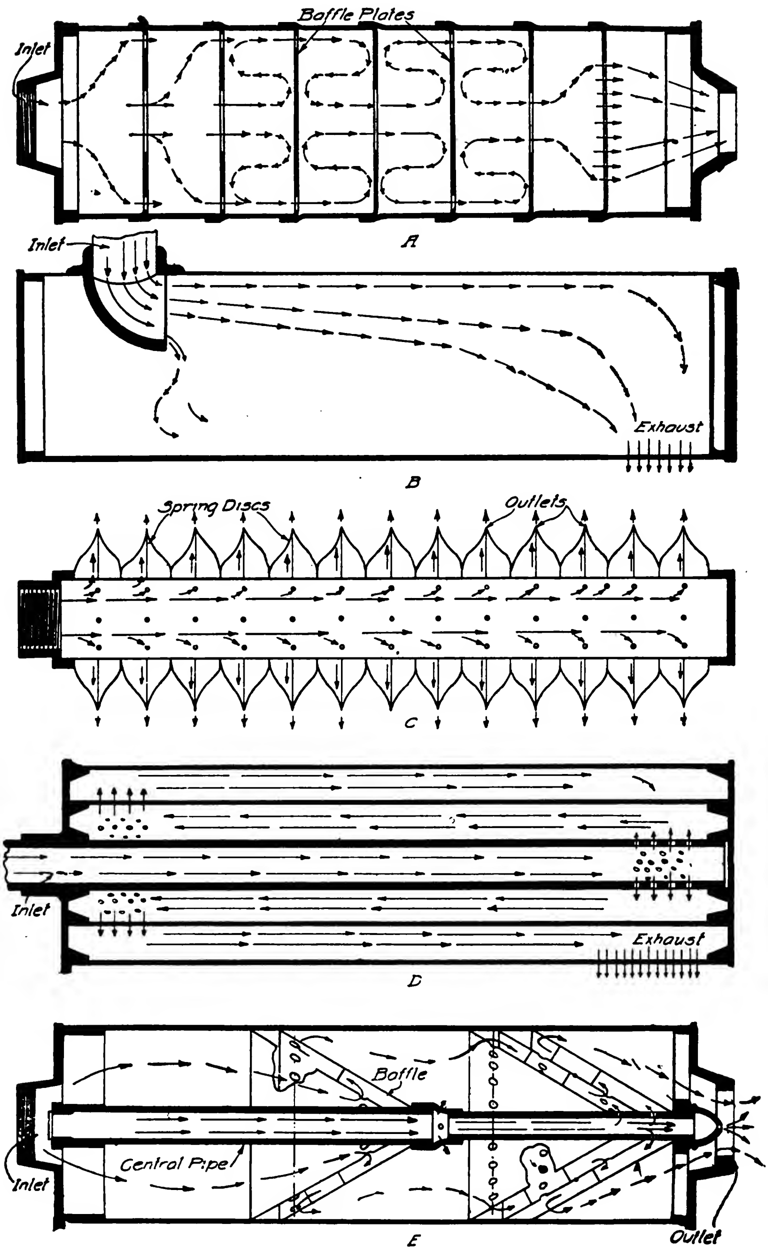


Fig. 200. Five of the Many Different Types of Mufflers
Courtesy of N. W. Henley Publishing Company, New York City

type. Cone-shaped baffles which force the gases to expand and then pass through very small apertures and expand again form the basis of *E*. This is the so-called ejector type, the passage of the gases from the large to the small end of the various cones being supposed to create a suction behind it which draws the gas out from the exhaust pipe continuously.

Muffler Troubles. When the engine mysteriously loses power, it is well to look at the muffler. A dirty muffler filled up with oil and carbon, which results from the use of too much oil in the motor, will choke up the passages so that considerable back pressure is created. When this is suspected, tap the muffler all over lightly with a wooden mallet, and the exhaust gases will blow the sooty accumulations out.

Cut-Outs. Formerly, the majority of cars were equipped with muffler cut-outs. By pressing the foot on the button operating the cut-out, the engine was allowed to exhaust directly into the atmosphere, cutting out the muffler. It served as a warning signal; it gave a good means of checking up the firing of the various cylinders; and several years ago, it was supposed to give greater power. Since its use was overdone, many cities and states prohibited such an arrangement on a car. Furthermore, the power loss has been proved a fallacy; consequently, the cut-out has gradually gone out of use.

On six-cylinder motors, and particularly motors with more than six cylinders, the sound of the exhaust is not an accurate guide to the firing of the cylinders, except for the expert mechanic with unusually keen hearing. The explosions of the six-, eight-, and twelve-cylinder engine overlap to such an extent that the weak explosion between two healthy ones cannot be detected. A missing cylinder can be found in this way, but not one that is simply getting a poor or weak spark.

COOLING SYSTEMS

WATER COOLING

Though nearly all successful automobile motors, as well as most other internal-combustion engines, are water-cooled, there is so much obvious fault to be found with this system of securing a result —involving first the generation of heat and then its waste by a complicated refrigerating system, instead of its utilization by converting more of the heat units into useful work—that it is scarcely credible that water cooling can persist indefinitely.

Water-Jacketing. The first essential in water-cooling a motor is to provide the cylinders with water jackets, through which the cooling water is circulated in contact with the outside of the walls within which the heat is liberated.

Water jackets are of two types, integral and built-up. The latter system of construction, though adding to complication and conducive to leakage, permits of lighter construction, besides diminishing the likelihood of hidden flaws in the cylinder castings, which, with cored jackets, are not likely to reveal themselves until they cause a breakdown, perhaps after the engine has been long in use.

Integral Jackets. With integral jackets, the usual system is to form the jackets by cores, in the founding, so that there are no openings in the jackets except those for removing the core sand and wires and for connecting the pipes of the circulating system. In many of the best examples of motor design, however, the core openings are left very large but with plane faces, and are closed by screwed-on or clamped-on plates, thus making the construction practically a compromise between the completely integral and the completely built-on jackets.

Fig. 201. Detailed View of Cadillac Cylinder Chassis

For example, in such modern construction as that shown in Fig. 2, a large plate will be noted on the ends of the cylinders. This covers a tremendous core hole, by the use of which the internal construction of the water jackets is made practically perfect in the foundry. This also allows easy inspection and cleaning, the removal of the two end plates enabling a person to see right through the water jacket from end to end. This latter-day construction overcomes all objections previously raised against troubles with complicated water-jacket cores. A detail of this cylinder block, showing clearly the arrangement of the end plates, the water passages around the cylinder bores, and other points, is presented in Fig. 201. The designers of large block castings for cylinders were forced to provide for easy inspection of this kind for self-protection, although in this connection, it is no more than fair to state that foundry men have made just as rapid advances in the art of casting automobile-engine cylinders and other complicated parts as the designers of machines have made in every other way.

Built-On Jackets. There are a number of forms of built-on water jackets, but few of these are in use at present. The best of these was the old Cadillac jacket, a cylindrical one-piece member with a junk ring, top and bottom, to hold tightly against water leakage. The form more often used is the applied plate, or sheet, which must be held by screws, flanges, or clamps. As these are not really successful in holding the water continuously, particularly against the combination of hot water, internal pressure, twisting, and racking action which comes from traveling over bad roads at high speeds, they are giving way to the older form of jacket.

An important advantage of applied jackets of the type just described is their freedom to yield in case the water freezes in them. The danger of cracked cylinders, which not infrequently results from exposure to cold weather in ordinary automobile motors having jackets integral with the cylinder, is eliminated.

A particularly neat method of water-jacketing, which has been applied with some success abroad, consists in the electro-deposition of copper jackets on the cylinders, through the use of wax molds, to produce the desired forms. Jackets thus applied, though somewhat expensive, are said to be practically indestructible and completely proof against leakage.

Welded Applied Jackets. The method of welding by the oxy-acetylene process promises to produce a cylinder with a cast-iron center and a sheet-metal water-jacket exterior made of pressed steel or of flat plates. The designers who consider this combination the best in that the thin sheet metal of copper or steel is lighter, radiates more heat, and will yield under freezing strains, will now be able to obtain such a combination at a reasonable cost. So far, however, it has been restricted to racing cars, in which the lightest possible weight is obtained regardless of cost. In a car to sell at an ordinary price, the cost might be prohibitive.

Radiators and Piping. It has often been pointed out that all cooling of automobile engines is, in reality, air cooling; the water-cooled motor is simply one in which the heat units to be disposed

Fig. 202. Horizontal Plate Type of Tubular Radiator Used on Studebaker Cars
Courtesy of Studebaker Corporation, Detroit, Michigan

of are conveyed from the cylinders to the radiator by the circulating water, to be dissipated in the air that passes through it, instead of directly lost in air passing over thin flanges cast on the cylinders. A water-cooling system therefore constitutes a sort of indirect-air cooling. This being the case, the chief justification for water cooling consists in the margin it allows for much greater cooling areas in contact with air than it is possible to provide by mere extensions of the cylinder surfaces themselves.

A typical pleasure-car radiator of the tubular type is shown in Fig. 202. As will be noted, the flanges have a continuous horizontal appearance, but the vertical tubes which carry the water can be seen in the background. These actually carry the water; the horizontal flanges simply serve as a heat-radiating surface. This type is rapidly increasing in popularity for pleasure cars of medium and low price, at the expense of all others.

The total cooling area of the radiators employed in automobiles will range all the way from ten to ninety square feet; the latter

Fig. 203. Vertical Tubular Spiral Fin Type of Riker Truck Radiator with Cast Headers
Courtesy of Locomobile Company of America, Bridgeport, Connecticut

surface is not unusual in the best type of honeycomb radiators with hexagonal openings and very thin water spaces.

The smaller areas are found in the cheaper types of radiators built up of straight, round, or flat tubes, and provided with fins to increase the area exposed to the air. Radiators of these types, unless very large, are often inadequate to cool a motor when it is laboring under continued heavy usage, as in pulling on the low gear through deep sand or mud or up long heavy grades. Under such conditions, a motor that may have run for months without any cooling trouble whatever in level country will often boil all the water out of the cooling system within a few minutes.

Types of Cells. In the cellular, or honeycomb, radiator, there are three forms of tubing in general use. These forms are: the square, with its flat sides set horizontally and vertically; the round, with the tubes staggered so as to make the number as large as possible; and the hexagon, which is also set staggered so as to use the maximum number. The square and hexagon are more used on pleasure cars,

Fig. 204. Renault Form of Radiator Situated Back of Engine

while the round form has been used on higher-priced motor trucks. A modification of the round-tube form is found in the radiator which utilizes the plain copper tubes, bunched and fitted into a header, or water tank, at the end, but which are not formed into a composite unit. This is used on both pleasure cars and trucks.

Types of Tubes. In the tubular form, there are two well-known types: the round vertical tube with spiral fin, or flange, welded or sweated on; and the so-called tube-and-plate construction, shown in Fig. 202, in which a set of horizontal plates is pierced with a number of holes, tubes set into these, and the whole dip-soldered into a unit. The former type is gaining rapidly for truck use on account of its freedom from leakage under the severe racking conditions of truck use. An example of this type is to be found in Fig. 203, which shows a welded tubular radiator. It is of interest to note that the welded type replaced a soldered honeycomb unit of the highest quality which could not be kept water-tight in war service.

Modifications of Cellular and Tubular Forms. In addition to the types shown in Figs. 202 and 203, there are a number of forms which partake somewhat of their characteristics but which show a marked individuality. The Renault form, which is placed at the dash instead of at the front, is shown in Fig. 204. It has a tank at the top and small tanks at the bottom and sides, the central bottom space being taken up by the fan. The tubes are of pure copper and are not fastened together as in the cellular radiator, but merely connected at the two ends. As compared with the average radiator of the cellular type of equal cooling capacity, this form requires greater height, width, and depth. Its dash position has the disadvantage of keeping the driver's compartment uncomfortably hot in the summer months.

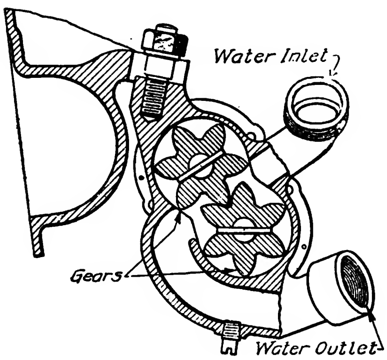


Fig. 206. Gear Type of Water Pump of Very Simple Construction

The piping of automobile cooling systems in a great many cars is made too small to afford free circulation, and this mistake in design, common in the earlier days of automobile engineering, is one that cannot be too carefully avoided.

In the experience of most automobile designers, the most satisfactory method of connecting up the piping of a circulating system is found in the use of ordinary steam hose, clamped around the ends of the pipe by small metal straps.

Circulation. An unobstructed and vigorous circulation of the water in a cooling system is a great factor in reducing the size of radiator required and in preventing overheating.

Pumps. The usual method of circulating the cooling water is to use one type or another of small pumps, driven by suitable gearing from the engine itself.

Gear pumps are often used for this purpose because of their extreme simplicity, but it is difficult to make them large enough to handle as great volumes of water as most designers now regard desirable.

A good example of the gear form of water pump is shown in Fig. 206. This is simply a pair of gears which mesh rather closely; the movement of the flat side of the teeth carries or forces the water

Fig. 207. Centrifugal Type of Water Pump as Used on Reo Cars

forward. In general, the gears are made of small diameter but wide face to take advantage of this action. The result is a very compact pump. The vane type of pump is really a modification of the gear pump in that a rotating member is placed in an eccentric chamber with a sliding arm on either side, which is held out into contact with the sides of the chamber by a central spring. This double sliding arm simulates the effect of the teeth of the gear form. This has small capacity and is not widely used on that account.

The consequence is that the centrifugal pump is now the type most preferred. In their best forms, centrifugal pumps consist of simple multi-bladed "impellers" revolving with close clearances in a housing.

One advantage of the centrifugal pump is that if any small object, such as a stick or pebble, should by any chance get into the circulating system—though strainers always should be provided to prevent this contingency—no serious harm is likely to result, whereas with a gear pump breakage is almost certain to ensue.

The construction of the centrifugal form can be seen in Fig. 207. This is not as clear as it might be because the impeller is sectioned at

Fig. 208. Thermosiphon System of Cooling as Used on Overland Cars

the point where the water chamber is largest; in short, at the water-outlet space. The impeller fits the casing very closely except at the water outlet where the water is thrown off by the centrifugal force generated in rotation. The centrifugal form of pump is also fairly well illustrated in Fig. 210, where it will be noted that two of them are used on the two ends of the upper shaft.

Chiefly in motor-boat motors of the two-cycle types, reciprocating plunger pumps are used to circulate the cooling water. The volume of water handled by pumps of this type, of dimensions that can be conveniently employed, is not very large, however, and it is only the fact that the water is not re-used and is, therefore, cooler and of a consequently greater effectiveness that makes possible the use of plunger pumps in motor boats.

Thermosiphon. Circulation of the cooling water by the thermosiphon action, owing to the heated water in the jackets rising and the cooled water in the radiator descending, is the practice of an increasing number of designers, and has been demonstrated to be very effective with liberal jacket spaces and large-diameter piping.

The pioneer, and still the most prominent exponent, of thermosiphon cooling is the Renault Company, of France. A typical Renault motor-and-radiator combination with thermosiphon circulation is illustrated in Fig. 204.

A better example of the thermosiphon system, that is, a drawing which shows it much better is Fig. 208. In this the large open pipes with few bends, and those few very easy so as to reduce water friction to a minimum, are well shown, also the small difference in level between the top and bottom of the system. The difference in temperature causes the movement of the water. It is said that the pressure which the temperature variation produces is seldom more than a small fraction of a pound; for this reason it is necessary to reduce surface friction and losses at bends and at other similar points.

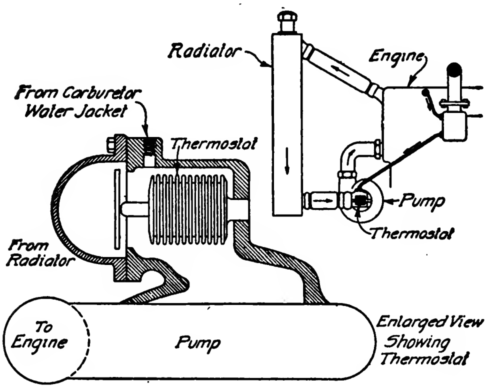


Fig. 209. Thermostatic Device in Latest Cadillac Water-Cooling System to Preserve Equilibrium and Even Temperature

Cadillac System. An entirely new idea in the control of the temperature of the cooling water is that used on the new eight-cylinder Cadillac motors. Here, each block of four cylinders has its own circulating system, with pump and piping, entirely distinct from the other. In each one a thermostat, like that shown in Fig. 209, is located on top of the pump housing. This controls the movement of a valve, which, when shut off, prevents the flow of water to the radiator, that is, when the temperature of the water falls below a certain figure at which the thermostat is set, it comes into action and cuts off the flow of water from the radiator to the pump. The result is that the pump can circulate only that part which comes through the very small pipe to the inlet manifold and carburetor and from there back to the pump. This continues until the water becomes heated; the raising of the temperature operates the thermostat which opens the valve, and the system is again complete. In the upper

Fig. 210. Thermostat and Water-Pump Group on Packard Twelve-Cylinder Motor
Courtesy of Packard Motor Car Company, Detroit, Michigan

right-hand part of this figure, the circulating system of one block of cylinders is shown in outline.

The method of controlling the temperature of the engine with an automatic check valve is receiving much attention; there is even talk of extending the same system of control to the exhaust gases and all sources of heat, interconnecting them with the fuel vaporizer so as to vaporize the maximum amount of fuel in the minimum time with the least heat loss. The thermostat and pump combination used on the Packard twelve-cylinder motor is shown in Fig. 210, in which it will be seen that two pumps are placed on the pump shaft, one at each end so that the thrust of each one balances the other. In the Cadillac, the two cylinder groups are separate, each having all the units shown in Fig. 209 except the radiator. In both the Cadillac and Packard systems, the thermostat is placed at the bottom of the system. It has been advocated by engineers for other companies that this would do the most good if placed at the top of the system.

The value of a thermostat may be gained from these figures. One particular make of thermostat, as used on a popular make of car, was tested out with the following results: Without it, the car did 14½ miles on a gallon of fuel at 15 m.p.h. and 13½ miles at 30 m.p.h. At the same speeds and with the thermostat set at 160 degrees, the same car under the same circumstances did 16½ miles at almost 15 m.p.h. With everything the same but with the device set to work at 180 degrees, the car did 19¼ and 16¼ miles, respectively. The gain at the lowest speed of 15 miles an hour from 14½ to 16½ and then to 19¼ miles per gallon represents gains of almost 14 and 38 per cent in economy.

Fans. In the earlier days of automobile designing it was deemed sufficient to secure circulation of air through the radiators by the movement of the car alone. This was soon found inadequate, however, for often when most cooling was needed, as in hill climbing or hard pulling on the level, the car would be moving at its lowest speed on low gear, with the result that the air draft through the radiator was not sufficient to cool the water.

This condition was remedied by the use of a fan behind the radiator, driven by a belt or gearing from the motor so as to draw a constant draft through the radiator in proportion to the speed of the engine rather than of the car.

Nowadays, practically all automobile power plants are provided with fans, the only exceptions being a few very small motors in which the difficulty of cooling is not so great as with the higher powers.

In some cases, instead of a separate fan, fan blades are placed on the flywheel, and so made to induce a draft through the bonnet that covers the engine, thus avoiding the necessity for the addition to the moving parts involved in the usual fan system. Such a flywheel fan is used in the engine illustrated in Fig. 204.

A later plan of even greater effectiveness is the housing-in of the whole rear end of the radiator, so that what air passes through must pass through the center where the fan is located. This is but another way of saying that all air must pass through at a high velocity, which insures efficiency. This plan fulfills one requirement of air cooling, that is, the large quantity of air which must be used.

Where this system is used now, the entire engine in front of the fan is made air tight. The hood, which has no openings anywhere, is set into carefully fitted rubber strips to cut off any possible leakage. The same precautions of drawing all the air through the radiator, and through that alone, are observed elsewhere. While this method is effective, it is a disadvantage in another way, for some direct cooling is effected through the cylinder walls, exhaust pipes, etc., in the ordinary system by the cold air passing over the radiator, particularly the air which comes in from around the hood top and sides.

Anti-Freezing Solutions. In using automobiles in very cold climates during the winter months, there is great danger of the water in the cooling system freezing when the car is standing still, or even with the motor running slowly if the temperature is very low. The result of such freezing is almost certain injury to the cylinders, through cracking of the water jackets, as well as the probability of bursting out radiator seams, with consequent leakage.

To avoid these difficulties it is not uncommon to use, instead of pure water, one kind or another of anti-freezing solution, usually compounded by the mixture of some chemical with water to lower its freezing point. Thus, glycerine or alcohol mixed with water will keep it from freezing at all ordinary winter temperatures. Glycerine is somewhat objected to because of its sticky, gummy nature, and also because of its deleterious effects upon the rubber hose of the piping system. Alcohol, if not replenished from time to time, will evaporate out of the water and thus permit it to freeze, or, if mixed in too great a quantity, it may introduce a fire risk otherwise avoidable.

A much favored anti-freezing solution consists of calcium chloride dissolved in water, in a quantity proportioned to the temperatures that it is desired to guard against.

All anti-freezing solutions are more or less objectionable in that they are more likely than pure water to corrode and clog up the circulating system, and there is no doubt that the elimination of the necessity for them by the substitution of air cooling for water cooling will mark a great advance in automobile development.

AIR COOLING

Though successfully employed in one or two automobiles and remarkably developed in some of its applications to aviation motors, air cooling is not considered by most engineers to be successfully applicable to the average automobile. That it will become more practical in the future, however, is the opinion of many.

Unfortunately, this is an instance where the better and simpler method does not meet with popular approval, that is, the cooling

Fig. 211. Diagrammatic Illustration Showing System of Air Cooling on Franklin Cars
Courtesy of H. H. Franklin Manufacturing Company, Syracuse, New York

of automobile cylinders is one of those cases in which the best in theory is not, by any means, accepted practice. The extent to which the public has adopted water cooling as compared with air cooling may be noted in these figures for 1916: Cooled by air, 1 car; cooled by water, 168; total, 169.

Flanges, or Fins. The usual method of air cooling, successfully employed in aviation and motorcycle motors and in a few automobiles, is to provide the cylinders with fins, or flanges, for increasing the area of the surface, supplementing this with means for blowing large volumes of air over the surfaces thus provided.

Air Jackets. Several of the most practical examples of air-cooled motors in aviation construction are those which have, in addition to the flanges, or fins, on the cylinders, air jackets to concentrate the drafts of air that effect the cooling.

Blowers and Fans. The most successful air cooling has been accomplished by types of blowers capable of inducing much more vigorous air currents than are drawn through the radiators of water-cooled automobiles by the types of fans commonly used in power plants of that character.

In the Franklin, the most successful air-cooled automobile motor, a side view of which can be seen in Fig. 211, the cooling is a sort of combination of the flange and the blower method. The fins are vertical and radial, with a close-fitting hood connected to an air-tight pan. At the only opening in this hood, which is at the rear end, is placed the fan (on the flywheel). This draws the air past the cylinder walls, where it is needed.

Internal Cooling and Scavenging. Perhaps more promising as a road to final and universal use of air cooling are the systems of pumping air through the interiors, instead of blowing it over the exteriors, of the cylinders. Such internal cooling, in addition to directing the maximum cooling effect where it is most needed on the oil-coated surfaces that are exposed to the heat of combustion, has the further advantage that it may be made to scavenge out all residual exhaust gases, which, besides helping to accumulate heat, also act so detrimentally upon the functioning of ordinary motors. This is a direct result of the admixture of retained exhaust gases with incoming fresh charges.

Methods of internal cooling and scavenging that appear of definite promise are those proposed in various recent schemes for pumping air first into the crankcase—either by using the under side of the piston as a pump, as in common two-cycle constructions, or by applying special pumps to the crankcase for this particular purpose—then into the cylinders by means of by-passes, with the result that it exerts a positive cooling effect inside the cylinder.

In England, some interesting experiments have been made on a theory of internal cooling in which water is introduced into the cylinders in the form of a spray, at certain points in the cycle. This is said to add power in addition to helping the cooling.

COOLING TROUBLES AND ADJUSTMENTS

Cleaning. It is highly important that the cooling system be entirely cleaned out at least once, and preferably twice, a year. When this is done, the water jackets and radiator should be flushed out with a strong current of water, preferably a hot soda solution. This should be forced through in a direction opposite to the usual course of the water. Thus, a hose can be put in the radiator filler cap and city pressure applied to force the water through; in this radiator, it will be made to go from bottom to top instead of the usual top to bottom. If this method, which is the usual and easy one, does not remove all dirt, sediment, and foreign matter, the radiator can be removed and boiled, or at least submerged, in a strong soda solution which will clean it out thoroughly. The radiator is the most important member of the system.

Replacements. When this is done, it is advisable also to look over all hose and hose connections. Many times the hose will have become worn or frayed through and cut or otherwise damaged from the outside, or the water may have attacked it from the inside, particularly if it has been through a winter when an anti-freezing solution was used. It is well, when cleaning the system, to replace all hose with new. The clamps are important as they determine the water tightness of the hose, so they should be looked over for missing nuts, broken screws, broken clamp ends, as well as to note if each one is applied straight and true over the hose and the end of the pipe on which it is placed.

Washing. If the radiator is splashed with mud or dirt, the washing should be done from the rear, with the hood removed. This method allows free use of the hose, and at the same time it insures against getting any water in the ignition system where it would cause trouble.

Adjusting=Fans. Usually, the fan is hung on an eccentric bushing held in a clamp. It is important that the fan belt be tight enough so that there is no slippage, otherwise the engine will heat up. To tighten a belt, loosen the clamping bolt on the fan eccentric, and then turn this eccentric so as to move the fan-shaft center away from the crankshaft-pulley center. The eccentric may be moved with the hands, in some cases; in others, a wrench is provided, and the fan eccentric made with surfaces on which the wrench fits; while still others need the application of a pointed tool and hammer to turn it. In the latter case, do this very carefully so as not to chip off any metal. Occasionally, the fan bearings need adjustment or lubrication. When they are of the plain type, a grease cup is generally provided, and after the engine is stopped, a couple of turns of this will be sufficient. If of the ball or roller type, they will be packed in grease, and if they show signs of running dry, the fan should be taken apart and the grease renewed. Use a good grade of cup grease for this purpose, not a hard grease.

Adjusting Pumps. Generally, the pump is made so as to need no adjustment. However, a leak may occur at one of the packing nuts. To remedy it, tighten the nut as far as possible, but if this does no good, remove the nut and add packing under it. Special packing is provided for this purpose, but if no other is available, a thick heavy piece of string can be well coated with graphite or a graphite grease and wound on as packing. In putting on packing of this kind, it should be wound on right handed, or in the same direction as the packing nut turns to tighten. Otherwise, tightening the nut will loosen the packing.

Summary of Cooling Troubles

Anti-Freezing Solutions. The following are satisfactory formulas for anti-freezing mixtures:

1. Mix equal parts of glycerine and water. Replace evaporation with clean water. Replace leakage with fresh solution.

2. Mix equal parts of denatured alcohol and water. Replace evaporation with alcohol and replace leakage with solution.

Radiators. Radiators must be kept well filled. Leaky radiators are difficult to repair. This work should be done by an experienced radiator man, never by a plumber.

Soft Water. Soft water should be used for filling tank. It should be borne in mind that the circulating water gets pretty hot, and that incrustation may result from hard water.

Engine Heats, Loses Power, and Knocks. These are all symptoms of lack of water circulation. To see if this is the case, look into the opening in the top of the radiator and see whether water is flowing in from the engine. If not, either the water-piping system is stopped

Fig. 212. Sectional View of the LaFayette Eight-Cylinder Motor Showing the Lubrication System

up, which can be checked by disconnecting, or else the circulating pump is not working properly. All modern engines are so proportioned that, in this event, the water continues to circulate by thermo-siphon action. Taking off the pump will verify this.

LUBRICATION SYSTEM

MOTOR LUBRICATION

When the lubrication system is referred to, that of the motor is generally meant. Motor lubrication is of the highest importance; for the motor must have efficient and continuous lubrication to run properly. Taken in its broadest sense, however, the title should refer to the entire lubricating means of the car; that is the way it will be handled here. The other units and parts of the car may not need as efficient or as continuous means of lubrication as the engine, and the presence or lack of lubricant is not so tremendously important; but all of it is of value and influence in the operation of the car, and should be well known.

Interior and Exterior Demands. The engine of a motor car requires two distinct kinds of lubrication. The interior parts, which are subjected to the greatest heat, rotate or slide at the highest rate of speed, and generally do the greatest amount of work, must have what amounts to a continuous stream of good lubricant. With the exterior parts, which do not rotate so fast, do less work, are not subjected to much heating, and will be kept cool by the atmosphere, there is no need for this continuous stream, nor for such a quantity or high quality of lubricant.

The exterior and interior systems must be considered separately. With reference to the internal oiling, there are two general systems in use: the pressure form, and the splash type. A third, which is now coming rapidly into use, is a combination of the two, called the splash-pressure system. For 1917, the relative popularity of these three is as follows: pressure, on 30 per cent; splash, on 35; splash-pressure, on 35.

In the pressure form (or its modification, the splash-pressure), the pressure may be produced in a number of ways: by a single large pump; by a series of small pumps, one for each bearing lead; or by a reservoir, or tank, kept filled by a separate pump (gravity pressure).

Splash-Pressure Feeding. One of the best and most successful types of lubrication systems is that in which the oil is fed under pressure to the different bearings.

In the splash-pressure system, the oil to all the crankshaft and connecting-rod bearings, to the timing gears, and to the upper portion of the cylinder walls is supplied through the medium of a gear-oil pump driven usually by worm gearing from the camshaft. The other bearings within the engine are lubricated by oil spray thrown from the crankshaft. Such a system is shown in Fig. 213.

Overland. The same units are necessary in all splash-pressure systems, but they can be and are used in widely different ways. It

Fig. 213. Pressure-Feed Lubrication System on Pierce-Arrow Cars
Courtesy of Pierce-Arrow Motor Car Company, Buffalo, New York

is of interest to the repair man to know the details of a number of these methods so as to be able to repair and adjust the mechanisms more readily, also to more quickly point out their troubles. One of the most simple systems in use is that of the Overland, as shown in Fig. 214. In this, the oil pump at the bottom of the oil sump *A* is driven from the camshaft rear end. After passing through the strainer *B*, the oil continues through an outside pipe to the sight feed *C* on the dash. This simply indicates that the system is working continuously.

From here it passes back through the pipe *D* to the inner distributing pipe *E;* this serves to keep the troughs *FF*, filled. At the middle part of the downward stroke, the scoop on the bottom of each connecting rod dips into its own oil reservoir and splashes up a fine spray of oil. At high speeds, the four rods fill the whole interior of the crankcase and the lower parts of the four cylinders with a mist of oil. This is sufficient to lubricate everything thoroughly. In a system of this

Fig. 214. Constant Level Splash System on Overland, in which Pump Maintains Oil Supply at Predetermined Level

kind, the strainer is of great importance and must be kept clean. Similarly, the oil sump should be drained very frequently, at least every 1000 miles.

Studebaker. The Studebaker system is very similar, except that the oil pump is outside of the crankcase and set higher up. It is of the simple gear type and is not liable to derangement. The system is equipped with an oil-level indicator on the side of the case, which shows the quantity within the case.

Single-Pump Pressure Feeding. The drilled crankshaft, as shown in Fig. 213, is a necessity in all pressure systems, as it also is in all combination splash-pressure systems. This can be seen, and perhaps the whole system explained more clearly, by referring to Fig. 215. In this the single pump working direct is used, thus differing from the reservoir system explained above. This diagram shows also how the oil is forced to flow through the three bearing leads to

Fig. 215. Lubrication System of Cadillac Eight, Showing Pump and Path of Oil, Also Auxilliary Circuit for Crankshaft

the interior of the crankshaft, whence it follows in to the pins upon which the connecting rods work. These rods are drilled, and the oil is thrown out by centrifugal force, passing up through the rods to the piston, thence onto the cylinder walls. In addition, the latter are sure to receive sufficient lubricant, for the rotating shaft and rods throw off a good deal in the form of a mist which settles upon the cylinder walls.

Generally, pockets are provided inside the motor to catch the mist and force it to flow to the camshaft and other bearings besides the crankshaft, but in this case it will be noted that the camshaft bearings have individual supplies through the medium of a camshaft oiling pipe.

Fig. 216. Pressure Lubrication System Used on Stearns-Knight Motors
Courtesy of F. B. Stearns Company, Cleveland, Ohio

An objection to lubricating systems of this type is that in case there are several leads to different bearings one of them may become obstructed without anything to indicate this condition or to overcome it until the bearing involved becomes overheated and ruined. If one lead becomes obstructed, the oil can still continue to feed out through the others, thus relieving the pressure in apparently the normal manner and failing to reveal a serious derangement.

Stearns. The Stearns-Knight system is shown in Fig. 216. The oil is circulated by a pump (not visible in this sketch) at the front end of the eccentric shaft *D*. After passing through a screen and the pump, it is forced through a strainer *A* in the filter *E*, thence through pipes to the pump-shaft bearings, eccentric-shaft chains, and main crankshaft bearings. It reaches the crankshaft bearings through the oil inlet *F*, the drilled holes in the crankshaft being indicated at *G*. From these holes, it reaches the hollow center of the connecting rods *H*, and thus to the piston pins and piston outer walls. At the bottom of each connecting rod, there are three small radial holes through which sufficient oil escapes to lubricate the inner and outer sleeves which take the place of the valves. A gage on the dashboard, or cowlboard, indicates the oil pressure and should read from 1 to 5 pounds with the throttle closed and the motor idling, and from 40 to 60 pounds when the throttle is wide open and the motor running normally or at high speed.

Regulator Connected to Throttle. The variation on this pressure is controlled entirely by the by-pass in the main oil lead, which is connected directly to the throttle-control mechanism. This by-pass consists of a body with an oil port and a piston with a series of holes. When the throttle is closed, and the motor idling, these holes and port register, so oil passes through freely, relieving the pressure on the bearings. When the motor is speeded up and more oil is needed, the piston is turned by the throttle connection so that the holes and ports no longer register and the oil cannot escape as freely and must be forced through to the bearings. This by-pass is adjustable by means of the small blade *B*, Fig. 216, which is rotated from the center to right or left and locked by the clamp bolt *C*. The safety valve *I* within the crankcase is set at the factory for the maximum pressure to be used in the system. If this is approximated, this valve is forced open and the oil escapes back into the crankcase, thus lowering the pressure. The oil-level indicator *J* is operated through the float *K* in the oil well and indicates the quantity. In cleaning and replacing filter screen *A*, be sure the holes register. The system used on the Stearns-Knight eight-cylinder V-type motor is essentially the same, with a few differences of location due to the form of engine.

On high-speed and multi-cylinder motors (which are almost invariably high-speed forms), the lubrication assumes an importance not hitherto attached to it. This is responsible for the pressures used

Fig. 217. Pressure System with Many Individual Features on Marmon Engine
Courtesy of Nordyke & Marmon Company, Indianapolis, Indiana

and for the wide spread use of mechanically driven positive pumps. Formerly, pressures of from a few ounces to 4 or 5 pounds were considered sufficient. Now, pressures as high as 60 and 70 pounds are not unusual. These tremendous pressures, however, have necessitated a system much more carefully constructed, assembled, and used than was the case previously.

Marmon. The Marmon system is not radically different from that just described, but there are a number of small individual points worthy of mention. The filling is not through the usual crankcase breather pipe, but through an opening in the top of the cylinder head *1*, Fig. 217. From this opening the oil flows around the valve push rods (the motor had overhead valves as will be noted) down into the bottom of the oil pan *2*. After screening at *3*, it passes through the throttle-controlled regulator to the oil pump *4* on the rear end of the camshaft. The main feed pipe is marked *5*, the pressure gage *6*, lead to crankshaft bearings *7*, hollow in crankshaft *8*, connecting-rod bearing *9*, cylinder walls *10*, ball check valve *11* to govern pressure in main feed pipe and excess oil through hollow rocker-arm shaft *12*, connecting to oil container *13* above valve tappets.

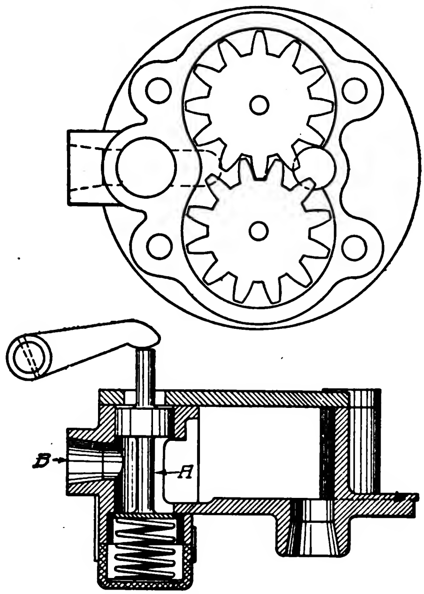


Fig. 218. Detail of Throttle-Connected Plunger in Marmon Oil Pump

In Fig. 218, a detail of the regulator is shown. Oil enters the pump body from the left through the opening *B*. The passage from *B* to the gears is controlled by the opening in the plunger *A*, which is operated by the movement of the throttle lever through the small tappet seen on top. When the throttle lever is depressed, the plunger moves down, and its upper, or piston, portion closes off a portion of the oil hole, restricting the supply. The spring under its lower extension is used to return it to position. Its shape is such that the oil has no tendency to act upon it, either to open or close it. In this system, the pressure varies from 12 to 60 pounds.

Types of Oil Pumps. There are but three or four types of oil pumps now in use, these being the gear, plunger, plunger operated by a cam, and in a few cases the vane pump. While essentially the same as the forms used for pumping water described previously, they are smaller in actual size and have some few different details. In the gear form, which is shown in Fig. 219, one gear is driven directly from the engine and, in turn, drives the other, their rotation forcing the oil along in the direction of rotation. Usually a by-pass with a check valve is provided, and when the pipe is obstructed or the pressure rises for any other reason, this opens and the oil passes around the pump at low pressure, equalizing the system.

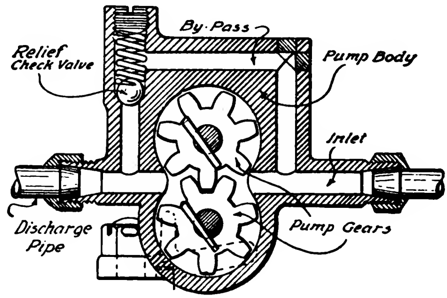


Fig. 219. Gear Type of Oil Pump of Marked Simplicity

The cam-operated plunger form is shown in Fig. 220. This is the method of drive adopted for mechanical lubricators, but few engines have an individually constructed pump of this type. It is simple, easy to regulate, seldom gets out of order and can be arranged to give a different supply at each plunger should the system warrant or necessitate this. A good example of the plunger form is the oil pump on the Reo engine, shown in Fig. 221. This works as follows: When the pump plunger *A* is moved upward by the curved eccentric *B*, it draws oil through the ports *C* and the screen *D*, as the entire lower part is submerged in the oil. When the maximum amount of oil is drawn into the pump chamber in this way, the plunger descends, the ball *E* rises, and the oil flows up inside the hollow plunger to the top ports *F*, through these to the surrounding chamber *G*, and thence to the outlet *H* and into the oil pipes. This form is very accurate and reliable.

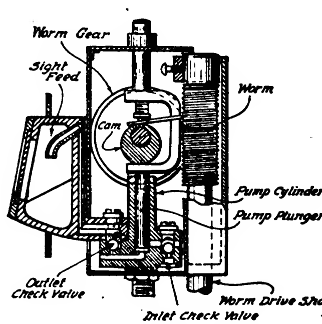


Fig. 220. Cam-Actuated Plunger Form of Oil Pump

Methods of Driving Pumps. Another point of considerable importance to the repair man is the method of driving the pump, since this influences its location and its accessibility. There are but two general methods of driving. One is by means of a special oil-pump shaft, in which the pump will quite generally be found in the bottom of the oil sump or very close to it; the other is from some part of a shaft used for other purposes, in which case the position may vary widely. Examples of the first, or special-shaft method, will be seen in Overland, Fig. 214, and Cadillac, Fig. 215. Examples of the second method are seen in Stearns, Fig. 216, and Marmon, Fig. 217, in both of which the camshaft is used.

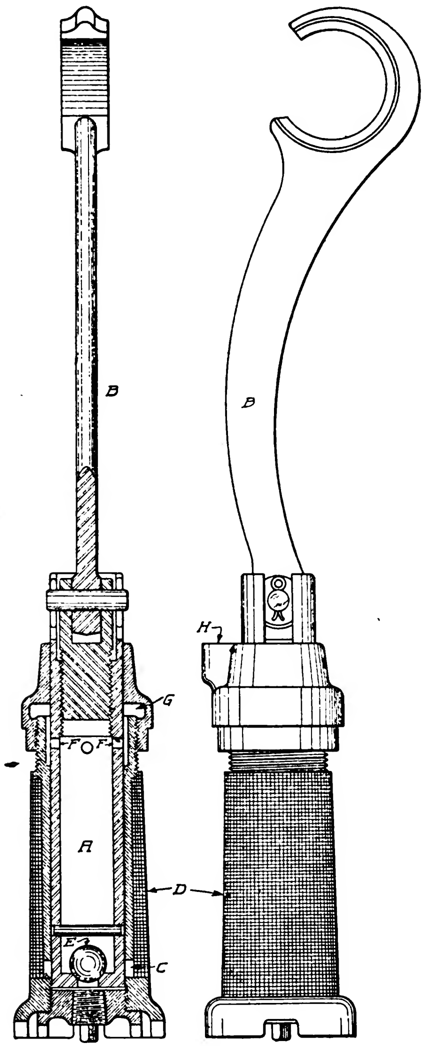


Fig. 221. Typical Plunger Pump
Courtesy of Reo Motor Car Company, Lansing, Michigan

In Fig. 222, a gear is placed directly upon the rear end of the camshaft meshing, with another immediately below it which forms the pump. This is the Scripps-Booth eight. Attention is called to these additional points, the hollow crankshaft for oil circulation at *A*, the method of carrying the oil leads and regulator up to a handy point on top of the motor at *B*, and the air cooling flanges on the bottom of the oil pan at *C*. The purpose of the latter is to reduce the temperature of the oil after it has been used and returned to the oil-supply reservoir and before it has been used a second time. The oil pump on the end of the camshaft is marked *D*.

In Fig. 223, the oil pump is a simple plunger operated by a cam

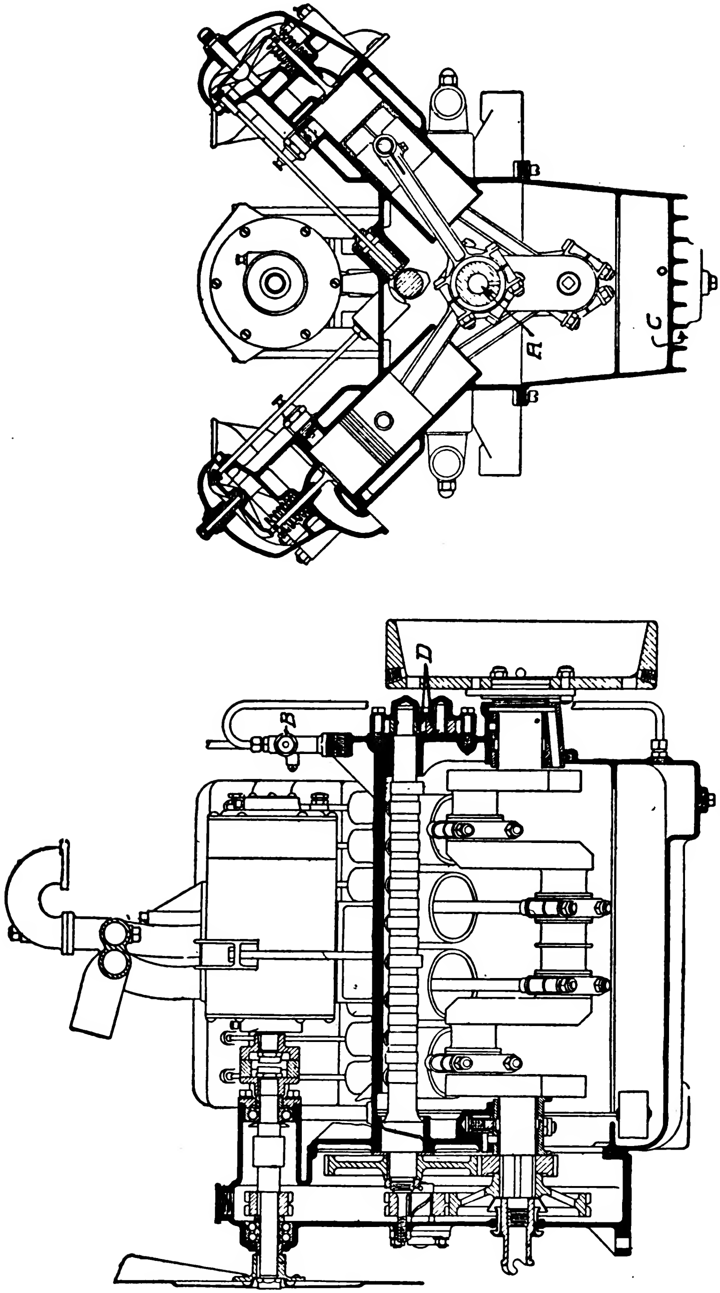


Fig. 222. Section and End Elevation of Scripps-Booth Eight, Showing Oiling System
Courtesy of Scripps-Booth Corporation, Detroit, Michigan

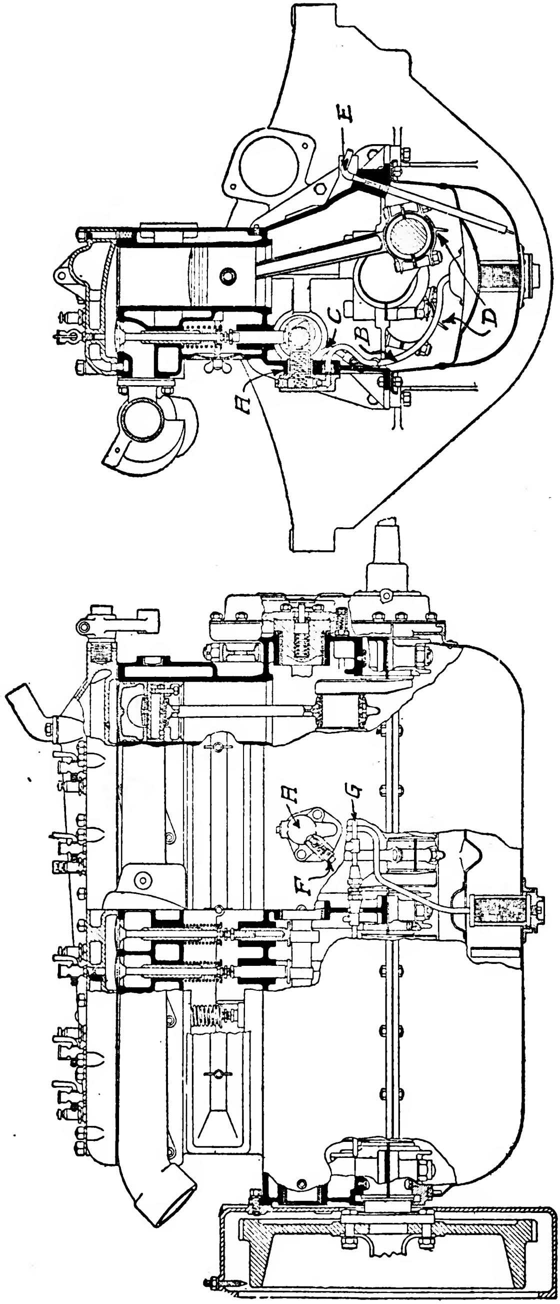


Fig. 223. Side and End Sections of Engine with Horizontal Plunger Type of Oil Pump

on the camshaft. It projects out at right angles on the side between cylinders 2 and 3. It is possible to arrange a system of this kind so that an extra cam is not needed, one of the regular valve cams doing the work of pumping the oil. This makes a simple and inexpensive arrangement. The oil suction pipe is marked *B* and the pipe carrying the supply to the bearings is marked *C*. Attention is called to the connecting-rod oil scoops *D*, the feed adjustment *E*, the pressure-relief valve *F*, and to the main oil lead *G*.

Individual Pump Pressure Feeding. The expedient of feeding the oil by individual pumps, independently driven and capable of individual adjustment which enables them to feed any desired amount of oil to any particular bearing regardless of the amount that may be fed to any other bearing, has been widely applied. In such a system, if obstruction of any one of the leads should occur, it is almost certain to be forced out by the action of the pump, which, in all lubricating systems of established type, is made capable of working against enormous pressure.

Fig. 224. Detroit Eight-Feed Multiple Oiler as Used for Motor Lubrication
Courtesy of Detroit Lubricator Company, Detroit, Michigan

One of these lubricators, made for eight feeds, is shown in Fig. 224. By extending the casing and the longitudinal shaft inside and adding more pumps, this type is capable of extension to any desired number. The eight-feed form shown allows of one lead to each of the three main bearings of a four-cylinder engine, one each to the four cylinder walls, with a lead remaining for the gear case at the front of the motor.

Gravity Feeding. Feeding of oil by gravity to one or more bearings is a method that has been employed with some success, but it is now encountered only in rare instances in automobile power plants.

Splash Lubrication. The feeding of oil to bearing surfaces by the simple expedient of enclosing a quantity of it in a reservoir in which the working parts are also contained is a successful and widely used scheme in automobile motor construction.

In the splash lubrication system, as will be shown in detail later, the lower ends of the connecting rods "splash" up the oil which is in the bottom of the crankcase in the form of a huge puddle. Since this method, formerly almost universal, has been criticised as wasteful of oil as well as productive of much needless smoke, it has been modified

Fig. 225. Typical Screw Type Grease Cup with Wing Handle

Courtesy of Lunkenheimer Company, Cincinnati, Ohio

Fig. 226. Lunkenheimer Grease Cup with Removable Barrel

Fig. 227. Lunkenheimer Grease Cup with Spring Cover for Quick Filling

by the majority of makers so that the scoops on the ends of the connecting rods dip into small narrow troughs provided for this purpose. Another objection to this system is that at high speeds too little oil is thrown around the interior of the cylinders and crankcase, since the initial rotation of the rods has churned or beaten the entire supply into a mist, while at low speeds too much is thrown around for the work the engine is doing.

The latter objection has been overcome in the newer engines by making the troughs into which the connecting-rod scoops dip movable and attached to the throttle lever, so that when the latter is opened wide to develop maximum power, the troughs are brought up higher, allowing the scoops to dip down deeper and thus supply a greater amount of lubricant.

External Lubrication. In the lubrication of the external parts of the motor, such as the pump shaft, magneto shaft, oiler shaft, fan shaft, generator shaft, air pump shaft, etc., an entirely different method of lubrication is necessary—one that is more simple in every respect, allows the use of more simple lubricating devices, and does not require anything like the care and adjustment previously pointed out for the internal parts.

Oil and Grease Cups. Chief among the devices used for lubricating these outside parts are oil and grease cups, the oil cups being used in decreasing quantities and the grease cups in increasing quantities. Formerly, oil cups were much used, but they gave poor satisfaction, collected dirt, and were unsatisfactory generally. In the use of grease cups, there are but three things to observe: They should be large enough, accessible, and easy to fill.

For application to spring eye-bolts there is a particular type of grease cup. This grease cup is of the type that feeds by being occasionally screwed up a small distance as the bearing uses up the lubricant, and its positive action is rendered more certain by the use of a detent (not illustrated) that holds the cover in any position in which it may be left. The grease is contained in the entire cap which, when unscrewed from the lower portion, is readily and conveniently filled by scooping up the grease.

A form quite generally used is the simple cup shown in Fig. 225. This is a screw-compression cup from which the lubricant is forced out by screwing down on the reservoir. This form is prevented from coming loose by the compression spring, here shown very much compressed below the ratchet, which governs the screwing down of the reservoir. To fill the reservoir, the ratchet portion is held down and the top screwed off, turning in the reverse of the usual direction. Although the top is fitted with a wing handle, it can hardly be considered easy to refill.

Another widely used form is seen in section in Fig. 226. This has a larger handle and, in this respect, may be considered easier to fill. A type which is rapidly coming into use and has all the advantages of the other two, and more, is shown in Fig. 227. This is a plain screw type with a large handle, but the cap is of sheet brass and is sprung into place. As this is sprung off by the plunger inside when screwed away out, filling is reduced to a matter of seconds. The plunger screws all the way in and affords pressure all the way.

Fig. 228. View of Locomobile Chassis, Showing Complete Oiling System

Instructions as follows: Spring Grease Cups 1, 2, 7 to 10, 17 to 20, and 29 to 32 should be given full turn every day and kept filled; Distance Rod Grease Cups 15, 16, 21, 22, 23, 24, 26 and 27 should be given a full turn every other day or once in 500 miles and kept filled; Steering Tie Rod and Steering Pivot Grease Cups 3 to 6 should be given full turn every day and kept filled; Water Pump Grease Cup 11 should be turned down every day—special heavy mineral grease or beef or mutton tallow should be used in these; Torsion Bar Pivot Grease Cup 14 should be turned down once a week or every 1000 miles; Brake Shoe Supporting Bracket Oil Cups 25 and 28 should be turned down once a week; Engine Oiling System should be drained every 2000 miles and refilled through plug *A;* Steering Worm Gear Case should be filled with grease every 2000 miles through plug *B;* Oil-Pump Gear Housing should be packed with grease once a season through plug *C;* Transmission Case should have grease added, through plug *E*, every 2000 miles to bring supply up to proper level; Rear Axle Housing should be drained every 5000 miles and refilled with grease through plug *F;* Clutch Universal T. U. J. and Universal Joints P. U. J. should be packed with grease once a season; Generator, Starting Motor, Spark and Throttle Levers, Steering Column, Carburetor Regulating Collar, and Brake Shaft Equalizers should be oiled every 1000 miles; Magneto and Air Compressor should be oiled, Transmission, Steering Worm-Gear Case, and Ball and Socket Universals in Steering Connections should be greased every 2000 miles; Foot Pedal Shafts and Hand Lever Shafts should be oiled every 5000 miles or once a season; Fan Bearings, Clutch Brake Ball Bearing, and Steering Column Screw and Nut should be greased every 5000 miles or once a season.

The simplest form of oil cup has a hole in one side, which is covered with a spring-held cover. To use it, the cover is lifted with the fingers until the hole is uncovered, then the point of the oil can is inserted and the oil forced in.

GENERAL LUBRICATION

Lubricating the Whole Car. It is best for both the private owner and the repair man to have a definite regular system for going over the grease and oil cups on the chassis. As shown in Fig. 228, there are a number of cups varying from 30 to 32 and upward, as well as oil holes, which need to be looked after occasionally. The worker should get an oiling chart and fix firmly in his mind the requirements of the various parts to be oiled or greased and should regulate his oil and grease cups by hand from day to day and week to week so as to produce the desired results.

Lubrication of Other Parts. The precise lubrication of the clutch, transmission, rear axle, and other more important units will be found discussed in detail under their respective headings.

There are signs at present that the lubrication of the motor may be controlled through the medium of a thermostat in order to conserve every unit of heat needed in the vaporization of the fuel and thus increase the efficiency of the engine as a whole. There would be a double advantage in this, for lubrication would be placed on a more economical basis. In using the thermostat, smoking and carbonization would be reduced, and their heat utilized. This process, carried out to a logical conclusion, might result in forced lubrication of all points on the chassis by means of the oil-pump system. A system of forced lubrication somewhat like the above has been produced in the Fergus car, but here the idea was to reduce the amount of work in connection with lubrication. The number of points outside of the automatic oiling system, which required oil or grease application by hand, has been reduced in this car from 80 to 11. Some 18 points in the springing system have been eliminated entirely by enclosing the springs in leather boots, grooving and drilling them, and forcing oil in under pressure from the main pump. It is questionable, however, whether the results as obtained in this case are worth the cost in money and complication, for this system gives a freak appearance to the car.

Oils and Greases

Characteristics of Good Oils. The variety of oils and greases recommended for automobile use is so extensive, and there are so many cheap and worthless lubricating compounds on the market, that it is almost impossible for the purchaser without technical knowledge to discriminate between them. The various tests from time to time recommended, whereby the user may ascertain for himself the quality of the lubricant he is using, are rarely of positive value, since the compounders of the shoddy oils and greases are usually sufficiently expert chemists to concoct admixtures that will successfully pass such simple tests as are available to the average layman, and will fail only under the more critical analysis of a competent chemist, or under the severe and more risky practical demonstration that results from long use, in the course of which the worthlessness of the lubricant is likely to be found out only at the cost of serious injury to the mechanism. The consequence is that the only really safe policy to follow is the purchase of the highest grades of oils and greases, marketed by concerns of established reputation.

The oils generally found best for gasoline-engine cylinder lubrication are the mineral oils derived from petroleum, though castor oil is found to possess peculiar merits for the lubrication of air-cooled motors working at high temperatures in which the friction of steel surfaces working over steel surfaces is often involved. This oil is exclusively employed in aviation motors, such as the Gnome, which is built with steel cylinders and pistons, and it is often utilized in racing automobile motors. Its chief merit seems to be that instead of withstanding the high temperatures, which is the result sought in the use of mineral oils of high fire test, it burns up clean without leaving any deposit upon the cylinder walls. It has to be fed in excessive quantities, which makes its use a rather expensive method of lubrication. But for the peculiar services for which it is adapted, it certainly proves most satisfactory.

In greases and oils used for the lubrication of parts not exposed to such high temperatures as prevail in gasoline-engine cylinders, the admixture of vegetable and animal greases and oils with mineral oils and greases is not objectionable and often may be of considerable benefit.

Graphite is a solid lubricant and is very advantageous to employ in many parts of an automobile. In the deflocculated form, admixed in very small percentages with cylinder oils, gearbox greases, etc., there is no question but what it greatly conduces to smooth running and to long life of bearings. Its resistance to the very highest temperatures makes it constitute a considerable safeguard against immediate injury in case of neglect to replenish the lubricants as often as is properly required.

Oil Tests. *Heat Test.* The reaction known as the heat test is very easily made with any lubricating oil. There is perhaps no other test which indicates so decisively and so quickly the purity, the durability, and the degree of refinement of an oil.

This test consists of heating a sample of oil to a temperature of between 300° F. and 500° F.—depending upon the flash point—and holding it at this temperature for a period of from ten to fifteen minutes. A good quality of oil will show a slight change in color, turning to a darker shade, but the oil will remain clear.

A poorly refined and impure oil will show an immediate alteration in color and will change to a dense black. As the heat is maintained, a black precipitate settles, the quantity of the precipitation depending upon the impurity of the oil.

Oil will act in just the same way when subjected to the heat of the explosions in the internal-combustion motor, and thus there is a continuous precipitation of black sediment if the oil is poor. This is what causes the costly wear of all parts in moving contact within a short time.

Emulsion Test. The emulsion test shows the quality of lubricating oils about as accurately as does the heat test on straight or blended hydrocarbon oils, but it is not reliable when animal or vegetable oils are present.

Reclaiming Oil. It is now authentically stated by some scientists that oil does not wear out and can be reclaimed for motor use if the proper equipment and method are used. A number of manufacturers and service stations are now reclaiming this oil with wonderful success. The government reclaimed cylinder oil used in aeroplanes and it is authentically stated that 40 per cent of the oil used in the motors was returned to the reclaiming station and that from 50 to 90 per cent of this oil was treated in such a manner that it was as good, if not better than, the original oil. The cost of the reclaiming was less than 10 cents a gallon. The most generally used process of reclaiming this oil is by heating it after it has been emulsified with soda ash and water. When this is done, the impurities separate from the oil with the ash. After the oil is thus treated it is dumped into the reclaimer. Live steam is passed into the oil and a violent agitation is set up. This is done to distill off the gasoline that had collected in the oil when it was in use.

Testing Oils for Acid, Etc. Oils must be purchased with much care. Once an oil is found which does the work satisfactorily, it should be adhered to consistently. No two oils are exactly alike, and for that reason, no two will do the same work under the same conditions in the same way. So, it is advisable to experiment only until an oil is found which will do the work. Thereafter, stick to that brand. As an instance of the impurities which may be found in oils, acids may be mentioned. These are fatal to delicate and closely machined parts, such as ball bearings, cylinder walls, pistons, etc., and consequently they should be watched for.

Pure mineral oils contain little acid, and what they do contain is readily determined. Vegetable and animal oils, on the other hand, all have acid content and under the action of heat this may be liberated. A simple home test may be practiced as follows: Secure from a druggist a solution of sodium carbonate in an equal weight of water. Place this in a small glass bottle or vial. To test an oil, take a small quantity of the lubricant and an equal amount of the sodium solution. Put both in another bottle, agitate thoroughly, and then allow it to stand. If any acid is present, a precipitate will settle to the bottom, the amount of the precipitation being a measure of the amount of acid present.

Another method is to allow the acid, if there is any, to attack some metal. To do this proceed as follows: Soak a piece of cloth or, preferably, wicking in the oil suspected of containing acid. Select a piece of steel at random and polish it to a bright surface. Wrap the steel in the soaked rag or wicking, and place in the sunlight but protect it from wind or weather. Allow it to stand several days, and if there is no sign of etching of the surface, repeat with a freshly soaked rag, being careful to use the same oil as before. After two trials, if no sign of the etching appears, you may consider it free from acid.

Principles of Effective Lubrication. To render lubrication positive and effective there are certain conditions regarding the design of bearings and the feeding of lubricants that must be scrupulously observed.

The proper application of a lubricant to a revolving shaft passing through a bearing requires that definite space be provided between shaft and bearing for the lubricating material. The amount of this space varies with the size of the shaft, the speed of rotation, and other conditions, but in a general way it can be specified that the space must be greater as the shaft diameter increases, and greater for heavy oils and low speeds than for light oils and high speeds. For the crankshafts of automobile engines, to take a specific example, it is rarely desirable to have the bearing smaller than from .0005 to .0015 inch larger than the shaft. The annular space thus provided, as suggested at *A* in the end and sectional views in Fig. 229, is occupied by the lubricant, which, contrary to another general impression, will not be squeezed out unless the shaft is loaded above its

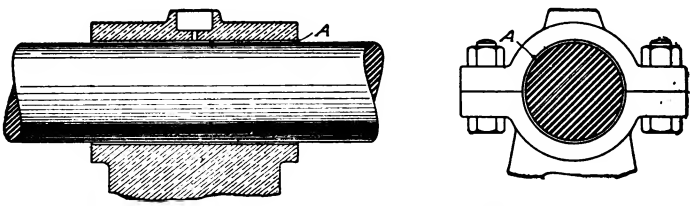


Fig. 229. Condition of Bearing for Proper Lubrication

capacity; this is more likely to occur because the bearing area is too small than from any other condition likely to be encountered.

With the bearing area large enough—which means that the specific pressure on its projected area must not be excessive—the tendency of the oil to remain in its place by capillary attraction, perhaps helped by the pressure under which it is fed into the bearing, is much greater than the tendency of the load upon the shaft to force it out.

From the foregoing, it is evident that the condition of effective lubrication is that in which the shaft literally floats in an oil film of microscopic thickness, this film completely surrounding it and so protecting it from any contact whatever, under normal conditions, with the bearing surface. The necessity for the accurate fitting of bearings is to provide an oil film of uniform thickness.

LUBRICATION TROUBLES AND REMEDIES

Care of Lubricant in Cold Weather. Nearly everyone realizes the amount of care necessary with cooling water in freezing weather, but few realize that extreme cold has practically the same effect upon lubricants. In the coldest weather, a lighter grade of oil specially made to withstand low temperatures should be used. If a special oil cannot be obtained, the lighter thinner quality will suffice, as even when thickened up by the low temperatures this oil will flow more readily than the thick oils. Sometimes the slow circulation of the oil in cold weather allows the motor bearings to run dry and heat. This trouble can be remedied by changing to a lighter oil. The same is true of the clutch oil which is in the multiple disc running in oil. Thick oil in this in cold weather will often thicken up and stick so the clutch will not work well.

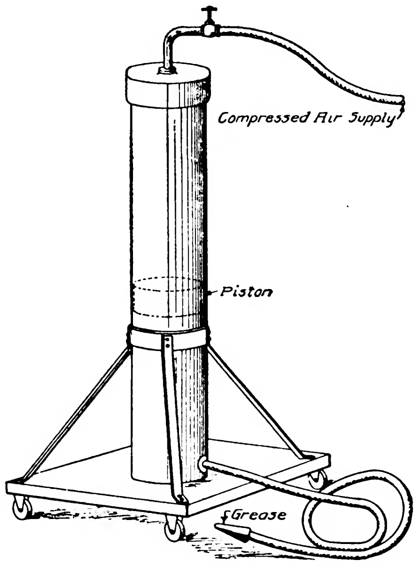


Fig. 230. Mammoth Grease Gun for Garage Use
Courtesy of "Motor World"

Mammoth Grease Gun. For the average shop which handles a good many cars a day, too much time is wasted in using an ordinary method of filling a transmission, rear axle, or other large part, with grease. A mammoth grease gun can be constructed to do this same work in a few seconds. A form operated by compressed air is shown in Fig. 230. It consists of a steel cylinder about 8 inches in diameter and perhaps 7 feet long mounted vertically on a platform which is set on castors so that it can be wheeled around the shop as needed. A free piston is placed in the cylinder, above the grease, and air admitted through the central opening in the screw top by screwing on a compressed air hose. The outlet hose at the bottom is made long enough to reach any ordinary point on the average car. When a transmission is to be filled, the platform is wheeled up to the car, the bottom hose put in the transmission, and the cock opened.

Then the air hose is connected and the pressure turned on; the grease will be forced out in a hurry, filling the case in a few minutes regardless of the quantity needed.

Getting Oil Barrels Out of Sight. The oil barrels around the garage are in the way; they collect dirt and spread oil into everything within reach and take up much valuable space. A good way

Fig. 232. Method of Elevating Oil Barrels to Save Space

to get rid of them is to build a rack close to the ceiling, Fig. 232, and put them up there. A pipe with a faucet at its lower end for drawing oil leads down from each barrel; these pipes are grouped over a small pan which catches the drip. Filling these barrels is easier than it seems. Connect a pipe from the barrel of new oil to the overhead barrel to be filled, apply the air pressure at the bung, and the oil will be forced up.

Oil Settling Tanks. If lubricating systems are drained as often as both manufacturers and oil people recommend, there is a good deal of oil around, which is heavy and of a doubtful quality. But if this oil can be allowed to stand, or can be filtered, a large quantity of it can be used for other purposes. If a tank of fairly large size is made with a series of faucets or cocks at different levels, somewhat like that shown in Fig. 234, enough of the oil can be saved to resell at a good profit, or, if there is no idea of selling it, it can be used for other machinery or for other purposes, where the need for high-quality oil is not so great. The oil drawn off the crank-case is poured in at the top and gradually settles, the heavier sediment going to the bottom, the thickest oils next, and so on, until the top will show a fair quality of light oil, and the layer next to it a fair quality of medium oil, and so on down to the bottom.

Fig. 234. Settling Tank with Cocks at Various Levels for Saving Oil

Oil Filtering Outfit. If one has the apparatus, filtering is much superior. A simple filtering outfit is shown in Fig. 235; this consists of the tank with provision around the inside for supporting a fine brass screen and two or more funnels, one above the other. The mouth of each of the funnels is filled with cotton waste, and the funnel set in place, then the next one is filled and set above it, and finally, the brass gauze is laid across at the top. As the oil is drawn off, it is poured in at the top. The wire catches any large particles, while the oil in filtering through the

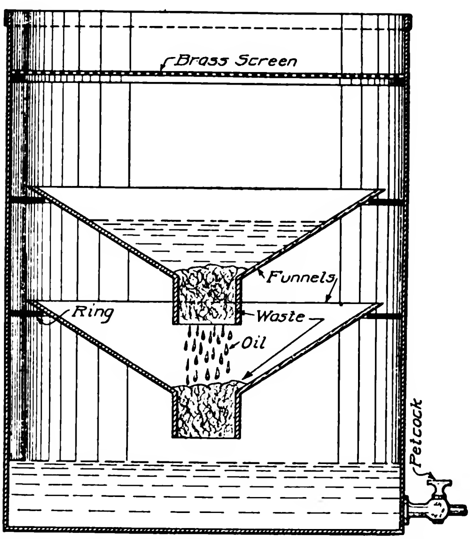


Fig. 235. Filter of Simple Construction for Filtering Oil

two or three bunches of waste will lose practically all its impurities, coming out perfectly clear. After each use, the waste is removed and burned, and new waste put in its place.

Oil measures, funnels, and other containers should always be kept clean. The oil left on them soon collects dust and dirt, and the next time some of this old oil will be poured into the engine with the fresh oil. All oils do not mix, and chemical action may be set up between old oil of one quality on the can and new oil of another quality in the can. Kerosene or a little gasoline should be poured in the containers or funnels to clean them off. This liquid should be rinsed out of the cans and put into a settling or filtering tank and practically all of it recovered.

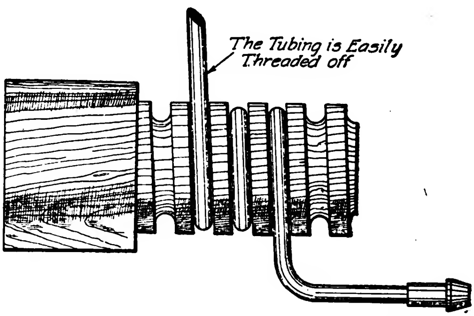


Fig. 236. Hard Wood Fixture for Bending Oil Pipe

Bending Oil Pipes. Frequently an oil pipe which has a curve or spiral in it, or even a series of coils has to be replaced. If bent by hand, a kink may be made in the pipe which will lead to a future break. A simple fitting for bending these pipes can be made in a few minutes. Take a piece of hard wood about 3 inches square and 9 inches long and turn it up round in the lathe, then down one end, as shown in Fig. 236, and cut the spiral grooves or threads in it. These should be about $\frac{5}{16}$ inch in width and cut with a round-nosed tool so as to get a smooth bottom to the grooves. When a pipe is to be bent, fill it with resin, a fine lead rod, or anything flexible. The wood can be held in the side of the vise and the tubing wound onto the threaded end. If the pipe is of a heavy gage, anneal it by heating and plunge it into cold water before starting to bend it. After bending, melt out the filler.

Summary of Troubles with Lubrication Systems

Crankcase Oil. This should be changed about every 500 miles as, by this time, the lubricating qualities of the oil are nearly exhausted. After draining the oil, wash out the crankcase with kerosene and see that the kerosene is removed before putting in fresh oil.

Grease Cups. These are usually located on the rear axle, steering knuckles, steering-column base, and many other parts. They should be kept constantly filled with cup grease. These grease cups should not be confused with small oil holes having caps which can be raised but not unscrewed. Grease cups should be screwed down occasionally in order to force the grease down to the bearing surface.

Neglect of Lubrication. Neglect of lubrication is responsible for many troubles. Any automobile requires careful attention to its lubricating system. The owner will find it to his advantage financially to see that all necessary parts are properly lubricated.

Steering Gear. The steering-gear parts require occasional lubrication. These parts include steering rod; worm, or sector, and gear; steering link at both ends; foot-pedal pivot or bearing; and all joints.

Too Much Oil in Crankcase. Usually drain cocks are provided in the crankcase and are so located that when they are opened they will drain off only the surplus oil.

Troubles with Mechanical Lubricator. If one of the sight feeds fills with oil, it indicates too rapid feeding of oil. Shut off the valve on the top of the lubricator till the glass is clear. If it does not clear up shortly, the probability is that it is necessary to clean the lubricator.

Mixing Gas-Engine Cylinder Oil with Fuel. This is advocated by the makers of a few two-cycle engines, the proportion being one-half pint of best gas-engine cylinder oil with every five gallons of gasoline. This, however, is not considered good practice.

BEARINGS

Types of Bearings Required for Different Locations. As the portion of a mechanism upon which, more than upon any other element, its continued operation and long working life depends, the bearings of any piece of machinery should be of the most approved design and most perfect construction. The crankshaft and connecting-rod bearings, which are the most important on the motor, are of the plain type on the majority of engines. Of the 1914 cars but six different makes had ball bearings for the motors, and, of these, two used plain bearings on some models, so that only four makers actually believed in ball bearings for engine shafts. For camshafts there is more difference of opinion, while on fan shafts almost all makers use ball bearings. The other shafts, as pump, oiler, magneto, air-pump, generator, etc., are generally of the plain, solid, round type.

Engine bearings, however, are generally of the split, or halved, type, the upper and lower halves being practically duplicates. A reason for this construction appears as soon as one considers the application of the bearings to the shaft. It is granted that a crankshaft must be as firm and solid as possible, and hence it must be made in one piece. As ball bearings also are made in one piece, there arises at once the difficulty of getting the bearings into place on the one-piece shaft. This difficulty has necessitated cutting the shaft or else making it especially large and heavy in those cases where balls are used. With the split type of bearing there are no troubles of this kind and the bearings are adjustable for the inevitable wear.

Plain Bearings. The conditions that determine the proper proportioning and fitting of plain bearings have already been referred to in a preceding paragraph.

The materials of plain bearings are commonly varied to meet different conditions. With liberal bearing areas, in situations where it is desired to bring about a perfect fit with the minimum amount of labor, and to protect the shaft from wear in case there is failure of the lubrication, the various types of babbitt metal—which usually are alloys of tin and lead, with sometimes some admixture of antimony and other alloys—are widely regarded as the most serviceable. Probably the greatest advantage of a babbitted bearing is that, if the lubrication should fail, the low melting point and the soft material of the bearing will insure its fusing out without injury to the more expensive and valuable shaft.

Brass and bronze bearings, particularly the phosphor bronzes and the bronzes in which the proportion of tin is high and that of copper low, with sometimes the admixture of a proportion of zinc or nickel, will allow the use of materially higher pressures per square inch than can be safely permitted on babbitted bearings.

Steel shafts in cast-iron bushings, and even in hardened-steel bushings, make much better bearings than one might think, and though immediate trouble is to be anticipated with such a bearing should its lubrication fail, even momentarily, this trouble is more or less true of any bearing that can be devised. Since steel-to-steel and steel-to-cast-iron permit much the highest loadings per unit of area that are permissible with any type of metal-to-metal bearing, the merits of these materials are perhaps less appreciated than might be desirable. Steel pins through steel bushings, however, are not an uncommon construction for the piston-pin bearings in high-grade engines.

One noticeable feature of plain bronze or other plain bearings for automobile use is that they are always grooved for oil circulation. This is done by easing off the edges, then cutting a spiral groove by hand diagonally across to the other edge or to the center point where a similar groove from the other side is met. In a solid bearing, the groove is generally cut both ways from a centrally drilled oil hole, while in split bearings the grooves in each half usually form a modified letter *x* when viewed in plan, that is, two grooves start spirally inward from each edge near the ends, and all four meet in the center. This central point may be the spot where the oil enters or where it leaves. These grooves are seldom of very great depth, perhaps .008 to .010 (eight to ten thousandths).

New Oilless Bearings. A form of bearing that is new to the automobile but old in years is now coming into use. This is made of special wood which previously has been impregnated with oil. By saturating the pores of the wood with oil in this way, it is claimed that no lubricant need be used on the bearing for years. They are turned and fitted the same as bronze or other bushings.

Another oilless bearing is made of bronze with graphite inserts; this bearing is sufficiently soft to form the lubricant, yet sufficiently hard to retain its form and shape. Approximately one-half of the inner surface of the bearing is graphite, the two alternating in various ways, that is, the graphite is put in in spirals, in circles, in double diagonals, in a herringbone pattern, in zigzags, and otherwise.

Roller Bearings. Roller bearings, constituted by the interposition of a number of small rollers between shafts and casings, are a type of bearing widely employed in automobiles.

A much-favored construction is the tapered roller bearing illustrated in Fig. 237. This stands up very well under both thrust and radial loads.

Another type of roller bearing is that illustrated in Fig. 238, which is the type used on the Ford rear axle. This is one in which the rollers are small flexible coils made of strip steel, finally hardened and ground accurately to size. This type of roller can be depended upon to work without breakage or injury even though there be con-

Fig. 237. Timken Roller Bearing
Courtesy of Timken Roller Bearing Axle Company

siderable deflection or inaccuracy in the alignment of shaft or casings, the flexibility of the individual rollers taking care of such small errors.

Fig. 238. Hyatt Flexible Roller Bearing Partly Disassembled to Show Components
Courtesy of Hyatt Roller Bearing Company, Newark, New Jersey

It will be noted in Fig. 238 that there is a solid steel shell to go on the shaft and fit it tightly, and another to fit into the case or support, whatever it may be, perhaps attached there permanently. Between these two comes the cage carrying the flexible rollers. Any load imposed upon the shaft is transmitted to the inner sleeve and by it to the flexible rollers; these rollers absorb the load so that none of it reaches the outer case. Furthermore, shocks coming to the case from without are absorbed by the flexibility of the rollers and, *vice versa,* shocks to the shaft do not reach the case.

Ball Bearings. Probably the best of all bearings, except for certain special applications in which it is difficult to utilize them in sufficiently large sizes to assure durability, are the annular ball bearings of the general type illustrated in Figs. 239 to 243, inclusive. The basic feature of the most successful of modern annular ball bearings is their non-adjustability, the balls being ground very accurately to size and closely fitted between the inner and outer races so as to allow practically no play.

Fig. 239. Annular Ball Bearing

The reason that the best ball bearings are not made adjustable is that in any conceivable type of ball bearing one or the other of the races rotates and the other remains in a fixed position. The result is that there must be a loaded side to the race that does not rotate, with the consequence that when wear occurs, it wears the ball track deeper at this point than on the unloaded side. With the bearings thus worn, it is almost impossible to make an adjustment, for the attempt can result only in tight and loose positions as the balls come out and in of the spot that is more deeply worn.

Fig. 240. Section of Annular Ball Bearing

This condition has led the designers and manufacturers of the various types of high-grade annular ball bearings that are now on the market to discard adjustment as of no value and to substitute in its place qualities of material and hardness of surface which, in combination with the provision of sufficient sizes, are found to reduce wear to so small an amount that it is almost inappreciable. A bearing thus made can be therefore depended upon to outlive almost any other part of the mechanism in which it is placed.

The carrying capacities of ball bearings, as compared with those of roller bearings, are much greater than a casual consideration might lead one to suppose. Theoretically, the contact of a roller bearing—between a roller and one of the races—is a line contact, while that between a ball and a ball race is a point. But, practically, since some deformation occurs in even the hardest materials under sufficient load, the line contact in the roller bearing becomes a rectangle and the point contact in the ball bearing becomes a circle. Now the vital fact is that the area of the rectangle in the one case is substantially equal to that of the circle in the other—with given quality of materials and a given loading. So a ball bearing is fully as capable of carrying high loads as a roller bearing; besides, it avoids the risk of breakage

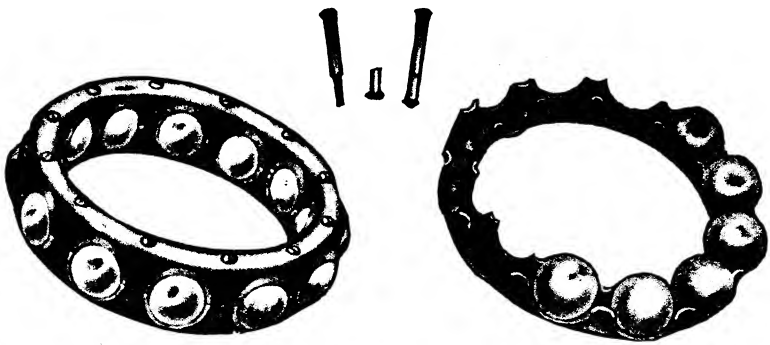


Fig. 241. Ball Cage of Annular Ball Bearing

that usually exists with rollers because of the impossibility of making them perfectly true and cylindrical.

To assemble ball bearings of the type illustrated in Fig. 240, either of two expedients may be adopted. One is to notch one or both of the ball races, so that by slightly springing them a full circle of balls can be introduced through the notch. The other scheme is to employ only enough balls to fill half of the space between the races, which permits them to be introduced without any forcing, after which they are simply spaced out at equal intervals and thus held by some sort of cage, or retainer, such as is illustrated in Fig. 241.

Ball bearings of the common annular type are quite serviceable to sustain end thrust as well as radial loads. For the best results under such loads, however, it is essential that the load be distributed equally around the entire circle of balls, for which reason the system illustrated in Fig. 242 is a means of avoiding the unequal distribution of pressure likely to result from the slightest inaccuracy of fitting. In

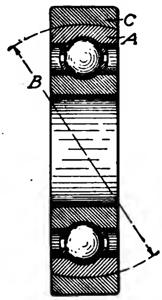


Fig. 242. Bearing Designed to Equalize Loads

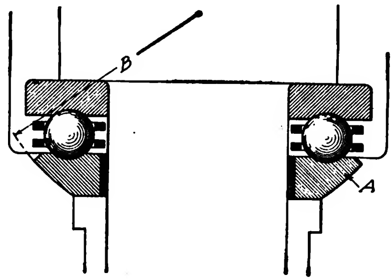


Fig. 243. Annular Ball Bearing Mounted for Thrust Loads

this construction the outer ball race, shown at *A*, is provided with a spherical outer surface, permitting it to rock slightly in the mounting *C*, into the position shown in an exaggerated degree at *B*. It thus floats automatically to a position at exact right angles to the shaft upon which it is mounted, and so insures even loading of the whole ball circle.

An annular ball bearing designed for thrust loads alone is illustrated in Fig. 243. In this bearing, the lower race *A* is provided with a spherical face, described from the radius *B*, so that, as in the case of the bearing illustrated in Fig. 242, when in use it automatically floats under the load into such a position that all the balls are under equal pressure.

Fig. 244. Bearing for Combined Radial and Thrust Loads
Courtesy of New Departure Manufacturing Company, Bristol, Connecticut

To secure uniformly satisfactory results from ball bearings, it is not only necessary in the first place to have them of the best materials, accurately made, and of sufficient sizes, but thereafter they must be always protected from dust and grit and from water and acids which tend to cause rust. They must also be kept lubricated.

Combined Radial and Thrust Bearing. The need for a bearing which would take ordinary radial loads well and also sustain thrust has led to the development of combined radial and thrust bearings, one being illustrated in Fig. 244. This is constructed to take either form of load equally well, and for this reason has displaced a pair of ball bearings in many circumstances where formerly it was thought necessary to use a radial ball bearing to sustain the load and a thrust ball bearing to absorb the end thrust. In this way it represents an important economy. Furthermore, it is economical of space, as it takes less room than the former pair of bearings used for the same two purposes.

FLYWHEEL SUB-GROUP

Importance of Flywheel. With the growing tendency toward smoother and more even running and the demand for lower low speeds and higher high speeds, the flywheel, which was looked upon as a necessary evil for many years, is now receiving more attention. The designers realize that the flywheel plays an important part in balancing—that if it is too heavy the engine will be slow to pick up speed and will not run very fast, and that if it is too light, the engine will be very "touchy" and will not withstand quick variations from high to low or low to high speed, nor will it throttle down very slowly.

Flywheel Characteristics. *Weights.* With weights being reduced to the limit in order to get higher engine speeds, the flywheel has received some paring down. Formerly, designers erred if at all on the heavy side with flywheels, but when they began changing the entire design of the engine to save a few pounds, they did not overlook the flywheel. In the flywheel, too, the growing use of counterweights has had an influence.

Sizes. Designers realize, now that the hampering sub-frames are out of the way, that the larger the diameter the better the flywheel effect for equal or less weight. As a result, many flywheels have been increased in diameter as they have been reduced in weight.

Shapes. Flywheel shapes, that is, sections, used to be rectangular or almost square, with a solid web or spokes practically in the center. Clutches, starter-ring gears on the outer surface, and other contributing causes have changed the character of flywheels so that few have the rectangular shape or character now. The method of using fan blades as flywheel spokes has also fallen into disuse; although at one time it was widely tried and appeared to be a means of eliminating the fan entirely.

Something of the present shape of flywheels can be seen by referring back to Figs. 217, 222, and 223. In the first figure, the flywheel has a triangular section with a solid web set at an angle so as to bring the flywheel nearer the engine; the inner surface is tapered to suit the clutch. In Fig. 222, the shape is entirely different and apparently much lighter. This is an eight-cylinder engine. Here the flywheel

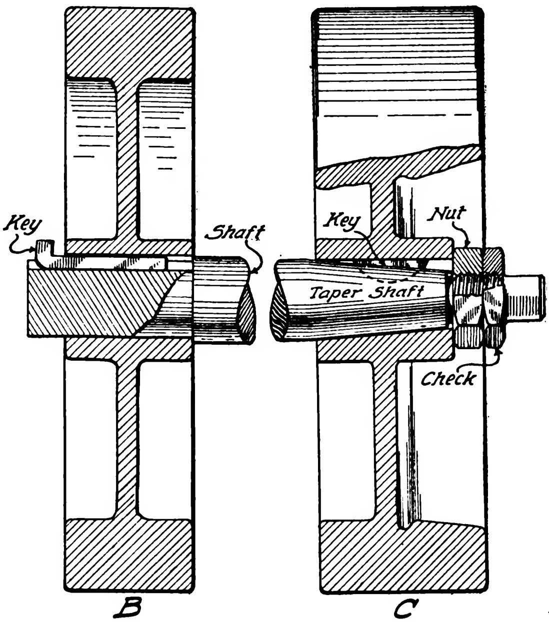


Fig. 245. Three Common Methods of Fastening Flywheel: *A*, Flange and Series of Bolts; *B*, Plain Key; *C*, Key, Taper and Nut
Courtesy of N. W. Henley Publishing Company, New York City

section as a whole has a short U-section, being externally a short section of a cylinder. The web, too, is perfectly straight at one end. The inside is cut out for the clutch, but with a very slight angle. The shape of the flywheel in Fig. 223 is somewhat similar to that of Fig. 217, but it is wider and not so thick. It shows a larger diameter, too. The exterior is plain and straight except at the front edge where the starting-ring gear teeth are cut into a raised portion of it. The web is straight and solid, close to one end, but not flush with it as in Fig. 222.

Methods of Fastening Flywheels. That part of the flywheel which is most interesting to the repair man is the method of fastening, or rather the inverse of this, the method of removal. There are three general methods of fastening flywheels to crankshafts, and these are shown in Fig. 245. They are the plain round end with a key, as shown at *B;* the tapered end with key, nut, and lock nut, as shown at *C;* and the method of bolting to a circular flange integral with the crankshaft, as indicated at *A*. The first is widely used for stationary gas and marine engines of very low price, but very little, if at all, on automobile engines. The second has been used, but is rapidly going out, as it is, like the first, a low-priced method which did not prove satisfactory. The third method is rapidly becoming universal.

In use, the flywheel flange on the crankshaft is generally five or six inches or a figure between these, in diameter, with six to ten bolts. In the form shown at *C*, Fig. 245, the flange is exterior to the flywheel, but in Figs. 217 and 223, the more general method of grooving the flywheel hub to receive the flange will be noted. In Fig. 245, the bolt shown has a countersunk head let into the flywheel surface; in general, the bolt head is either standard or else round and set into a countersink. In this case, it is slotted for a screwdriver. Also a single nut is shown, whereas a nut and lock nut, or, at least, nut and lock washer, are always used.

Flywheel Markings. As has been noted previously under Valves and Valve Timing, the surface or rim of the flywheel generally carries upon it marks to indicate to the repair man the timing of the motor. Some makers give only one or two marks for a single cylinder, reasoning, with some degree of correctness, that if the first cylinder is set right, the others must be pretty nearly so, and that more marks would only confuse. Others put on their flywheel all the marks for all the cylinders.

Summary of Engine-Group Treatment. In Parts I, II, and III, the entire engine group has been discussed in detail. The different sections have been handled according to present practice and methods of operation. It is easily possible that the near future may bring about the elimination of one or more of these groups or its combination with some other.

The engine, too, has been discussed in its present form only, although some attempts have been made here and there to indicate the trend of developments. He would be a very foolish man who, knowing the past history of the automobile engine, would say that it has now reached perfection and will always have its present form. On the contrary, there seems every reason to believe that hardly a single feature of our present-day engine, at least in its present form, will be found in the up-to-date engine of ten or twenty years from now. This constant change renders a work of this kind almost impossible of absolute up-to-dateness, for changes are actually made and put into use while the book is being printed. As far as possible, however, the work aims to discuss the modern developments and yet to give the repair man, in particular, the information he needs as he comes in contact with cars of all classes, ages, and conditions.

SUMMARY OF INSTRUCTIONS

VALVE SUB-GROUP

Valves

Q. For what purposes are valves used?

A. Valves are used (1) to admit the mixture created in the carburetor into the cylinders at the proper time in the stroke and in the proper quantity (called admission or inlet valves); and (2) to allow the burned gases to be exhausted from the cylinders at the proper time in the cycle (called exhaust valves). At all other times the valves remain tightly closed. The valves, closing upon a machined seat and opening and closing at precise times and in an exact manner, give a control over the operation of the engine which is not possible in any other way.

Q. How are these valves opened and closed?

A. By means of cams, or projections, upon a rotating shaft called the camshaft, these projections raising the valve off its seat, or opening it, at the proper time. When the projection allows the valve to come down onto its seat, or close, a strong spring comes into action, forcing it to do this in a positive manner.

Q. How is the camshaft operated?

A. By gears or chains from the crankshaft, these being designed and assembled carefully, so that the camshaft will revolve at precisely half the speed of the crankshaft.

Q. Why should the camshaft revolve at half the crankshaft speed?

A. Because the operation of opening and closing the valves comes on every other stroke only, and the camshaft really works twice as slowly as the crankshaft.

Q. What is the general form of a valve?

A. The usual form is called a poppet valve, and its section is that of a letter **T**, having a long slender stem at the top of which is a large flat head. The lower surface of this head is machined off to fit the seat in the cylinder, while the upper surface is rounded up to the center, where a slot for a screwdriver is provided.

Q. Are there other forms of valves?

A. The piston form of valve is little used, but the sliding-sleeve valve is used on all Knight type of engines and some others. In addition, a few motors have been built with rotating-disc valves. The piston valve is similar to the usual piston, having a reciprocating motion in a special round-valve chamber made for this purpose. In its movements up and down, it uncovers ports in the walls, thus giving the equivalent of the poppet-valve opening. The sliding sleeve is a hollow cylindrical member entirely surrounding the piston and reciprocating in the same manner. In its up-and-down motions, ports in it register with ports in the cylinder walls at the proper points in the cycle, thus corresponding to the opening of the poppet valve. The rotating-disc valve acts on the same plan but consists of a flat or a conical disc which is gear-driven from the crankshaft. It has a hole, or port, in it which registers with other ports in the cylinder at the correct time in the cycle. There are other forms of valve but none in wide use.

Q. What are the advantages of the poppet valve?

A. Its simplicity is its greatest asset. The poppet valve is the simplest and most easily understood form of all. In addition, it will withstand continuous operation at the highest temperatures.

Q. What are its disadvantages?

A. It affords a comparatively small opening, smallest at the beginning and ending of the suction stroke, where it should be largest; it has a noisy hammering action which makes for rapid wear, constant adjustment, and frequent renewal; the actual seat is so small and is exposed to such variations of temperature and other severe conditions that it tends to wear out and leak very rapidly, thus reducing the power and speed, rendering action uncertain and calling for frequent regrinding; finally, the necessity for ready accessibility for adjustment allows the driver, or operator, to alter the action with a consequent influence upon the output.

Q. Can any of the disadvantages be overcome?

A. The opening cannot be changed, but the noise can be reduced by enclosing the whole valve action in removable covers. The influence of hammering in the way of wear, need for adjustment, renewal, leakage, etc., can be minimized by the use of tungsten steel, which is harder and wears much more slowly. The use of this material also lessens power and speed losses, uncertain action, and frequency of regrinding.

Q. Is there any way in which the design can influence these?

A. Recent tendencies and experiments have shown that with an arrangement for positive, or mechanical, closing of the valve, springs can be made very small and weak, thus eliminating the cutting action of the usual stiff spring on the cams and reducing the hammering action and the noise.

Q. Have sleeve valves any springs?

A. No. They are operated by eccentrics from the eccentric shaft, which corresponds to the camshaft in a poppet-valve system. These are positive at all times, that is, the sleeves are always mechanically operated and thus are unvarying.

Q. What is the general shape of valve enclosures?

A. As simple as possible. Frequently, all the valve mechanism is enclosed by a single rectangular plate. More usually, it consists of two such plates. With a single plate, a pair of, or at most three, bolts are used to hold it in place; with two plates, these generally have two bolts each.

Valve Timing

Q. How is the valve timing arranged?

A. The inlet is allowed to open as soon after the upper dead center as the designer considers reasonable, and closes as far past the lower dead center as will allow the maximum charge to enter and still not let any of it blow out. It should be remembered that when the piston passes the lower center, it begins to rise and reduce the volume in the cylinder. Similarly as to the exhaust, it is allowed to open as much before the lower dead center as will insure full power, and is held open as long as possible, this sometimes overlapping the inlet opening and always passing the upper dead center.

Q. What is the average valve timing?

A. The timing of fifty-six American motors, including perhaps one hundred different models, averaged as follows: inlet opened from upper dead center to 21° beyond—average 10° 48′; inlet closed from 15° to 46° 22′ beyond lower dead center—average 35° 7′; exhaust opened from 31° to 57° 30′ ahead of lower dead center—average 50° 10′; exhaust closed from upper dead center to 21° beyond—average 9° 20′.

Q. How does the repair man know what the correct timing is?

A. Practically all makers give it in their instruction books and other literature as well as marking it upon the flywheel surface.

Cams

Q. How are the cams usually made?

A. On all modern motors, the cams are formed integral with the camshaft, which is machined, hardened, and ground as a unit. This keeps the timing always the same, which is sometimes not the case when cams are made separate and keyed and pinned in place. Moreover, the integral cams are more accurate, because the machines which have been developed for this purpose insure absolute accuracy.

Valve Guides

Q. What is the valve guide?

A. That member which forms the bearing as well as the support for the valve stem. Its importance can be judged from the fact that the guide holds the valve in line with its seat so that it seats itself accurately.

Q. How are valve guides usually made?

A. Generally, they are of cast iron and removable, being screwed into the cylinder from below. The diameter is made as small as possible and still give sufficient stiffness and strength; the length is made as great as possible, for the entire length of the valve guide is bearing surface for the valve stem.

Exhaust Manifold

Q. What is the influence of the exhaust manifold?

A. To remove the exhaust gases from all cylinders as quickly and as thoroughly as possible. If this is not done, the burned gases will retard the next outflow of gas, until finally the engine may be stopped because it is not receiving rich enough fuel. The best form of exhaust manifold is the one which does this work most quickly and most thoroughly.

Q. What is its general form?

A. A long cast-iron member of round or rectangular section, slightly larger at the outlet end, and bolted to the cylinder casting.

Q. How can this be improved?

A. Recent experiments have shown that an arrangement of shape and size can be effected which will bring about an ejector effect immediately back of each exhaust orifice. This will produce a slight suction upon each succeeding volume of burned gas, which will increase the efficiency of the exhaust and thereby improve the power of its motor.

Muffler

Q. What is the purpose of the muffler?

A. To reduce the pressure of the exhaust gases so that when emerging into the atmosphere they will do this without noise. As they emerge from the cylinders, the pressure is fairly high, and if they were allowed to pass immediately into the air, the noise would be deafening.

Q. How is this silencing accomplished?

A. By successive expansions, each of which reduces the pressure considerably. The gases come into a small central tube and are allowed to expand into another surrounding chamber of perhaps double the area, with consequent reduction of pressure. Then they are allowed to expand into another chamber, perhaps twice as large as this, with further reduction of pressure. This process is continued until practically all pressure is eliminated, so that the gases will emerge without noise.

COOLING SYSTEMS

Q. How are explosion motors cooled?

A. Mainly by the indirect method in which water surrounding the cylinders removes their heat and then is itself cooled in the radiator. The direct, or air-cooling, method is now used by but one maker, Franklin.

Q. What is the general cooling method?

A. There are two methods in general use, called the natural, or thermosiphon, and the pump systems. The former is so-called because the natural increase in temperature of the water is used to circulate it to the radiator and back. The latter is called a pump system, because a pump is used to force the water around.

Q. Are there other differences between the two?

A. In the thermosiphon system, the difference in pressure created by the increasing temperature is so slight that all bends must be made very easy and all pipes made very large, so the water will pass easily. Also the system as a whole must be short and compact with radiator close to motor, and with little difference in level between the highest and lowest points. The added weight of larger pipes and their appearance just about balance the simplicity and smaller number of parts.

Q. What general types of radiators are in use?

A. The cellular (which may have square, round, or hexagonal cells) and the tubular form with horizontal fins sweated on are the two forms generally used.

Q. How does the water circulate in these two forms?

A. In the cellular form the water is in very thin sheets between the cells, with a consequently high ratio of air space to water space. The water is forced to follow a zigzag path to add to the cooling effect. In the tubular form, the water flows from an upper to a lower tank through the vertical tubes, which are of relatively larger diameter as compared with the water space in the cellular form—$\frac{3}{8}$ against $\frac{1}{32}$.

Q. What is the usual form of pump?

A. Four forms of pumps are used for water circulation: the centrifugal, the gear, the plunger, and the vane. The first two are used about equally on the majority of American pleasure cars, the last two having but a few adherents.

Q. What is the latest move to improve water circulation?

A. The use of a thermostat to control the flow of the water according to its temperature. This device holds the water in the cylinders until a certain predetermined temperature is reached, when it opens and allows the water to flow through the radiator and be cooled. By setting this so that this predetermined temperature is high, but not so high as to be dangerously close to the boiling point, the efficiency of the engine is increased, for a hot engine works better than a cold one and gives more power.

Q. What is the purpose of the fan?

A. To increase the efficiency of the radiator by drawing more air through it and thus cooling the water more.

Q. How is the fan generally driven?

A. The belt drive, using a flat or V-type belt is general because of its simplicity, but a few better cars have gear or chain drive; the latter method has increased in recent years particularly with the V-type motors, for in those it has been found easy to drive the fan from a shaft in the immediate vicinity.

Questions for Home Study

1. Describe in detail the timing of the Knight motor.
2. Tell how to regulate and check up the valve action from the flywheel marking.
3. How are silent-chain camshaft drives adjusted? How are gears?
4. How is the valve-stem clearance adjusted?

LUBRICATION SYSTEMS

Q. What is meant when lubrication is referred to?

A. In general, the lubrication of the engine, because that is so much more important than the lubrication of any other part or group of parts. If the engine is run without lubricant, even for a very short time, it is ruined. On the other hand, many of the car parts can be run without lubricant for days and days, yet no damage will result.

Q. What are the most used systems for the internal oiling of the engine?

A. The most used systems are: the splash, the pressure, and a combination of the two, known as the splash-pressure, or constant-level, system. The first is simple, oil being provided in troughs into which the connecting rods dip, thus spreading the oil all over the interior of the motor and lubricating everything. The pressure system forces oil under pressure to all the important bearings and surfaces by means of interior-drilled oil leads or special pipes. It requires a pump, driven from some engine shaft, one or more strainers (for the oil is used over and over), the special drilling or piping, a gage on the dash to tell the driver how the system is working, and in some cases an adjustable pressure valve. The splash-pressure form has the oil leads to the important points only. Then the excess runs down into the crankcase and fills troughs into which the connecting rods dip. In some cases, these troughs are filled by direct individual leads off of the main oil pipe. Then when the rods dip into the oil, all benefits of the splash system are obtained. The fact that the pump maintains a constant level of oil in the troughs has led to calling this the constant-level system.

Q. What pressure is used in the pressure system?

A. Prior to the introduction of V-type and high-speed motors, a few pounds less than 5 was considered sufficient. Now, many motors have a system which works under 40, 50, 60, and even 70 pounds pressure. The oil leads are smaller, but the amount of lubricant which the bearing receives is much greater than previously.

Q. What is the external lubrication of the motor?

A. The lubrication of the accessories, such as magneto, water pump, starting motor, generator, air pump, fan, etc. Practically all these have oil holes, oil cups, or grease cups. The last named must have a special heavy grease or pure mutton or beef tallow, as a thick lubricant is needed to resist the passage of the water and not wash away. Otherwise the external lubrication is fairly simple and requires little attention.

Q. What are the most used types of oil pumps?

A. Like the water pump, all forms are used but the most popular are the cam-operated plunger, the gear, and the plunger.

Q. How are these driven?

A. By gear from any convenient shaft, as camshaft, crankshaft, water-pump shaft, magneto shaft, etc. When the pump is enclosed in the crankcase, it is almost invariably driven from one of the camshafts.

Q. How are other parts of the car lubricated?

A. Aside from clutch, transmission, rear axle, and wheels, practically all parts are lubricated by means of grease or oil cups or oil holes. The latter are rapidly being eliminated for the sake of cleanliness.

Q. What are possible future developments in oiling?

A. At present, there are two tendencies noticeable, one being the extension of forced lubrication to many parts outside the engine.

In the case of the Fergus car, the springs are enclosed in leather boots and lubricant supplied from the engine oil pump. Similarly, clutch and transmission are oiled from the engine pressure system. The 1917 Marmon car is claimed to have but four or five lubricant points outside of the engine system. Another maker has adopted the leather-enclosed and lubricated springs. All these signs point toward less lubrication for the driver and owner to do, more points being included in the engine system. The other noticeable point mentioned has been partially covered; it is the reduction in number of points requiring individual attention, by other means than extending the engine pressure system to them.

Q. How should graphite be used?

A. Graphite should be used very sparingly, for a little of it goes a long way. It is not like grease which is used up very quickly, but is more or less indestructible. When a combination of graphite and grease is used, it will be found to last twice as long at any given point as the same quality of grease alone. Graphite in its very finest form, when introduced into the engine system, is beneficial as it seems to put a kind of polish, or surface finish, on the cylinders, which resists wear. After this has been put on, less lubricant, by at least 20 per cent, can be used in the engine. It should, however, be used in very small quantities, two tablespoonfuls to a gallon of oil being sufficient

Q. What is its big advantage?

A. In addition to the fact that it seems to fill up the pores and surface scratches of the parts on which it is used so as to give them a fine finish, graphite has the advantage of resisting the very highest temperatures very well, so that its use constitutes a safeguard against immediate injury in case of neglect.

Q. What are oilless bearings?

A. There are two forms of oilless bearings, one of hard wood which has been impregnated with lubricant by boiling in oil, or some similar impregnation process, and the other is a bronze and graphite combination, in which about half the bearing surface consists of plugs or strips of pure graphite. These graphite surfaces supply the lubricant for the entire bearing, which never needs additional lubricant, so it is claimed.

Questions for Home Study

1. Describe the lubricating system of the Pierce-Arrow car.

2. How is the Cadillac eight motor oiled? Give details.

3. What is the usual method of changing the amount of oil pumped, in a pressure system?

4. Select some method of driving the oil pump, which seems simple to you, and describe it, telling why you selected it.

5. How would you lubricate spring leaves, with what and how often? fan bearings? front wheel bearings? magneto shaft? differential?

6. How do you select a good engine oil?

FLYWHEEL GROUP

Q. How does a light flywheel affect an engine?

A. The engine will be easy enough to start and stop, but very touchy on changing speeds—too quick a change will kill it. Moreover, it will not run very slowly.

Q. How do present flywheel sizes compare with those of former years?

A. Present flywheels are larger in diameter but narrower and lighter in weight. The increase of diameter made by the elimination of subframes allowed cutting down the width and weight because the flywheel effect is equal to its mass times its radius, so that by increasing the radius the mass can be reduced.

Q. What are the usual methods of flywheel fastening?

A. The flange forged on the crankshaft and through bolts is almost universal. A few motors are still made with a round crankshaft end and a large key; or with a tapered shaft end, and a key, a nut, and a lock nut. The latter form is used when the crankcase is of the barrel type with removable end plates and is so made as to allow removal of the crankcase end plate at the rear. In some few cases the flywheel is made this way so as to allow putting on or taking off a ball bearing at the rear end of the crankshaft.

Q. What are the markings on the flywheel rim?

A. The timing is now generally marked on the surface of the flywheel to guide the owner or repair man in making adjustments or in assembling the engine correctly. The adjustments vary; some makers give the complete timing for a single cylinder, others give a few points for all, and still others give all the points for all the cylinders. The latter is the best way.

INDEX

The page numbers of this volume will be found at the bottom of the pages; the numbers at the top refer only to the section.

If you do not find what you want under one heading, stop and think what other headings it could be under.

Note.—For page numbers see foot of pages.

Note.—For page numbers see foot of pages.

Note.—For page numbers see foot of pages.

Note.—For page numbers see foot of pages.

Note.—For page numbers see foot of pages.

Note.—For page numbers see foot of pages.

Note.—For page numbers see foot of pages.

Note.—For page numbers see foot of pages.

Note.—For page numbers see foot of pages.

Note.—For page numbers see foot of pages.

Note.—For page numbers see foot of pages.

Note.—For page numbers see foot of pages.

Note.—For page numbers see foot of pages.