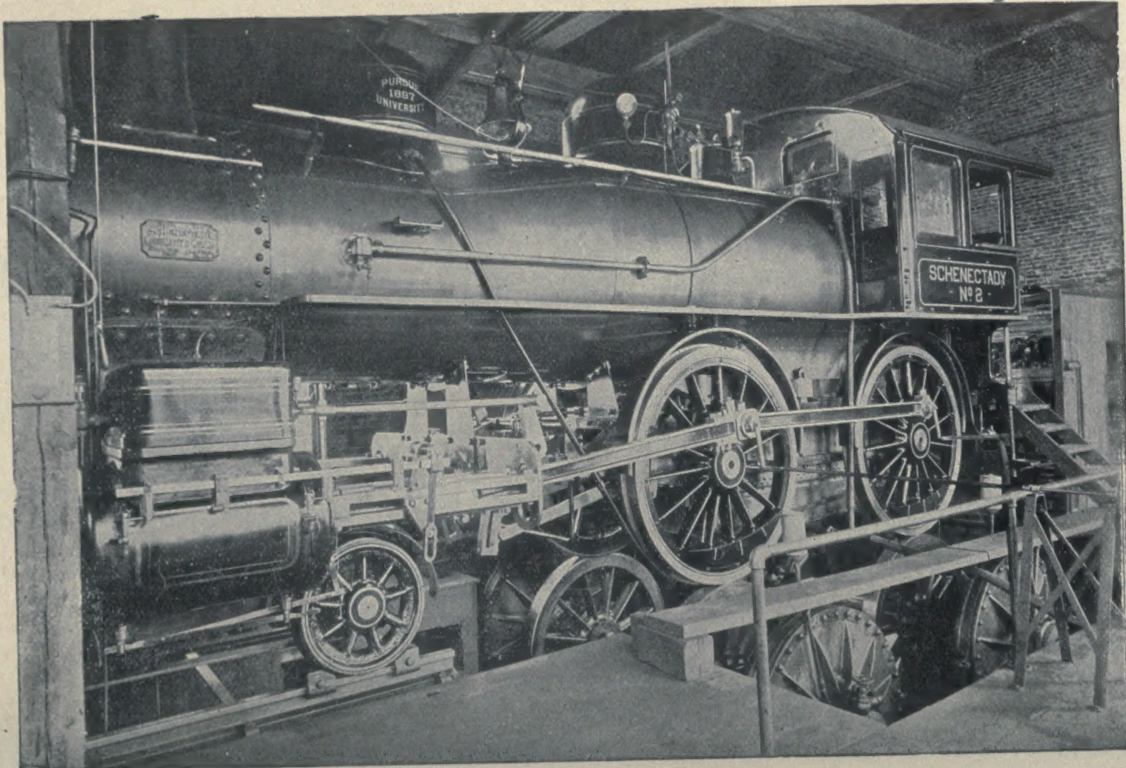
2.2



Locomotive-testing Plant, Purdue University.

[*Frontispiece.*]

A HANDBOOK OF ENGINEERING LABORATORY PRACTICE.

BY

RICHARD ADDISON SMART, M.E.,
Formerly Associate Professor of Experimental Engineering, Purdue University.

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PREFACE.

THIS volume is intended primarily as a manual for the use of students in the routine of experimental work in Steam-engineering, Strength of Materials, and Hydraulics.

It may also serve in a limited way as a guide to those engineers in active service whose familiarity with the ordinary methods of testing is limited.

The chief object in view has been to provide in convenient form such directions for the conduct of the various tests and experiments comprising the course as the student will need to enable him to take charge of and conduct the particular work assigned him in an intelligent manner and with little delay. With a large class of students beginning a variety of experiments at the same time it is essential that the directions be such as to make each student or group of students as nearly self-directive as possible.

No attempt has been made, therefore, to preface the consideration of the subject from an experimental standpoint with an exposition of the theoretical considerations involved; it is assumed that the class-room work, which should be carried on in connection with that of the laboratory, will supply the theoretical instruction.

The methods of testing described under the various general heads are not intended to cover the subject in an exhaustive way. Only such tests have been described as may be carried on in connection with the complement of apparatus to be found in the better equipped laboratories of experimental engineering, and the methods explained are those which the author has found to be most easily employed in every-day practice. Both the manner of arranging apparatus and the method of conducting the tests are capable of great variation to suit the needs of special investigations.

Since the equipment of the majority of engineering laboratories does not permit all the students in a class to take up the course of experiments and tests in the same order, it becomes necessary to make the directions for the various tests complete in themselves and avoid, so far as possible, reference to tests described in preceding sections. This necessitates the occasional repetition and duplication of directions which occur in the volume.

Acknowledgment is hereby made of thanks due to Prof. W. F. M. Goss, for valuable assistance in the preparation of the volume; to Prof. W. Kendrick Hatt, who assisted in the preparation of the chapter on Strength of Materials; to Mr. C. H. Robertson, and to others who have aided in the completion of the work.

R. A. SMART.

LAFAYETTE, IND.
Sept. 1, 1898.

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ENGINEERING LABORATORY PRACTICE.

CHAPTER I.

INTRODUCTION.

1. The Laboratory Course.—The course in laboratory practice in Engineering is designed to familiarize the student with processes of investigation, to give experience in the conducting and reporting of experimental engineering work, to secure data which shall verify and supplement theoretical instruction, and to give a practical knowledge of the construction and management of machinery and apparatus.

2. Method of Instruction.—The method of instruction should be such as will throw the investigator, as far as is practicable, on his own resources, giving only such directions as are necessary to facilitate the work and secure uniformity of results.

Since the working up of the data obtained is an extremely important part of the work, it is desirable that this be done under the immediate direction of the instructor. The time required to work up the data and prepare the report should be considered when grading the reports, in connection with the accuracy of the results and the proficiency shown in the conduct of the test and the management of the apparatus. It will be found convenient to record the dimensions and constants of the various pieces of laboratory apparatus in a book which may be kept at hand for convenient reference. This book will be referred to in what follows as the "Commonplace-book."

3. **Care of Apparatus.**—One mark of a good engineer is the care which he exercises in handling machinery. While to the beginner the apparatus may all be new, a little care and close observation will enable him to become familiar with its operation. The student should be held responsible for all apparatus, both large and small, which is placed in his charge and should see that small apparatus issued to him is returned immediately after the test. He should always leave such apparatus in good order.

4. **Keeping the Records.**—It is important that all original data be preserved. To this end, the record of observations should be kept on a prepared "Running Log" which may be handed in with the report. When the Running Log is kept by one man and the observations are taken by another, such observations should be handed to the log-keeper as soon as taken. In some cases it may be found convenient to have a number of logs, kept by different men. In such cases they should be signed, dated, and handed to the principal log-keeper immediately after the test.

5. **Reports.**—The reports should be made out in ink, except the portion which is made during the conduct of the test. Where one experiment is assigned to two or more men, one report, bearing the signature of each man, should be handed in.

6. Graphic Presentation of Results.—Reports of tests intended to show the relation of one variable factor to another should generally be accompanied by a curve, or set of curves, having the various values of the dependent variable as ordinates. The scale chosen should be such as to make the curve as large as will go on the plotting-paper furnished. It is generally best to connect the several points found by a straight line, instead of attempting to draw a smooth curve through them. The points from which the curve is located should be indicated by a suitable sign, and the scale of the ordinates and abscissæ should be clearly indicated on their respective axes of coordinates. It may sometimes be found desirable to plot several curves on one sheet to facilitate comparison.

CHAPTER II.

ELEMENTARY MEASUREMENTS.

7. Measurement of Time.—In the conduct of ordinary tests, such as those of engines, boilers, pumps, etc., the measurement of time should be made with the second-hand of a watch. In order to avoid confusion the second-hand should point to zero when the minute-hand is on the even minute; otherwise the test might be started with the second-hand at zero and end with the minute-hand at zero, thus making an incorrect time-reading. In all important tests two or more watches should be made to correspond exactly, or their difference noted, before the test is begun, so that if one watch stops the time-reading may not be lost.

Time-signals.—Signals are usually given by bell or whistle. The following is a convenient arrangement: thirty seconds before the time for taking observations three warning signals are given; ten seconds before the time two warning signals are given; and at the exact time one signal is given, at which the observations are taken.

Stops.—In case it is necessary to stop an engine-test between gongs, note the exact time that the stop is made and indicate the same on the Running Log. Note the time the engine starts again and ring the next gong at such a time after the start that the elapsed time between the previous gong and the stop, plus the elapsed time between the start and the subsequent gong, shall just equal the ordinary running time between gongs.

8. Measurement of Speed. Speed-counters.—The simplest instrument for the measurement of speed is

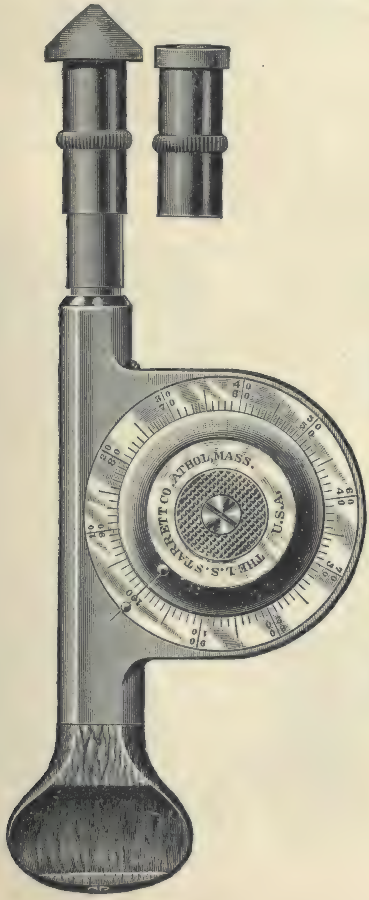

FIG. 1.—STARRETT SPEED-COUNTER.

the speed-counter, one form of which is shown in Fig. 1. They are made in many different forms, some with one and others with two dials. Those provided with rubber tips for contact with the shaft are especially recommended. When well made they are reliable for speeds as high as two or three thousand revolutions per minute.

9. **Revolution-counters.**—This instrument, shown in Fig. 2, is largely used where special accuracy is required or where it is desirable to make a more permanent arrangement for speed measurement. The majority of such instruments are not accurate above 300 or 400 revolutions per minute.

10. **Tachometers.**—The tachometer is an instrument for measuring rate of speed. It is usually permanently connected to the shaft or pulley whose speed is to be measured. An instrument of this type is the Boyer speed-recorder (Fig. 3), which is extensively used in railway service. The drum upon which the record-paper turns is actuated directly by the driving mechanism and moves in proportion to the distance passed over or to the number of revolutions. The pencil which produces the record is actuated by a rotary pump connected with the driving mechanism and so constructed as to raise the pencil an amount proportional to the rate of speed. The gage, which is in cord connection with the pencil-motion, gives a visible indication of the rate of speed. Fig. 3*a* is a detail view of the drum mechanism.

11. **Measurement of Areas. The Polar Planimeter.**—The planimeter is an instrument for finding the area of any plane figure. The form in common use was invented by Amsler and exhibited by him at

FIG. 2.—CROSBY REVOLUTION-COUNTER.

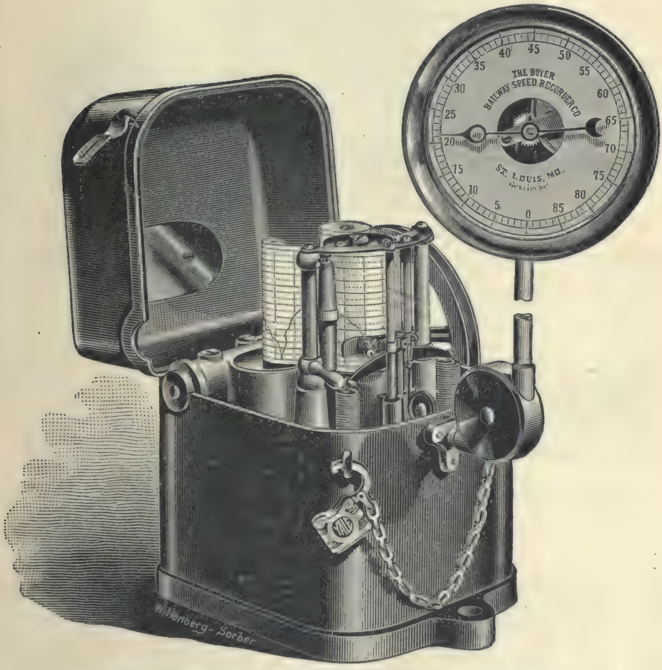

FIG. 3.—BOYER RAILWAY SPEED-RECORDER.

the Paris Exhibition in 1867. It consists of an arm *EP* (Fig. 4) to which is pivoted a second arm *EF*

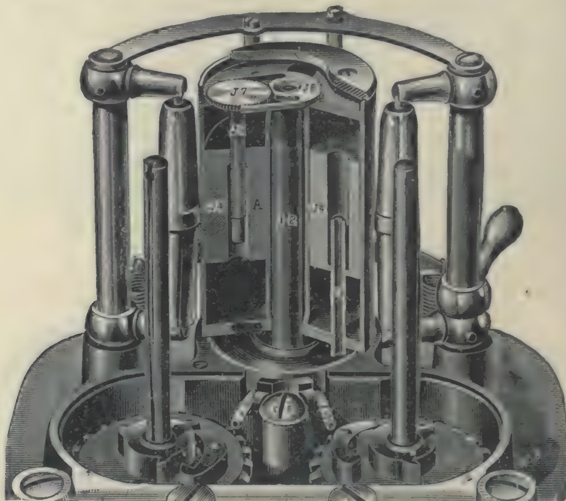

FIG. 3*a*.—DETAILS OF MECHANISM.

carrying a record-wheel *D* and a tracing-point *F*. When in use the point *P* is fixed and the point *F* is

FIG. 4.—POLAR PLANIMETER.

moved by hand around the outline of the figure whose area is desired, in the direction of the hands of a watch. The rotation of the record-wheel *D* is proportional to the area circumscribed, which is shown by the graduations on the wheel to a given scale. The wheel may lie at D or on an extension of the arm EF, beyond the point E, the mathematical conditions being the same in either case. For the purpose of the following demonstration the position of the wheel will be assumed to be on the arm EF extended.

12. Theory of the Polar Planimeter.*

Let $r = oc$ (Fig. 5);

$r' = ob =$ radius of zero-circle;

$m = og = og' = og''$;

$n = hg = h'g' = h''g'' = pi$;

$L = cg = c'g' = c''g''$;

$\beta =$ angle $ogc = opy = og'c'$;

$d\theta =$ angle $coc' = gog' = cac'$.

The values of r', m, n, and L are constant for any given setting of the instrument.

The zero-circle of the polar planimeter may be defined as the circle generated about the pole-point o as a center, which when traced by the instrument will cause no movement of the record-wheel. In any irregularly shaped figure through which the zero-circle passes, the differential area (dA) may be taken as that portion of the figure outside the zero-circle and between two radial lines separated by the angle $d\theta$.

That is,

$$dA = bcc'e.$$

By subtracting the triangle oeb from the triangle occ' we have

$$dA = bcc'e = occ' - oeb.$$

---

* The theory of the planimeter which is given herewith has been adapted from Carpenter's "Experimental Engineering" by C. H. Robertson, M.E., Instructor in Engineering Laboratory, Purdue University.

But

$$\text{triangle } occ' = cc' \times \frac{r}{2} = rd\theta \times \frac{r}{2} = \frac{r^2 d\theta}{2}.$$

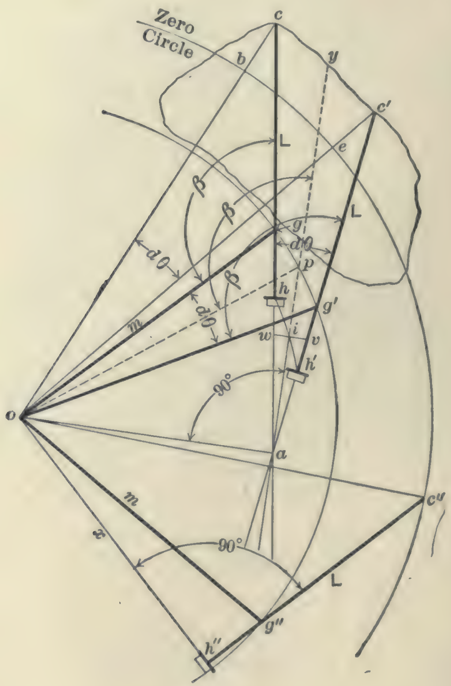

FIG. 5.

In the same manner

$$\text{triangle } oeb = \frac{r'^2 d\theta}{2};$$

therefore

$$dA = \frac{r^2 d\theta}{2} - \frac{r'^2 d\theta}{2} = \frac{r^2 - r'^2}{2} d\theta. \quad . \quad . \quad (1)$$

In tracing the area $bcc'e$ the record-wheel movement for bc is equal and opposite to that for $c'e$; eb, being on the zero-circle, causes no movement, and hence in tracing the area dA the only effective movement of the record-wheel is that for the side cc'. For this infinitesimal area the side cc' may be taken as the arc of a circle, in the tracing of which the angle ogc ($= \beta$) remains constant. The path of the record-wheel will be hh'. The component of hh' which turns the record-wheel is shown geometrically by wv, drawn perpendicular to the bisector of the angle cac' and midway on hh'. It may be considered as an arc of a circle about a as a center. While the tracer moves through the infinitely small distance cc' the corresponding differential record will be

$$dR = wv = ai \times d\theta.$$

But

$$ai = ap - ip = m \cos \beta - n;$$

therefore

$$dR = (m \cos \beta - n)d\theta. \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Now in the triangle ogc

$$(oc)^2 = (og)^2 + (cg)^2 + (2og \times gc \times \cos \beta),$$

or

$$r^2 = m^2 + L^2 + 2mL \cos \beta. \quad . \quad . \quad . \quad . \quad . \quad (3)$$

In the triangle $oh''c''$ the tracing-point c'' is on the zero-circle and the plane of the record-wheel is radial; hence $c''h''o$ is a right triangle and

$$(oc'')^2 = (c''g'' + g''h'')^2 + x^2,$$

or

$$r'^2 = (L + n)^2 + x^2.$$

But

$$x^2 = m^2 - n^2;$$

therefore

$$\begin{aligned} r'^2 &= L^2 + 2Ln + n^2 + m^2 - n^2 \\ &= L^2 + m^2 + 2Ln. \quad . \quad . \quad . \quad . \quad (4) \end{aligned}$$

Subtracting (4) from (3), we have

$$r^2 - r'^2 = 2Lm \cos \beta - 2Ln,$$

or

$$\frac{r^2 - r'^2}{2} = L(m \cos \beta - n). \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Combining (5) and (1), we obtain

$$dA = L(m \cos \beta - n)d\theta. \quad . \quad . \quad . \quad (6)$$

Now, substituting the value of $d\theta$ as found in equation (2), we obtain

$$dA = LdR.$$

Hence, integrating between the limits 0 and R, we have, since L is constant,

$$\int dA = L \int_0^R dR;$$

$$A = LR. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

It is seen from equation (7) that the area A is equal to the length of the arm L from pivot to tracing-point, multiplied by the distance R corresponding to one revolution of the record-wheel, and is independent of the other dimensions of the instrument.

It can readily be proven that the above demonstration is true for areas not adjacent to the zero-circle or partly inside and out.

13. Area of the Zero-circle.—In case the exact area of the zero-circle is not known the following method may be employed to determine it: With a pair of compasses draw arcs of two concentric circles the radius of each of which is known to be greater than that of the zero-circle. For convenience let the arcs subtend an angle of 90°. Place the fixed pole of the planimeter at the center of the arcs, and with the tracing-point trace successively the periphery of the two arcs between their limiting radii, noting the respective readings on the record-wheel. Let the areas of the two sectors be a and a', and the corresponding readings of the record-wheel be R and R'. Let the radius of the zero-circle be r'. Then, since the reading of the record-wheel is equal to the area outside of the zero-circle, we have

$$a = \frac{\pi}{4}r'^2 + R \quad \text{and} \quad a' = \frac{\pi}{4}r'^2 + R',$$

and adding, we obtain

$$\frac{\pi}{2}r'^2 = a + a' - (R + R'). \quad . \quad . \quad . \quad . \quad . \quad (8)$$

$$\therefore \text{ area of zero-circle} = 2[a + a' - (R + R')]. \quad (9)$$

14. Adjustable Planimeter.—From equation (7) it will be seen that the area corresponding to one complete revolution of the record-wheel is equal to the length of the arm L multiplied by the circumference of the wheel, the unit of measurement being uniform. For instance, if the arm L is 5 inches long and the record-wheel has a circumference of 2 inches, one complete revolution will signify 10 square inches, and, since the wheel is divided into 100 parts and a vernier is provided, the instrument will read to hundredths of a square inch. Now if the length of the arm L be changed to 0.775 inch, one revolution of the wheel will correspond to 1.55 square inches or 10 square centimeters and the instrument will read to hundredths of a square centimeter. Hence by changing the length of arm L the scale of the instrument can be changed.

The ordinary form of instrument in use has a fixed arm and reads to hundredths of a square inch. An instrument is made, however, with an adjustable arm (Fig. 6). It may be made to read in different units,

FIG. 6.—ADJUSTABLE POLAR PLANIMETER.

and can be set to read the mean height in inches of an indicator-diagram as follows:

Calling p the height of the mean ordinate of the diagram and l the length of the diagram, then we have the area

$$A = pl.$$

From equation (7) we have

$$A = LR;$$

whence

$$LR = pl;$$

and

$$\frac{L}{l} = \frac{p}{R}.$$

Now since the arm L is adjustable, we can make it equal to the length of the diagram l. We will then have p, the height of the mean ordinate, equal to the reading of the record-wheel, to the proper scale.

15. Directions for Use.—1. Handle the instrument with care, as it is liable to injury.

2. Wipe it off carefully before and after using.

3. See that the wheel revolves freely and the recording edge is smooth and bright.

4. Place the diagram to be evaluated on a smooth, level drawing-board, having first covered the latter with a sheet of smooth calendered paper. Fasten with thumb-tacks or pins.

5. Place the pole-point in such a position that when the tracing-point is near the geometrical center of the figure the two arms are approximately at right angles.

6. Trace in the direction of the hands of a watch.

16. Planimeter Exercise (*a*).—Read the theory of the planimeter (Sections 12 and 13) carefully.

Find the area of the zero-circle by the method explained in Section 13.

Find the average error of the instrument as follows: Draw carefully three rectangles an inch square. Go over each several times and find the mean error of the instrument. Repeat with three figures of four square inches each. In the Report, give make and number of instrument, area of zero-circle, and average per cent of error, including all readings and calculations made. Keep a record of results for use in the next experiment.

17. Planimeter Exercise (*b*).—Find the areas of figures on the blank furnished.

The diameter of the record-wheel is —— inches.

Compute the length of arm L, using one revolution of the wheel as a basis of computation.

The arm m is —— inches in length. Compute length of arm n.

In the Report give areas found; also above dimensions, with formulæ used and calculations in full.

18. Lineal Measurements. Micrometer Caliper.—This instrument is used for outside measurements only. The micrometer-screw has forty threads to the inch; hence each revolution will advance it one fortieth ($= 0.025$) of an inch. The band surrounding the screw is divided into 25 parts, which allows the movement to be read to thousandths ($\frac{0.025}{25}$) of an inch. The object to be measured is held between the measuring-points and the knurled handle turned until lightly touching the piece. Care should be taken not to exert too great a pressure, as this will strain the instrument and vitiate the result. Take care to secure the same degree of pressure in all cases.

19. Vernier Caliper.—This instrument is used for both outside and inside measurement. For the former the scale is graduated in fortieths of an inch and the vernier reads to thousandths. In using the vernier read first the position of the zero-mark on the vernier relative to the scale. This will give tenths and quarters of tenths. Then by reading the number of the mark on the vernier nearest opposite a mark on the scale, that number, in thousandths of an inch, is added to the reading previously obtained to give the desired result. For example, suppose the zero-mark on the vernier to read three inches, four tenths and three spaces

$= 3.0 + 0.4 + (3 \text{ times } \frac{1}{40} \text{ or } 3 \text{ times } 0.025 \text{ or } 0.075)$
$= 3.475.$

Then if mark number 11 on the vernier is nearest opposite a mark on the scale the complete reading is

$$3.475 + .011 = 3.486.$$

For inside measurement add 0.25 of an inch to the vernier-reading. Never bring the jaws together while the piece to be measured is between them. If the distance is too great, remove the piece, decrease the distance, and apply again until the caliper will just slide over the surfaces to be measured. Great care should be taken not to strain the instrument by forcing it onto the piece. It is very delicately made and should be handled with care.

20. Sweet's Measuring-machine.—This machine is a micrometer caliper having a greater range than the one previously described. The micrometer-screw has a range of one inch, but the tail-piece may be set at distances of even inches from the zero position of the screw by means of distance-pieces. The instrument is furnished with a scale, graduated on its upper edge to read in sixteenths of an inch and on its lower edge to decimals of an inch.

The graduated disk has two sets of graduations, that on the left corresponding to the upper scale and that on the right to the lower. The latter is read in the same manner as an ordinary micrometer, reading to thousandths directly. The former reads in binary fractions, the space between five figures corresponding to one thirty-second. The numbers are arranged as shown in Fig. 7. Beginning at 0 and following the line of chords to the right, the numbers are in regular order, every fifth one being counted. Five complete revolutions corresponding to half the travel of the screw, or one half an inch, are necessary to pass the 16 divisions, thus making each division (= five spaces) correspond to one thirty-second of an inch. Since there are 40 small divisions between the successive

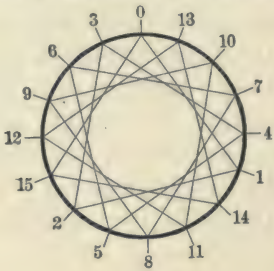

FIG. 7.

numbers (as between 1 and 2), any desired fraction of a thirty-second can readily be obtained.

The following is a portion of the directions accompanying the instrument:

"To measure objects larger than an inch bring the index-bar to zero, insert the proper distance-piece, and clamp the tail-spindle. Next bring the screw to exact contact with distance-piece, turning the latter to be sure it is held squarely between the measuring-points. When the friction slips leave the distance-piece held between the points while you see that the index-bar is adjusted as above; then proceed with the measurement.

"The index-bar has been carefully set to correct the inaccuracy in the pitch of the screw. Do not alter it because it seems to give contrary readings. A little difference of temperature or an atom of grit will make noticeable change in the readings.

"The graduations of the circle upon the right of the central line indicate thousandths, and are read in connection with the scale upon the front edge of the index-bar. Those upon the left are numbered by thirty-seconds and the scale upon the back edge of the index-bar is used as a 'finder.' To set the machine at any desired thirty-second bring the central or 'reading line' as near the place as can be done by means of the scale upon the index-bar. The number indicating the thirty-second will then be found near at hand. Bring this to the front edge of the bar. In measuring binary fractions of thirty-seconds always remember that upon this scale it requires five marks to count one."

21. Exercise with Measuring-instruments. — Read Sections 18, 19, and 20 on micrometer and vernier calipers.

Measure the five pieces shown in Fig. 8 and make Report as indicated in the following blank form:

REPORT ON MICROMETER AND VERNIER EXERCISE.

Observer...................... *Date*..........

Measured with Micrometer.	Vernier.	Sweet's Micrometer.
No. 1 A =	No. 1 C =	No. 1 B =
" 2 C =	" 2 B =	" 2 A =
" 3 A =	" 3 D =	" 3 C =
" 3 B =	" 3 D′ =	" 4 D =
" 5 E =	" 4 A =	" 4 E =
" 5 F =	" 4 B =	" 5 L =
" 5 G =	" 4 C =	
" 5 H =	" 5 A =	
" 5 K =	" 5 B =	
	" 5 C =	
	" 5 D =	
	" 5 J =	
No. 4 F =		

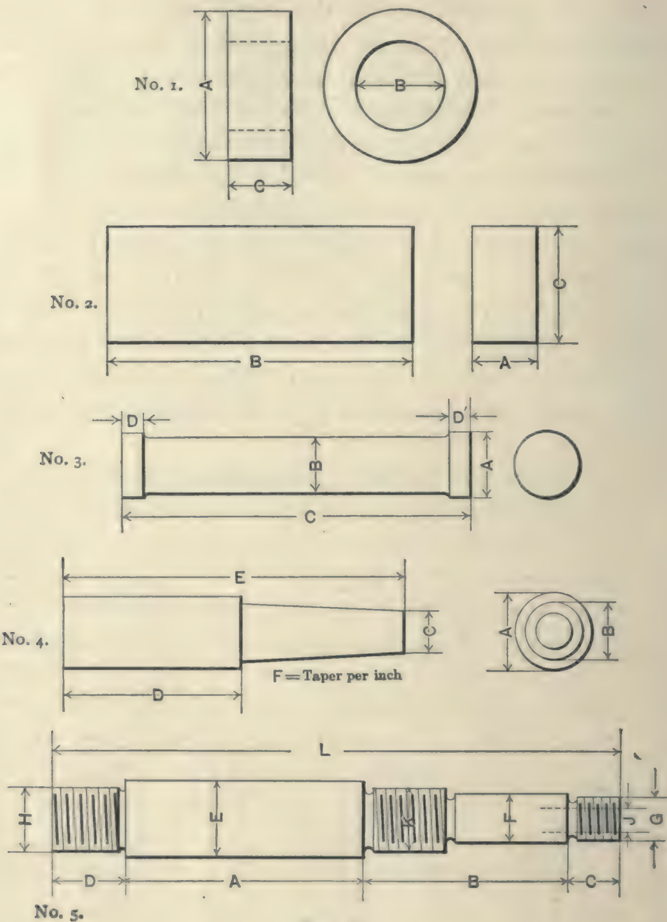
No. 1.
A
B
C
No. 2.
B
C
A
No. 3.
D
D′
B
A
C
No. 4.
E
C
A
B
D
F = Taper per inch
L
H
E
K
F
J
G
D
A
B
C
No. 5.

FIG. 8.

CHAPTER III.

MEASUREMENT OF LIQUIDS.

22. Methods of Measuring Water.—The accurate measurement of large quantities of water is an important factor in the testing of hydraulic and steam machinery. The methods of measurement in common use may be briefly summarized as follows: By the use of

1. Weighing-barrels or tanks.
2. Orifices and nozzles.
3. Weirs.
4. Meters.

The use of weighing-barrels in this connection does not warrant description here.

23. Formulæ for Flow of Water through an Orifice.—The theoretical velocity of water flowing under any head is the same as the velocity attained by falling through a distance equal to that head. If the head be represented by H and the resulting velocity by V, then

$$V = \sqrt{2gH}. \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Now if the issuing stream were of the same cross-sectional area as the orifice and flowed with the velocity due to its head, the rate of flow would be represented by the formula

$$Q = F\sqrt{2gH}, \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where Q is the rate of discharge in cubic feet per second, and F is the area of the orifice in square feet.

With an orifice in a thin plate the conditions mentioned above do not exist. The velocity of discharge is less than the theoretical velocity and the area of the stream is less than that of the orifice. It becomes necessary, then, to introduce into formula (2) a coefficient C, representing the ratio of the actual flow to the theoretical. The formula then becomes

$$Q = CF\sqrt{2gH}. \quad . \quad . \quad . \quad . \quad (3)$$

24. Determination of Coefficient of Discharge of an Orifice in a Thin Plate.—The coefficient C in formula (3), Section 23, is determined by experiment. It varies slightly with the form of the orifice and with the head. The apparatus required to make such a determination includes a suitably arranged stand-pipe to which the orifice may be attached and in which a given head of water can be maintained, and a calibrated tank to receive the stream of water discharged. The quantity of water discharged in a given time under a given head may thus be measured directly and the coefficient computed by means of the formula.

Specific Directions.—Run tests under six different heads, as may be specified by the instructor. Prepare Running Log and post observers in accordance with the following schedule of observations:—

1. Log and time—In charge.
2. Weight of water.
3. Head.

Start the pump which supplies the stand-pipe, giving attention to the lubricator and the cylinder-cocks.

Regulate the head of water in the stand-pipe by the pump-throttle. The length of each test is governed by the capacity of the tank into which the issuing stream is directed, and readings of time and quantity of water discharged should be taken at regular intervals of such a length that at least six (6) readings may be secured under each head.

When the desired head has been secured, close the tank discharge-valve and note time. Take readings as explained above until the capacity of the tank is reached. Discharge the tank, change the head, and repeat. In case the several readings for any head do not show a steady flow, repeat the test under that head.

The Report should be made out on the form shown below, and should be accompanied by the Running Log.

25. Form.

FLOW OF WATER

THROUGH A..............................

Observers { ....
....

Date........

FORM OF ORIFICE OR NOZZLE (Sketch).

FORMULA.

Diameter, feet........

Area, sq. feet.........

Number of Experiment.	Head in Feet.	Time in Seconds.	Cubic Feet. Total.	Cubic Feet per Second.	Coefficient of Discharge.	Notes.
Average.						

26. Calibration of an Orifice.—Orifices of various forms are often used to measure a constant flow of water. It is convenient in such cases to calibrate them, i.e., to determine the rate of discharge under different heads. For this purpose the issuing stream is directed into a weighing-barrel, while the head is kept constant, and the quantity of water discharged per second is noted. These results, obtained under different heads, are plotted in the form of a curve.

Specific Directions.—Run tests under six different heads as may be specified by the instructor. Proceed as follows: Prepare the Running Log. Drain the weighing-barrel and start the flow of water, carefully regulating the same to secure the desired head. Set the poise on the platform-scale to read twenty (20) pounds in excess of the weight of the barrel when the stream is flowing and the discharge-valve is open. Begin the test by closing the discharge-valve and noting the time when the beam rises and the poise reading. Set the poise to read a little under the full weight of the barrel, and when the beam rises again note the time and the poise reading. The barrel may now be emptied, the head changed, and a new test begun.

During each test keep the head constant by regulating the supply-valve.

The Report should be made out in accordance with the form shown below, and should be accompanied by a curve, carefully plotted on cross-section paper, using the various heads as abscissæ and the flow in cubic feet per second as ordinates.

27. Form.

FLOW OF WATER

THROUGH A ....

Observers { .... / .... *Date*........

FORM OF ORIFICE OR NOZZLE (Sketch). Diameter, feet........

Area, sq. feet.........

Number of Experiment.	Head in Feet.	Time in Seconds.	Pounds, Total.	Pounds per Second.	Cubic Feet per Second.	Notes.

28. Determination of the Coefficient of Discharge of a Nozzle.—The rate of discharge from a properly designed nozzle approaches closely the theoretical rate. If the proper internal curvature of the nozzle is secured, there is no contraction of the area of the jet beyond the tip of the nozzle. The velocity of the jet is, however, reduced below the theoretical by friction, and a coefficient must be introduced in formula (3), Section 23, to give the actual rate of discharge. To determine the value of the coefficient for a given nozzle under different heads proceed as explained under the "Specific Directions," Section 24.

29. Formulæ for Flow of Water over Weirs.—The rate of flow of water over a rectangular overfall weir with complete and perfect contraction is given by Francis' formula as follows:

$$Q = \tfrac{2}{3}CH^{\frac{3}{2}}(b - 0.1nH)\sqrt{2g},$$

where Q = flow in cubic feet per second;

H = head in feet over weir from crest to surface of still water back of weir;

b = breadth in feet at water-level;

n = number of contractions; i.e., the area of cross-section of channel in front of weir, divided by area of wetted perimeter;

C = a coefficient of discharge.

In Section 186 is given a table of the value of the coefficient C for different heads and breadths.

The formula for flow over a triangular overfall weir is

$$Q = \tfrac{4}{15} CbH^{\frac{3}{2}} \sqrt{2g}.$$

30. Measurement of Head.—Measurements of the head of water over a weir are usually made with a hook-gage. This instrument is placed on the up-stream side of the weir and a sufficient distance from it to avoid the effects of the surface-curve near the weir. It consists of a metal hook with a fine, sharp point, which may be raised or lowered to the level of the water and readings made of its position by a suitable scale. To take a reading the hook is lowered until the point is below the surface; it is then raised until the point just pierces the surface and a reading of the scale made. This reading when compared with that when the hook-point is level with the crest of the weir, called the zero-reading, will give the head over the weir.

The zero-reading may be determined in several ways. In some cases it may be done with a spirit-level and straight-edge. Where this method cannot be used, a small quantity of water is allowed to flow over the weir and the hook-gage read, at the same time measuring the depth of water over the crest with a thin and finely graduated scale. The hook is then lowered by the amount measured. Another method is to grease the edge of the weir and let the water stand as near the level of the crest as possible, then read the gage.

31. **Water-meters.** — Water-meters are liable to error from many sources and should therefore always be calibrated under the conditions with which they are to be used before their readings can safely be relied upon for experimental purposes. Among the many sources of error may be named change in temperature and head, the presence of dirt or air in the water, and the constant errors of calibration.

32. **Calibration of Water-meters.**—The calibrating of a water-meter could be easily done if the per cent of error were constant for all rates of flow. Since this is not the case, it becomes necessary to calibrate for different rates. This may be accomplished with the aid of a tank of sufficient size, graduated in cubic feet. A pressure-gage should be placed in the supply-pipe between the meter and the valve, to register the head. Three observers are necessary for the work: one to take the meter-reading, one to take that on the tank, and the third to keep log and time. The operation is as follows: Open the supply- and discharge-valves and allow the water to flow for a few minutes until the rate of flow, as shown on the pressure-gage, becomes steady; then close the discharge-valve, and as soon as water appears in the gage-glass on the tank, at a signal from the time-keeper, take simultaneous readings of the meter and tank. Repeat the readings

every minute until the tank is full. Empty the tank. Throttle the admission-valve a little so as to change the rate of flow and repeat. Make experiments at six different rates or pressures. The observations should be recorded on a Running Log, which should be made out to cover the following:

1. Time.
2. Pressure.
3. Tank-reading.
4. Meter-reading.
5. Temperature.

The Report should be made out in the form shown below and should be accompanied by the original Running Log.

33. Form.

REPORT ON CALIBRATION-TEST

OF.............................WATER-METER.

Observers { ....
.... *Date*........

a. Number of test........
b. Duration of test, minutes........
c. Pressure of head, average........
d. Temperature of water, average........
e. Rate of discharge per minute by meter........
f. Rate of discharge per minute by tank........
g. Total volume by meter........
h. Total volume by tank........
i. Total excess or deficiency in meter reading........
j. Per cent of error (+ or −)........

CHAPTER IV.

MEASUREMENT OF GASES.

34. **Methods.**—The flow of gases may be measured by the following methods:

1. By flow through an orifice.
2. By determination of velocity.
3. By some form of meter.
4. By Pitot tube.

35. **Flow through an Orifice.**—Where the flow of gas is at a constant rate, an orifice may be conveniently employed in determining the rate of flow. Fig. 9 shows the arrangement of an orifice for this

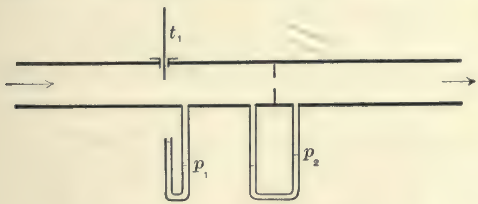

FIG. 9.—ARRANGEMENT OF ORIFICE.

purpose. At p_1 and p_2 are U-tubes for measuring the pressure before and after passing the orifice, and at t_1 is a thermometer for measuring the initial temperature.

36. **Formula for Flow of Air through an Orifice.**—The flow of air through an orifice can be computed

with the aid of the following, called Fliegner's formula:*

$$G = 0.530F\frac{p_1}{\sqrt{T_1}} \quad \text{when} \quad p_1 > 2p_a;$$

$$G = 1.060F\sqrt{\frac{p_a(p_1 - p_a)}{T_1}} \quad \text{when} \quad p_1 < 2p_a;$$

where p_1 is the absolute pressure in the reservoir, p_a is the atmospheric pressure, T_1 is the absolute temperature of the air in the reservoir in degrees Fahrenheit, G is the flow in pounds per second, and F the area of the orifice in square inches.

37. **Formula for Flow of Steam through an Orifice.**—The flow of steam through an orifice may be calculated by the following, called Napier's formula:†

$$G = F\frac{p_1}{70} \quad \text{when} \quad p_1 = \text{or} > \tfrac{5}{3}p_a;$$

$$G = F\frac{p_1}{42}\left\{\frac{3(p_1 - p_a)}{2p_a}\right\}^{\frac{1}{2}} \quad \text{when} \quad p_1 < \tfrac{5}{3}p_a.$$

The nomenclature is the same as in Fliegner's formula, just preceding.

38. **Experiments on Flow of Steam.**—The purpose of these experiments is to verify existing formulæ for the flow of steam and to determine the change in the rate of flow under different conditions of pressure and moisture. The apparatus consists of an orifice of suitable dimensions (see Fig. 10) provided with gages, a condenser for measuring the steam, and two calorim-

* See Peabody's "Thermodynamics," page 135.

† *Ibid.*, page 140.

eters for ascertaining the quality of the steam. The apparatus also includes a water-jacket for regulating the moisture of the inflowing steam to suit the desired conditions.

Specific Directions.—To determine the change of rate of flow with change in the ratio of final to initial pressure, run a series of five tests with constant initial

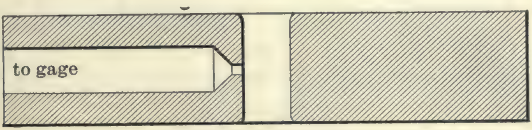

FIG. 10.

and variable final pressure. The conditions should be as follows:

For the first test, final pressure as low as obtainable.

For the second test, final pressure to be 0.3 of difference between initial and atmosphere.

For the third test, final pressure to be 0.5 of difference between initial and atmosphere.

For the fourth test, final pressure to be 0.7 of difference between initial and atmosphere.

For the fifth test, final pressure to be 0.9 of difference between initial and atmosphere.

Cooling-jacket to be cut out.

Each test should be of 15 to 20 minutes duration, the conditions of the test to exist for five minutes before the first observation is taken.

The following observations should be taken every two minutes: initial, intermediate, and final pressure. The following should be taken every four minutes: pressure and temperature in each calorimeter. The weight of condensed steam should be taken once for the test, and the barometer read twice during the test.

Use only enough cooling water on the condenser to condense the steam. Be sure that the pressure-gages are not subjected to a pressure beyond their range.

The Report should include:

1. Sketch and description of apparatus.

2. Sketch and dimensions of orifice.

3. Tabulated statement of results for each test.

4. A curve having ratio of final absolute pressure to initial absolute pressure for abscissæ and flow of steam in pounds per hour for ordinates.

In order to determine the effects of different percentages of moisture in the steam repeat the above series, manipulating the cooling-jacket to secure increasing amounts of moisture in the steam.

39. **Method by Determination of Velocities.**—This method has a limited application, but may sometimes be found convenient to employ. It involves the use of an instrument for determining the velocity of flow, such as an anemometer or Pitot tube. The velocity, thus determined, in connection with the cross-sectional area of the pipe or conduit, gives the rate of flow.

CHAPTER V.

MEASUREMENT OF PRESSURE.

40. Pressure-gages.—The most common instrument for the measurement of pressures in excess of a few pounds is the Bourdon gage (Fig. 11), which consists essentially of a curved tube, oval in cross-section,

FIG. 11.—BOURDON GAGE.

having one end closed and the other in communication with the pressure to be measured. The tendency of an internal pressure is to make the cross-section round and thus straighten the tube. The motion produced serves to rotate a pointer by an amount proportional to the pressure. Such instruments may be used for pressures of either liquids or gases provided they are not heated above 125° or 150° F., as excessive temperature will lengthen the levers and draw the spring temper of the tube. When used for steam-pressure, a siphon or trap should be used to prevent the steam from entering the gage.

When making a selection of such a gage to measure a given pressure, it should be borne in mind that, since these gages are apt to be inaccurate at the lower points of their travel, the lowest total range should be chosen which is compatible with the pressure to be measured.

41. Vacuum-gages.— Bourdon gages of special design are used for the measurement of vacuo, movement of the pointer being obtained by means similar to that described for pressure-gages. They are generally graduated to read in inches of mercury below atmospheric pressure.

42. Calibration of Gages.—*Method by Comparison with Standard.*—In order to test the accuracy of pressure-gages they should be calibrated by being subjected to known pressures within their range and their error noted. In the method by comparison with standard the gage to be tested is placed in pipe-connection with a standard gage of known error and both subjected to pressure. This pressure may be of water, oil, or steam. If either oil or water be used, the pressure may be secured by a steam- or hand-pump. The difference between the readings of the two gages may then be noted and a table of corrections made for the gage under test.

Specific Directions.—Before making the test see that the pump-lubricator is filled and started. Start the pump slowly and gradually increase its speed until the maximum pressure, depending upon the available steam-pressure, is reached. Stop the pump and read the gages. Allow the pressure to decrease by even five-pound steps as shown on the standard gage by manipulation of the outlet-valve. Take simultaneous readings of both gages at each pressure and enter the same on the form shown below. Check all readings once by repeating the test.

In preparing the Report enter in the column headed "Actual Pressure" the corrected reading of the standard gage. The corrections, if there are such, will be found posted near the gage. In the column of "Corrections" enter the difference between the corrected reading of the standard gage and the reading of the gage under test. These differences should be preceded by the minus or plus sign, according as the gage under test reads above or below the standard gage. Take a gage to pieces, sketch the mechanism and explain its action. Submit the sketch and explanation with the report.

43. Form for

CALIBRATION OF STEAM-GAGE

BY COMPARISON WITH........................

Make and number of gage ....

Observer .... *Date*......

Standard Gage.		Actual Pressure.	Reading of Gage.	Correction (− or +) to be added.	Standard Gage.		Actual Pressure.	Reading of Gage.	Correction (− or +) to be added.	Remarks.
Pounds.	Correction.				Pounds.	Correction.				

44. Calibration of Gages.—*Method by Comparison with Crosby Gage-tester.*—Gages may be calibrated by subjecting them to liquid pressure, the same pressure being made to sustain weights of known amount. The apparatus, shown in Fig. 12, consists of a chamber filled with oil, to which the gage is attached and

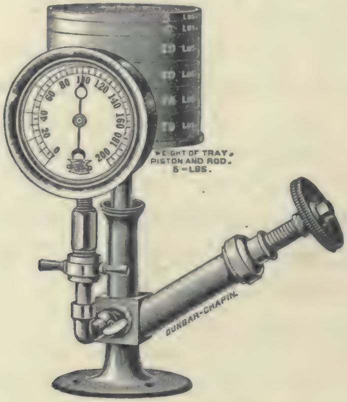

FIG. 12.—CROSBY GAGE-TESTER.

which terminates in a cylinder having a nicely fitting piston of one fifth of a square inch cross-sectional area. The piston is furnished at its upper end with a platform upon which accurate weights may be placed. The piston and platform together weigh one pound, and require therefore a pressure of five pounds per square inch (acting on the piston-area of $\frac{1}{5}$ of a square inch) to sustain them. In communication with the oil-chamber referred to is a reservoir fitted with an adjusting plunger which is operated by the hand-wheel shown on the right. This is used to force oil into the system as occasion demands in order to keep the platform and weights floating.

Specific Directions.—Open the cock connecting the gage with the oil-cylinder and screw in the plunger until the piston and platform have risen two or three inches above the lowest position. Twirl the platform to avoid a false reading due to piston friction, and take a reading of the gage, recording the same, together with the actual pressure (five pounds), in the proper columns on the form shown above. Add successive weights by five-pound steps and take corresponding readings, twirling the platform each time while taking the reading. Continue up to the limit of the gage and repeat, to check the results.

In preparing the Report, leave the columns headed "Standard Gage" blank. In the column of "Corrections" enter the difference between the actual pressure and the reading of the gage under test. These differences should be preceded by the minus or plus sign, according as the gage-reading is greater or less than the actual pressure.

45. **Correction of Gages.**—If an error appears as a result of calibration it may generally be corrected. If the error is a constant one, the hand may be removed with a needle-jack and moved an amount corresponding to the error. If the error is an increasing or diminishing one, it can be corrected by changing the length of the levers which operate the pointer. It is generally desirable to set the gage to read correctly at the pressure under which it will be most frequently used, especially if it is to register a constant pressure, as that of a boiler. In such a case, the gage should be subjected to the desired pressure and the needle placed to indicate the same on the dial.

46. **Manometers.**—For the measurement of small

pressures or vacuo the U-tube manometer is in common use. It consists usually of a U-shaped tube of glass, partially filled with mercury or water and pro-

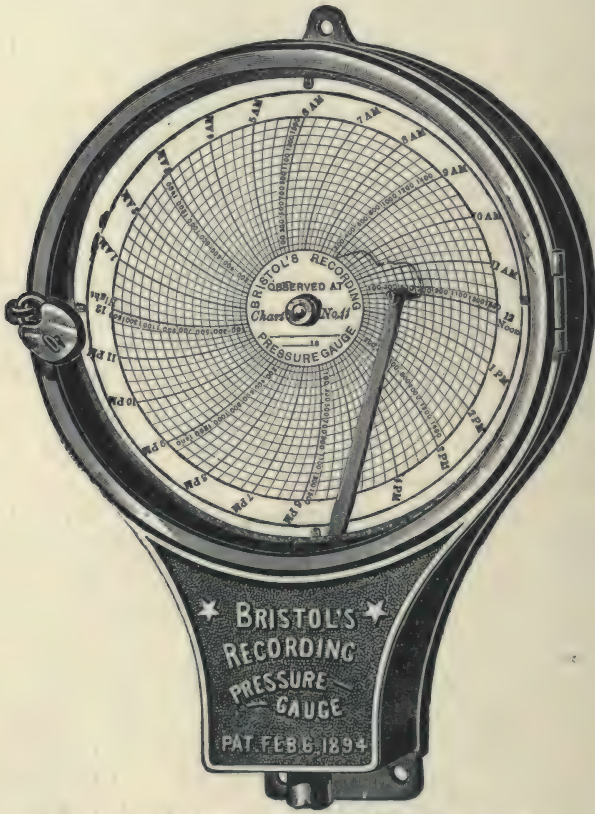

FIG. 13.—BRISTOL RECORDING PRESSURE-GAGE.

vided with a scale for reading the difference of level of the liquid in the two legs. One branch of the tube is connected with the pressure or vacuum to be measured, and the other is open to the atmosphere.

The difference of level of the liquid in the two branches, measured in inches, multiplied by the weight of a cubic inch of the liquid gives the pressure in pounds per square inch above or below atmosphere.* In reading the height of mercury columns, read the level at the top of the meniscus or convexity; in reading a water-column, read the bottom of the meniscus.

47. **Bristol Recording-gage.**—This gage, one form of which is shown in Fig. 13, is so arranged that the pressure or vacuum actuates a pen which leaves a continuous record on a revolving disk of paper. The disk is operated by clockwork. The instrument is of special value in recording the fluctuation of pressures subject to considerable variation. It is a valuable adjunct in making tests of boilers, the record obtained more nearly representing the average pressure than is possible with periodic observations.

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* The weight of a cubic inch of mercury at 60° F. is 0.490 pounds ; of water at 60° F. 0.0360 pounds.

CHAPTER VI.

MEASUREMENT OF TEMPERATURE.

48. Mercurial Thermometers.—Measurements of temperature are usually made by means of mercurial thermometers, which depend for action on the expansion of mercury in a bulb and capillary tube when subjected to heat.

Mercurial thermometers when used in engineering work should frequently be tested for accuracy, as they are liable to error from many sources, such as variable diameter of bore, permanent change of volume of bulb from use, etc. Great care should be exercised in handling, to reduce breakage and damage to a minimum.

49. Rules for Care of Thermometers.—The following rules should be observed in connection with the use of mercurial thermometers:

1. Keep the thermometer in its case when not in use.

2. Exercise care in inserting and removing from the thermometer-cup.

3. See that there is no water in the cup before inserting thermometer.

4. Keep the cup filled with heavy oil, and wrap the stem with waste at the mouth of the cup to avoid contact with the metal.

5. Be sure that the range of the thermometer is high enough for the temperature to which it will be exposed.

6. Do not carry the thermometer wrong end up.

7. Return the thermometer to its own case when through using.

50. Calibration of Thermometers. — *Method by Comparison with Standard.*—In order to test the accuracy of thermometers, they should be subjected to known temperatures and their errors noted. This may be done by comparing their readings with those of a standard thermometer whose error is known.

Specific Directions.—Place the thermometer to be calibrated and the standard in adjacent cups of the same depth in the testing-drum. Allow steam to run through the drum for a few minutes to warm it up, then throttle the discharge until a pressure of five pounds is maintained upon the gage. Allow the mercury in the thermometer to come to rest (five to ten minutes) and take simultaneous readings of the two thermometers, removing them from their tubes only far enough to bring the mercury to view, and taking the readings as quickly as possible to avoid the cooling effects due to partial removal from the tubes. Close the discharge-valve again until the pressure is raised to ten pounds, and repeat. Carry the pressure by five-pound steps up to the limit of pressure, and descend in the same manner. Be sure that time is allowed for the mercury to come to rest before reading. Read Section 49 before beginning the test. Report on the form shown below, omitting the columns headed "Steam-gage" and the barometer reading.

51. Form for

CALIBRATION OF THERMOMETER

BY COMPARISON WITH...

THERMOMETER CHECKED:

Distinguishing mark............ *Range of scale*...........

Scale....... .... *Range of test*.............

Observers .... *Date*...........

No.	Standard Thermometer.		Steam-gage.		True Temperature.	Thermometer Tested.		Remarks.
	Reading.	Known Error.	Reading.	Known Error.		Reading.	Correction (+ or −) to be added.	
								Barometer:

52. Calibration of Thermometers.—*Method by Comparison with Temperature due to Steam-pressure.*—The temperature of saturated steam varies with the pressure according to a known ratio. If, therefore, the pressure be known, the corresponding temperature can be ascertained.

Specific Directions.—Follow the method given in Section 50, using only one thermometer, the one under test, and noting the reading of the steam-gage attached to the drum. After the test, copy the corrections for the gage from the sheet posted near by and find the true pressure. Then by reference to the Table of Properties of Saturated Steam, Section 182, find the true temperature, after which the error of the thermometer can readily be found. Note that the pressures given in the table are absolute, therefore add barometric pressure to the corrected gage-pressure before referring to the table. As this method depends upon the steam being saturated, the water-jacket on the steam-pipe should be used if any doubt exists as to the condition of the steam. Read Section 49 before beginning the test. Report on the form shown above, omitting the columns headed "Standard Thermometer."

53. Rate of Rise and Fall of a Mercurial Thermometer.—The object of this experiment is to give the investigator an idea of the time required for the mercury in a thermometer to rise to the height corresponding to the temperature to which it is exposed.

Specific Directions.—Three thermometers are necessary: (*a*) to give the lowest temperature available, which may be the temperature of the atmosphere; (*b*) to give the highest temperature available as of steam under pressure; and (*c*) the thermometer to be experimented upon.

To determine the rate of rise, (1) let the reading of the thermometer *c* agree as nearly as possible with the reading of *a*; (2) expose *c* to the highest temperature available, and read and record its temperature at intervals of fifteen seconds until its reading agrees nearly or quite with that of *b*. To determine the rate of fall, reverse the process.

Repeat each experiment, and if the results do not agree closely perform the work two or more times. Plot the mean results of the two series which most nearly agree. No report other than the curve will be required. Read Sections 6 and 49.

54. Variation of Thermometer-reading with Stem-immersion.—The reading which a thermometer will give varies somewhat with the length of stem exposed to the temperature. To determine that variation, two thermometers are needed. They should first be placed in tubes of medium length and compared at intervals of ten pounds steam-pressure for a range of one hundred pounds. One should then be assumed as standard and left in the tube, while the other is moved to a tube of a different length and again compared. It should be again moved and the work repeated. The Report should follow the form given below. Read Section 49 before beginning the test.

55. Form for Experiment on Stem-immersion.

REPORT ON VARIATION OF THERMOMETER-READING
WITH STEM-IMMERSION.

Observers { .... / .... *Date*........

Steam-gage.			Reading of Standard Thermometer in Medium Tube.	Thermometer Checked.			Notes.
Reading.	Known Error.	True Pressure.		In Medium Tube.	In Long Tube.	In Short Tube.	
							Thermometer checked: Designating mark.... .... Scale .... Range of scale .... Depth of medium tube....inches " " long tube........ " " " short tube........ " No. degrees covered: in medium tube............. in long tube. .... in short tube ....

56. Pyrometers.—*Copper-ball Calorimeter.* — The determination of temperature by this method involves the use of the following apparatus: a copper ball about one inch in diameter and a copper cup provided with a non-conducting jacket. The ball is introduced into the medium whose temperature it is desired to ascertain and left long enough to arrive at the correct temperature. It is then transferred quickly to the jacketed cup in which is a known weight of water at a known temperature. Knowing the weight of the cup and ball and their specific heats, the following formula can be applied: Let W_1, W_2, and W_3 be respectively the weights of the ball, cup, and water. Let t_1 be the initial and t_2 the final temperature of the water; let T be the initial temperature of the ball, and S be the specific heat of copper. Then

$$W_1S(T - t_2) = (W_2S + W_3)(t_2 - t_1),$$

from which

$$T = \frac{(W_2S + W_3)(t_2 - t_1)}{W_1S} + t_2.$$

57. Le Chatelier Pyrometer. — This instrument furnishes a very convenient means of measuring temperatures up to the melting-point of platinum. It consists of a joint of two wires having different thermo-electric properties, such as platinum and an alloy of platinum and iridium. This joint when heated generates an electric current which is proportional to the temperature. By using a sensitive mirror-galvanometer, the current and hence the temperature can be ascertained.

The instrument must be calibrated before it is ready for use. This is done by subjecting the joint to known temperatures and noting the resultant deflections of the galvanometer. From the figures obtained, a curve of deflections and temperatures may then be plotted. The instrument should be calibrated as nearly as possible under the conditions with which it is to be used.

CHAPTER VII.

CALORIMETERS.

58. Definition.—The steam-calorimeter is an instrument for determining the amount of moisture contained in steam. There are several different forms which may be roughly classified as follows:

1. Condensing calorimeters.
2. Superheating calorimeters.
3. Separating calorimeters.

Two of the most convenient and reliable forms are the Peabody Throttling Calorimeter, belonging to the second classification, and the Carpenter Separating Calorimeter, belonging to the third classification.

59. Peabody Throttling Calorimeter.—This calorimeter depends for its action upon the property of dry steam by which it becomes superheated by throttling.

The calorimeter consists of an orifice *a*, Fig. 14, in communication with a chamber *b*. The latter is fitted with a thermometer *c*, a pressure-gage *d*, and an exhaust-pipe and valve *e*. Steam in entering the chamber through the orifice is superheated and the contained moisture is evaporated into steam. The cut shows a convenient form of the instrument, made from ordinary pipe fittings. All the parts should be carefully and thoroughly covered to reduce radiation.

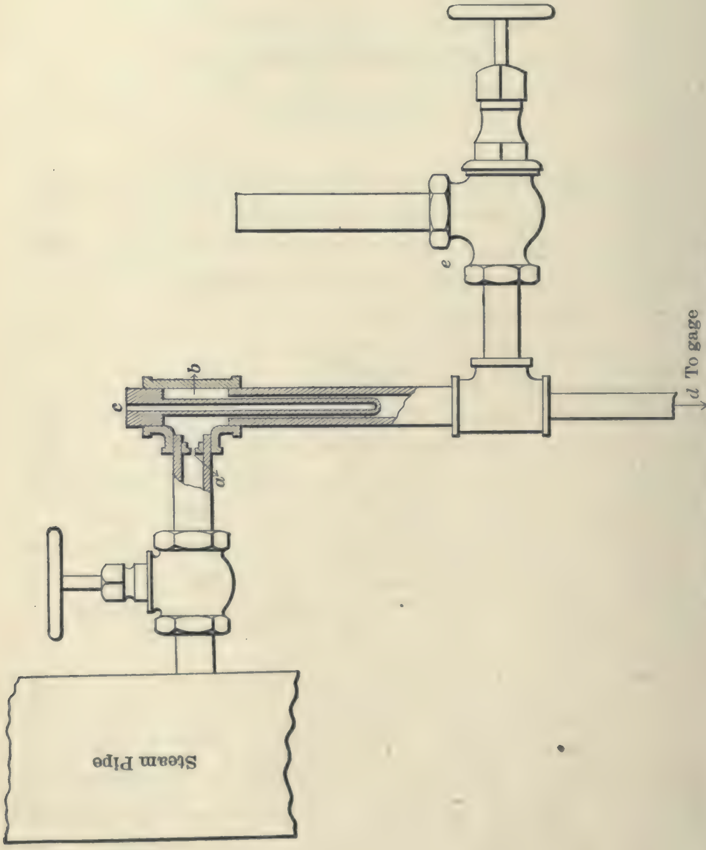


FIG. 14.—THROTTLING CALORIMETER.

The formula is derived in the following manner: Let

p_1 = boiler-pressure, absolute;
p_2 = pressure in calorimeter, absolute;
t_s = temperature in calorimeter;
r_1 and q_1 = heats of vaporization and of the liquid corresponding to p_1;
λ_2 and t_2 = total heat and temperature corresponding to p_2;
C_p = specific heat of steam;
x_1 = quality of steam required.

Then the heat in a pound of steam flowing to the orifice will be

$$x_1r_1 + q_1;$$

and that in a pound of steam in the chamber *b*, after passing through the orifice, will be, assuming that all the moisture is reevaporated,

$$\lambda_2 + C_p(t_s - t_2).$$

Now, assuming that no heat is lost or converted into work during the transformation, these two quantities must be equal. Whence

$$x_1r_1 + q_1 = \lambda_2 + C_p(t_s - t_2),$$
$$\therefore \quad x_1 = \frac{\lambda_2 + C_p(t_s - t_2) - q_1}{r_1}.$$

60. Limitations of the Throttling Calorimeter.— It is apparent, on consideration of the foregoing formulæ, that if the entering steam contains too great a percentage of moisture, it may fail to superheat on passing through the orifice. This, then, is the limiting condition under which the calorimeter can be used.

The point at which superheating ceases varies ordinarily from about 3 per cent with low steam-pressures to 7 per cent at very high pressures. The precise limit under any given pressure varies slightly with the pressure in the calorimeter.

61. Use of the Throttling Calorimeter. — Care should be taken in placing a calorimeter that a fair sample of steam is obtained. To this end the calorimeter-pipe should extend well into the steam-pipe and should be provided with perforations inside the steam-pipe. The A. S. M. E. recommends that the calorimeter-pipe be ½ inch in size, that it extend into the steam-pipe to within ½ inch of the opposite wall, that the inner end be plugged, and that it be provided with not less than twenty ⅛-inch holes distributed along and around its length, no hole being closer than ½ inch to the inner end. The instrument should be well wrapped with hair-felt or asbestos, to prevent radiation. It should be started at least ten minutes before the first observation is to be made, to allow the conditions to become settled. A pressure of 4 or 5 pounds should constantly be maintained by manipulating the discharge-valve. The thermometer should be put in place after the instrument is started and removed at the end of the test. *Never close the discharge-valve* without first shutting off the calorimeter-gage. The observations to be taken are pressure of steam in pipe, pressure and temperature of steam in calorimeter, and barometric pressure. The report should be kept on the calorimeter form shown below.

In testing a small boiler the calorimeter may be shut off part of the time in order to avoid the waste of a large quantity of steam. In making a combined engine- and boiler-test when the water is measured before entering the boiler, the length of time which the calorimeter is in action should be carefully noted, in order to calculate the weight of steam lost, as explained in Section 37.

62. Form for Calorimeter Test.

TEST FOR DETERMINING THE QUALITY OF STEAM
BY USE OF THROTTLING CALORIMETER No. ......

Tests made in connection with.......................No. ......

Made by.................... *Date*.............

Gong Number.	Time.	Difference.	Steam-pressure by Gage.	Observed Temperature of Steam.	Pressure in Calorimeter by Gage.	Observed Temperature in Calorimeter.	Notes.

Barometric pressure........
Absolute steam-pressure........
Temperature corresponding with steam-pressure........
Absolute pressure in calorimeter........
Temperature corresponding with pressure in calorimeter........
QUALITY OF STEAM IN........
Per cent of priming........
Degrees superheated........

63. Carpenter Separating Calorimeter.—This instrument consists of a cylindrical vessel, so constructed that all the moisture contained in the steam passing through it will be separated and retained, the dry steam only passing on to the receiver, where the quantity collected is indicated by a gage-glass graduated in pounds and tenths at a temperature of 110° F. The separating vessel is provided with a gage-glass and scale graduated in hundredths of a pound, at a temperature corresponding to steam of ordinary working-pressure. The quality of steam is found as follows: Suppose the weight of moisture collected in a given time, as shown on the scale of the separating-chamber, be represented by W, and the weight of dry steam collected in the same time by W_1. Then the percentage of moisture to the whole quantity is

$$y = \frac{W}{W + W_1}.$$

The percentage of dry steam is

$$x = 1 - y = \frac{W_1}{W + W_1}.$$

64. Directions for Use.—In using the instrument, allow steam to blow through it until it is thoroughly heated, and allow sufficient water to gather in the separating-chamber to reach the zero-mark on the scale. Fill the condensing-vessel with cold water and note carefully the initial level on each glass. The test may now be run until the separating-chamber is full. The instrument should be well wrapped from the main steam-pipe to the elbow connecting with the calorimeter proper.

65. Barrel Calorimeter.—The barrel calorimeter belongs to the first division of the classification given above, viz., the condensing calorimeters. It is much less accurate than the calorimeters previously described, and, while one of the earliest forms, is now but seldom used. It consists usually of a weighing-barrel filled with water into which may be directed the sample of steam. The steam may be introduced through rubber hose or a steam-pipe, the latter method being preferred. When using pipe there should be provided a cock opening to atmosphere just before the pipe enters the barrel. The lower end of the pipe should be fitted with a T, opening horizontally, and may be drilled with $\frac{1}{8}$-inch holes for some distance from the lower end, in order to secure an equal rise of temperature throughout the barrel.

The method of making a determination is as follows: Fill the barrel with water and turn on steam until the temperature of the water has risen to about 150° F. This is to heat the barrel and reduce the error due to its cooling effect. Drain the barrel. Now refill the barrel, open the air-cock so that the water-level in the pipe may be the same as that in the barrel and weigh. Take a reading of the temperature. Close the air-cock and turn on the steam. When the temperature has risen to about 125° F., turn off steam, open the air-cock, and again weigh. The quality of the steam may now be calculated from the formula derived as follows:

Let x_1 = quality of steam;
t_3 = initial temperature of water;
t_2 = final temperature of water;
w_1 = initial weight of water;
w_2 = final weight of water;
p_1 = pressure of steam;
r_1 and q_1 correspond to p_1;
q_2 correspond to t_2;
q_3 correspond to t_3.

Then

$$(x_1r_1 + q_1 - q_2)(w_2 - w_1) = w_1(q_2 - q_3),$$

from which

$$x_1 = \frac{w_1(q_2 - q_3)}{(w_2 - w_1)r_1} - \frac{(q_1 - q_2)}{r_1}.$$

This formula assumes that the constant of the instrument is zero and that there is no radiation. The preliminary heating of the barrel, as explained above, makes the calibration-constant a negligible quantity, and if the test is of short duration it is customary to disregard the radiation.

66. Calorimeter Exercise.—The apparatus consists of three calorimeters of different types connected to the same steam-supply and with the same manner of attachment. A suitable water-jacket is provided to govern the quality of the steam supplied. The different instruments used are:

1. A throttling calorimeter.
2. A separating calorimeter.
3. A barrel calorimeter.

Three observers are needed, one for each calorimeter. Run simultaneous tests, adapting the time of observations on Nos. 1 and 2 to that which will be convenient for the barrel calorimeter. Run three tests, changing the quality of steam each time by means of the water-jacket on the steam-pipe. Let the observers change positions so that each will run a test on each calorimeter.

In the Report present a copy of all running logs, table of calculated results arranged for convenient comparison, and a curve of the quality of steam shown by each calorimeter based upon a straight line representing dry steam. For formula and directions concerning each calorimeter, see Sections 59 to 65.

CHAPTER VIII.

MEASUREMENT OF POWER.

67. Classification.—Machines for the measurement of power may be divided into two general classes: those which absorb the power measured, called absorption-dynamometers; and those which form a connecting link in the transmission of the power to be measured, called transmission-dynamometers.

68. Absorption - dynamometers. The Prony Brake.—The form of absorption-dynamometer in most common use is the Prony brake, of which there are many varieties. One of the simplest forms, which may be taken for illustration, consists of a rope placed over or wrapped around a pulley which receives the power to be measured. The rope is provided with adjustable weights, and the friction induced by the revolution of the pulley is such as to sustain the weighted end of the rope against gravity. An increase of load is obtained by adding more weights, which causes the rope to bear on the pulley with greater force, thus increasing the friction. Since it is difficult to obtain the weight which will just be thus sustained, it is customary to attach a spring-balance to the other end of the rope as a compensating device, as in Fig. 15. The lower end of the balance is attached to some fixed point.

The power absorbed by such a brake is given by the following formula:

$$H.P. = \frac{2\pi rn(W - w)}{33000},$$

where r is the radius of the wheel plus half the diameter of the rope in feet, n is the revolutions per

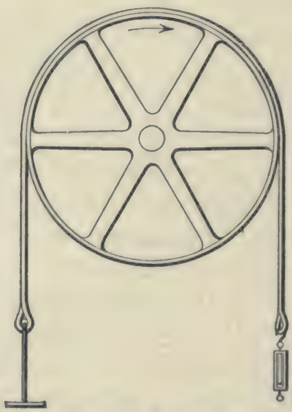


FIG. 15.—ROPE PRONY BRAKE.

minute, W is the weight on the tight side of the rope and w is the weight on the slack side as shown on the spring-balance.

A common modification of the rope-brake is the substitution of a steel band or bands for the rope. This band has attached to it at intervals of a few inches blocks of hard wood which bear on the wheel and form the rubbing medium. Another form of Prony brake is shown in Fig. 16. The parts lettered *a* and *b* are of hard wood, and the load is obtained by tightening the hand-wheel *h*. The load is measured by a platform-scale which registers the retarding force at the radius r. Since the scale sustains not only the downward pressure due to the revolution of the pulley, but also the weight of the brake-arm itself, this latter amount must be ascertained and deducted from the reading of the scale to determine the power

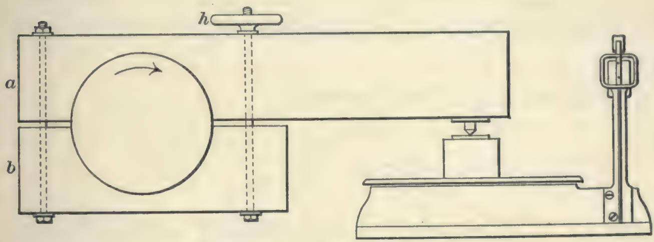


FIG. 16.—BLOCK PRONY BRAKE.

given off by the pulley. By making W equal to the reading of the scale and w the weight of the brake-arm at the radius r, the above formula will apply to this form of brake. By slight modifications the same formula may be made to apply to all forms of the Prony brake.

69. Special Forms of Prony Brakes.—In the Purdue Laboratory are several special forms of brakes, two of which will be here described.

Pipe-brake.—This is a form of Prony brake in which four $\frac{3}{8}$-inch iron pipes are substituted for the rope. These pipes run in grooves turned in a wooden band bolted to the fly-wheel. A system of reducing-levers is introduced on the tight side to weigh the load, and a large spring-balance is employed to measure the back pull. This spring-balance is connected to an equalizing device by which the pull on all the pipes is maintained alike and the balance registers the pull on a single pipe. Water is circulated through the pipes to carry off the heat generated.

In operating the brake, determine the load under which it is desired to run the engine and place enough weights on the scale-pan to equal this load. After the engine is started, tighten the hand-wheel on the slack side until the lever rises and floats at its middle position.

The formula for horse-power is

$$\text{H.P.} = \frac{(3a - 4b + c)2\pi rn}{33000},$$

where a is the weight on scale-pan not including weight of pan, b is the back pull as shown by the corrected spring-balance reading, r is the effective brake-arm, n is the revolutions per minute, and c is the unbalanced weight of scale-pan, lever, links, pipe, etc.

The value of the constant quantities may be found in the Commonplace-book.

Band-brake.—In this brake the power is absorbed by a steel band running on a heavy wooden pulley. The band is surrounded by a strip of muslin which receives and distributes a spray of water for cooling purposes. The wooden lever to which the ends of the band are attached rests upon platform-scales, and the load is applied by means of a hand-wheel which tightens the band on the pulley. The directions for management of the pipe-brake apply in a general way to this brake. The formula in Section 68 may be used by making the item w equal the unbalanced weight of the lever-arm and connections. The value of the brake-constants may be found in the Commonplace-book.

70. Transmission-dynamometers. — A form of transmission-dynamometer which may be easily and cheaply constructed has been devised by Prof. W. F. M. Goss. It is shown diagrammatically in Fig. 17.

This dynamometer consists of a differential lever by which the difference in tension of the two sides of a belt is determined. This lever is pivoted to a fixed

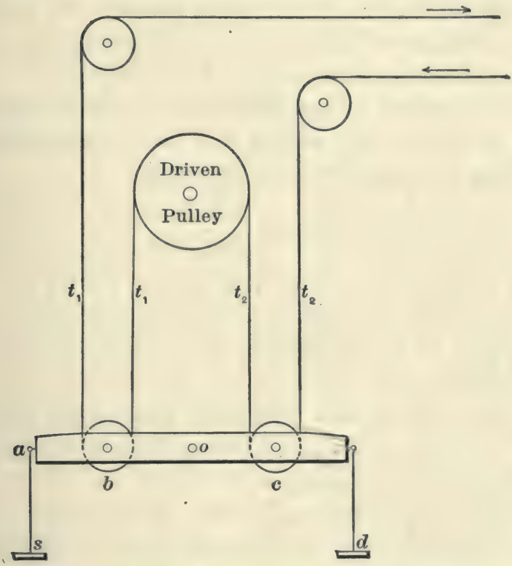


FIG. 17.—BELT TRANSMISSION-DYNAMOMETER.

point *o* and carries the pulleys *b* and *c*. It is provided with a scale-pan *s*, and a combined dash-pot and counterweight *d*. The power transmitted by the belt is measured by the speed in feet per minute at which it runs multiplied by the difference in tension of the two sides, as shown on the dynamometer. The force tending to raise the left end of the lever is twice the tension t_1 of the tight side of the belt; that tending to raise the right side is twice the tension t_2 in the slack side. Hence the resultant movement tending to produce rotation of the lever is twice the difference in tension of the two sides of the belt, acting on an arm *bo* (= *oc*) equal to the distance from the fulcrum of the lever to the center of the pulley supported by it. Since the lever-arm of the scale-pan *ao* is twice the above, a weight on the pan equal to the difference in tension of the belt will balance the lever.

The belt speed is known from the revolutions per minute of the driven pulley and its circumference in feet. The formula for horse-power is

$$\text{H.P.} = \frac{\pi d n w}{33000},$$

where d is the diameter of the driven pulley plus the thickness of the belt in feet, n is its revolutions per minute, and w is the weight in pounds necessary to balance the lever.

The observer in charge should keep such a weight on the scale-pan as will cause the lever-arm to move evenly between the stops.

71. Efficiency of Screws.—The screw is one of the elementary mechanical movements and one that forms an essential part of a great variety of mechanisms. The efficiency of the screw may be defined as the ratio of the work done by the screw in lifting a given load through a certain height to the work done upon the screw. This ratio varies for different loads lifted. The factors in the first member of the ratio are the distance passed through by the moving force, expressed in any convenient unit, and the mean force exerted in pounds. The factors in the second member of the ratio are the load lifted in pounds and the height through which it is raised.

In order to determine the efficiency of the screw the following test may be made: The apparatus consists of a jack-screw fitted with a lever of convenient length, say 36 inches, and a spring-balance at the end of the lever. The jack-screw is placed on the table of a testing-machine, which serves to register the load.

Specific Directions.—Place the jack-screw to be tested on the center of the testing-machine table, with a block of hard wood above and below it. Balance the poise-lever and run the movable head down until in contact with the screw. Place the poise at the one-thousand-pound mark and run the head down until the poise-lever rises and remains in balance. Back the screw down and then run it up by means of the lever and spring-balance, and note the reading on the balance the instant the poise-lever rises. Be careful to exert the pull at right angles to a vertical plane through the lever-arm. Now move the poise to the two-thousand-pound mark, run the movable head down until this load is balanced, and repeat the test. Make six tests at one-thousand-pound steps, and repeat the observations once or twice under each load. At each test note the number of full threads exposed to view.

In calculating the efficiency of the screw the determination may be based upon one complete revolution of the screw. Although only momentary conditions are observed, these conditions may be assumed to hold true for a complete revolution. Suppose the height through which the screw is raised be equal to the pitch (p) of the screw in inches, or one revolution.

Let the load lifted be W pounds and the corresponding pull on the balance be P. Then the work done by the operator at the end of the lever-arm in raising the load, expressed in inch-pounds, will be

$$2\pi \times 36 \times P.$$

The work given out by the jack in moving the load will be

$$pW.$$

The efficiency in per cent is therefore

$$100\frac{pW}{2\pi \times 36 \times P}.$$

The Report should be made out on the form shown below.

72. Form for

EFFICIENCY TEST OF SCREW.

Made by { ....
.... *Date*........

Outside diameter of thread in inches........
Pitch " " " " ....
Form of thread....
Effective length of hand-bar used in inches........

	1	2	3	4	5
Load under which efficiency was obtained................					
Work which the screw would do in one revolution, in inch-pounds....................					
Pull on lever in pounds........					
Work which would be done upon the screw in one revolution, in inch-pounds.......					
Efficiency....................					

NOTES:

73. Efficiency of Hoists.—This test is conducted for the purpose of determining the relation between the work put into a chain-hoist on the hand-chain, and that given out by the hoist in lifting the load. The method consists in putting a definite load on the hoist and noting the stress or weight on the hand-chain necessary to keep the load moving upward; that is, the weight on the hand-chain necessary to keep the load moving after it has been started by hand, since the friction at starting is much greater than that after the load is in motion.

Specific Directions.—In calculating the efficiency, the following factors are necessary: the value of the load raised, the weight on the hand-chain required to raise it, and the ratio of the velocity of the hand-chain to that of the load-chain. With the Weston differential hoist, this velocity-ratio is equal to $2AL \div (AL - AK)$, Fig. 18.

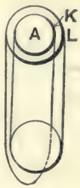


FIG. 18.

But since the circumference is proportional to the radius, we may employ the number of link-pockets for our unit of measure: the velocity-ratio may therefore be found by subtracting the number of pockets in the small wheel from the number in the large wheel and dividing this difference into twice the number in the large wheel. With other forms of hoists, the ratio may be determined by experiment. Tie a piece of string on a link of the load chain opposite some fixed part of the hoist and put a similar piece on the hand-chain. Move the former a considerable distance and observe the corresponding movement of the hand-chain. Repeat several times and calculate the velocity-ratio from the mean of the observations. This ratio should be expressed in the form of a fraction, the denominator being 1.

The weight lifted, in pounds, may be taken as a unit representing the work done; the stress in pounds on the hand-chain, multiplied by the factor representing the velocity-ratio, will measure the corresponding work put into the hoist. The efficiency in per cent is equal to 100 times the work delivered by the hoist divided by the work supplied.

Make determinations in both hoisting and lowering with six loads, increasing by one-hundred-pound steps, and report on the form shown below.

The last item on the report, "Ratio of work done by falling load to work done on hand-chain in lowering," is not expressed as an efficiency, since the chief purpose of the hoist is to raise and not to lower the load. It should be expressed as a ratio thus: $1 : x$; the work done on the hand-chain being taken as the 1.

Note.—The weight of the scale-pans should be included as a part of the load.

74. Form for

TEST OF......................HOIST.

Made by { ....
.... *Date*........

VELOCITY-RATIO........

	1	2	3	4	5	6	7
Load lifted in pounds..........							
Stress on hand-chain in pounds.							
Work put into the machine.....							
Efficiency in hoisting..........							
Stress on hand-chain necessary to lower....................							
Work done in lowering.........							
Ratio of work done by falling load to work done on hand-chain in lowering...........							

NOTES:

75. Belt Testing.—Belts are tested to determine the power which they will transmit under different conditions of tension, speed, and load, and the coefficient of friction between them and the pulley.

The apparatus should be so arranged that the belt may be run under different initial tensions and the power absorbed by some form of brake.

Specific Directions. — Run four tests of twenty minutes each, with initial tensions of 20, 40, 60, and 80 pounds per inch width of belt. Let the brake load be as large as can be carried with a slip of not to exceed 3 per cent.

Observe:

1. Time.
2. Revolutions of driving-pulley.
3. Revolutions of driven pulley.
4. Initial tension (when at rest).
5. Total tension (in motion).

6. Net load on brake.

The Report should include, in addition to a copy of the Running Log, the following items:

a. Kind of belt.

b. Width and thickness.

c. Condition of belt.

d. Rough or smooth side to pulley.

e. Diameter of driving-pulley, inches.

f. Diameter of driven pulley, inches.

g. Length of brake-arm, inches.

h. Initial tension, per inch of width.

i. Speed of belt, in feet per second.

j. Slip, in per cent.

k. Tension on tight side, T_1.

l. Tension on slack side, T_2.

m. Horse-power of belt.

n. Equivalent horse-power at 100 feet per second.

The per cent of slip is found as follows:

Let r be the actual revolutions of the driven pulley, and r_1 the calculated revolutions without allowing for slip. Then the per cent of slip will be

$$100\frac{r_1 - r}{r_1}.$$

The values of T_1 and T_2 are found as follows: The total tension on the belt is composed of the sum of the tensions on the two sides or item $5 = T_1 + T_2$. If T_1 and T_2 are equal, no motion of the belt will result. If T_1 be greater than T_2, then motion will result and power will be transmitted proportional to that difference. This is expressed by the following formula:

$$T_1 - T_2 = 2\frac{(\text{item } g) \times (\text{item } 6)}{(\text{item } f)};$$

from which, with the relationship expressed above, the values of T_1 and T_2 can be found.

76. Belt Slippage.—A knowledge of the slippage of belts is of importance when selecting sizes for pulleys, since it is evident that if this slip is neglected the driven pulley will fail to reach the intended speed.

Specific Directions.—The apparatus required to determine the per cent of slip consists of two speed-counters and a gong or whistle for signals. An observer with a counter in hand should be stationed at each shaft connected by the belt, while a third keeps time and log. Upon signal, the counters are applied simultaneously to each of the shafts and the revolutions taken for a given interval of time (two minutes), which is ended by a second signal. From the known diameters of the two pulleys calculate the number of revolutions which the driven would make in the interval covered by the observation, provided there were no slip, and let this be called r_1. Let the observed revolutions of the driven pulley be r_2. Then $r_1 - r_2$ will represent the slip, and the per cent of slip will be

$$100\frac{r_1 - r_2}{r_1}.$$

Several observations should be made and the results averaged. The Report should include width, thickness, and kind of belt, diameter of driver and driven pulleys; also the following: (*a*) revolutions of driver and driven per minute for each observation, and mean; (*b*) speed of belt in feet per second; (*c*) revolutions which driven should make if no slip, average; (*d*) slip in revolutions per minute, average; (*e*) per cent of slip, average.

In connection with the report, solve the following:

PROBLEM.—A main shaft running at the rate of 200 R.P.M. carries a driving-pulley 48 inches in diameter. What should be the diameter of the driven pulley in order that it may run at 300 R.P.M., there being no slip? What should be its diameter if there is to be 3 per cent of slip?

77. Tests of Paper Friction Wheels.—The use of paper wheels for the transmission of power is being rapidly extended, and a knowledge of their capacity and wearing qualities is correspondingly valuable.* For the investigation of this subject a machine is in use in the Purdue Laboratory which consists of a paper pulley, driving a secondary shaft which is fitted with a Prony brake. The paper pulley is held against its follower by means of a bell-crank lever and weights. The experiments may be conducted according to the following:

Specific Directions.—(*a*) Note lengths of lever-arm, diameters of pulleys, etc., unbalanced weight of levers, brake, etc.

(*b*) Place on the scale-pan sufficient weights to make a normal pressure between pulleys of 75 pounds per inch of width. Place a light load on the brake and take simultaneous speed-readings of both pulleys, noting slip from known diameters of the two pulleys. Increase the brake-load to make about 5 per cent of slip, and repeat. Make tests with two intermediate brake-loads.

(*c*) Change the normal pressure to 120 pounds and again to 140 and 160 pounds per inch of width, and repeat as under (*b*).

(*d*) Report should cover all measurements and constants, tabulated logs of each test, giving time,

* See paper on "Paper Friction Wheels," Trans. A. S. M. E., vol. XVIII. p. 102.

speeds, brake-load, and normal pressure; a tabulated statement of results of each test giving normal pressure, horse-power transmitted, slip and coefficient of friction; and four curves showing relation of horse-power transmitted to normal pressure with constant slip, relation of horse-power to slip with constant pressure, and relation of coefficient of friction to slip with normal pressure constant, and to normal pressure with slip constant.

The coefficient of friction in this case is the ratio of the tangential pull to the total normal pressure, and is calculated as follows: Let r be the effective brake-arm, r_1 be the radius of the driven pulley, p the net brake-pull, P the normal pressure per inch of width, and w the width of the narrower pulley in inches. Then the coefficient of friction is

$$f = \frac{\frac{pr}{r_1}}{Pw} = \frac{pr}{Pr_1W}.$$

Caution.—Wipe off surfaces of driver and follower with piece of perfectly clean waste, and see that bearings are oiled before starting.

CHAPTER IX.

STRENGTH OF MATERIALS.

78. Testing-machines.—Machines for the testing of materials may be said, in general, to consist of (1) a power system by which stress is applied to the specimen, and (2) a weighing system by which the stress applied is measured. The power system may consist of a train of gears or an hydraulic cylinder, either of which may be operated by power or by hand. The weighing system usually consists of a system of levers and a poise by which the stress is balanced as on an ordinary pair of scales. An exception to this is the Emery Testing-machine, in which an hydraulic head and scale take the place of the system of levers commonly employed. In some Continental machines a mercury column is used to measure the stress.

The usual form of testing-machine is that in which the load is applied through a train of gears and screws operated by power, and the stress is measured by a system of levers. They are of the vertical type, in which the tensional and compressional specimens are held in a vertical position. The vertical screws connected with the power system operate a movable head, to which the lower end of the tension specimen is connected. The upper end of the specimen is connected to the upper head which is a part of the weighing system and rigidly connected with the table of the machine, the latter resting in turn on the lever system. In compressional tests the specimen is placed directly between the movable head and the table.

79. Riehlé Screw-power Testing-machines.—In Fig. 19 is shown a Riehlé Testing-machine of 300,000 lbs. capacity. As shown in the cut, it is arranged for either tensional, compressional, or transverse tests. The screws *s*, *s* are operated by power through a system of gears shown under the frame of the machine. The speed of the screws is controlled and their motion reversed at will, by manipulation of the three levers, l_1, l_2, l_3, located in a position near the poise-lever, convenient to the operator. These screws operate the movable head *b*. The upper head *a* is connected with the table *t* which rests on the system of levers *e*, *f*, *g*, *h*. Along the last lever, *h*, the poise *p* is made to travel by the hand-wheel *w*. The lever *h* is balanced by the adjustable counterpoise *c*. The head *a* may be raised or lowered to accommodate different lengths of specimens.

For adjusting the machine four different speeds are provided, for both upward and downward movement. These are secured by manipulation of levers l_1, l_2, and l_3. For testing, two speeds are provided, using levers l_1, l_2, and handle *i*.

Specimens may be tested in tension up to 6 feet in length, with an allowance for a total elongation of 3 feet.

In Fig. 20 is shown in perspective the Riehlé patent high-faced wedge for flat specimens. The serrated surface is slightly convex, and grips the specimen first on a line parallel to its axis. As the wedge-

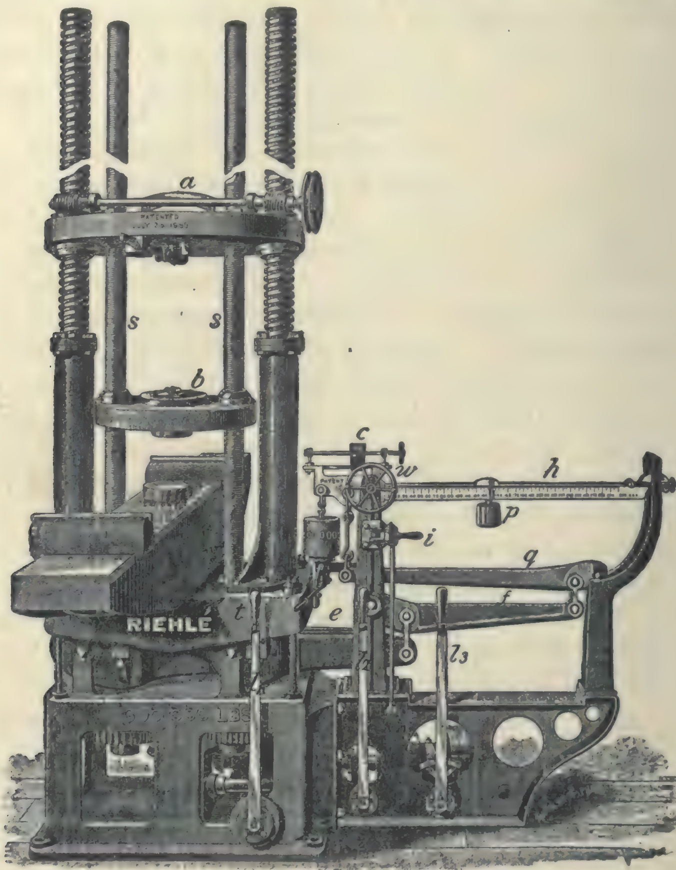


FIG. 19.—RIEHLÉ 300,000-POUND TESTING-MACHINE.

teeth sink into the specimen a hold is received over its entire width. It is claimed that by the use of this device a more centrally applied stress is secured.

Fig. 21 shows a plan of the arrangement with the specimen *D* in place. The curvature of the faces of the wedges *cc* is exaggerated to render the action

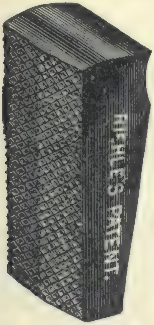


FIG. 20.—RIEHLÉ PATENT HIGH-FACED WEDGE.

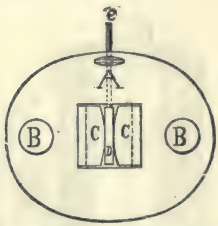


FIG. 21.—ARRANGEMENT OF WEDGES.

more easily understood. For round specimens, wedges are provided with *V* grooves of different sizes, into which the specimen fits.

80. Riehlé 100,000-lb. Testing-machine.—In Fig. 22 is shown a form of Riehlé machine having a capacity of 100,000 lbs. The general arrangement is that usually employed. It differs from the previous example principally in the use of a fixed upper head. The machine shown in the cut is provided with a special form of automatic poise which adjusts itself to balance the increasing loads. The poise-lever is in the form of a screw, and the poise is a nut which is revolved on the screw by means of a train of gears and a splined rod back of the poise-lever and parallel with it. This is well shown by the detail view. The splined rod is driven by a belt operated from the driving-mechanism of the machine, and its motion is controlled by an electromagnetic clutch carried on the back end of the poise-lever. The poise-lever is connected at its outer end to an auxiliary lever which carries at its free end two contact-points which operate the electromagnetic clutch. The operation is as follows: As a load is applied to the specimen, the poise-lever rises and the auxiliary lever falls,

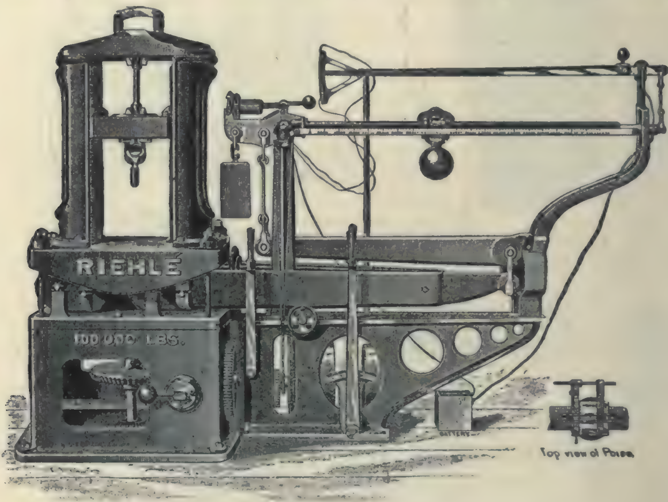


FIG. 22.—RIEHLÉ 100,000-POUND TESTING MACHINE.

making contact with the lower contact-point. This energizes one side of the clutch, which, through the rod and gears, moves the poise-weight along the poise-lever until the latter is balanced and, falling, breaks the electric contact. If for any reason the load should decrease, contact would be made at the upper contact-point, the other side of the clutch would be energized, and the poise would be moved backward until a balance was secured. In later designs provision is made for adjusting the speed of travel of the poise to the size of the test-piece.

81. Olsen 100,000-lb. Testing-machine. — A design of testing-machine of 100,000 lbs. capacity, made by Tinius Olsen & Co., is shown in Fig. 23. The

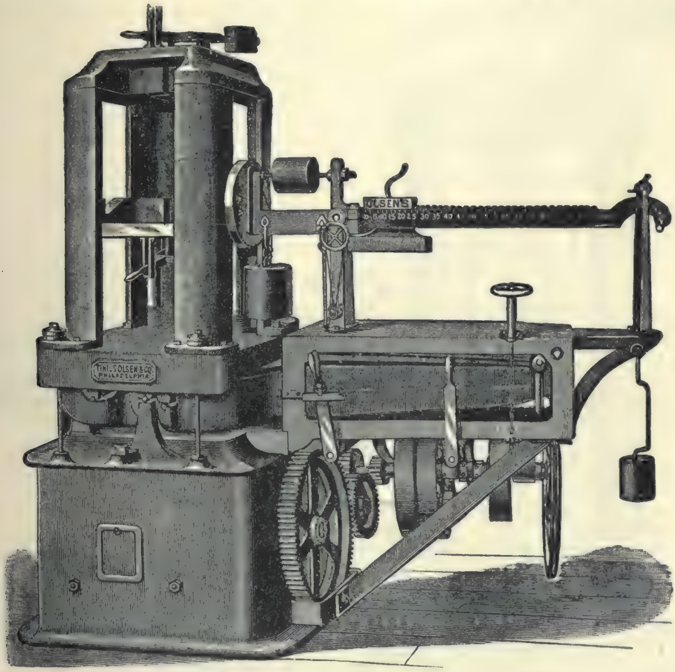


FIG. 23.—OLSEN 100,000-POUND TESTING-MACHINE.

machine differs from those already described in the arrangement of the driving mechanism and the weighing levers. Four straining-screws are employed, instead of two as in the Riehlé machine. The poise-lever is fitted with a vernier-dial at its back end, which is graduated to 10 pounds. Several adjusting speeds are obtained by manipulation of the two levers shown, and the slowest testing-speed is controlled by the hand-wheel, which throws a pair of grooved friction-wheels into action.

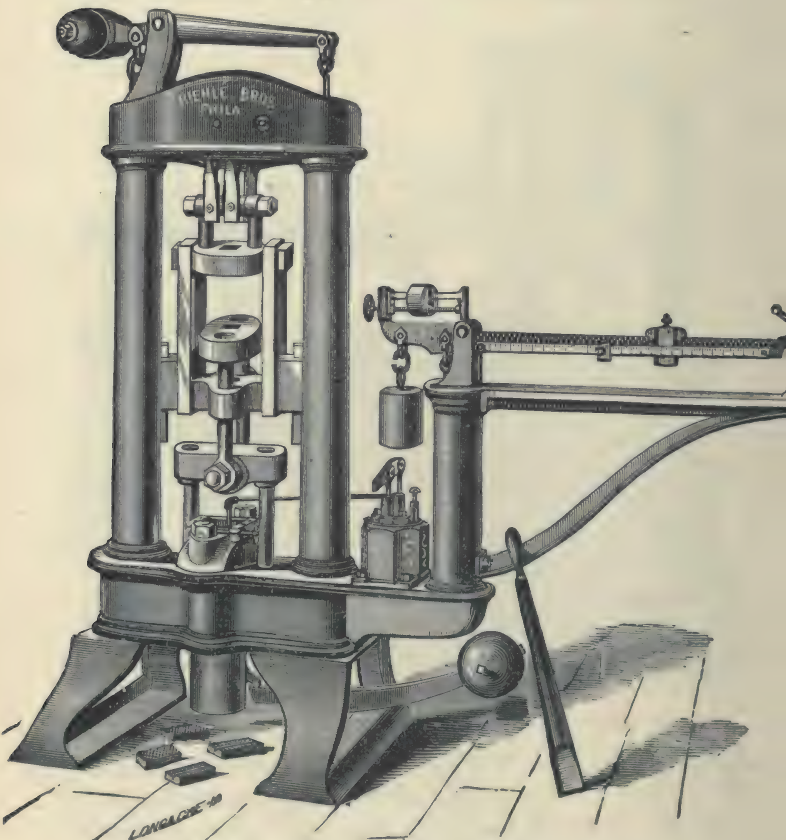


FIG. 24.—RIEHLÉ HYDRAULIC TESTING-MACHINE.

82. Riehlé Hydraulic Testing-machine.—Testing-machines are made by Riehlé Brothers in which the power is applied by hydraulic pressure. The train of gears, which forms the power-system in the usual design of machine, is replaced by an hydraulic cylinder connected to the movable head. Fig. 24 shows a Riehlé hydraulic machine of 50,000 lbs. capacity. This type of machine may be conveniently used for stresses not exceeding the above-mentioned capacity. For stresses above that amount the leakage of the hydraulic cylinder renders the action of the machine unsatisfactory.

As shown by the cut, the pump is situated on the table of the machine between the upright columns and the poise-system. The pump is operated by a handle which may be detached when not in use. Attached to the pump is a small check-valve controlled by a lever, which when opened allows the oil to flow from the hydraulic cylinder back to the pump. This allows the large counterweight to raise the plunger with the attached movable head to its normal position after the breaking of a specimen.

83. Emery Testing-machine.—One of the most accurate forms of testing-machines made is the Emery Hydraulic Testing-machine, made by Wm. Sellers & Company. The following description is given by the makers:

The essential peculiarity of the Emery testing-machine is the method by which the stress produced upon the piece tested is conveyed to the scale and accurately weighed by mechanism that is entirely frictionless, and hence responds to the same increment of load regardless of the amount of strain upon the specimen. This result is accomplished by receiving the load upon a flat closed cylinder called the "hydraulic support." The general scheme is indicated in Fig. 25, which shows merely the relation of the parts, no attention being paid to proportion.

The depth of the hydraulic-support cylinder *A* is exceedingly small. The end is closed to prevent the escape of the contained fluid by a thin sheet of metal, *b*, upon which rests a piston, *c*, considerably smaller than the internal diameter of the cylinder; this piston is secured to the cylinder by thin flexible fixing-plates, *dd*, which permit a very small movement in the direction of the axis of the cylinder while rigidly securing it against any lateral movement. This longitudinal movement of the piston from no load to full load is not more than .003 inch, and as there is no hydraulic packing and no sliding, there is no friction beyond that of the fluid. This hydraulic chamber is connected by a pipe *e*, with a smaller but similar chamber *B*, placed in the scale; the piston c' of this latter chamber acts through the block *H* against the first lever *C* of the scale, which thus receives a fraction of the load upon the piston *c* determined by the relation between the areas of the two hydraulic cylinders *A* and *B*.

The scale-body is a rigid cast-iron frame carrying the steel scale-levers, all the supports and connections of which are thin, flexible plates of steel firmly secured to the levers and their supports, and having a sufficient exposure between their fixed ends that the amount of bending due to the movement of the levers shall be well within the elastic limit of the material. The long arm of the lever *C* is coupled by the bar *D* with the short arm of the poise-frame lever *E*; the long arm of this lever carries all the standard weights of the scale, and the method of putting them on or taking them

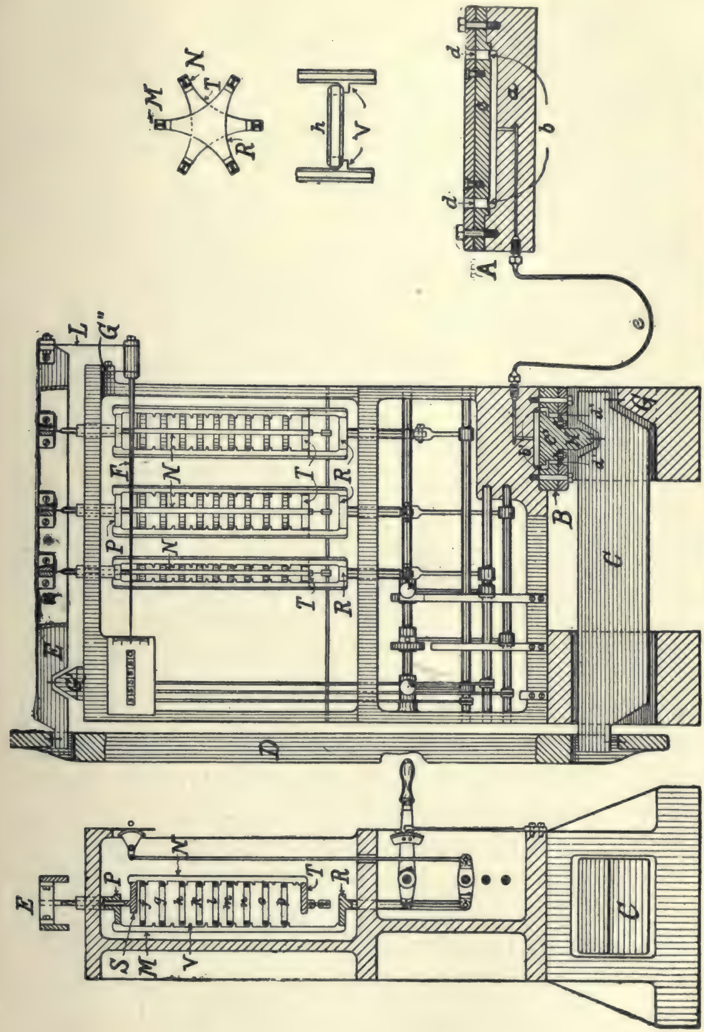


FIG. 25.—EMERY TESTING-MACHINE; GENERAL SCHEME OF WEIGHING-HEAD AND SCALE.

off, without handling, is peculiar to the Emery system. Suspended from this lever *E* at suitable intervals by thin fulcrum-plates are "poise-frames" *N*, consisting of an upper cross-head *S* and a lower cross-head *T*, united by three vertical bars disposed at equal intervals about the cross-heads.

These bars are provided on their faces with short projecting brackets *V*, having a horizontal surface and a bevelled surface corresponding with similar surfaces formed on the weights *h*, which are short cylinders or rings with bevelled edges; the weights are carried by the flat surfaces and centered by the bevelled surfaces. A "weight-frame," *M*, for carrying the weights when not in use, of similar construction, has its three vertical bracketed bars alternating with the bars of the poise-frame; this weight-frame is guided, and is raised and lowered in a vertical line without touching the poise-frame, by a rock-shaft and a hand-lever coupled to the rod projecting from the cross-head *R*. The brackets on the weight-frame bars are differently spaced from those on the poise-frame, and when the weight-frame is at the top of its stroke it carries all of the weights clear of the poise-frame; a small movement downwards transfers one weight to the poise-frame, the bevelled surfaces on the brackets centering the weight if it becomes displaced sideways by a too sudden movement. A further movement transfers another, and so on; that is, the movement of the weight-frame in either direction transfers the weights singly and successively from one frame to the other; the weights *f* and *g* are shown carried by the poise-frame, *j* and *k* by the weight-frame, while *h* is being transferred from one to the other.

The operating hand-lever is provided with a notched segment, into which a click-spring plays so that the operator feels when he has moved the lever the right distance to transfer a weight to or from the poise-frame without having to watch the indicator as formerly, and the arrangement of the six bars surrounds the weights by a cage that effectually prevents any displacement and consequent interruption of the test, as sometimes occurred when the weights rested on simple shelves secured only by short-pointed pins. There is hence no necessity for opening the glass case that encloses this part of the scale, and the weights are never exposed to any risk of alteration. The weights in the first poise-frame have a value of 100 pounds, the next frame carries weights of a value of ten times as much, or 1000 pounds, the next 10,000 pounds, and so on; and the readings are summed up by a series of segments connected to the several operating shafts and provided with figures denoting the number of weights on each poise-frame. A horizontal slot in a vertical plate near the upper left-hand corner of the scale is so placed that the reading of the figures shown through this slot denotes the number of pounds pressure applied to the specimen.

The final lever of the scale is an indicator-needle F, which has a movement at its point of $1\frac{3}{4}$ to 2 inches, and this movement, calculated from the mechanical ratios of the hydraulic chambers and of the levers in the scale, is not less than 300,000 times the movement of the piston c in the first hydraulic chamber, and may on large machines be 6,000,000 times as much. The transfer of fluid from one chamber to the other is almost imperceptible, and while it takes force to move the metal sheets and to bend the steel fulcrums, yet this force is all returned as the various parts resume their position of equilibrium, the needle returning to

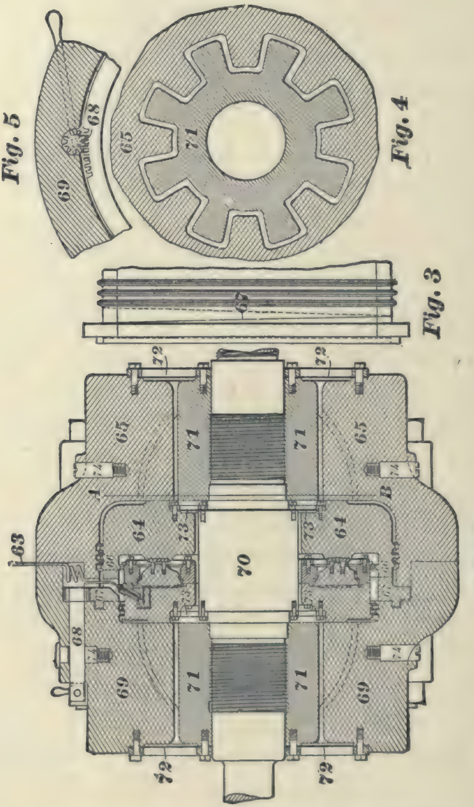


FIG. 26.—SECTION THROUGH WEIGHING-HEAD OF EMERY TESTING-MACHINE.

the same zero-point after being disturbed in either direction.

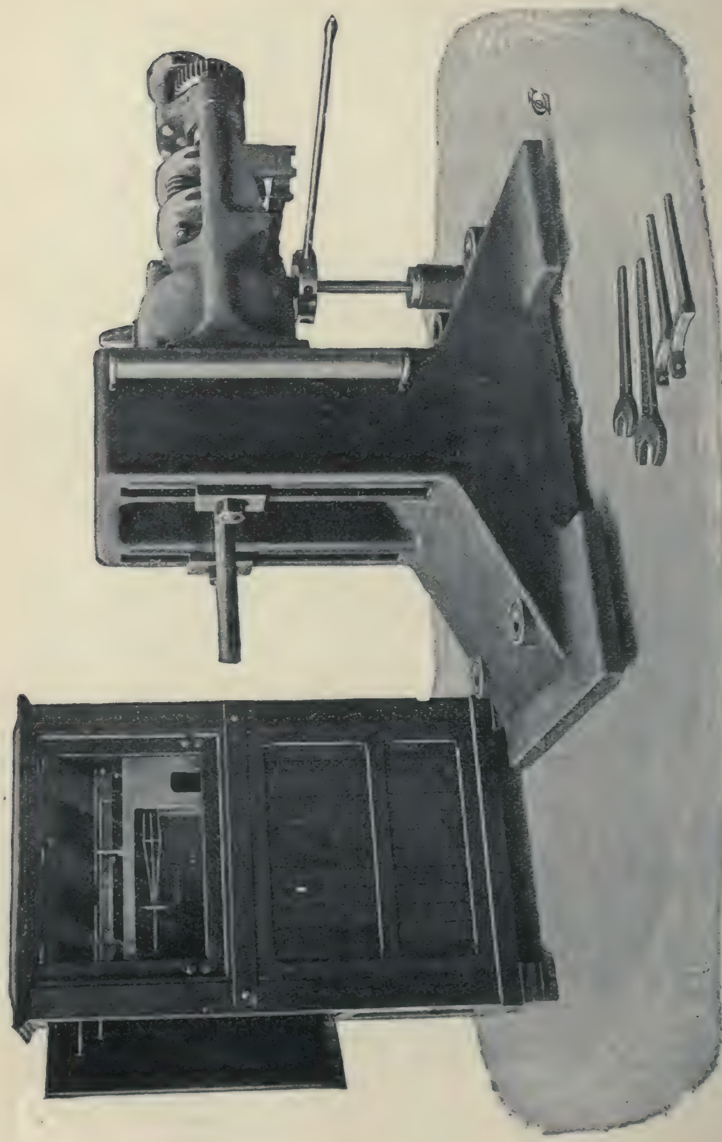
The weighing-head, Fig. 26, consists of two circular or annular beams, 65 and 69, firmly secured together by bolts placed around their periphery, and by the straining-screws which pass through both beams and clamp them by a shoulder and nut. This head and the straining-head fit easily upon the bed which maintains the axes of the two heads in the same straight line. A draw-bar, 70, is secured in the axis of these beams by two thin annular steel plates, 72; these plates hold the draw-bar securely in line with the axis of the machine, while permitting a free motion to a limited extent in the direction of the axis. The projecting end of the draw-bar is provided with a screw-thread by which the compression-platform or the tension-holder is secured to it. The draw-bar is enlarged in the middle, and against each of the two shoulders thus formed is secured a thin annular steel plate, 73; these plates are for the purpose of carrying and centering the hydraulic support, which is made annular, instead of circular, as shown in Fig. 25. The hydraulic support is maintained in fixed relation with the draw-bar laterally, while it is left free to move relatively to it in the direction of its axis through the small distance required. On each side of the hydraulic support steel collars, 71, are screwed and secured to the draw-bar; these collars are provided on the periphery with a series of ribs (Fig. 26, 4) parallel with the axis of the draw-bar, and which lie between without touching, similar ribs projecting from the interior surface of the annular beams. The ends of all these ribs on the two beams and the collars are accurately faced to true planes at right angles to the axis of the draw-bar, and the distance between the two extreme faces of the hydraulic support is made slightly less than the distance between those two planes. Movement of the draw-bar in either direction carries the hydraulic support against the ends of the ribs in one annular beam, brings the ends of the ribs on one of the collars on the bar against the opposite side of the hydraulic support, and produces pressure on the contained liquid which is transmitted through the pipe 63 to the small hydraulic chamber in the scale.

In order to prevent the shock of recoil, resulting from the rupture of a large specimen of high steel, from doing injury to the thin brass plates in the hydraulic support, the abutting piece 64 of the support which rests against the ribs in the annular beam 65, when strains of tension are applied, is made larger in diameter than the hydraulic support proper, and is provided with a spiral or screw-face, 66, which engages with a corresponding screw-face formed on a rotable ring, 67, fitting in the other annular beam, 69. After the initial load has been applied this ring is rotated by the pinion-shaft 68 to bring the screw-faces in contact (see Fig. 26, 3), and the abutting piece 64 is thus clamped firmly to the annular beam against which it rests. When the specimen breaks its first blow is delivered through the draw-bar and ribbed collar to this abutting piece, 64, which transmits it through the ring 67 to the rear annular beam, 69, and as these beams 65 and 69 are rigidly united, the blow is absorbed by the total mass of these two beams. The hydraulic support is thus thoroughly protected, and these machines can be used regularly for breaking high steel specimens up to the full capacity of the machine without any risk of injury.

The weighing-head is returned to its place on the bed after movement due to recoil by a set of spiral springs locked up in boxes secured to the bed; these springs are strong enough to move the head, and their resistance diminishes greatly the movement due to recoil, while the friction of the head upon the bed rapidly wipes out the oscillations. The annular beams, bolted together as described, constitute one built-up beam to resist the bending due to the pressure on the draw-bar midway between the straining-screws. The hydraulic support is thus inclosed in a rigid mass of cast iron and effectually protected against injury from violence or from being gummed up by oil from the straining-cylinder, as has occurred with the upright machines, and the frictionless movement of this support under all conditions of service is thus insured.

The draw-bar is provided with suitable grips and holders for tension or compression specimens.

The Emery testing-machines are now made horizontal instead of vertical: in the first place to make all sizes of machines of one type, and in the second place to get certain advantages in overcoming the shocks of recoil. The stress is produced by a "straining head," which is an hydraulic cylinder with a piston packed to receive fluid pressure in either direction, and the piston-rod passing through a packed bearing in one end is provided with a screw-thread, similar to that on the draw-bar, to receive the various holders. The fluid is supplied to this straining-cylinder through two systems of jointed pipes, which are connected through the valves at the scale-case with the pressure-pump and the tank respectively, so that each pipe acts either as a pressure-pipe or an exhaust-



pipe, depending upon the direction in which the strain is to be exerted upon the specimen.

The weighing- and straining-heads are mounted on a suitable frame or bed and are held together by heavy straining-screws.

In Fig. 27 is shown a special form of Emery machine of 30,000 pounds capacity for weighing the tractive force of locomotives on shop testing-plants. The draw-bar of the locomotive is connected to the draw-bar of the weighing-head, and the latter thus receives the stress due to the tractive force. The weighing-head is provided with mechanism for producing an initial stress upon the draw-bar in either direction. This initial tension for the machine illustrated is equal to about 25,000 pounds, and operates to push the draw-bar ahead when the locomotive is running forward and the reverse when it is running backward. A special form of scale is used in which the levers are provided with sliding-weights, as in an ordinary pair of scales, instead of the arrangement shown in Fig. 25. Provision is made for raising or lowering the weighing-head to accommodate different heights of draw-bar.

84. Riehlé Wire-tester.—A very convenient form of wire-tester is shown in Fig. 28. The power is applied by a hand-wheel which gives motion to one pair of grips through the medium of a nut and splined collar. The other pair of grips is attached to an accurate spring-balance, reading to 600 pounds. The needle of the balance is so arranged that it remains at the highest point reached, after fracture takes place. Provision is made for taking up the recoil after fracture, to prevent injury to the balance. The machine is arranged for quick adjustment to accommodate different lengths of specimens.

FIG. 28.—RIEHLÉ WIRE TESTING-MACHINE.

85. Olsen Cement-testing Machine.—A special form of machine for testing cement is shown in Fig. 29. The specimen is held between two shackles and the power is applied slowly by means of a hand-wheel. A system of levers weighs the load to which the specimen is subjected, the poise being conveniently moved by means of a small hand-wheel and endless cord.

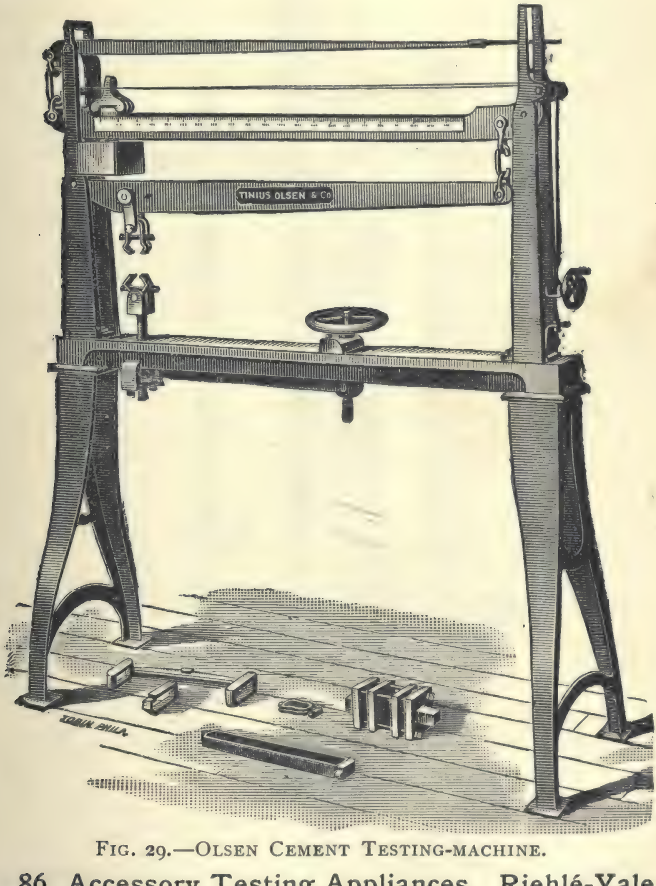


FIG. 29.—OLSEN CEMENT TESTING-MACHINE.

86. Accessory Testing Appliances. Riehlé-Yale Extensometer.—In order to determine the elastic limit and modulus of elasticity, it is necessary to know the rate of deformation of the specimen as

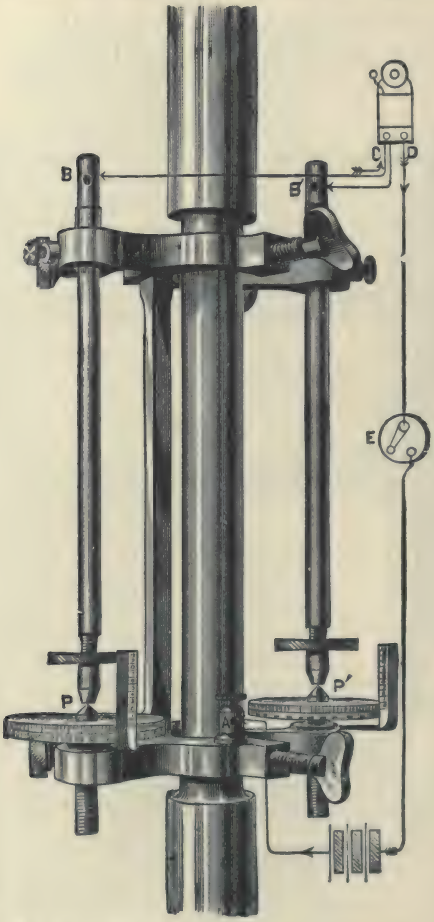


FIG. 30.—RIEHLÉ-YALE EXTENSOMETER.

stress is applied. For this purpose, use is made of an instrument known as an Extensometer, one form of which is shown in Fig. 30. This form is usually used in tensional tests, but may also be used to a limited extent in compressional tests. The instrument consists of a pair of clamps, each fitted with three sharp-pointed thumb-screws, by which they may be fastened to the specimen. A distance-piece or spacer is so arranged that the clamps will be exactly 8 inches apart. This distance-piece is removed as soon as the instrument is in place and before the stress is applied. The upper clamp carries two rods fitted at their lower ends with adjustable contact-points. The lower clamp is fitted with two micrometer-screws, reading to ten-thousandths of an inch, by which the elongation is measured. Electrical connection is made, as shown, with a battery and bell. The ringing of the bell announces the completion of the circuits at the points P and P' as the micrometer-screws are raised to measure the elongation of the specimen. By this means a uniform pressure of contact is secured.

87. **Autographic Recording Apparatus. The Henning Portable Recorder.**—The Autographic Recorder is an instrument for producing stress-strain diagrams or curves showing the variation of strain with stress. One of the newer forms of autographic recorders is the Henning Portable Recorder, shown in Fig. 31. The drum is attached by means of cord and pulleys to the poise, and revolves in proportion to the increasing stress. A proper reduction of the length of travel of the poise is made. The stretch of the specimen actuates the pencil-lever, the movement of the latter being ten times the elongation of the specimen up to elastic limit. After that point is reached the pencil-lever strikes a stop and is then raised bodily

with its carriage, giving a record directly proportional to the elongation. The instrument can be applied to

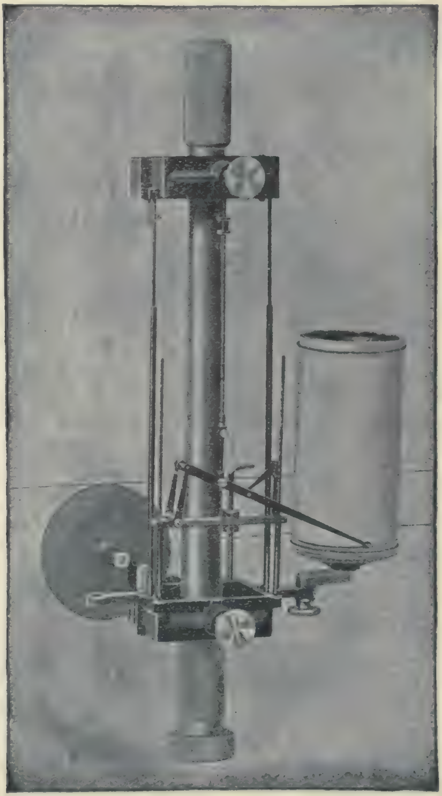


FIG. 31.—HENNING PORTABLE RECORDER.

specimens from $\frac{1}{8}$ inch in diameter to 2 by $1\frac{5}{8}$ inches in cross-section. It can be used for compression as well as extension, and may be used for gage-lengths of 6, 8, 10, and 12 inches. The wedges must be blocked up when the instrument is kept on the specimen to the point of rupture.

88. Deflectometer.—This instrument, Fig. 32, may be used to record the contraction of short specimens under compressional stress or the deflection of speci-

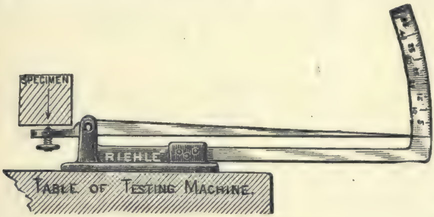


FIG. 32.—DEFLECTOMETER.

mens under transverse stress. The cut shows the manner of arranging the instrument and renders further explanation unnecessary.

89. Laying off Gage.—As is explained later, specimens in tension are sometimes marked for a length of 8 inches in one-inch lengths, preparatory to testing. The instrument shown in Fig. 33 is conveniently

FIG. 33.—RIEHLÉ LAYING-OFF GAGE.

arranged to assist in marking the specimen. At one end of the gage is a per-cent scale, arranged to read directly the per cent of elongation in 8 inches after fracture.

90. Methods of Testing. Tension.—Materials are tested in tension to determine, among others, the following properties, viz.: Ultimate Strength, Elastic Limit, Moduli of Elasticity and Resilience, Percentage of Elongation, and Reduction of Cross-sectional Area.

91. Definitions. — *Ultimate Strength.*—The ultimate strength may be defined as the maximum stress borne by the specimen per square inch of original area. It is obtained by dividing the maximum load in pounds by the original area of cross-section in square inches.

Elastic Limit.—Considerable confusion exists in the definition of the elastic limit. The term is used to indicate three different points:

(1) The unit-stress beyond which a portion of the deformation remains permanent after the load has been released.

(2) The unit-stress at which the deformation ceases to be proportional to the load applied, i.e., the "proportional elastic limit."

(3) The point in the stress-strain diagram where the deformation increases rapidly without any increase in the load, or the unit-stress corresponding to the scale-beam load when the beam, which has been kept balanced, "drops" suddenly.

The detection of the first elastic limit involves a release of the load, and presents many practical difficulties. Indeed any load produces a slight set. The second elastic limit is the elastic limit ordinarily determined when an extensometer is used. With the ordinary material encountered it is not very definite, especially when very delicate measurements are made. The third or "apparent" elastic limit, that measured in commercial testing, and by best usage called the "yield-point," is most easily fixed. The commercial yield-point is usually too high on account of too great a speed of test. In determining the yield-point, the student will do well to check the scale-beam indication by using a pair of dividers as follows:

Space the dividers eight inches, and put one leg in the lower gage-mark. Chalk the surface of the specimen around the upper gage-mark. As the test progresses swing the upper end of the divider to mark a line on the chalked surface. The space between these lines will widen rapidly at the yield-point. Note also that just above the yield-point the specimen begins to scale.

The following definition of apparent elastic limit has been proposed by Prof. J. B. Johnson:* "The apparent elastic limit is the point on the stress-diagram of any material, in any kind of test, at which the rate of deformation is 50 per cent greater than it is at the origin." It is best determined from the stress-strain diagram.

Modulus of Elasticity.—This is the number expressing the ratio of the stress per square inch to the deformation per inch accompanying that stress, within the elastic limit. Thus if P equal any increase of stress per square inch, and d is the total increase of deformation under that load, per inch of length, expressed in inches, then the modulus of elasticity

$$E = P/d.$$

We may, in determining this modulus, use for d the average deformation per inch corresponding to successive increments of load of P pounds per square inch, these deformations being observed between certain specific limits.

Modulus of Resilience.—The modulus of resilience

* "Materials of Construction," by J. B. Johnson. John Wiley & Sons.

is the amount of work, in foot-pounds, done in deforming a cubic inch of the specimen up to elastic limit. It is equal to one half the stress per square inch at elastic limit multiplied by the total elongation in feet, per inch of length up to elastic limit; or to the square of the stress at elastic limit divided by twice the value of E.

Percentage of Elongation.—This is the difference between the final and original distances between gage-marks, expressed as a percentage of the latter. It is a measure of the ductility of the material.

Percentage of Reduction of Cross-sectional Area.—This is the difference between the smallest area after fracture and the original area, expressed as a percentage of the latter.

92. Form of Specimens for Tension.—Forms of specimens conforming closely to those recommended as standard by the French Commission are shown in Fig. 34. They are arranged so that the per cent of elon-

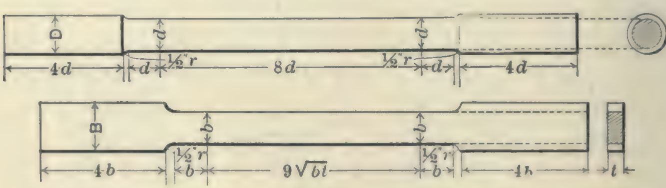


FIG. 34.*—STANDARD FORMS OF SPECIMENS FOR TENSION.

gation shall be the same, for the same material, when different lengths of specimen are used. It will be seen that the recommended relation between gage-length and cross-sectional dimensions is, for round specimens,

$$l = 8d,$$

* Reproduced from Johnson's "Materials of Construction."

and for square specimens

$$l = 9\sqrt{bt}.$$

For cast iron and for some other materials special forms of specimens are used in place of those mentioned above.

The specimens should be prepared with great care. The machining should be done in such a manner that the material is not torn or otherwise weakened, and it is recommended that all machined surfaces be finished by filing. When a sheared specimen is straightened, this straightening must be done cold.

93. Method of Testing for Ultimate Strength.—This test is the one commonly employed in commercial testing to determine the characteristics of metals in tension. For purposes of comparison it serves as a fair indication of the quality of the material.

Specific Directions.—The specimen should first be examined for cracks and flaws, as these may seriously affect the results of the test. Such defects should be noted on the report. The specimen should then be carefully measured in all dimensions, reading the dimensions of the cross-section to the thousandth of an inch, and making the record on the blank form. If the length of the specimen will permit, marks should be made upon it an inch apart for a space of eight inches. The outside marks are called gage-marks. This is done with a laying-off gage, and is for the purpose of determining the elongation after rupture.

Balance the machine on which the test is to be made, first noting that the four check-nuts at the corners of the table are only loosely screwed down.

After balancing the machine, the specimen should be carefully placed between the wedges, care being taken to have it centrally and vertically located. The wedges should be oiled on the back with heavy oil before being placed in position.

Start the machine at a slow rate of speed and keep it running continuously until fracture occurs. Note the time of starting the test and the time when fracture occurs. The test should last from five to ten minutes.

The scale-beam should be kept floating at all times during the test. When operating machines fitted with a hand-poise, take care not to run the poise out beyond the point necessary to float the beam, and, except in the case of the autographic apparatus, do not run it back when the beam falls for any reason, unless the maximum stress has been reached and it is desired to find the load at the point of rupture. In such a case be sure to note the maximum load before moving the poise back.

The following points should be noted:

1. Time of starting test.

2. Load on specimen when the beam first falls. This is called the yield-point, and occurs at from 50 to 75 per cent of the maximum load. Do not confuse this with drop of the beam due to slipping of the wedges.

3. Maximum load.

4. Load at rupture.

5. Time of rupture.

After rupture occurs, stop the machine, remove the specimen, clean and return the wedges to their proper place. Leave the testing-machine in good order.

Place the fractured ends of the specimen carefully together, measure the elongation in eight inches, and determine the per cent of elongation. With a vernier caliper determine as closely as possible the minimum area of the fracture.

In the case of the more ductile metals a rapid pulling out occurs near the point of fracture just before breaking. When this occurs the measured amount of elongation will vary in the same material, according as the fracture is between or near the gage-marks. If the fracture were just midway between the gage-marks, nearly all of the elongation would fall between those marks, and the measured elongation would be a maximum. But if the fracture should occur near a gage-mark, much of the elongation would fall outside of the marks, and the measured elongation would be less than in the previous case. To correct for this variation, an "equivalent elongation" may be calculated by the following method:

Suppose the specimen, after rupture, to be divided into x equal spaces between gage-marks, and that, after rupture, the fracture is y spaces from the nearest gage-mark. Mark two points, A and B (Fig. 35), on the

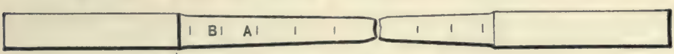


FIG. 35.

long piece at y and $\frac{1}{2}x$ spaces, respectively, from the fracture. Place the pieces carefully together and measure from the gage-mark on the short piece to point A. This distance plus twice the measured distance from A to B should be taken as the final length of the specimen, and minus the original length, is called the equivalent elongation. In some specifications it is required that the fracture shall occur within the middle third of the length.

The fracture should be carefully examined and pronounced either coarse or fine, and in metals either fibrous, granular, crystalline, or silky. It should also be noted as plane, oblique, cup-shaped, half-cup, or irregular. Tie the two pieces of the broken specimen together, attach a card on which is noted the kind of material, and the principal results of the test and place in the case provided for the purpose.

The Report should be made out on the blank form for "Tensional Tests," and should include the following items: Kind of material, sketch of specimen, dimensions of cross-section, area of cross-section, distance between gage-marks, time of test, yield-point, maximum stress, ultimate strength, reduction of area, percentage of elongation (actual), equivalent elongation, sketch of fracture, character of fracture, notes.

94. Determination of Elastic Limit by the Extensometer.—In the determination of the elastic limit by the extensometer, the test is conducted in substantially the same manner as that prescribed for finding the ultimate strength, except that instead of a continuous application of stress from start to the point of rupture the stress is applied in definite increments, and after the application of each increment the test is stopped and a measurement made of the deformation. For this purpose an extensometer, a description of one form of which is given in Section 86, is used. These measurements are continued until shortly after the elastic limit is reached, when the instrument is removed and the stress applied continuously up to the point of rupture.

Specific Directions. — Prepare the specimen and place in the testing-machine as directed in Section 93.

From the known properties of the material under test, determine approximately the probable load per square inch at elastic limit, and reduce this to the corresponding actual load. Divide this actual load into fifteen (15) equal increments and enter them in tabular form on the extensometer log.

Place a load corresponding to one increment on the specimen and then place the extensometer in position. In adjusting, be sure that the clamps are concentric with the specimen and that the axes of the micrometer-screws are parallel with and equidistant from it. In tightening the adjusting-screws be careful not to overstrain them. See that the contact surfaces are clean and the electric circuit in order. In attaching the wires to the extensometer, so arrange them that there will be no tension in them tending to pull the instrument out of line.

Now take a zero-reading. This is done in the following manner: Place the micrometer on one side at zero and move the upper contact piece until contact is made as shown by the ringing of the bell. Now back the upper screw off, and again bring it down until the bell just begins to ring. Then back the micrometer away from the upper contact point. Repeat the operation on the opposite side.

Apply the second increment of stress to the specimen and take a reading of the extensometer, this time having the upper contact pieces in their original position and making contact by means of the micrometer-screws. Repeat this process as rapidly as practicable until the sudden increase in the rate of deformation indicates that the elastic limit has been passed. Remove the extensometer, and finish the test as provided in Section 93, under the head of Ultimate Strength.

The Report should be made out on the blank form for tensional tests, and should be accompanied by the extensometer log and a stress-strain diagram (see Section 95). The items called for in addition to those given for tests of ultimate strength are: Elastic limit, modulus of elasticity, and modulus of resilience. Calculate the modulus of elasticity between the limits of 8000 and 18,000 lbs. stress per square inch or use a diagram as in the following section.

95. **Stress-strain Diagrams.**—The stress-strain diagram is a curve, the ordinates of which represent the stress on the specimen in pounds per square inch and the abscissæ represent the corresponding total deformation per inch of length. From an inspection of this diagram the behavior of the material under stress, and in a general way its characteristics, may be determined. For many materials the diagram will be nearly a straight line up to the elastic limit. In Fig. 36 is shown a typical diagram in two scales for wrought iron.

In case the diagram is plotted from the results of an extensometer test, it can only be drawn to a point a little beyond the elastic limit. Such a scale should be chosen as will exhibit to best advantage the characteristics of the curve. Make the even thousands come at the heavy division-lines on the coordinate paper. See to it that the diagram can be read easily.

To determine the modulus of elasticity, E, from the strain-diagram, proceed as follows: From the abscissa representing an elongation of .001 inch per inch of specimen, erect an ordinate to intersect the line drawn

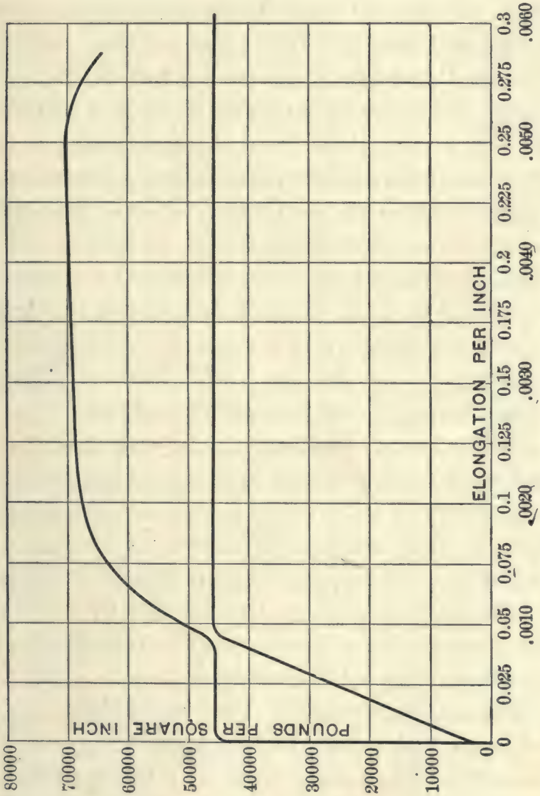


FIG. 36.—STRESS-STRAIN DIAGRAM.

from the origin parallel to the straight part of the stress-strain curve. Find the stress corresponding to the point of intersection. This multiplied by 1000 will give E.

96. Autographic Records.—Many forms of instruments have been devised for autographically producing a stress-strain diagram during the progress of the test. One of these, the Henning Portable Recorder, is described in Section 87. In the majority of designs two movements are provided: one a drum-movement, attached to the weighing-poise and revolving in proportion to the outward movement of the latter; and the second a pencil-movement, connected in some manner with the specimen and moving in proportion to the deformation of the latter. In the best designs two rates of pencil-movement are provided. Up to elastic limit the movement is magnified to render the characteristics of that part of the curve more easily seen. After elastic limit the rate of movement is much slower, in order that the latter part of the curve may be kept within reasonable limits.

97. Methods of Testing in Compression.—Materials are tested in compression to determine their crushing strength and strength to resist bending; also at times their elastic limits, and, if ductile, their plastic limits. Short specimens, those whose length is less than five diameters, usually fail by crushing or flowing. Long specimens usually fail by bending toward the side of least resistance.

98. Short Specimens.—The materials may be divided into two general classes, in accordance with their behavior when subjected, in short specimens, to compressional stress. In the first classification are the plastic materials, such as wrought iron, soft steel, copper, the alloys, etc., which fail by flowing. After the elastic limit is passed, further compression results in an increase of the cross-sectional area under a continually increasing load. For such materials there are two fixed points independent of shape of specimen, i.e., the elastic limit and the plastic limit. It has been found that the elastic limit of these materials is nearly the same as their elastic limit in tension, and for this reason and in view of the difficulty of measuring the deformation of short specimens, compressional tests upon them are seldom made.

The second classification embraces the brittle materials, such as stone, brick, wood, cement, cast iron, etc., which fail by crushing due to the shearing on definite angles. With these materials the ultimate strength is easily determined.

Preparing the Specimen.—If the material be metal, the specimen should preferably be turned and the ends faced up carefully to insure that they are plane and perpendicular to the axis of the specimen. If the material be of stone, cement, or some similar substance, the specimen is usually cubical in form; and the bearing-surfaces should be made as nearly plane and parallel as possible by grinding, and should then be bedded in a thin layer of plaster of paris. Sized paper should be put between the specimen and the plaster of paris bed to prevent absorption of water by the specimen. To secure a true bed, the plaster is allowed to set for about ten minutes while the specimen is on the table of the testing-machine, the movable head being run down in contact with the upper layer of the bed. The use of pasteboard or lead liners is not recommended.

Specific Directions.—Prepare the specimen as directed above. Measure all dimensions and record on the blank report-sheet furnished. Balance the testing-machine with the specimen on the table. Apply the stress continuously until rupture occurs, or, in the case of the plastic materials, until the amount of deformation is quite marked. In the case of stone, cement, etc., if the specimen begins to spall or flake off before rupture occurs, note the load when such action begins. Avoid injury from flying fragments. Take the time of starting and stopping the test. If the conditions of the test are proper, but little spalling will occur. The specimen will break suddenly, and the interior cone or pyramid will be evident.

The Report should include the following items: Kind of material, sketch of specimen, dimensions of cross-section, area of cross-section, height, time of test, maximum stress, ultimate strength, sketch of specimen after test, notes. When a compressometer is used, a stress-strain diagram should be constructed.

99. Long Specimens or Columns in Compression.—A specimen of length greater than ten diameters usually fails by bending toward its side of least resistance. The maximum strength of an ideal or perfect column, centrally loaded, must be taken as the load obtained by multiplying the area of cross-section by the elastic limit of the material, a result independent of the length. The unavoidable imperfections of material and of workmanship and the difficulty of centering the load will, however, produce some bending before this maximum load is reached.

When the column is once bent, the deflection increases rapidly, and the material on the concave side of the column is subjected to the twofold stress due (1) to the direct compression of the load, and (2) to the bending produced by the load acting with a lever-arm about the neutral axis of the section. The column will completely fail at the point where this twofold stress exceeds the crushing-strength of the material. This load at failure depends on (1) the strength of the material of the column; (2) the value of E; (3) the character of the ends, whether square or round; (4) the condition of application of the load, whether eccentric or not; and (5) on the ratio of the length l of the column to its radius of gyration r.

In the case of very long columns ($l/r > 150$) the maximum load is that which will hold the column at any given deflection, and which, when allowed to continue acting, will so increase the deflection as to cause failure. This breaking load is given by the equation

$$P = uEI \div l,$$

where $P =$ total load at point of flexure;
$E =$ modulus of elasticity;
$I =$ moment of inertia;
$l =$ length of specimen at point of flexure in inches;
and $u =$ a constant.

This equation is known as Euler's formula, and the values of u are 4 and 1 for square and round ends, respectively.

The specimens used ordinarily will not be long enough to come under this head. For the ordinary length of specimen the load on the scale-beam will increase with an increasing deflection of the column until the twofold stress, mentioned above, will exceed the crushing strength of the material. At this point the maximum load is indicated, and after this the scale-beam drops off with increasing deflection.

For all ordinary cases this load is given approximately by the Rankine-Gordon Formula, or by some one of the other well-known formulæ (as, for instance, Prof. J. B. Johnson's parabolic formula) which are intended to represent the results of experiments on columns.

It is necessary in testing columns to define as accurately as possible the condition of the ends. They should be either completely fixed or perfectly free to turn. The first condition is difficult to obtain. The second condition may be obtained by the use of clamps with attached knife-edges, the column being so fitted to the clamps that the neutral plane, when the column is unstrained, coincides with a plane joining the knife-edges. The perfection of the adjustment may be tested with moderate loads.

Specific Directions.—The aim of the laboratory experiments with columns is to fix in the student's mind the behavior of columns of varying lengths. Select a piece of 2 × 4-inch wooden scantling and cut it into lengths of 86.7, 57.8, 43.35, 21.67, and 6 inches. Stretch a fine wire along the length of the specimen in the plane of the neutral axis. Test these pieces in compression with round ends, noting at suitable intervals of loading the lateral deflection at the neutral plane from the wire stretched along the column, and the maximum load. The deflection may be read from a small scale fixed to the center of the column. In the case of the 6-inch specimen use the compressometer.

Plot the results as a curve showing the relation between $l \div r$ and maximum scale-beam load for the different columns. Compare the results of experiments with the values derived by calculation from various formulæ supplied by the instructor.

100. Cross-bending Tests.—Cross-bending tests are used to determine, in case of brittle materials like cast iron, the modulus of rupture and the resilience, and in case of ductile materials like wrought iron and soft steel, the elastic limit and modulus of elasticity. Other tests on springs, rails, rail-joints, etc., determine the stiffness, i.e., the deflection at given loads, the elastic limit, and, in some cases, the ultimate strength. Tests on composite structures, like brake-beams, truck-bolsters, etc., are made to determine the stiffness, the elastic limit, and manner of failure.

Specific Directions.—In preparing a specimen for test (supposing the specimen to be a prismatic beam) stretch a fine copper or steel wire between two pins which are driven directly above the points of support on the line of intersection of the neutral plane with the side of the beam. A suitable weight should be hung on the wire to keep it taut. Fix a micrometer on the beam so as to read the deflection of the neutral plane below the fixed wire. Connect the micrometer in circuit so that the contact of the micrometer with the wire is indicated by the ringing of an electric bell consequent on the completion of the circuit. In case of large wooden beams, a polished steel scale may be attached to the side of the beam at mid-span, and the deflection read by eye to hundredths of an inch, taking care to avoid parallax by reading when the wire is in coincidence with its image on the polished surface. The deflection should not be read with reference to any part of the frame of the machine. The specimen must be protected if necessary from the indentation of the knife-edges by the use of bearing-plates.

Measure the beam in all dimensions and length of span. Place the beam so that one principal axis of inertia of the section shall be horizontal. Compute, for the case of a prismatic beam, the probable center load at the elastic limit from the formula

$$P = \frac{4RI}{le},$$

where R is the value of the elastic limit in tension, I the moment of inertia, l the length of span in inches, and e the distance in inches from the neutral axis to the outermost fiber. Divide this load into ten equal parts, and apply these part loads successively as increments to the center of the specimen, endeavoring to read the deflection without stopping the test. Note the load at rupture and manner of failure. Note any side buckling. In some cases the load may be released after each increment in order to determine the set.

The Report should include a diagram whose abscissæ are the deflections, and whose ordinates are the loads at the center. The results derived should be, when possible to obtain them, stress in outer fiber at elastic limit, modulus of rupture, modulus of elasticity, and resilience.

The modulus of rupture is the value of R as computed from the formula

$$R = \frac{Plc}{4I}.$$

In consequence of the tendency to equalization of the stress over the cross-section above the elastic limit and of the failure of Hooke's law, the value of R determined from this formula (which is based on Hooke's law) will in some cases be greater than the ultimate strength of the material in tension.

The elastic limit in flexure will be fixed by the elastic limit of the outer fiber, and can be computed by the formula given above, assuming that a small longitudinal bar in the surface of the beam behaves just as it would if tested by itself in tension. The elastic limit in flexure will, however, be greater than in tension for the case of square or flat plates of steel.

The ultimate resilience of a brittle material (where the elastic limit is near the ultimate strength) will be

$$\frac{P}{2}d,$$

P being the load at the center, and d the deflection at that load. E is computed from the formula

$$E = \frac{1}{48}\frac{Pl^3}{dI}.$$

101. Cement-testing.—The usual tests applied to cement are those for tensile strength, fineness, soundness, and time of initial and final set.

Specific Directions.—The work will include tests on two Portland cements and two natural cements. In order to obtain uniform and representative results for the tensile strength great care must be exercised to observe the following directions:

(1) *Portland Cement.*—(*a*) *Neat Tests.*—Arrange moulds, oiled inside, on a non-absorptive plane surface. Take 1½ pounds of cement and some water at 70° F. Mix water and cement thoroughly, using enough water, about 20 per cent, to make a stiff plastic mixture, and work mixture at least six minutes. Put mixture in moulds, pressing it firmly in moulds with thumbs, but do not pound the briquette. Strike off both surfaces of briquette with trowel. Set the moulds away on a non-absorptive surface in a damp atmosphere. Except for one-day tests they should be kept in moist air 24 hours and then put under water. The student will scratch the proper number on the briquettes and return on the following day to immerse them in water.

(*b*) *2-to-1 Mortar Tests.*—Take some of the laboratory sand and sift it through Nos. 20 and 30 sieves. Use 1 pound of what passes No. 20 and is held on No. 30, with ½ pound of cement. Mix thoroughly and add 12 per cent of water. Work at least 4 minutes. Fill moulds to overflowing and pound down mortar with flat side of trowel, beginning at sides of briquette. These briquettes are disposed of as in (1, *a*).

(2) *Natural Cement.*—Take 1½ pounds of cement and 30 per cent of water and mix briquettes as directed in (1, *a*). Do not allow the cement to assume initial set before filling the moulds. Then take ¾

pound of cement and $\frac{3}{4}$ pound of sand and mix as in (1, *b*). These briquettes may be immersed in water a few hours after hardening.

(3) *Concrete.*—Concrete should be a compact mass as free as possible from pores or open spaces. The materials—broken stone, or gravel, and sand—are bound together by the cement. The proportion of the three different materials should be selected so that the sand practically fills the voids in the gravel or broken stone and the cement fills the voids in the sand. Rather more than this quantity of cement should be used to allow for imperfect mixing.

Fill a box holding one cubic foot with gravel. Shake down well and strike off level. Weigh box and contents. Then pour water on gravel until the water rises to the surface. Weigh again and calculate the percentage of voids in the gravel. Then determine the weight of a cubic foot of sand. Supposing the weight of a cubic foot of sand to be 165 pounds, calculate the per cent of voids in the sand.

Now make a mixture of gravel, sand, and Portland cement, with minimum amount of water, using enough cement to fill the voids. Directions for mixing will be supplied by the instructor.

Make three 4-inch cubes, and allow them to set in air one day and in water 27 days. Test in compression after 28 days. Make another series with the proportion 1 sand, 3 gravel, 1 cement, and test as before. Report all data obtained, and report the character of gravel and sand supplied, noting whether or not the surface of the gravel was clean and whether the sand was sharp and free from clay or loam.

For Fineness.—If any time remains, determine the fineness of grinding by sifting $\frac{1}{2}$ pound of cement through the three sieves Nos. 50, 80, and 100, weighing the residue which remains on each. Report on color and uniformity of residues.

For Constancy of Volume or "Soundness."—Make on a slab of glass two thin-edged pats, 3 inches in diameter and ½ inch thick, of stiff plastic consistency. After thorough setting put one cake under water and examine it from day to day to detect any radial cracks or changes of form. Do not confuse these with the irregular surface-checks which appear when the cement is mixed too wet, or is dried rapidly.

For Portland cements a more severe test is the heat test, conducted as follows: Expose a pat of neat cement, after setting, to the action of steam for three hours, then place it in boiling water for three hours more.

Perhaps the best test for soundness is the boiling test, as follows: Make two balls 1½ to 2 inches in diameter and allow them to set in damp air for 24 hours. Place these in a beaker filled with water and bring to boiling-point in 30 minutes. Boil for three hours. The test-pieces are examined after slow cooling. They should not show cracks, nor should they warp, nor become soft and crumbly. In case of natural cements these tests are not so satisfactory.

This test is made to detect the presence of free lime, the future slaking of which will destroy the work into which such cement enters. The mixing of sulphated lime with cement will insure passing the boiling tests. As sulphated lime, above 2 per cent, is detrimental to cement, the complete test should include a test for sulphuric acid. Four (4) per cent of sulphuric acid is maximum allowable.

Time of Setting.—Mix pats similar to those for the test for soundness. When a needle $\frac{1}{12}$ inch in diameter loaded with $\frac{1}{4}$ pound ceases to penetrate the entire mass, setting is said to have begun. When a needle $\frac{1}{24}$ inch in diameter loaded with 1 pound will not penetrate the mass at all, setting is said to be complete. The time of complete setting is roughly determined at times by the fact that the cement offers considerable resistance to indentation with the finger-nail.

After One Week.—Test briquettes in tension as soon as taken from water, noting the breaking-load in the laboratory record. Apply stress at the rate of 400 pounds per minute. Insert pieces of rubber bands between briquette and edges of grips in order to obtain break in center of briquette.

Crushing Strength.—It is not usual to make compression tests in America. The results in tension vary directly with those in compression, so that the tensile strength is a satisfactory index of the value of the cement in compression. The student will make one 2-inch cube of each series mentioned and test in compression after one week as directed in Section 98.

102. Wire Rope in Tension.—*Preparation of Specimen.*—In preparing specimens of wire rope for tension tests the chief difficulty is to so hold the ends that the strain may come equally on all parts of the cross-section and a break in the middle of the specimen length may occur. By the use of very long conical wedges, working in steel bushings, satisfactory results may be obtained; the wedges grip the rope as a whole. Or an artificial socket may be made in the steel bushing as follows:

Bind the specimen with wire about six inches from the ends, to prevent unwinding, and wind the intervening length with cord to keep the strands in place.

Slip the bushing over the ends. Unwind the strands down to the binding-wire; cut out the hemp core if necessary, and turn each separate wire back on itself toward the center to form a conical head, which may be drawn into the bushing so that it may assume the proper shape. The head should be boiled in caustic soda to remove grease, then washed in hot water, dipped in chloride of zinc and afterwards in molten solder. The head is then drawn into the bushing and melted Babbitt metal poured around it. For cables of small strength lead may be used in place of Babbitt. A method of testing which gives satisfactory results is that in which a number of the wires are tested individually to determine the uniformity of the rope.

103. Rattler Test for Paving-bricks.— Paving-bricks are tested for durability by placing them in a rattler of suitable form and noting the amount of wear when revolved at a given rate of speed. The results from the machine give a true index of the essential properties of paving-bricks, namely: toughness and vitrification. The machine should be constructed according to the dimensions recommended by the National Brick Manufacturers' Association. The charge should be the number of bricks nearest to 10 per cent of the volume of the cylinder of the rattler. At times a mixed charge of brick and foundry shot is used.

It is found that the diameter of 28 inches and a charge of 10 per cent of the volume will give the maximum wear. The wear of a brick during the first part of a test is due to the chipping of each brick into a rounded mass; after that the wear proceeds steadily. The test should continue long enough to include the effect of the wear beyond the chipping stage; 2000 revolutions will accomplish this purpose. It is found that beyond a minimum of 18 inches the length of the rattling-chamber makes no difference in the proportion of wear when the per cent of charge is the same, and that, within limits, the rate of revolution makes little difference; 24 to 36 R.P.M. may be used. A machine is in use in the Purdue Laboratory which conforms closely to the dimensions given above. It differs from the ordinary tumbler in the provision for inserting brick in the end, thus avoiding the necessity of removing a slat. The special experimental work will be assigned to the student by the instructor.

104. Impact Tests.—The method of conducting impact tests has not been standardized, nor is there any uniformity in the construction of machinery for such tests. The difficulty in such tests is to so arrange the impact that the entire energy of the blow may be used in deforming the specimen. Part of the energy may disappear in:

(1) Deforming the specimen locally at the point of impact. The loss of energy depends on the relative inertia of the moving weight and the specimen, and on the velocity of impact.

(2) In moving the abutments, which may not be rigid and will absorb energy

(3) A small amount of energy may disappear in vibration.

It may be said in general that impact must result from the fall of a large weight through a small distance, and that the abutments must be solid, or of such character that a known amount of energy will be absorbed. The specimen must be broken with a single blow.

The experimental work assigned will consist of experiments on longitudinal impact of wire specimens. As no standard form of impact machine has yet been prescribed, a machine has been designed for use in the Purdue Laboratory which meets the requirements mentioned. The apparatus consists principally of a framework of two upright posts bridged over at a certain height above the floor, a lifting mechanism to raise the weight and the specimen, and a revolving drum on which the record of the motion of the weight is taken. The specimen is attached at its upper end to a cast-iron cross-head which slides on ways fastened to the posts; to its lower end is attached the weight. The specimen with cross-head and weight attached is raised to a certain height, and in falling the cross-head strikes a cross-piece on the frame which arrests its motion suddenly. The specimen sustains the impact due to the continued motion of the weight. The weight consists of a cylindrical casting of 845 pounds with hollow center to receive the bushing or grip. The apparatus is used in the following manner:

Specific Directions.—Take a specimen of Norway iron $\frac{5}{16}$ inch in diameter and about 10 feet long and mark it off in one-foot lengths. Measure its diameter. Run one end through the cylindrical weight and fasten the wire in the steel bushing with the conical wedges. Drive the wedges in tight. Draw the bushing up inside the cast-iron cylinder until it bears against the interior shoulder. Pass the upper end of the wire through the cross-bridge into the upper bushing. Drive the upper wedges. Release the weight so that it is supported by the bridge through the specimen and the upper steel bushing. Allow the pencil, attached to the weight, to mark the zero-line on the drum. Then arrange the pencil so that it will be sure to trip at the proper time. Attach the tongs to the upper bushing and lift the weight, specimen and upper bushing about 8 feet. Wind up the propelling-cord on the drum and at a signal from the operator release the drum. When

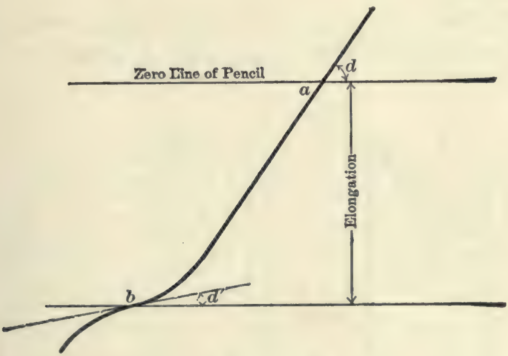


FIG. 37.

the small weight whose descent turns the drum strikes the floor, the vibrating tuning-fork is turned on the drum and the tongs released. The weight descends and fracture of the specimen occurs; the pencil, shot out at the proper time, marks a record on the drum. Repeat the test on another specimen. The drum-record will be about as shown by Fig. 37.

The energy expended in breaking the specimen will be $\int Td\lambda$

where $$G\lambda = \int Td\lambda + \tfrac{1}{2}M(v_1^2 - v_0^2),$$

in which $G =$ weight of hammer;
$T =$ tension in specimen;
$\lambda =$ total elongation;
$M =$ mass of G;
$v_1 =$ final velocity;
$v_0 =$ initial velocity.

This neglects the small amount of energy absorbed at the bridge. Let the student compute this amount appro: 'mately.

Divide this energy, in foot-pounds, by the volume of the wire in cubic inches and the ultimate resilience

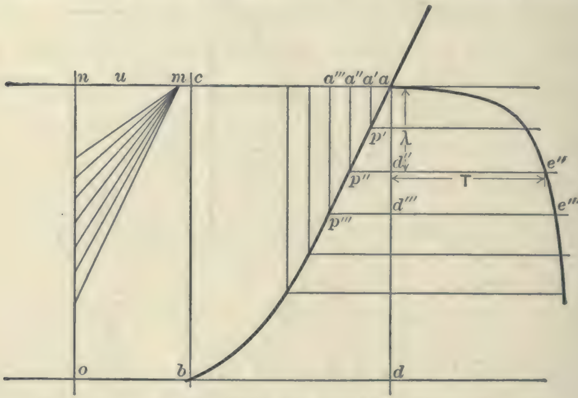


FIG. 38.

in foot-pounds per cubic inch will result. Determine the time of impact given by the horizontal projection of *ab*. Compare the elongation measured on the specimen with the elongation recorded on the drum. Measure the diameter of contracted area. Determine the velocity of the drum from the tuning-fork record. From the known masses and the curve *ab* construct a stress-strain diagram for the specimen as in Fig. 38.

Divide *ac* into ten parts, and erect ordinates to meet the curve in points p, p', etc. Find the successive velocities at these points graphically, i.e., lay off length *mn* proportional to u, the velocity of the drum, and draw from *m* lines parallel to tangents at p, p', etc. These parallels to the tangents will cut off from *no* lengths which, taken to scale, are the velocities of the weight at p, p', etc.

Lay these velocities off on the ordinates $a'p'$, $a''p''$, etc. The acceleration at any point p is $\frac{\Delta v}{\Delta t}$, and should be computed.

Then if T is the tension in the specimen,

$$T = G + Mp,$$

where p is the acceleration.

Compute the successive values of T and lay these off from the axis of elongation *ad* along $d''e''$, etc. Join the points with a curve, and determine the work done, or resilience, as measured by the area between the "load-elongation curve," and axis *ad*. Test two similar specimens in the 300,000-lb. Riehlé machine as directed in Sections 93 and 102.

Report comparison of results in impact and tension as to ultimate stress, total elongation, elongation in that foot containing ruptured section, and total resilience.

105. Cold-bending Test.—The following test is often prescribed for boiler and similar material: The material shall bend double without showing cracks or flaws, both while cold and after being heated to a cherry red and cooled in water at 80° F.

The specimen may be partly bent in a vise and afterwards closed down flat in a testing-machine. In case an interior radius is specified, an auxiliary plate must be dressed to this radius and inserted. The specimen should bend without initial cracks or roughness which will start larger cracks. Rivet-metal is commonly tested by cold bending at a nicked section. The bar should have one deep nick, not a number of successive shallow nicks. The test indicates the toughness of the material.

106. Drifting Tests.—In the drifting test a hole is punched or drilled near the edge of a plate and then enlarged by a drift-pin. This test, like the cold bend, indicates the ductility of the metal.

CHAPTER X.

STEAM-BOILER TESTING.

107. Objects of the Test.—Among the objects commonly sought in testing boilers are the following: To determine the capacity and efficiency of a given boiler under a given set of conditions, to determine the change of efficiency of a boiler under different conditions, and to determine the amount of coal and water necessary to supply a given engine with steam.

The method employed in making the tests will vary in its details to suit the particular object in view. The general principles underlying the various methods are, however, much the same.

108. Comparison of Tests under Different Conditions.—The evaporative or commercial efficiency of any given boiler under a given set of conditions is usually expressed as the number of pounds of water evaporated per pound of dry coal. If the conditions of operation remain the same, this forms a just basis for the comparison of different boilers. If, however, the conditions of operation, such as the steam-pressure or the feed-temperature, are not the same, this basis of comparison is not suitable, since it requires more heat-units to evaporate a pound of water at the higher steam-pressure or the lower feed-temperature.

To secure a fair basis of comparison under all conditions, it is customary to reduce the actual evaporation per pound of dry coal to an equivalent evaporation per pound of dry coal from a feed-temperature of 212° F. into steam at the same temperature, i.e., at atmospheric pressure. This is commonly called the equivalent evaporation "from and at 212° F."

109. Horse-power of Boilers.—The accepted definition of a boiler horse-power is the evaporation of 30 pounds of water per hour from a feed-temperature of 100° F. into steam at 70 pounds pressure. This is equivalent to the evaporation of 34½ pounds per hour from and at 212° F.

110. Boiler Efficiencies.—The efficiency of a boiler is usually expressed as the ratio of the heat supplied the boiler in the form of coal to that delivered by the boiler in the form of steam. This evidently includes both the efficiency of the boiler proper and that of the furnace. Properly speaking, the efficiency of the boiler is the ratio of the heat supplied as coal minus that lost in the ash, cinders, and waste gases to the heat delivered in the steam. The efficiency of the furnace is, then, the ratio of the heat supplied as coal to that absorbed by the boiler.

In finding either of these efficiencies, determination must be made of the heating value of the coal and of the temperature and chemical composition of the waste gases. Such determinations are only undertaken in connection with the more elaborate tests of boilers.

111. Determination of Heating Value of Fuels.—The determination of the heating-value of fuel is made by burning a known weight of the material and measuring the heat evolved. The method of burning must be such as to produce perfect combustion. The fuel may be burned in air or in the presence of oxygen or some oxide. The measurement of heat is usually made by absorbing it in a known weight of water and noting the resulting rise in temperature. From this and the constants of the apparatus employed, the heat produced can be determined.

For determining the heating-value of coal, the instruments used are known as coal-calorimeters. They are made in a variety of forms, for description of which the reader is referred to the various papers and articles on the subject.* In selecting the sample of coal care should be taken to insure a representative sample. A good method of procedure is to draw off a shovelful from time to time during the conduct of the test, the intervals being such as to secure a sample weighing from 75 to 100 pounds. Immediately upon the close of the test this should be broken up to about egg size, carefully mixed and quartered. The quarter selected should then be broken to nut size and again mixed and quartered. The final quarter should be broken to pea size, and placed in an air-tight jar to await the calorimetric determination.

112. Flue-gas Analysis.—In order to ascertain the degree of perfection attained in the combustion of fuel, recourse is had to the analysis of the flue-gases, the results of which serve to indicate the character of the combustion. The method of obtaining the sample and of analyzing the gases may be found by reference to the existing works upon the subject.†

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* Trans. A. S. M. E., vol. XIV, p. 816 and vol. XVI, p. 1040. Carpenter's "Experimental Engineering," Chap. 14.

† Hempel's "Method of Gas Analysis," Trans. A. S. M. E., vol. VI., p. 786. Carpenter's "Experimental Engineering," Chap. 14.

113. Graphical Logs.—The graphical log is useful in determining the constancy of the conditions under which the test was made. It is plotted from the running log of the test, taking time as the abscissæ and the various observed quantities as the ordinates, using a suitable scale for each. In case the test is made in connection with an engine test, the graphical log may be made to include the observations for both.

114. Methods of Testing Boilers.—Following is the code of rules for testing boilers prescribed by the American Society of Mechanical Engineers, adopted at their 1884 meeting: *

CODE OF RULES FOR BOILER TESTS.

PRELIMINARIES TO A TEST.

I. *In preparing for* and conducting trials of steam-boilers the specific object of the proposed trial should be clearly defined and steadily kept in view.

II. *Measure and record the dimensions*, position, etc., of grate- and heating-surfaces, flues and chimneys, proportion of air-space in the grate-surface, kind of draught, natural or forced.

III. *Put the boiler in good condition.* Have heating-surface clean inside and out, grate-bars and sides of furnace free from clinkers, dust and ashes removed from back connections, leaks in masonry stopped, and all obstructions to draught removed. See that the damper will open to full extent, that it may be closed when desired. Test for leaks in masonry by firing a little smoky fuel and immediately closing damper. The smoke will then escape through the leaks.

* Trans. A. S. M. E., vol. VI, p. 676.

IV. *Have an understanding with the parties* in whose interest the test is to be made as to the character of the coal to be used. The coal must be dry, or, if wet, a sample must be dried carefully and a determination of the amount of moisture in the coal made, and the calculation of the results of the test corrected accordingly.

Wherever possible, the test should be made with standard coal of a known quality. For that portion of the country east of the Allegheny Mountains good anthracite egg coal or Cumberland semi-bituminous coal may be taken as the standard for making tests. West of the Allegheny Mountains and east of the Missouri River Pittsburg lump coal may be used.*

V. *In all important tests* a sample of coal should be selected for chemical analysis.

VI. *Establish the correctness of all apparatus* used in the test for weighing and measuring. These are:

1. Scales for weighing coal, ashes, and water.

2. Tanks, or water-meters for measuring water. Water-meters, as a rule should only be used as a check on other measurements. For accurate work, the water should be weighed or measured in a tank.

3. Thermometers and pyrometers for taking temperatures of air, steam, feed-water, waste gases, etc.

4. Pressure-gages, draught-gages, etc.

VII. *Before beginning a test*, the boiler and chimney should be thoroughly heated to their usual working temperature. If the boiler is new, it should be

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* These coals are selected because they are about the only coals which contain the essentials of excellence of quality, adaptability to various kinds of furnaces, grates, boilers, and methods of firing, and wide distribution and general accessibility in the markets.

in continuous use at least a week before testing, so as to dry the mortar thoroughly and heat the walls.

VIII. Before beginning a test, the boiler and connections should be free from leaks, and all water connections, including blow- and extra feed-pipes, should be disconnected or stopped with blank flanges, except the particular pipe through which water is to be fed to the boiler during the trial. In locations where the reliability of the power is so important that an extra feed-pipe must be kept in position, and in general when for any other reason water-pipes other than the feed-pipes cannot be disconnected, such pipes may be drilled so as to leave openings in their lower sides, which should be kept open throughout the test as a means of detecting leaks, or accidental or unauthorized opening of valves. During the test the blow-off pipe should remain exposed.

If an injector is used it must receive steam directly from the boiler being tested, and not from a steam-pipe or from any other boiler.

See that the steam-pipe is so arranged that water of côndensation cannot run back into the boiler. If the steam-pipe has such an inclination that the water of condensation from any portion of the steam-pipe system may run back into the boiler, it must be trapped so as to prevent this water getting into the boiler without being measured.

STARTING AND STOPPING A TEST.

A test should last at least ten hours of continuous running, and twenty-four hours whenever practicable. The conditions of the boiler and furnace in all respects should be, as nearly as possible, the same at the end as at the beginning of the test. The steam-pressure should be the same, the water-level the same, the fire upon the grates should be the same in quantity and condition, and the walls, flues, etc., should be of the same temperature. To secure as near an approximation to exact uniformity as possible in conditions of the fire and in temperatures of the walls and flues, the following method of starting and stopping a test should be adopted:

X. *Standard Method.*—Steam being raised to the working pressure, remove rapidly all fire from the grate, close the damper, clean the ash-pit, and as quickly as possible start a new fire with weighed wood and coal, noting the time of starting the test and the height of the water-level while the water is in a quiescent state, just before lighting the fire.

At the end of the test remove the whole fire, clean the grates and ash-pit, and note the water-level when the water is in a quiescent state; record the time of hauling the fire as the end of the test. The water-level should be as nearly as possible the same as at the beginning of the test. If it is not the same, a correction should be made by computation, and not by operating pump after test is completed. It will generally be necessary to regulate the discharge of steam from the boiler tested by means of the stop-valve for a time while fires are being hauled at the beginning and at the end of the test, in order to keep the steam-pressure in the boiler at those times up to the average during the test.

XI. *Alternate Method.*—Instead of the standard method above described, the following may be employed where local conditions render it necessary:

At the regular time for slicing and cleaning fires have them burned rather low, as is usual before cleaning, and then thoroughly cleaned; note the amount of coal left on the grate as nearly as it can be estimated; note the pressure of steam and the height of the water-level—which should be at the medium height to be carried throughout the test—at the same time; and note this time as the time of starting the test. Fresh coal which has been weighed should now be fired. The ash-pits should be cleaned at once after starting. Before the end of the test the fires should be burned low, just as before the start, and the fires cleaned in such a manner as to leave the same amount of fire, and in the same condition, on the grates as at the start. The water-level and steam-pressure should be brought to the same point as at the start, and the time of the ending of the test should be noted just before fresh coal is fired.

DURING THE TEST.

XII. *Keep the Conditions Uniform.*—The boiler should be run continuously, without stopping for meal-times or for rise or fall of pressure of steam due to change of demand for steam. The draught being adjusted to the rate of evaporation or combustion desired before the test is begun, it should be retained constant during the test by means of the damper.

If the boiler is not connected to the same steam-pipe with other boilers, an extra outlet for steam with valve in same should be provided, so that in case the pressure should rise to that at which the safety-valve is set, it may be reduced to the desired point by opening the extra outlet without checking the fires.

If the boiler is connected to a main steam-pipe with other boilers, the safety-valve on the boiler being tested should be set a few pounds higher than those of the other boilers, so that in case of a rise in pressure the other boilers may blow off, and the pressure be reduced by closing their dampers, allowing the damper of the boiler being tested to remain open, and firing as usual.

All conditions should be kept as nearly uniform as possible, such as force of draught, pressure of steam, and height of water.

The time of cleaning the fires will depend upon the character of the fuel, the rapidity of combustion, and the kind of grates. When very good coal is used and the combustion not too rapid, a ten-hour test may be run without any cleaning of the grates other than just before the beginning and just before the end of the test. But in case the grates have to be cleaned during the test, the intervals between one cleaning and another should be uniform.

XIII. *Keeping the Records.*—The coal should be weighed and delivered to the fireman in equal portions, each sufficient for about one hour's run, and a fresh portion should not be delivered until the previous one has all been fired. The time required to consume each portion should be noted, the time being recorded at the instant of firing the first of each new portion. It is desirable that at the same time the amount of water fed into the boiler should be accurately noted and recorded, including the height of the water in the boiler, and the average pressure of steam and temperature of feed during the time. By thus recording the amount of water evaporated by successive portions of coal, the record of the test may be divided into several divisions, if desired, at the end of the test, to discover the degree of uniformity of combustion, evaporation, and economy at different stages of the test.

XIV. *Priming Tests.*—In all tests in which accuracy of results is important, calorimeter tests should be made of the percentage of moisture in the steam or of the degree of superheating. At least ten such tests should be made during the trial of the boiler, or so many as to reduce the probable average error to less than one per cent, and the final records of the boiler-test corrected according to the average results of the calorimeter tests.

On account of the difficulty of securing accuracy in these tests the greatest care should be taken in the measurements of weights and temperatures. The thermometers should be accurate to within a tenth of a degree, and the scales on which the water is weighed to within one-hundredth of a pound.

ANALYSIS OF GASES—MEASUREMENT OF AIR-SUPPLY, ETC.

XV. In tests for purposes of scientific research, in which the determination of all the variables entering into the tests is desired, certain observations should be made which are in general not necessary in tests for commercial purposes. These are the measurement of the air-supply, the determination of its contained moisture, the measurement and analysis of the flue-gases, the determination of the amount of heat lost by radiation, of the amount of infiltration of air through the setting, the direct determination by calorimeter experiments of the absolute heating value of the fuel, and (by condensation of all the steam made by the boiler) of the total heat imparted to the water.

The analysis of the flue-gases is an especially valuable method of determining the relative value of different methods of firing, or of different kinds of furnaces. In making these analyses great care should be taken to procure average samples—since the composition is apt to vary at different points of the flue,—and the analyses should be intrusted only to a thoroughly competent chemist, who is provided with complete and accurate apparatus.

As the determinations of the other variables mentioned above are not likely to be undertaken except by engineers of high scientific attainments, and as apparatus for making them is likely to be improved in the course of scientific research, it is not deemed advisable to include in this code any specific directions for making them.

RECORD OF THE TEST.

XVI. A "log" of the test should be kept on properly-prepared blanks, containing headings as follows:

Time.	Pressures.			Temperatures.					Fuel.		Feed-water.	
	Barometer.	Steam-gage.	Draught-gage.	External Air.	Boiler-room.	Flue.	Feed-water.	Steam.	Time.	Lbs.	Time.	Lbs. or cu. ft.

REPORTING THE TRIAL.

XVII. The final results should be recorded upon a properly prepared blank, and should include as many of the following items as are adapted for the specific object for which the trial is made. The items marked with a * may be omitted for ordinary trials, but are desirable for comparison with similar data from other sources.

RESULTS OF THE TRIALS OF A..................BOILER AT....................TO DETERMINE..................

1. Date of trial..............................		
2. Duration of trial..........................	hours	
DIMENSIONS AND PROPORTIONS.		
(Leave space for complete description.)		
3. Grate-surface....wide....long....area...	sq. ft.	
4. Water-heating surface....................	sq. ft.	
5. Superheating-surface.....................	sq. ft.	
6. Ratio of water-heating to grate-surface...		
AVERAGE PRESSURES.		
7. Steam-pressure in boiler, by gage........	lbs.	
*8. Absolute steam-pressure.................	lbs.	
*9. Atmospheric pressure, per barometer.....	in.	
10. Force of draught in inches of water.......	in.	
AVERAGE TEMPERATURES.		
*11. Of external air..........................	deg.	
*12. Of fire-room.............................	deg.	
*13. Of steam.................................	deg.	
14. Of escaping gases.........................	deg.	
15. Of feed-water.............................	deg.	

* See reference in paragraph preceding table.

FUEL.		
†16. Total amount of coal consumed	lbs.	
17. Moisture in coal........................	per cent	
18. Dry coal consumed......................	lbs.	
19. Total refuse, dry....pounds = ...	per cent	
20. Total combustible (dry weight of coal, Item 18, less refuse, Item 19)..........	lbs.	
*21. Dry coal consumed per hour.............	lbs.	
*22. Combustible consumed per hour..........	lbs.	
RESULTS OF CALORIMETRIC TESTS.		
23. Quality of steam, dry steam being taken as unity............................		
24. Percentage of moisture in steam.........	per cent	
25. Number of degrees superheated..........	deg.	
WATER.		
26. Total weight of water pumped into boiler and apparently evaporated‡.............	lbs.	
27. Water actually evaporated, corrected for quality of steam §......................	lbs.	
28. Equivalent water evaporated into dry steam from and at 212° F.§.............	lbs.	
*29. Equivalent total heat derived from fuel in British thermal units §.............	B. T. U.	
30. Equivalent water evaporated into dry steam from and at 212° F. per hour.....	lbs.	
ECONOMIC EVAPORATION.		
31. Water actually evaporated per pound of dry coal, from actual pressure and temperature §............................	lbs.	
32. Equivalent water evaporated per pound of dry coal from and at 212° F.§..........	lbs.	
33. Equivalent water evaporated per pound of combustible from and at 212° F.§....	lbs.	

* See reference in paragraph preceding table.

† Including equivalent of wood used in lighting fire. One pound of wood equals 0.4 pound coal. Not including unburnt coal withdrawn from fire at end of test.

‡ Corrected for inequality of water-level and of steam-pressure at beginning and end of test.

§ The following shows how some of the items in the above table are derived from others:

Item 27 = item 26 × item 23;

Item 28 = item 27 × factor of evaporation;

COMMERCIAL EVAPORATION.		
34. Equivalent water evaporated per pound of dry coal with one sixth refuse, at 70 pounds gage-pressure, from temperature of 100° F. = Item 33 multiplied by 0.7249.	lbs.	
RATE OF COMBUSTION.		
35. Dry coal actually burned per square foot of grate-surface per hour..............	lbs.	
*36. Consumption of dry coal per hour. Coal assumed with one sixth refuse.† Per sq. ft. of grate-surface...........	lbs.	
*37. Per sq. ft. of water-heating surface ...	lbs.	
*38. Per sq. ft. of least area for draught ..	lbs.	
RATE OF EVAPORATION.		
39. Water evaporated from and at 212° F. per sq. ft. of heating-surface per hour......	lbs.	
*40. Water evaporated per hr. from temperature of 100° F. into steam of 70 lbs. gage-pressure.† Per sq. ft. of grate-surface.............	lbs.	
*41. Per sq. ft. of water-heating surface.....	lbs.	
*42. Per sq. ft. of least area for draught....	lbs.	

Factor of evaporation $= \frac{H - h}{965.7}$, H and h being respectively the total heat-units in steam of the average observed pressure and in water of the average observed temperature of feed, as obtained from tables of the properties of steam and water;

Item 29 = item 27 × $(H - h)$;
Item 31 = item 27 ÷ item 18;
Item 32 = item 28 ÷ item 18 or = item 31 × factor of evaporation;
Item 33 = item 28 ÷ item 20 or = item 32 ÷ (per cent 100 − item 19);
Items 36 to 38. First term = item 22 × $\frac{5}{6}$;
Items 40 to 42. First term = item 39 × 0.8698;
Item 43 = item 29 × 0.00003 or $= \frac{\text{item 30}}{34\frac{1}{2}}$;
Item 45 $= \frac{\text{difference of items 43 and 44}}{\text{item 44}}$.

* See note *, p. 134. † See note §, p. 135.

COMMERCIAL HORSE-POWER.		
43. On basis of thirty pounds of water per hour evaporated from temperature of 100° F. into steam of 70 pounds gage-pressure (=$34\frac{1}{2}$ lbs., from and at 212°)†.	H.P.	
44. Horse-power, builders' rating at....sq. ft. per horse-power......................	H.P.	
45. Per cent developed above, or below, rating†................................	per cent	

† See note §, p. 135.

115. Abbreviated Directions.—*Apparatus.*—Tanks and scales for weighing water, scales for weighing coal, calorimeter, barometer, thermometers for temperature of room, feed-water, and waste gases.

Method.—Calibrate all apparatus. Prepare blank logs and post observers. Note Rules VII and IX before starting. Start by standard or alternate methods, Rules X and XI. Take readings of time, boiler-pressure, barometer, draught, temperature in smoke-box, quality of steam, pounds water supplied, pounds water lost by calorimeter, leakage, etc., pounds coal fired, per cent of moisture in coal, pounds dry ash. Observe Rules XII, XIII, and XIV during the test. Make test ten hours long if possible, making running observations every ten minutes. If possible keep coal and water record so that quantities may be computed for each hour. Dry a sample of coal, not less than 50 pounds, in order to determine per cent of moisture. If using standard method of starting and stopping, dump the grates at end of test and weigh all the ash, minus any unburned coal, which should be removed, weighed, and the weight deducted from the total amount of coal fired. If using the alternate method, do not dump the grates until the ash is removed and weighed, and do not weigh back any unburned coal found on grate or in ash.

Report.—Make report on forms given and submit a graphical log (Section 113) of the test. For method of working up the test and calculating the various desired results, see Section 161. The method of conducting special boiler-tests is given under separate heading (Secs. 160 and 162).

CHAPTER XI.

THE STEAM-ENGINE INDICATOR.

116. General Description.—The steam-engine indicator is an instrument used for recording the pressure on the engine-piston at each point of its stroke. It consists of the following elements:

The *Cylinder* and *Piston*, the former in pipe connection with one end of the engine-cylinder in such a manner that the pressures in the latter are received by the indicator-piston.

The *Indicator-spring*, attached to the piston and opposing the force of the steam-pressure, allowing a limited motion, proportional to that pressure.

The *Pencil-motion*, by which the motion of the piston is multiplied, the resultant motion of the pencil being a straight line.

The *Drum*, which gives motion to a card in direct proportion to the motion of the engine-piston, but of a total length usually not exceeding four inches. The drum is actuated by a cord of braided linen and its motion is controlled by a spring, the tension of which may be varied to suit the speed.

117. The Crosby Indicator.—A sectional view of the Crosby indicator is shown in Fig. 39. The principal parts are a piston, 8, moving within the cylinder, 4, and connected with the pencil-lever, 16, by means of a piston-rod, 10, swivel-head, 11, and link, 14. The pencil mechanism, by which the pencil, 23, is

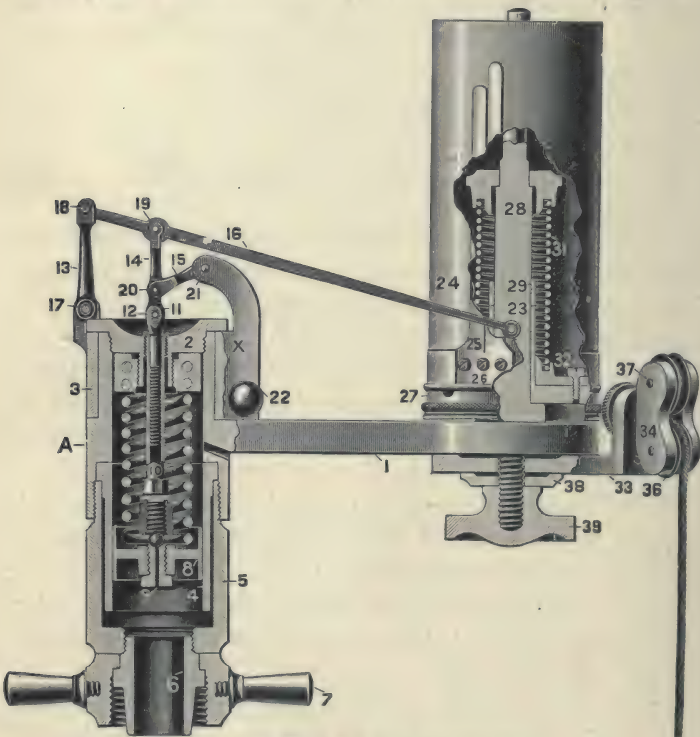

FIG. 39.—THE CROSBY INDICATOR.

caused to move in a straight line, consists of a system of links mounted on a sleeve, 3. The motion of the piston is resisted by a spring fastened at its lower end to the piston by means of a ball-joint and at its upper end to a cap, 2, which forms the upper cylinder-head. The drum, 24, drum-spring, 31, and connected parts are easily understood by reference to the cut.

To remove the piston and pencil mechanism from the indicator, unscrew the cap, 2, and lift the cap, sleeve, 3, and connected parts from the indicator.

To insert the spring, unscrew the piston and piston-rod from the swivel-head, holding the cap, 2, from turning. Take the socket-wrench from the cover of the indicator-box, slip it over the piston-rod, and unscrew the latter from the piston. Now with the piston-rod still in the socket of the wrench slip the spring over the piston-rod until the bead of the spring rests in the concave end of the rod; then invert the piston and pass the transverse wire of the spring through the slotted portion of the piston-socket and screw the piston-rod firmly into place. The lower piston-screw, 9, should be loosened slightly before this last operation and afterwards set up against the bead lightly to prevent lost motion, but not enough to prevent the bead from turning.

Caution.—In the under side of the shoulder of the piston-rod *B*, Fig. 40, is an annular channel formed to receive the upper edge of the socket on the piston *A*. When attaching the piston to the rod always screw the piston-rod onto the socket as far as it will go; that is, until the upper end of the socket, a', is brought firmly against the bottom of the annular channel, b^2, in the piston-rod. This insures correct alignment of the piston within the cylinder.

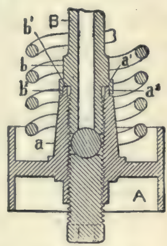

FIG. 40.

Having the spring and piston together, hold the sleeve and pencil-motion in an upright position, slip the piston-rod up over the threaded portion of the swivel-head, 11, Fig. 39, until the threads on the upper head of the spring engage those on the cap, 2, and screw the spring firmly onto the cap. Now allow the cap to turn and screw the piston-rod onto the swivel-head until the top of the rod is nearly flush with the shoulder on the swivel-head. The piston may now be inserted in the cylinder and the cap screwed into place.

To change the location of the atmosphere-line, unscrew the cap and remove the piston, and pencil-movement. Unscrew the piston-rod from the swivel-head to raise the atmosphere-line and the reverse to lower it. One turn will change the position of the pencil $\frac{1}{8}$ of an inch.

To change the drum tension, remove the drum, lift the knurled nut at the top of the drum-spring from its square seat, turn in the direction required, and replace.

To change to a left-hand instrument, first remove the drum by a straight upward pull; then, with a screw-driver remove the steel top-screw in the drum base and screw it into the vacant hole marked *L*. Next, reverse the position of the adjusting handle in the arm and the position of the metallic point in the pencil lever; then replace the drum.

118. **The Tabor Indicator.**—The special feature of the Tabor Indicator is the means employed to secure a straight-line motion for the pencil. This is secured by means of a curved slot, fastened to the cylinder-cap, in which travels a roller attached to the pencil-lever (Fig. 41).

The method of fastening the piston, rod, and spring together differs from that employed in the Crosby indicator in that the point of flexibility occurs, not between the spring and the piston, but between the piston and the rod.

To remove the piston and pencil mechanism from the indicator, unscrew the cylinder-cap and lift it with the connected parts from the indicator.

To insert the spring, unscrew the small nut under the piston from the piston-rod and remove the piston.

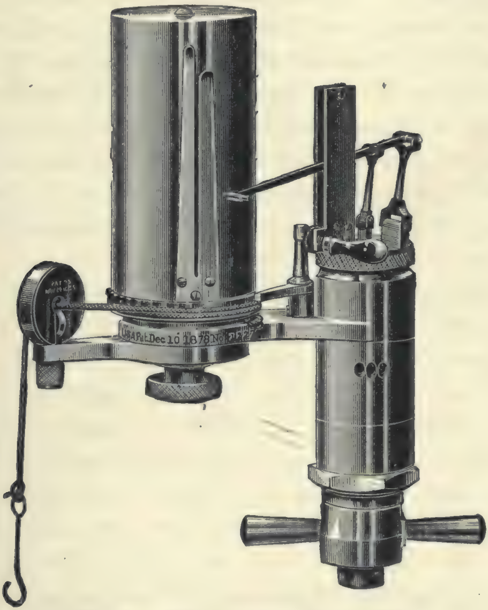

FIG. 41.—THE TABOR INDICATOR.

Slip the spring over the piston-rod, the end marked *T* uppermost, and screw it to the cap; then screw the piston to the lower end of the spring. Now move the pencil-motion down until the lower end of the piston-rod enters the piston and the square shoulder enters the square socket provided in the piston. Holding it in this position, replace the small nut below the piston, screwing it firmly home. The piston may now be replaced in the cylinder and the cap screwed in place.

To change the drum tension, remove the drum, drive out the small taper-pin which holds the knurled nut and unscrew the latter. Now grasp the drum-carriage firmly, lift it clear of the stops, turn in the required direction, and lower into place. Do not loose hold of it or the spring will rapidly uncoil and become detached. Replace the nut, taper-pin, and drum.

119. Choice of Spring.—Such a spring should be used that the maximum pressure to which it will be subjected is not greater than one and three quarter times the scale of the spring. Following is a table of the scale of spring to be used with different steam-pressures:

Steam-pressure (gage).	Scale of Spring.
40	30
60	40
80	50
100	60
140	80
175	100
210	120
250	150

120. Use of the Indicator.—The indicator is one of the most delicate and costly instruments which the engineer uses in ordinary practice. It requires careful handling and a thorough knowledge of its construction and operation in order to secure accurate results and prevent damage to itself.

Before the Test.—Remove the indicator carefully from its box, handling it so far as possible by the cylinder. Never handle an indicator by the drum, as this is loose in most makes and comes off readily. Lift the pencil up and down slowly to see that it is perfectly free. Remove the pencil-motion and piston by unscrewing the knurled nut at the top of the cylinder. Thoroughly clean all working parts.

Insert the spring in the pencil-motion as explained in Sections 117 and 118. Cover the piston with a thin coat of heavy oil and replace in the cylinder. See that the moving parts of the drum and pencil-motion are lubricated with watchmaker's oil.

After blowing out the cock with steam, attach the indicator to the engine, and adjust the guide-pulleys so that when the cord is attached to the reducing-motion it will be parallel to the motion of the indicator-rig or, if a brumbo pulley is used, will be tangent to it. Adjust the cord so that the drum will not strike either stop when the cord is attached to the rig. If a hook is used on the drum-cord a convenient mode of attaching it to the cord is to pass the end of the latter through the eye of the hook and then make two half-hitches around the shank. This hitch may be easily untied by slipping it over the end of the hook. If the drum tension needs altering it may be changed as explained in Sections 117 and 118.

Taking the Card.—Place the blank card on the drum so that both ends will be under the clips and not project out from the drum. By so doing the card will be less liable to come loose and will lie flat when taken. See that the pencil is firmly placed and sharp. For very accurate work a brass point should be used in connection with "metallic paper." Taking the loop of cord attached to the reducing-rig in one hand, pull the drum-cord out to the end of its travel several times and then attach to the loop. Adjust the pencil-pressure to give a fine line. Open the cock half-way and allow steam to blow through the relief for two or three revolutions, then open full and draw the diagram. Close the cock, draw the atmosphere-line, and unhook the drum, taking care not to let it snap back against the stop. Remove the card and examine to see if there are any irregularities in the diagram. If these appear call the attention of the instructor to them. They may be due to disarrangement of parts or grit in the indicator-cylinder. If the latter, the piston should be removed, the cylinder blown out, and the piston oiled and returned. This should be done occasionally on all engine-tests. If the indicator is used on a gas-engine the piston should always be removed from its cylinder when not actually in use, as it is liable to be overheated if left on the engine between cards.

After the Test.—Remove the indicator immediately, using waste to prevent burning the hands. Remove the piston and spring and clean all parts thoroughly. Oil the piston and working parts and put together without the spring. Never dip any part of the indicator in water for the purpose of cooling it quickly.

121. Errors of the Indicator.—The two most fruitful sources of error in the mechanism of the indicator are the pencil-motion and the spring. To test the former, place a card on the drum and draw the atmosphere-line. With the spring out place the pencil in contact with the paper and raise it up to the full height of its travel. Repeat at several different points on the card, holding the drum firmly in each position. Test the perpendicularity of the lines with a triangle and straight-edge.

122. Testing Indicator-springs.—Indicator-springs are often tested under hydraulic pressure and even by pressure exerted by a rod upon the under side of the piston, the lower end of the rod resting on suitable scales. Most satisfactory results, however, may be obtained by a test under steam-pressure, in which case the conditions of the test are similar to the conditions of actual use, but it has generally been found difficult to maintain a constant pressure and to accurately determine its value. A steam-gage is too sluggish in action to properly serve in this connection. A method of testing has been devised by Prof. W. F. M. Goss which overcomes these difficulties. The apparatus consists of a steam-drum having a pressure-regulating valve which responds to change in volume rather than to change in pressure, the pressure remaining constant at any point desired. The details of the arrangement are shown by Fig. 42.

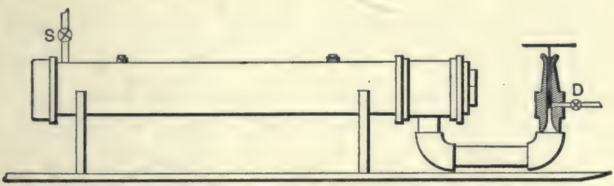

FIG. 42.—INDICATOR-TESTING APPARATUS.

As is clearly shown by this sketch, a piston of known area is arranged to receive the pressure in the drum, against which it is held by standard weights placed upon the holder at its upper end. The piston is free to move between stops, and as it rises it increases the area of port-opening through which the steam within the drum is allowed to escape. The piston therefore serves as a means of controlling and weighing the pressure within the drum.

The area of the piston is one fifth of a square inch. The piston with weight-holder weighs one pound. A pressure of five pounds per square inch may therefore be maintained with no weights upon the holder. The weights to be used are those supplied with the Crosby Gage-tester. The value of these weights (which is stamped upon them) is five times their actual weight.

Specific Directions.—Attach the indicator (or indicators) by means of the usual indicator-cocks. Open wide the discharge-valve *D* (Fig. 42). Have no weights upon the weight-holder, place one hand on it, and gradually open the steam-supply valve, *S*. Thoroughly warm the steam-drum, allowing the weight-holder to rise under pressure of the hand. Observe the amount of motion which the weight-holder has, so that in the work to follow it may not be allowed to strike against its stops. Load the weight-holder with the desired weight and adjust the steam-supply valve, if necessary. Open and close the indicator-cock several times; finally leave it open; twirl the weight-holder, and make the record on the indicator-card by revolving the drum by hand. Be sure that on the ascending scale the pencil rises to the pressure and on the descending scale falls to the pressure, in order to discover any lost motion or friction which may exist.

There should be one observer to manipulate the testing apparatus and one for each indicator to be tested.

The Record.—Before putting the paper on the indicator-drum draw upon it two parallel vertical lines about a quarter of an inch apart (*a* and *b*, Fig. 43).

When testing with differences of pressure on the ascending scale, make lines by means of the indicator toward the right, beginning with the left vertical; when the differences of pressure are on the descending scale, make lines toward the left, beginning with the right vertical.

For springs under thirty pounds to the inch make

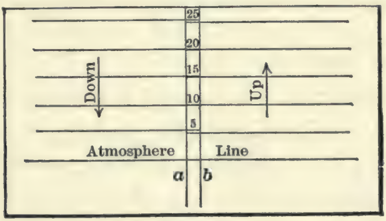

Fig. 43.

a record for every five pounds change in pressure; for springs above thirty pounds, for every ten pounds change in pressure. Care should be taken that the spring is not subjected to a greater pressure than it is made to stand (see Section 119). Take several cards; then remove and clean the indicators.

With a scale corresponding to that of the spring, measure the pressures from the atmosphere-line up to the several lines drawn, and record the same on their respective lines.

The Report should be made out on the blank form given below. Paste the card to the report sheet.

123. Form for

CALIBRATION OF INDICATOR-SPRING NO.......

IN CONNECTION WITH......................INDICATOR NO.......

Observers { ....
....   *Date*........

SCALE OF SPRING........

No.	Actual Pressure.	Reading.		Error.		Remarks.
		Up.	Down.	Up.	Down.	

Attach card here.

124. The Indicator-diagram.—The diagram drawn by the steam-engine indicator furnishes the means for determining the action of the valve, for analyzing the action of the steam in the cylinders, and for determining the power developed. In Fig. 44 is shown a typical diagram taken from a locomotive at speed.

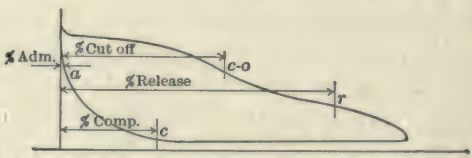

FIG. 44.

The Point of Admission, a, is the point at which the valve opens for the admission of steam to the cylinder.

The Steam-line, from *a* to *c–o,* is the line drawn during the time when the steam is passing into the cylinder.

The Point of Cut-off, c–o, is the point at which the valve is just closed, the admission of steam ceases, and expansion begins.

The Expansion-curve, from *c–o* to *r*, is the line drawn while the steam is expanding behind the piston.

The Point of Release, *r*, is the point at which the valve opens communication with the exhaust-port and the steam is released from the cylinder.

The Exhaust-line, from *r* to *c*, is the line drawn while steam is being exhausted from the cylinder. The lower portion is also called the *Back-pressure Line*.

The Point of Compression, *c*, is the point at which the valve closes communication with the exhaust-port and the steam retained in the cylinder begins to compress.

The Compression-curve, from *c* to *a*, is the line drawn while compression is taking place.

The Initial Pressure is measured from the atmosphere-line to the highest point of the steam-line. Do not confuse this with a high point sometimes appearing just at the beginning of the stroke, due to inertia of the moving parts of the indicator.

The Least Back-pressure is measured from the atmosphere-line to the lowest point of the back-pressure line.

The Events of Stroke are the points of admission, cut-off, release, and compression.

The Per Cent of Stroke at the different events is the distance of the piston from its initial or admission end when the event occurs, expressed as a per cent of the total length of stroke.

125. Locating the Events of Stroke.—The location of the events of stroke, especially for cards taken at high speed, requires much care and considerable skill. In locating, for instance, the point of cut-off, the best method is to follow with the eye *up* the expansion-curve until the point is reached at which the reverse curve *begins*. This point may be taken as the point of cut-off. Similarly, for release, follow down the expansion-curve until the point is reached at which the reverse curve leading to the back-pressure line begins. This is the point of release. When determining these points for the purpose of finding the weights of steam, it is essential that the valve be entirely closed at the points located. It will therefore be found more accurate, when doubt exists as to the precise location of the point, to locate it too far on the expansion-curve rather than the reverse. Do not continue the expansion or compression curves up and down, as shown in Fig. 45. This is a common method of locating the events, but is apt to obscure the real point sought.

FIG. 45.

126. Determining the Per Cents of Stroke. When the events are located, draw ordinates through them and at the ends of the card. Make a scale somewhat longer than the longest card, about an eighth of an inch, and divide it into one hundred parts. If this scale be placed so that the ends exactly coincide with the end ordinates, the percentage of stroke may be read directly for each event and properly recorded on the corresponding ordinate. All percents should be taken from the admission-end of the card.

127. Mean Effective Pressure.—The mean effective pressure for one end of the engine is the average pressure during the forward stroke on that end, minus the average pressure during the return stroke. As shown by the card, it is the average length of all the ordinates intercepted between the upper and lower lines of the card, multiplied by the scale of the spring. For rough approximations the M.E.P. may be determined from the following formula, neglecting clearance and compression:

$$\text{M.E.P.} = \frac{(1 + \text{hyp. log } R)P_1 - RP_2}{R},$$

where R is the ratio of expansion or the piston-displacement divided by the volume at cut-off, P_1 is the initial pressure, and P_2 the back-pressure, absolute. The results thus obtained will always be greater than the actual values.

128. Mean Effective Pressure by the Method of Ordinates.—First, by use of two triangles draw ordinates at each end of each diagram, perpendicular to the atmosphere-line. Next construct on a piece of paper a scale of ten equal parts such that the sum of the parts will be a little greater than the length of any of the diagrams. To use this scale place it obliquely across the card in such a position that the first and last division points will fall on the end ordinates already drawn. Make points on the card opposite each division on the scale, and afterwards draw ordinates through each of these points. If this work be properly done, each diagram will be divided into ten vertical sections of equal width (Fig. 46). It remains

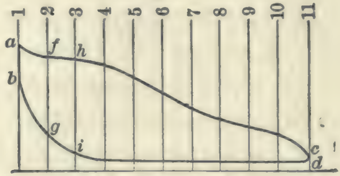

FIG. 46.

to obtain the average height of these sections which, since the sections constitute the card, may be accepted as the average height of the card. Lay off on a strip of paper having a straight edge (Fig. 47) the effective

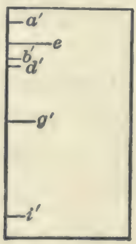

FIG. 47.

height of the card as observed on the first ordinate, that is, lay off *ab* (Fig. 46) on the paper strip as a^1b^1; add to this the height of the last ordinate *cd*, as b^1d^1; and then take half the distance a^1d^1 as a new starting point *e*, and add the effective length of all the other ordinates making $fg = eg^1$, $hi = g^1i^1$, etc., until all the intermediate ordinates are taken off. When this is accomplished the distance measured on the strip from a^1 to the last point is approximately the sum of the height of the vertical slices, and this distance divided by ten (there being ten spaces) will give the average height of the card. This average height in inches multiplied by the scale of the spring gives the M.E.P. of the card. The reason that half the sum of the first and last ordinates is taken will appear when it is remembered that the result sought is the average height of the ten spaces and not of eleven lines. In other words, the first and eleventh ordinates are considered as the same line, a condition which can be illustrated by rolling up the card until they coincide.

129. Mean Effective Pressure by the Planimeter.—The usual method of finding M.E.P. is to measure the area of the card with a planimeter (see Sections 11 and 15) and divide the area thus found by the length parallel to the atmosphere-line. The quotient, which is the height of the mean ordinate in inches, is multiplied by the scale of the spring to give the M.E.P. The length of the card is found as follows: Place a straight-edge on the card coincident with the atmosphere-line, and with a triangle draw ordinates at each end of the card. The length can now be measured to hundredths of an inch, holding the scale parallel to the atmosphere-line.

130. Condensed Directions for working up Cards.—1st. Locate the events of stroke, admission, cut-off, release, and compression, with great care on all cards. Be sure that the last three are well on their respective hyperbolic curves. In this connection it should be remembered that when doubt exists as to the exact location of, for instance, the point of cut-off, much less error in calculating the weight of steam at that point will result from locating the point too late than the reverse, since after cut-off occurs the change in weight is very slight compared with the change immediately preceding cut-off. Do not attempt to continue the expansion and compression curves up and down as in Fig. 45, as this is apt to obscure the real location of the event. Submit some of your first work to the instructor before proceeding.

2d. Draw ordinates through the points located with a fine hard pencil or, if metallic paper is used, with a brass point. Draw them perpendicular to the atmosphere-line and about two inches long.

3d. Draw end ordinates, locating them with great care.

4th. Find areas with the planimeter. These should be checked by two men to within one per cent and

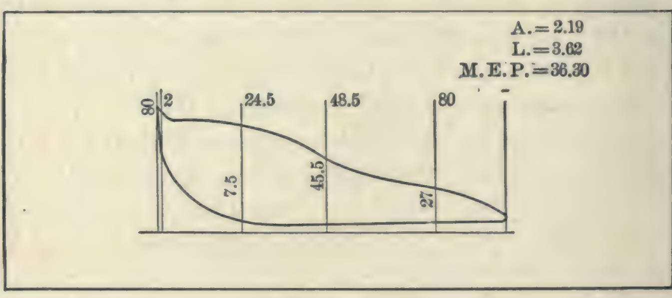

FIG. 48.

the two readings averaged. Use a smooth board covered with a sheet of foolscap to run the planimeter on, and see that the record-wheel does not mount the card. Do not dig the tracing-point of the planimeter into the card and thus destroy its outline. In case the card is dim, make fine pencil-points about ¼ inch apart around its outline before tracing with the planimeter. Enter the result as shown in Fig. 48.

5th. Measure the length of the card parallel to the atmosphere-line, reading to hundredths of an inch. This need not be checked.

6th. Calculate the M.E.P. to two places of decimals. Do not use a slide-rule for this work. This calculation must be checked. In figuring M.E.P., it will be found more accurate to multiply the area by the scale of spring and then divide by the length. This method should be followed. Do not figure on the back of the card.

7th. Measure pressures at cut-off, release, compression, and find initial and least back-pressures. These should all be taken from the atmosphere-line, and the results should be marked on each ordinate as shown in Fig. 48. The initial pressure is generally taken as the highest point on the card unless there are indications that the highest pressure is due to excessive compression, indicator inertia, or some cause other than initial steam-pressure.

8th. Measure per cents of stroke at the same points and enter on the proper ordinate. These should be read to one place of decimals.

131. Calculations from the Card. Horse-power.—The work developed in the cylinder of the engine is the product of two factors. The first may be called the total mean effective pressure, and is the product of the M.E.P. and the net area of the cylinder in square inches. The second is the distance through which the foregoing pressure is exerted per minute or the product of the length of stroke in feet by the number of effective strokes per minute. The first factor is expressed in pounds, the second in feet per minute, and the product, foot-pounds per minute, may be reduced to the equivalent horse-power by dividing by 33,000.

To determine the horse-power of the ordinary steam-engine, find the M.E.P. of the cards as explained in Section 128 or 129. Average this M.E.P. for each end of the cylinder and apply each value in the following formula:

$$\text{H.P.} = \frac{PLAN}{33000},$$

where P is the M.E.P., L the length of stroke in feet, A the net area of the cylinder (on the end in question) in square inches, and N the revolutions per minute. This will give the horse-power on each end of the cylinder. The total indicated horse-power of the engine is the sum of that for the two ends.

132. Use of the Engine Constant.—When the horse-power of the engine is to be found under a number of different conditions, the calculation may be simplified by the use of the engine constant. This is a factor which is determined for each end of the cylinder and is composed of the constant factors of the usual horse-power formula as follows:

$$\text{Engine constant} = \frac{LA}{33000}.$$

The horse-power is now found for each end of the cylinder by multiplying together the engine constant for that end, the M.E.P. for that end, and the R.P.M.

133. Weights of Steam from the Card.— In finding the steam-consumption from the card and in tracing the action of the steam in the cylinder it is necessary to find the weight of steam in the cylinder at the different events of stroke. The weight of steam at any point, as for instance at cut-off, is found from the indicator-card on the assumption that the cylinder is full of steam that is dry and saturated.

The factors in the calculation are, first, the volume in cubic feet of the space filled with steam at the point of cut-off, and second the weight of a cubic foot of steam at the pressure existing at cut-off. To determine the first factor, find the per cent of stroke at cut-off and add the per cent of clearance for the cylinder-end under consideration. These are both expressed as per cents of the piston-displacement, and hence if their sum be multiplied by the piston-displacement in cubic feet, the result will be the volume of steam at cut-off. The weight of a cubic foot of steam at the absolute pressure of cut-off may be found from the Steam Tables, section 182. This, multiplied by the volume, will give the weight of steam at cut-off by indicator.

The weights of steam at the other events of the stroke may be found in a similar manner.

It will be seen that inasmuch as a portion of the steam in the cylinder is not dry and saturated, but has been condensed and exists as water, the weights of steam shown by indicator will be in error to this extent.

134. Reevaporation.—As the steam enters the cylinder during the period of admission a portion of it is condensed by coming in contact with the cooler walls and the retained steam. After cut-off occurs the temperature of the expanding steam falls below that of the cylinder-walls and a portion of the moisture is reevaporated. The amount of this reevaporation per stroke during expansion is determined by subtracting the weight of steam at cut-off from that at release. The reevaporation per revolution is the sum of the weights per stroke for each end.

135. Clearance from the Card.—Two methods of determining clearance from the indicator-card are given below. The methods are both approximate, since they are based upon the assumption that the expansion and compression curves are hyperbolic curves. Since the compression-curve is generally nearer an hyperbola than the expansion-curve, it is preferably used for this work.

First Method.—Select two points *a* and *b*, Fig. 49, on the expansion or compression curve, and draw

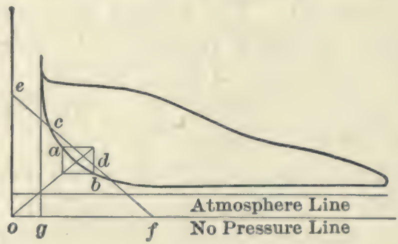

FIG. 49.

vertical and horizontal lines through each, forming a parallelogram having the line joining the points for a diagonal. Then the point at which the other diagonal produced intersects the line of no pressure will also mark its intersection with the clearance-line. The distance *og* in per cent of the whole length of the card is the per cent of clearance.

Second Method.—Draw a line *cd* through the expansion or compression curve. Lay off *ec* equal to *df*.

Draw through *e*, a line perpendicular to the atmosphere-line. This will be the clearance-line.

136. Method of Combining Indicator-cards.—In comparing the performance of a compound or multi-cylinder engine with that of a simple engine, it is sometimes found helpful to combine the cards from the different cylinders of the former, plotting them to the same scale of pressure and volume. The following method, although open to some criticism, is frequently used. The description will apply to the case of a compound receiver engine, but may readily be modified to suit any combination of cylinders.

The necessary data are:

Simultaneous cards from the same end of each cylinder.

Ratio of piston-displacement for the ends from which the cards were taken (expressed as a whole number).

Per cent of clearance for each cylinder for the end from which cards were taken.

Scale of spring of cards.

Barometric pressure.

Divide the cards into 10 equal spaces by means of ordinates drawn perpendicular to the atmosphere-line. Measure and record the pressures at both top and bottom of the card on each ordinate.

On a piece of coordinate paper assume ten half-inch spaces, as from *F* to *G*, Fig. 50, to represent the low-pressure piston-displacement. Assume an atmosphere-line *I–J* and construct the low-pressure card, using a scale of 20 pounds to the inch. Draw the Line of No Pressure, *HG*, at a distance below the atmosphere-line equivalent to the barometric pressure.

At the admission-end of the low-pressure card lay off a distance *FH* to represent the clearance-volume of the low-pressure cylinder. At the point *H* erect the Line of No Volume, *HK*.

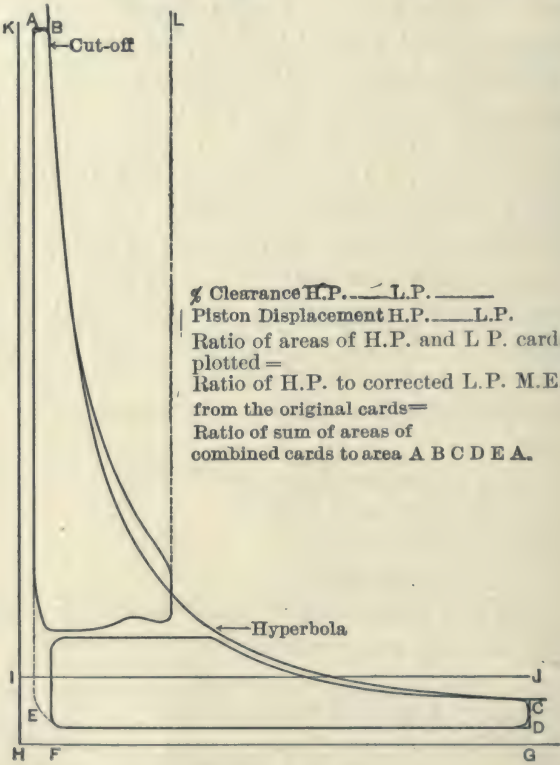

FIG. 50.

From *HK* lay off *KA* to represent the high-pressure clearance-volume. The scale of volumes should be the same as that used for the low-pressure card, viz.:

$$1 \text{ small division} = \frac{\text{L. P. displacement}}{100}.$$

From A lay off AL equal to the high-pressure displacement, or equal to

$$\text{distance } FG \div \text{cylinder-ratio.}$$

Now construct the high-pressure card, using the same scale of pressure and volume as given above.

Through the point of cut-off of the high-pressure cylinder draw an hyperbola with the lines of no pressure and no volume as axes. Draw the straight lines AB and CD, thus completing the theoretical card $ABCDEA$.

From the original cards determine the mean effective pressure. Multiply the low-pressure M.E.P. by the cylinder-ratio. The ratio of the high-pressure M.E.P. to the corrected low-pressure M.E.P. shows the ratio of the work done by the H.P. and L.P. cylinders. It should be equal to the ratio of the area of the two cards when plotted in combination.

Fill out the items as shown on Fig. 50. The original cards, pasted to a blank sheet, should accompany the report.

137. Exercise. Calculations from an Indicator-card.—The student will be provided with a blank form on which are an indicator-card and a list of items to be filled out. The first step is to carefully locate the events of stroke, cut-off, release, and compression, as explained in Section 125. Now measure the pressures at the several events and find the per cents of stroke (Section 126). Measure the area of the card with the planimeter (Section 130, Item 4) and determine the clearance (Section 135). The various calculations may now be made and entered in the proper place.

In calculating M.E.P.,	see Section		129;
Weights of steam,	"	"	133;
Horse-power,	"	"	131;
Reevaporation, item 5;	"	"	161,
Steam-consumption, item 11.	"	"	161,

CHAPTER XII.

STEAM-ENGINE TESTING.

138. Classification of Tests.—Tests of the steam-engine may be classified as follows: To determine whether the valves are correctly set, to measure the indicated and brake horse-power, to determine the friction of the mechanism, to determine the steam-consumption or commercial efficiency, and to investigate cylinder losses and the interchange of heat between the working-fluid and the cylinder-walls.

139. Valve-setting.—The economical use of steam in the steam-engine depends in a large measure upon its proper distribution in the cylinder. This requires careful setting of the valve or valves and adjustment of the valve-gear, which may be accomplished in one of two ways: first, by measurements taken directly from the valve and valve-seat in different relative positions, and second by use of the indicator. Thus the valves of Corliss engines and those having a complicated valve-gear are generally adjusted by taking a card from each end of the cylinder, using a slow speed and a light spring in order that the events of the stroke may be plainly marked. The valve connections may then be changed until the events are correctly placed.

The method by use of the indicator is the more accurate for high-speed engines and when the valves are not easily accessible, rendering actual measurement difficult. For low-speed engines, the method by measurement is to be preferred, as giving more accurate results.

140. General Definitions.—The *Head End* is the end of the cylinder farthest from the crank.

The *Crank End* is the end of the cylinder nearest the crank.

Steam-lap is the distance in inches which the valve moves from its mid-position to its position when the admission of steam to the cylinder begins, as shown in Fig. 51. The steam-lap is sometimes called outside lap, in the case of a valve taking steam on the outside.

Exhaust-lap is the distance in inches which the valve moves from its mid-position to its position when the release of steam from the cylinder begins, as shown in Fig. 51. In the case of a valve taking steam on the outside, the exhaust-lap is sometimes called inside lap. It may become equal to zero or become negative, in which latter case it is termed exhaust or inside clearance.

Lead is the amount in inches by which the valve uncovers the steam-port when the crank is on the dead-center.

The Events of the Stroke, admission, cut-off, release, and compression, may each be expressed as the distance from the position of the piston when the event takes place, to the end of the cylinder at which admission occurred or by the fraction representing the percentage of this distance to the full stroke. All head-end events should be measured from the head end of the cylinder and all crank-end events should be measured from the crank end, as shown on Fig. 44.

Equal Cut-off represents the condition when the per cent of cut-off for the head end of the cylinder is equal to the per cent of cut-off for the crank end.

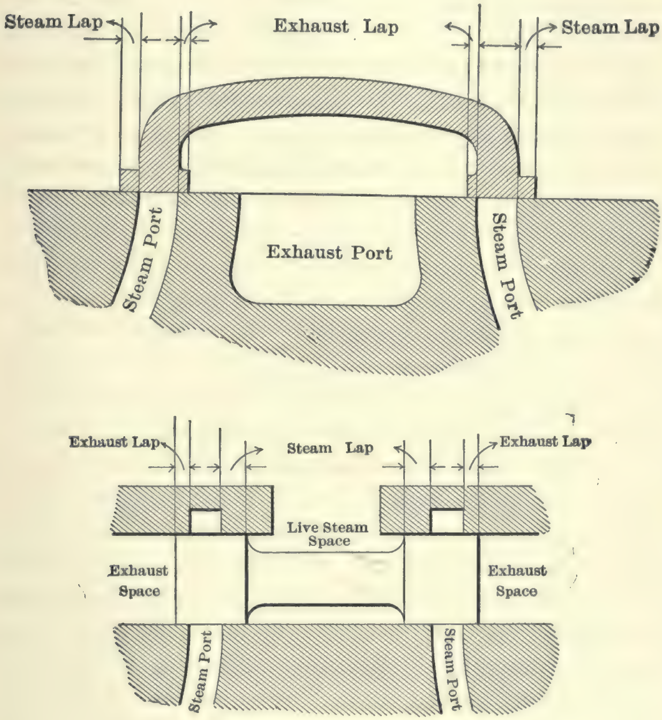

FIG. 51.

Equal Lead represents the condition when the amount of lead on the head-end center is equal to that on the crank-end center.

141. Specific Directions (for slide-valve engines). —*To Set for Equal Cut-off.*—The valve must first be so placed on its stem that its travel will be equal on both sides of the mid-position. To do this, move the engine (or turn the eccentric on the shaft) until the valve reaches one extreme point of its travel, and measure the amount by which the open port is uncovered. Then place the valve at the opposite extremity of its travel and take similar measurements of the other port. If the measurements do not agree, correct by moving the valve on its stem away from the port having the least opening, by an amount equal to one half of the difference between the measurements. Repeat the entire operation until correct.

The motion of the valve is now symmetrical with the ports, and it remains to so fix the eccentric on the shaft that the motion will bear the required relation to the motion of the piston, i.e., will cut off the steam on each end of the cylinder after the piston has travelled equal distances from the ends of the stroke. To do this, place the cross-head at the required per cent of stroke at which cut-off is to take place, as shown by marks on the guide, and move the eccentric on the shaft, turning it in the direction in which the engine is to run, until the valve is just cutting off the steam from the end of the cylinder from which the piston is travelling. Now fasten the eccentric in this position and turn the engine over until the piston has travelled the same distance in the other direction. If the valve is now just cutting off the steam from the opposite end of the cylinder, the setting is correct. If the valve fails to cut off, or has travelled too far, move it upon its stem until one half the error is corrected and then turn the eccentric on the shaft to correct the other half, that is, until the valve just cuts off. Now turn the engine to its first position and note the location of the valve. If not cutting off, correct as for the other end. Repeat this process until the desired result is obtained.

After setting the valve to the required performance as explained above, fill out the tabular statement on the form shown below. The per cent of stroke at release and compression can be obtained by reference to the valve and valve-seat plan, found in the Commonplace-book. From the results obtained, construct the theoretical indicator-card (Fig. 52), assuming 100

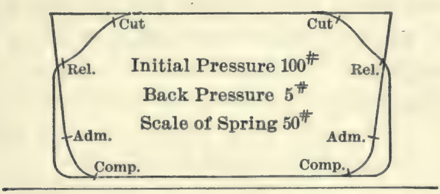

FIG. 52.

pounds initial steam-pressure and five pounds back-pressure, using a scale of 50 pounds to the inch and making the card four inches long.

To Set for Equal Lead.—The valve must first be so placed on its stem that its travel will be equal on both sides of the mid-position, as explained in the first paragraph of Section 141.

Then put the engine on the head-end center and move the eccentric on its shaft in the direction which the engine is to run, until the head-end port is open by the amount of the lead and any further motion of the valve in the same direction will open the port wider. Fix the eccentric at this point. Turn the engine over to the opposite dead-point and note if the lead on the crank end is the same. If it is not, divide the error into two parts and correct one half by moving the valve on its stem and the other half by slipping the eccentric. Repeat until correct.

After setting the valve to the required performance, fill out the tabular statement on the form shown below. The per cent of stroke at release and compression can be obtained by reference to the valve and valve-seat plan, found in the Commonplace-book. From the results obtained, construct the theoretical indicator-card (Fig. 52), assuming 100 pounds initial steam-pressure and five pounds back-pressure, using a scale of 50 pounds to the inch and making the card four inches long.

142. Form for

VALVE-SETTING.

DIRECTIONS: *Date........*

Mr..........................will set........................
.... valve of............................engine
to give...........................; engine to run...........
....
....

(Signed)...................*Instructor.*

REPORT:

Having complied with the foregoing directions I have obtained results which are as follows:

	Head End.	Crank End.
Per cent of admission....	....	....
" " " cut-off........	....	....
" " " release.......	....	....
" " " compression..	....	....
Lead in inches...........	....	....

(Signed)........................

[Attach card (or cards) to this space by pasting at the upper edge only.]

143. Valve-setting by Indicator.—In many cases it is impossible or inconvenient to set valves by measurement on account of their inaccessibility or for other reasons. In such cases recourse is had to the indicator-card, from which an approximate determination of the events of the stroke may be made. Let it be required to set the valve of an engine to give 75 per cent cut-off on each end of the cylinder, the engine to run over, and let it be assumed that the valve travel has been equalized, i.e., made symmetrical on both sides of the mid-position. The process consists in taking an indicator-card from each end of the cylinder with the engine under a medium load, using as light a spring in the indicator as is compatible with the steam-pressure. If the cut-off shown by the cards is not that desired, make such change in the angular advance of the eccentric or the length of the rod as will correct the error, and repeat until the desired result is obtained.

Specific Directions.—Read Sections 120 and 148 on the use of the indicator and on the care of the engine. Having the indicator in place and lubricator and oil-cups filled, start the engine and bring slowly up to speed and conditions of load desired. After the engine has been running a short time, take an indicator-card for each end and locate cut-off as explained in Section 125.

If it is not at the required per cent of stroke, stop the engine and shift the eccentric on the shaft the amount deemed necessary to correct the error. Repeat until correct.

Stop the engine, shut off lubricator and oil-cups, remove and clean the indicator, and leave the engine in good condition.

Measure the valve-travel and find the ratio of the length of the crank to that of the connecting-rod.

In the Report state the method of procedure, the number of adjustments made, and present the last card taken, with all events located and per cents of stroke entered at the respective places. Draw on the report sheet a Zeuner diagram, assuming the same cut-off as that for which the valve was set. The valve and seat dimensions may be found in the Commonplace-book. Compare the per cents of release, compression, and admission shown by the valve-diagram and by the indicator-card.

144. Steam-distribution of Locomotive Link-motion.—The Stephenson link-motion is in almost universal use in this country for locomotive valve-gears. Since the economy of the machine is, in a measure, dependent on the steam-distribution, the design of a link-motion which will give a suitable distribution at all cut-offs is a matter of importance in locomotive design.

The object of this experiment is to investigate the distribution of steam given by a link-motion of proportions similar to those used in locomotive practice. The apparatus consists of a model link-motion, so constructed that it can be set to the dimensions of the valve-gear of any locomotive in regular service.

Specific Directions.—The experiment consists in placing the reverse-lever in different positions and noting the per cents of stroke at which the several events occur. The events to be determined are (1) admission, (2) cut-off, (3) release, and (4) compression for each end of the cylinder and each notch of the reverse-lever, forward and back. The events are determined with reference to the per cent of piston travel accomplished when they take place. To this end the piston is provided with a scale graduated in 100 parts. All events for the head end are said to take place when the piston is at certain per cents of its travel *from* the head end, whether the piston is moving from or to the head end (see Fig. 44). Note that when the crank is uppermost and moving toward the cylinder the model is "running forward."

Commence at the longest cut-off, running forward, and proceed with each notch in turn as far as time will permit. Be careful to reverse the motion of the model when the reverse-lever passes the center notch. The Report should correspond to the following form:

145. Form.

REPORT ON STEAM-DISTRIBUTION OF LOCOMOTIVE LINK-MOTION.

Observers { ....
....

Date........

	Head End.				Crank End.			
Number of Notch.	Adm.	Cut.	Rel.	Comp.	Adm.	Cut.	Rel.	Comp.

146. Indicated Horse-power.—The factors in the indicated horse-power of an engine are the size of the cylinder, the revolutions per minute, and the mean effective pressure on the piston. Its determination involves the taking of indicator-cards and simultaneous readings of the speed for a sufficient length of time to secure observations showing the average performance of the engine. From the data thus secured the indicated power may be calculated.

Specific Directions.—This test should be conducted by two men, one taking indicator-cards and the other speed readings. These positions may be interchanged half-way through the test. The accessory apparatus needed is an indicator, a speed-counter, and a whistle. Prepare the blank log-sheet according to the form shown below. Before the test it will not be necessary to rule up more than the portion headed Running Log, leaving space for the other data as shown. Before the test read carefully Sections 120 and 148 on the use of the indicator and the care of the engine. Make the test forty-five minutes in duration, and take cards every five minutes. The speed-reading should be taken, beginning with the signal for the card and continuing for one minute.

After the test find the dimensions of the engine from the Commonplace-book. Calculate the M.E.P. from the cards by the method of ordinates as explained in Section 128. Find the indicated horse-power as explained in Section 131, using the average M.E.P. of the cards from each end.

Under the head of minimum and maximum horse-power, enter the horse-power shown by the cards having respectively the lowest and highest average M.E.P. for the two ends. Make out the report in the form shown below and accompany it with an average card, pasting the same to the report.

147. Form of

REPORT ON INDICATED HORSE-POWER

OF A ....

Observers { ....
{ ....

Date........

CONSTANTS OF THE ENGINE.

Dia. of cylinder......in. Area of piston, H. E.......sq. in.
Dia. of piston-rod......in. C. E.......sq. in.
Length of stroke......ft.

RUNNING LOG.

Number.	Time.	R. P. M.	M. E. P.		Remarks.
			H. E.	C. E.	
Total.....					
Average....					

	Average I. H. P.	Max. I. H. P.	Min. I. H. P.
H. E.	....	....	....
C. E.	....	....	....
Total.	....	....	....

148. Care of the Steam-engine.—The following are brief directions for the operation and care of the steam-engine. They are applicable in a general way to the ordinary types of stationary engines.

1. Inspect the engine, piping, etc., carefully, to see that the plant is in good order.

2. Fill lubricator with cylinder-oil and oil-cups

with engine-oil, and adjust the feed to the required amount. Oil around where necessary.

3. If condensing-engine, start air-pump and turn on cooling water to condenser.

4. Open cylinder and pipe-drains.

5. Start engine slowly and bring gradually up to speed. Shut drain-cocks.

6. Apply the load gradually as desired.

7. During the run watch lubricator and oil-cups. Feel the bearings occasionally. Use only enough cooling water to properly condense the steam.

8. After the run, remove the load gradually, stop engine and air-pump. Shut off condenser cooling water and stop lubricator and oil-cups. Open drains. Clean the plant thoroughly.

Lubricators.—In Fig. 53 is shown a sectional view of a sight-feed lubricator. The top and side connections lead to the steam-pipe, the latter at a point nearest the engine. Steam enters the upper connection, is condensed, and as water flows through the small curved pipe to the bottom of the large chamber, which is filled with oil. The oil thus displaced enters the top of the second small pipe, flows downward by the regulating-valve, rises through the glass, which is filled with water, and reaches the main steam-pipe through the side connection. In filling the lubricator it is necessary to shut off the regulating-valve and the valve in the upper connection. The oil-chamber may then be drained and filled. The left-hand glass serves to indicate the level of oil in the chamber. If the sight-feed glass becomes clogged with oil, it may be cleaned by shutting the feed-regulating valve and opening the small valve immediately to the right of

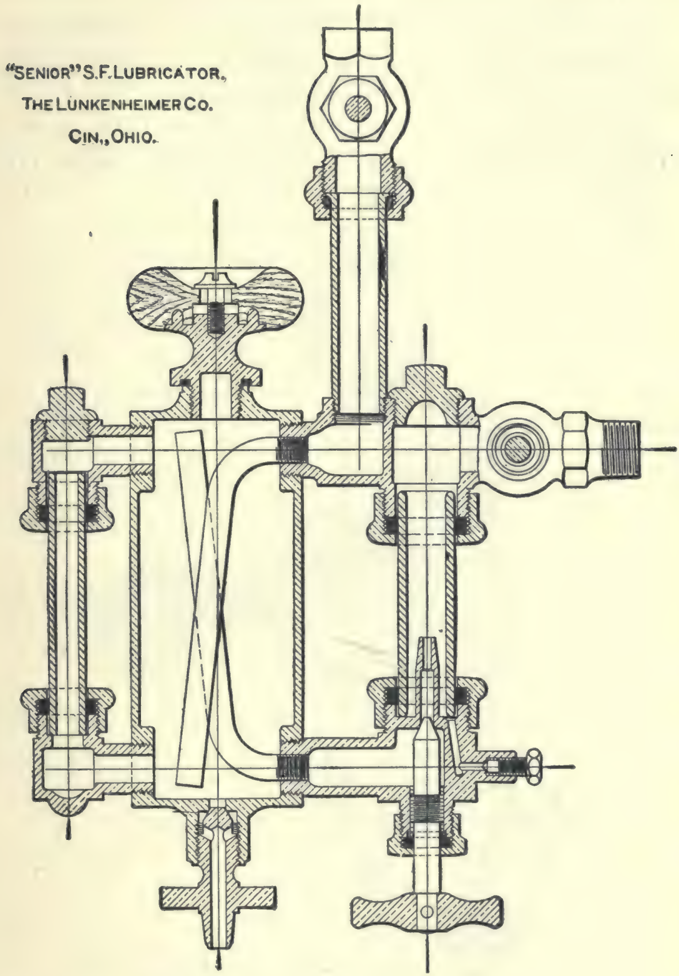

FIG. 53.—LUNKENHEIMER LUBRICATOR.

the latter. Steam will then blow through from the main steam-pipe and clean the glass. On closing the small valve allow the glass to fill with water of condensation before opening the feed-valve.

In Fig. 54 is shown a lubricator of another make. This instrument is fitted with a condensing-bulb *A2*,

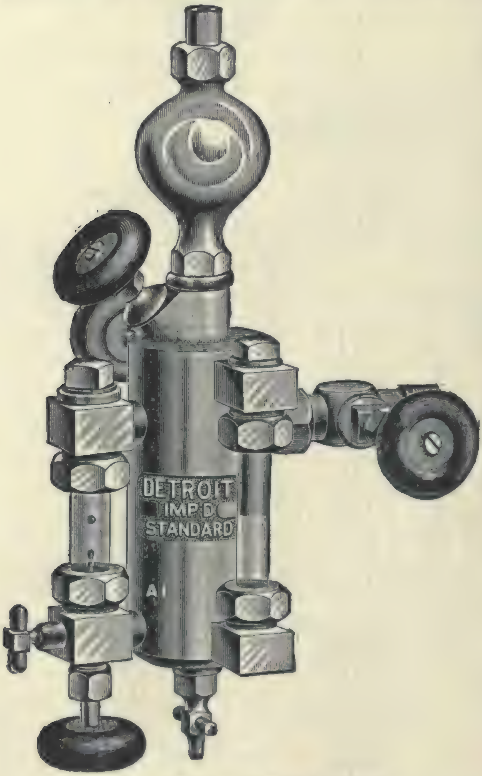

Fig. 54.—Detroit Lubricator.

the latter being provided with a valve *A4* between it and the body of the lubricator. In filling the oil-chamber this intermediate valve is closed, thus retaining the water of condensation in the condensing-bulb.

149. Friction of the Mechanism.—All the power developed in the cylinder of the steam-engine reappears at the brake-wheel except that absorbed by the friction of the mechanism. The purpose of this test is to determine the ratio between this frictional horse-power (F.H.P.) and the indicated horse-power (I.H.P.). The method consists in taking simultaneous observations of the indicated and brake horse-powers under the conditions of running for which the friction is desired.

In case it is impossible to fit the engine with a brake, the friction of the engine may be found when the engine is running light by observing the I.H.P. under no load. This, however, does not represent the friction when the engine is under load, since that quantity varies somewhat under different conditions of running.

Specific Directions.—Run twelve tests, the first to be under no load, the twelfth to be under the maximum load, and the remainder to be under loads distributed between the first and twelfth. The tests should be four minutes in duration, witn cards and observations every two minutes. The auxiliary apparatus needed is an indicator, a speed-counter, and a whistle.

Prepare a Running Log in accordance with the following form:

RUNNING LOG.

Test No.	No. of Gong.	Time.	No. of Card.	Steam pressure.	R.P.M.	Brake Load.	M. E. P.	
							H. E.	C. E.

Before the test read Section 120 on the use of the indicator and Section 148 on the care of the engine. Start the engine slowly under no load, and after the proper conditions are obtained take a few preliminary cards before commencing the test.

The Report should include the Running Log, sample cards, a statement of the dimensions and constants of the engine, and the calculated results. It should be made out in accordance with the form given below. The directions for finding M.E.P. are given in Section 129; for I.H.P. in Section 131; for B.H.P. in Section 68 *et seq.*

The formula for mechanical efficiency is

$$100 \times \frac{\text{B.H.P.}}{\text{I.H.P.}}.$$

Accompany the report by two curves, one showing the relation between F.H.P. and I.H.P.; the other, the relation between mechanical efficiency and I.H.P. These should be plotted on a single sheet of plotting-paper.

150. Form of

REPORT ON FRICTION TEST

OF...

Observers { ....
.... *Date*........

Dia. of cylinder......in. Area of piston, H. E.......sq. in.
Dia. of piston-rod......in. C. E.......sq. in.
Length of stroke......ft.

SUMMARY OF RESULTS.

No. of Test.	Steam-pressure.	R. P. M.	I. H. P.	B. H. P.	F. H. P.	Mechanical Efficiency.
1						
2						
3						
4						
etc.						

151. Commercial Efficiency.—The commercial efficiency of the steam-engine is usually expressed as the number of pounds of dry steam used per I.H.P. per hour, or sometimes per B.H.P. per hour. To determine this quantity it is necessary to run the engine under the conditions which it is desired to investigate and measure the I.H.P. and the water-consumption. To this end the engine must be fitted with an accurate indicator reducing-motion, and the indicators, preferably one for each end of the cylinder, should be placed as close to the cylinder as possible to avoid the errors due to long connections. An absorption-dynamometer should be provided to absorb and measure the work done by the engine. The steam-consumption is preferably obtained by leading the exhaust-steam to a surface condenser, where it may be collected as water and weighed. The condenser may or may not be fitted with an air-pump. A calorimeter of some approved form, such as the throttling calorimeter, should be provided to determine the quality of steam used (see Section 59). This should be located as close to the engine as possible. In case the accessory apparatus, such as gages, thermometers, indicator-springs, and weighing-barrels, have not previously been calibrated, this must be carefully done before the test, keeping record of all results.

Specific Directions.—Observers will be needed for the test in accordance with the following schedule:

1. Log and time } in charge.
2. Weight of steam }
3. Indicator, head end.
4. Indicator, crank end.
5. Speed and load.

6. Miscellaneous observations.

Secure the following accessory apparatus: Two indicators with springs to suit steam-pressure (see Section 119), indicator-cards, one speed-counter, one whistle, one 212° F. thermometer, and one 400° F. thermometer if a throttling calorimeter is used. Prepare the blank Running Log, making provision for the following items:

1. Time.
2. R.P.M.
3. Brake load.
4. Back pull on brake (if any).
5. Steam-pressure.
6. Vacuum (if any).
7. Barometric pressure.
8. Pressure in calorimeter.
9. Temperature in calorimeter.
10. Temperature of room.
11. Weight of condensed steam.

The test should be from one hour to one hour and a half long, depending upon the constancy of the running conditions. Observations and cards should be taken every five minutes. Before the test, read Section 120 on the use of the indicator and Section 148 on the care of the engine. Having the indicators in place and observers posted, start the engine and secure the desired running conditions. Start the test by taking time, cards and observations and commencing the weighing of water.

During the test keep all running conditions as constant as possible. Watch the lubricator and oil-cups. Keep only sufficient cooling water on the condenser to prevent the condensed steam from vaporizing as it emerges. After the test, stop the engine, shut off the cooling water from the condenser, stop the lubricator and oil-cups, remove and clean the indicators, collect all logs and cards, and see that the former are dated and signed with the initials of the observer.

Report.—The Report should be accompanied by the Running Log or Logs, and all cards taken. It should include the following items:

CONSTANTS OF THE ENGINE.

Type of engine.	Clearance (both ends).
Make of engine.	Kind of brake.
Size of cylinder.	Brake constants.
Diameter of piston-rod.	Make of condenser.
Area of piston (both ends).	Make and numbers of indicators.
Piston-displacements.	Scale of spring.
Engine constants.	

OBSERVED DATA.

Averages.

Duration of test.	Barometer.
Steam-pressure.	Pressure in calorimeter.
R.P.M.	Temp. in calorimeter.
Brake load, net.	Temperature of room.
Vacuum.	Wt. of cond. steam (total).

CALCULATED DATA.

Mean effective pressure. H.E. and C.E. (Section 129).

Indicated horse-power. H.E. and C.E. (Section 131).

Indicated horse-power, total.

Brake horse-power (Section 68).

Frictional horse-power (Section 161, item 16).

F.H.P. in per cent of I.H.P.

Ratio of B.H.P. to I.H.P.

Quality of steam (Section 59).

Pounds of dry steam per I.H.P. per hour, by tank (Section 161, item 12).

* Pounds of dry steam per I.H.P. per hour by indicator (Section 161, item 11).

* Clearance from the card (Section 135).

In case no calorimeter is available, the steam may be assumed to be 98 per cent dry if the distance from boiler to engine is not great and the steam-pipe is well covered.

152. Investigation of Cylinder Losses.—In more extended investigations of steam-engine performance than that described in the preceding section, it is customary to make an analysis of the action of the steam in the cylinder, with a view to discovering the losses occasioned by changes of condition of the steam, interchange of heat between the steam and the cylinder-walls and kindred causes. One method of making a complete investigation of such losses is known as Hirn's Analysis.† Another method is the Entropy Temperature Analysis.‡

In order to determine the change in condition of the steam during different parts of the cycle, the

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* Calculate the weights of steam for this item for a pair of sample cards whose combined M.E.P. corresponds most nearly to the average for the test. The clearance is found from the same cards.

† See Peabody's "Thermodynamics of the Steam-engine," page 185.

‡ "Entropy Temperature Analysis of Steam-engine Efficiencies," by Reeve.

following items must be added to the "Calculated Data" as given in Section 151.

Absolute pressure at cut-off, head and crank end (average of all cards).

Absolute pressure at release, head and crank end (average).

Absolute pressure at compression, head and crank end (average).

Per cent of stroke at cut-off, head and crank end (average).

Per cent of stroke at release, head and crank end (average).

Per cent of stroke at compression, head and crank end (average).

Weight of steam per revolution at cut-off (Section 161, item 2).

Weight of steam per revolution at release (Section 161, item 3).

Weight of steam per revolution at compression (Section 161, item 4).

Reevaporation per revolution (Section 161, item 5).

Reevaporation per I.H.P. per hour (Section 161, item 6).

Weight of steam per revolution by tank (Section 161, item 7).

Weight of mixture in cylinder per revolution, maximum (Section 161, item 8).

Per cent of mixture accounted as steam at cut-off (Section 161, item 9).

Per cent of mixture accounted as steam at release (Section 161, item 10).

In case it is desired to use Hirn's Analysis, the following observations will need to be added to the Running Log, as given in Section 151:

Weight of cooling water.

Initial temperature of cooling water.

Final temperature of cooling water.

Temperature of condensed steam.

153. Method of Measuring Clearance.—The clearance of a steam-engine cylinder is all of the clear space between the piston and the face of the valve, when the piston is at the beginning of its stroke. It is usually expressed as a per cent of the piston-displacement, and should be found for each end of the cylinder. The piston-displacement for each end is the area of the piston on that end in square feet, multiplied by the length of the stroke in feet.

The method of determining the clearance consists in placing the engine on center and filling the clearance-space with water, noting the weight required to fill. Knowing the temperature of the water, the volume can then be found. This volume divided by the piston-displacement for that end and multiplied by 100 will give the per cent of clearance for the cylinder end under consideration.

The process of getting the water into the cylinder depends largely upon the construction of the engine. It must be poured in at the highest point of the cylinder in order to avoid entrapping air in the clearance-space.

For a plain slide-valve engine, with the valve-box on the side, it may usually be poured in through the indicator-cocks. In such a case it will be necessary to disconnect the valve-rod and adjust the valve to cover the ports, clamping it in place. A block of wood with a rubber gasket may be used instead of the valve. For a slide-valve engine with the valve on top it is best to remove the valve-box cover and valve, and pour in through the port. For a Corliss engine, remove the steam-valves and use the ports thus exposed. In general an examination of the engine will suggest the course to be followed.

Specific Directions.—Provide two cans of water, *a* and *b*, weigh each carefully and note the temperature. With *a* fill the clearance-space as rapidly as possible and note the time occupied in filling. Then with *b* pour in to replace that lost by leakage, maintaining the level for one minute from the time the original filling was completed. Weigh both cans and note the weight of water used.

The weight used from can *a* will represent the weight required to fill the clearance-space, subject to the following correction: One half the amount used from can *b*, multiplied by the time in minutes occupied in the original filling, may be assumed to have leaked out during the original filling, and this amount is to be subtracted as a correction from the weight used from can *a*. From the corrected weight thus obtained and the temperature, the volume may be calculated.

If the correction to be made is large, the result will be only approximately correct. In such a case it may be well to attempt to stop the leakage, which is usually between the piston and the cylinder, by oiling the cylinder thoroughly with a heavy oil. It is often thought necessary that the engine be warmed up by steam before the clearance is obtained, that working conditions may be had, but it is doubtful if such a precaution is necessary.

154. Advanced Work in Steam-engine Testing. —*Effect of Load on Economy.*—To determine the most economical load for a given speed and steam-pressure, run a series of five tests at a constant speed and steam-pressure to be assigned by the instructor. For the first test let the load be zero. For the fifth test, let the load be as large as can be carried under the assigned conditions, and let the intermediate tests be under intermediate loads. The directions will assume that a condenser is employed to measure the water-consumption.

All tests should be of 30 minutes' duration, the conditions to be maintained for 15 minutes before the test begins, and the test to be conducted and worked up in all respects as explained in Section 151.

The Report should include:

1. A statement of the purpose of the tests.

2. A brief description of the plant.

3. A statement of constant conditions.

4. A copy of all calibrations, measurements, and observed data.

5. A tabulated statement of calculated results.

6. Curves showing the following relations:

(*a*) Indicated and brake horse-power with per cent of cut-off (if an automatic cut-off engine).

(*b*) Pounds of steam per I.H.P. per hour with indicated and B.H.P.

7. Conclusions as to the most efficient load under the conditions.

8. Sample cards.

Effect of Different Steam-pressures on Economy.—To determine the effect of different steam-pressures on the economy of a steam-engine, run a series of five tests at constant speed and two-thirds load under steam-pressures ranging from 40 to 160 pounds pressure.

Make all tests 30 minutes in duration, and let the conditions be maintained for at least 15 minutes before the test is begun. The tests should be conducted and worked up as described in Section 151.

The Report should include the following:

1. A statement of the purpose of the tests.

2. A brief description of the plant.

3. A statement of the constant conditions.

4. A copy of all calibrations, measurements, and observed data.

5. A tabulated statement of calculated data.

6. Curves showing the following relations:

(*a*) Indicated and brake horse-power with steam-pressure.

(*b*) Steam-consumption with steam-pressure.

155. Tests of Compound Engines.—The purpose of, and methods employed in, compound engine-testing are similar to those relating to the simple engine. Read the introductory portion of Section 151.

Specific Directions.—Observers will be needed for the test in accordance with the following schedule:

1. Log and time } in charge.
2. Weight of steam }

3. Indicators, high-pressure, head and crank.

4. Indicators, low-pressure, head and crank.

5. Revolutions, pressures, and miscellaneous observations.

6. Brake load.

Secure the following accessory apparatus: Four indicators with springs to suit steam-pressure (see

Section 119), indicator-cards, whistle, thermometers for temperature of room, and calorimeter.

Prepare the blank Running Log to cover the following items:

1. Time.
2. Counter or R.P.M.
3. Brake load.
4. Steam-pressure.
5. Pressure in receiver.
6. Vacuum.
7. Barometer.
8. Pressure in calorimeter.
9. Temperature in calorimeter.
10. Temperature of room.
11. Weight of condensed steam.

Conduct the test as specified in Section 151. The Report should cover:

1. Constants of the engine.
2. Running logs, averaged.
3. Tabulated data from cards showing M.E.P. and pressures and per cents of stroke at the different events (see Section 130).
4. Calculated data.
   Indicated horse-power, H.P., L.P., and total.
   Brake horse-power.
   Frictional horse-power.
   F.H.P. in per cent of I.H.P.
   Ratio of B.H.P. to I.H.P.
   Quality of steam.
   Pounds of dry steam per I.H.P. per hour by tank.
   Number of expansions in H.P.C.
   Number of expansions in L.P.C.
   Total number of expansions.

Ratio of work done in H. P. C. to that in L. P. C.
Ratio of maximum pressure on H.P. piston to maximum pressure on L. P. piston.
Initial pressures, H.P.C. and L.P.C.
Final pressures, H.P.C. and L.P.C.
Drop in pressure, H.P. final to L.P. initial.
Weight of steam at cut-off, H.P.C. per revolution.
Weight of steam at release, H.P.C. per revolution.
Weight of steam at cut-off, L.P.C. per revolution.
Weight of steam at release, L.P.C. per revolution.
Reevaporation during expansion, H.P.C.
Reevaporation during expansion, L.P.C.
Condensation (or reevaporation) between cut-off H.P.C. and cut-off L.P.C.

5. Present a representative set of cards.
6. Take head-end cards from same set (item 5) and plot to same scale of pressures and volumes (see Section 136).

156. Directions for Equalizing the Work of a Compound Engine.—The work done by the cylinders of a compound engine should be equally distributed between the two cylinders. This condition will be realized when the mean effective pressures are inversely proportional to the areas of the cylinders, the length of stroke being the same.

The method of equalizing the work is as follows: Take simultaneous cards from both cylinders and determine the average M.E.P. If the ratio between them is not inversely proportional to the cylinder areas, and it is found, for instance, that the M.E.P. of the L.P. cylinder is too small, shorten the cut-off on the L.P. cylinder. This will increase the back-pressure on the H.P. cylinder and increase the initial pressure of the L.P. cylinder. Take another set of cards, and if not correct, repeat the process.

In reporting results give:

1. A statement of the result to be accomplished.

2. A tabulated statement as below:

	M. E. P.—H. P. C.			M. E. P.—L. P. C.			Ratio of M. E. P. in H. P. C. to that in L. P. C.
	H. E.	C. E.	Ave.	H. E	C. E.	Ave.	
Eng. as found.							
1st change....							
2d change....							
Etc.							

3. A statement of the maximum piston-pressures after equalization.

157. Locomotive Testing.—Tests of locomotives are of two general kinds, those made on the road under conditions of actual service and those made on specially devised testing plants, where the engine may be placed under conditions similar to those met with in road service. For all tests involving an accurate determination of the engine and boiler performance the shop test is to be preferred, since by that method all conditions may be maintained with great constancy, a feature impossible with road tests.

The method of conducting the tests on the road varies according to the purpose for which the test is made, but for all ordinary road tests the following method, recommended by the American Society of

Mechanical Engineers,* is standard. The code provides for both road and shop tests.

158. A. S. M. E. Standard Method of Testing Locomotives.

I. Preparations for Test, and Location of Instruments.†

A. The locomotive should be put in good condition preparatory to the test. The boiler and tubes should be tight, and both the interior and exterior surfaces should be clean, and if possible free from scale. There should be no lost motion in the valve-gear, and the valves should be set properly. No change in the engines should be allowed during the progress of a series of tests, unless so ordered for the purposes of the trial.

A glass water-gage should be fitted to the boiler, if not already provided. A rod should be attached to the reversing-lever and carried forward to the front end of the boiler, where a graduated scale is provided and suitably marked, so that the position of the reversing-lever can be seen at a glance by the person taking indicator-diagrams. The throttle-valve lever should be provided with a scale to show the degree of opening of the throttle.

B. The valves and pistons should be tested for leakage with the engine at rest. The steam-valve can be tried by setting the engine so that the valve on one side will be at the center of its throw, in which

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* Transactions of the American Society of Mechanical Engineers, vol. XIV, p. 1312.

† The directions here given apply largely to both shop and road tests, but especially to the latter.

position both ports are usually covered, and pulling open the throttle-valve, blocking the drivers if there is a tendency for the engine to be set in motion. Leakage of the valve, if any occurs, will show itself by escaping at the smoke-stack, or at the open drain-cocks. The tightness of the piston may be tested by setting the engine so that it takes steam, blocking the drivers, and opening the throttle-valve. This should be tried first on one cylinder and then on the other, and if desired, it may be tried with the pistons at various points in the stroke. The leakage, if any occurs, will be shown either at the top of the smoke-stack or at the open drain-cock.

C. The following instruments should be verified or calibrated: Steam-gages, draught-gage, pyrometer, thermometers for calorimeter and feed-water, water-meter, tank, revolution-counter, indicator-springs, dynamometer-springs, and dynamometer recording mechanism. The radiation loss on the steam-calorimeter should be determined or the normal readings ascertained;* and the quantity of steam which passes through the instrument in a given time should be measured.

D. The quantities of steam consumed by the air-pump, the blower, and the whistle, under conditions of common use, should be determined, thereby obtaining data by which to correct for the steam thus used. This can best be determined for each one by observing the fall of water in the gage-glass when no steam is drawn from the boiler for any other purpose, the quantity being computed from the data thus

* Transactions A. S. M. E., vol. XI, p. 793.

found, and the dimensions of the boiler. The leakage of the boiler should also be found, using the same method.

E. To facilitate the measurement of coal and the determination of the quantity used during any desired period of the run, it is desirable to provide a sufficient number of sacks of a size holding a weight of, say, 100 pounds, and weigh the coal into these sacks preparatory to starting on the test. If desired, the sacks may be numbered, to facilitate the accuracy of record.

F. The instruments and other apparatus that should be provided, and their locations, are as follows:

To facilitate the work of operating the indicators and reading the instruments at the front end, the smoke-box should be surrounded with a wooden fence, or "pilot-box," as it may be called, resting on the top of the cow-catcher and extending back far enough to enclose also the sides of the cylinders. This box is floored over, and the enclosure thus provided forms a convenient place for the accommodation of the assistants at this end of the locomotive, and it affords them some measure of protection against wind and rain, as also the jolting and vibrations due to rapid travel.

A special steam-gage with a long siphon is to be used for registering the boiler-pressure. It can best be located on the left-hand side of the cab.

The indicator apparatus which is most suitable consists of a three-way cock for the attachment of the indicators, and some form of pantograph motion for the driving-rig. The pipes leading from the cock to the cylinder should be three-fourths inch diameter inside, and they should connect into the side of the cylinder rather than into the two heads. The indicator should also be piped so that a steam-chest diagram can be drawn by it. Sharp bends in the pipe should be avoided, and they should be well covered, to intercept radiation. The three-way cock should be provided with a clamp rigidly secured to the cylinder, and thus overcome any tendency of the indicators to move longitudinally with reference to the driving-rig. Absolute rigidity is highly essential in this particular. In both of these the reduced motion is transmitted to the indicator through a light rod, working horizontally. By this means a cord eight or ten inches in length is sufficient for connection to the indicator. Care should be taken to set the instrument in such a position that the cord-pin in the end of the rod travels in a direction pointing to the groove in the paper drum. Pantograph motions arranged as noted are preferable to the common pendulum and quadrant reducing mechanism, with its long stretch of cord.

A draught-gage consisting of a U tube containing water, properly graduated in inches, should be connected to the smoke-box and attached to the side of the pilot-box.

A pyrometer for showing the temperature of the escaping gases should be used in a position below the tip of the exhaust-nozzles.

The calorimeter should be attached either to the steam-dome at a point close to the throttle-opening, or to the steam-passage in the saddle-casting on one side, according as it is desired to obtain the character of the steam at one point or the other. The former location is preferred by the committee. A perforated half-inch pipe should be used for sampling and conveying the steam to the calorimeter-pipe. For descriptions of various forms of calorimeters which are adapted to locomotive use, see Trans. A. S. M. E., vol. X. p. 327, vol. XI. p. 790, vol. XII. p. 825.

The water-meter should be attached to the suction-pipe of the injector, and located at a point where it can be conveniently read when the locomotive is running. It should be provided with a check-valve to prevent hot water from flowing back through it from the injector, and a strainer to intercept foreign material.

To measure the depth of the water in the tank, a metallic float should be used, carrying a vertical tube which slides upon a graduated rod, the lower end of which rests upon the bottom of the tank. This should be placed at the center of gravity of the water-space. If the desired location cannot be used, provision should be made for ascertaining the level or inclination of the tank. The best device for this purpose is a plumb-line of a certain known length, provided at the bottom with a double horizontal scale, having one set of divisions parallel to the side of the tank and the other set at right angles to it. From the readings on these scales referred to the length of the line the level of the tank in both directions can be ascertained. A similar device should be attached to the boiler to correct for the variation in its inclination. The plumb-line may be conveniently attached for this purpose at some point near the front end.

The revolution-counter should be placed near the front end of the engine in plain view from the pilot-box. It is operated through a belt from the driver shaft. This recommendation applies to that form of counter which shows at a glance the exact speed in revolutions per minute.

A stroke-counter should be provided for showing the number of strokes made by the air-pump.

Electric connection should be made between the dynamometer-car and the pilot-box, so that dynamometer records and indicator-diagrams may be taken simultaneously. Another provision is a speaking-tube leading from the dynamometer-car to the locomotive-cab, and one also to the pilot-box.

G. It is needless, except for a complete record of directions for preparatory work, to call attention to the desirability of having the test, especially the road test, made under the supervision of a competent person, who is not only familiar with the details of testing, but also with the proper method of firing and mechanical operation of the locomotive. This is a most important factor, for it is only the clear-headed and able experimenter who is likely to obtain satisfactory work in this most difficult department of engineering tests.

In the matter of assistants, the conductor of the test is best able to judge as to the number required, the various duties of the different men, and the manner of taking records. A good test can be made with eight (8) assistants, distributed in the manner indicated in the following list, which gives their duties:

Two (2) cab assistants, who note the reading of the steam-gage and the water-meter, the position of the throttle-valve and reversing-lever, the height of water in the tank, the height of water in the glass water-gage, the level of the tank, the number of times the whistle is blown, the length of time the safety-valve blows, the length of time the blower is in action, the reading of the air-pump counter, the temperature of the feed-water in the tank, the time of starting and stopping the injector, the time of opening and closing the throttle-valve, and the number of sacks of coal used. These two observers have previously checked the weights of coal placed in the sacks.

Three (3) pilot-box assistants, one of whom reads the pyrometer, the draught-gage, the steam-chest gage, the revolution-counter, and marks on the indicator-diagrams the time, position of reversing-lever, steam-chest pressure, and revolutions per minute. He also takes the levels of the boiler at stopping-places. The other two observers are stationed at the cylinders and manipulate the indicators, one being employed on each side.

One (1) calorimeter assistant, who reads the calorimeter thermometers, and the gages connected with the instrument, if these are employed.

Two (2) dynamometer-car assistants, who record time of each start and stop, time of passing each station and each mile-post, time of taking each indicator-diagram as obtained from signals of the indicator men; and all these readings are marked so far as possible on the dynamometer-paper. One of these men also assists the cab observer in reading the tank-depth and its levels at stopping-places. These men also keep a record of the direction and force of the wind, and the temperature of the atmosphere.

An additional assistant is required if the gases are sampled and analyzed.

H. It is of paramount importance, after the complete preparatory work has been accomplished, that the locomotive be subjected to a preliminary run, of sufficient duration to make a fair trial of the testing apparatus, and to give the various assistants an opportunity to become trained in their duties.

II. Shop Test.

A. Preparation and Location of Instruments.

In preparing for a shop test the preparations described in Section 1 should be followed so far as the nature of the test requires. When run as a stationary engine the locomotive is not circumscribed by the conditions of road service, and many provisions required on the road are unnecessary. It is unnecessary to determine the quantity of steam consumed by the whistle and air-pump, for these are not brought into use on the shop test; and no occasion exists for finding the quantity lost at the safety-valve, for on the continuous shop run the steam-pressure can be maintained at a uniform point, and blowing-off readily prevented. It is unnecessary to use sacks for the convenient measure of coal, because the coal can be readily weighed up in lots as fast as needed for the test. It is unnecessary to provide a "pilot-box," and no fixed location of the instruments is required, as on the road test. The feed-water may be weighed before it is supplied to the tank, and the tank may be used in this case as a reservoir, the float showing its depth. The meter would thus be unnecessary as the principal instrument of measurement, but a meter is in all cases useful as a check upon this most important element in the data. The long indicator-pipes required on the road test may be dispensed with, and one indicator applied close to each end of the cylinder, a practice much to be preferred to the use of a three-way cock and the single indicator. The dynamometer-car is not required, but its equivalent should be provided, consisting of a dynamometer which registers the pull on the draw-bar, in the same manner as the device used on the road.

The number of assistants required on a shop test is less than that needed for a road test. A good test can be made with four (4) assistants distributed as follows:

One (1) assistant for operating indicators.

One (1) assistant for measuring water.

Two (2) assistants for general observations and coal measurement.

If the gases are sampled and analyzed, one more assistant is required.

B. Conditions of Test.

The test should be continued for a run of at least two (2) hours from the time normal conditions have been established.

At the close of the test the water height in the boiler and the height of water in the tank should be the same as at the beginning, or proper corrections made for any differences which may exist.

The fire-box and ash-pit are then cleaned, and such unburnt coal as may be contained in the refuse is separated, weighed, and deducted from the total weight of coal fired. The balance of the refuse is weighed, as also the cinders removed from the smoke-box.

During the progress of the test samples of the various charges of coal should be obtained, and at its close a final sample of these should be selected, dried, and subjected to chemical analysis and calorimeter test. The weight of the sample is taken before and after drying, to ascertain the amount of moisture contained in the fuel.

C. The Data and Results.

The data and results of the shop test can best be arranged in the manner indicated in Table No. 1.

TABLE No. 1.

DATA AND RESULTS OF SHOP TEST ON.............. ENGINE, MADE............189

GENERAL DIMENSIONS, ETC.,

To be accompanied by a complete description, with drawings and full dimensions.

1. Kind of engine...............
2. Size and clearance of cylinders................
3. Area of heating-surface............
4. Area of grate-surface............
5. Diameter of exhaust-nozzles............

TOTAL QUANTITIES.

		Whole Run.
6. Duration..............................	hrs.	....
7. Weight of dry coal burned, including 0.4 weight of wood......................	lbs.	....
8. Weight of water evaporated corrected for moisture in the steam.................	lbs.	....
9. Weight of ashes and refuse from ash-pan.	lbs.	....
10. Weight of cinders from smoke-box	lbs.	....
11. Percentage of ash, as found by calorimeter test..........................	per cent.	....
12. Total heat of combustion per lb. coal as found by calorimeter test.............	B. T. U.	....
POWER DATA.		
13. Mean effective pressure, high-pressure cylinders..........................	lbs.	....
14. Mean effective pressure, low-pressure cylinders..........................	lbs.	....
15. Average revolutions per minute.........	rev.	....
16. Indicated horse-power, high-pressure cylinders..........................	H.P.	....
17. Indicated horse-power, low-pressure cylinders..........................	H.P.	....
18. Indicated horse-power, whole engine....	H.P.	....
19. Pull on draw-bar......................	lbs.	....
20. Dynamometer horse-power..............	H.P.	....

TABLE NO. 1—*Continued.*

AVERAGES OF OBSERVATIONS.		Whole Run.
21. Average boiler-pressure..................	lbs.	....
22. Average steam-chest pressure...........	lbs.	....
23. Average temperature of smoke-box......	deg.	....
24. Average draught-suction.................	in.	....
25. Average temperature of feed-water......	deg.	....
26. Average temperature of atmosphere.....	deg.	....
27. Average percentage of moisture in the steam..............................	per cent.	....
28. Maximum percentage of moisture in the steam..............................	per cent.	....
HOURLY QUANTITIES.		
29. Weight of dry coal burned per hour......	lbs.	....
30. Weight of dry coal burned per hour per sq. ft. of grate-surface..................	lbs.	....
31. Weight of coal burned per hour per sq. ft. of heating-surface.....................	lbs.	....
32. Weight of water evaporated per hour....	lbs.	....
33. Equivalent weight of water evaporated per hour with feeding-water at 100° and pressure at 70 lbs.................	lbs.	....
34. Equivalent weight of water from 100° at 70 lbs. evaporated per sq. ft. of heating-surface............................	lbs.	....
PRINCIPAL RESULTS, COMPLETE ENGINE AND BOILER.		
35. Coal consumed per I.H.P. per hour......	lbs.	....
36. Coal consumed per dynamometer horse-power per hour......................	lbs.	....
37. Weight of "standard coal" consumed per I.H.P. per hour..................	lbs.	....
38. Weight of "standard coal" consumed per dynamometer horse-power per hour..............................	lbs.	....
BOILER RESULTS.		
39. Water evaporated per lb. of coal.........	lbs.	....
40. Equivalent evaporation per lb. of coal from and at 212°......................	lbs.	....
41. Equivalent evaporation per lb. of combustible from and at 212°.............	lbs.	....

TABLE No. 1—*Continued.*

CYLINDER DATA.

42. Mean initial pressure above atmosphere.................lbs.

		H.P. Cyl.	L.P. Cyl.
43. Cut-off pressure above zero.......	lbs.	....	....
44. Release pressure above zero.......	lbs.	....	....
45. Compression pressure above zero..	lbs.	....	....
46. Lowest back-pressure above or below atmosphere................	lbs.	....	....
47. Proportion of forward stroke completed at cut-off.................	per cent	....	....
48. Proportion of forward stroke completed at release................	per cent	....	....
49. Proportion of return stroke uncompleted at compression	per cent	....	....

CYLINDER RESULTS.

51. Total water consumed per indicated horse power per hour corrected for moisture in steam........................lbs.
52. Water consumed per I.H.P. per hour by cylinders alone (from line 51, less all measured losses)................lbs.

		H.P. Cyl.	L.P. Cyl.
53. Steam accounted for by indicators at cut-off......................	lbs.	....	....
54. Steam accounted for by indicators at release......................	lbs.	....	....
55. Proportion of feed-water used by cylinders (line 52) accounted for at cut-off......................	lbs.	....	....
56. Proportion of feed-water used by cylinders accounted for at release........................	lbs.	....	....

So far as these are in common with the data and results obtained on the road test, the forms used on both kinds of test are identical.

Reports should give copy of a set of sample indicator-diagrams, also combined diagram (in case of multi-expansion engine), and a chart showing graphically the principal data.

III. The Road Test.

A. Preparation and Location of Instruments.

The preparations required for the road test, and the proper location of instruments for the purpose, are fully described in Section 1, and repetition is unnecessary.

B. The Dynamometer-car.

With a suitable dynamometer-car the force required to move the train, or the pull upon the draw-bar, is registered upon a strip of paper travelling at a definite rate per mile. The scale upon which this diagram is drawn should be as large as is possible within reasonable limits; a scale of ¼ inch per 1000 pounds pull being suitable, as the maximum registered pull rarely exceeds 30,000 pounds. The height of the diagram should be measured from a base-line drawn upon the paper by a stationary pen, so located that when no force is exerted upon the draw-bar the base-line should coincide with zero pull.

The apparatus should be arranged to make a record of time-marks in connection with the curve showing the pull. A chronometer should be provided, having an electric circuit-breaker, by means of which a mark is made on the dynamometer-paper every five (5) seconds. A better apparatus may be used in which a continuous speed-curve is traced upon the paper parallel to the curve of pull. The ordinates of this curve, measured from a base-line, give the speeds desired.

The location of mile-posts and other points along the route should be fixed upon the dynamometer-paper by employing an additional pen, and operating it by means of electric press-buttons, which are placed at convenient points in the car.

As already noted, a similar device should be provided for marking upon the dynamometer-paper the time of taking indicator-diagrams.

The rate of travel of the paper per mile should be such that one inch measured upon the diagrams represents 100 feet for short-distance work, and for long-distance work $\frac{1}{2}$ inch or $\frac{1}{4}$ inch should be used to represent 100 feet of track. The driving mechanism for the paper should be so arranged that it can be changed to give these proportions. It is necessary to have all the registering-pens located upon the same transverse line at a right angle with the direction of the movement of the paper, in order that simultaneous data may be recorded.

C. Method of Conducting the Road Test.

The locomotive having been brought to the train, the steam-pressure being at or near the working-point, the fire being clean and in good condition, though not over 4 to 6 inches thick, the ash-pan being also clean, observations are taken, say five (5) minutes before starting-time, of the thickness and condition of the fire, the height of water in the boiler, the depth in the tank, the levels, the water-meter, and the air-pump counter; and thereafter the regular observations are carried forward, and coal is fired from the weighed sacks.

Indicator-diagrams should be taken as frequently as possible, the intervals between them not being over two minutes.

Other regular observations should be taken at close intervals. Calorimeter readings, when taken, should be continued for at least five (5) minutes at one-minute intervals.

At water stations careful records should be obtained of water heights and levels of boiler and tank.

As the end of the route is approached, the fire should be burned down so as to leave the same amount and the same condition as at the start. When the end is finally reached, the fire should be raked, and its condition carefully noted. If it differs from that which obtained at the beginning, an estimated allowance must be made for such difference.

At the close of the test the height of water in the boiler should be the same as at the beginning, or if not, the difference, corrected for inclination of the boiler, should be allowed for.

During the process of weighing the coal into sacks numerous samples should be obtained, and a final sample of these selected. This is to be dried and subjected to chemical analysis and calorimeter test. The sample is weighed before and after drying, and data obtained for determining the weight of dry coal used during the test.

The duration of the road test is the length of time which the throttle-valve is open.

D. The Data and Results.

The data and results of the road test may be tabulated in a form corresponding in general with that recommended for the shop test; viz., Table No. 1.

159. Locomotive-testing Plants.—The first plant for testing locomotives * was established at Purdue

* A second locomotive-testing plant has been built by the

University in 1891. The plant was designed by Prof. W. F. M. Goss, and consists, in its elements, of a locomotive, mounted on supporting wheels (see Frontispiece) in such a way that it can be run under its own steam at speeds equal to those attained in actual service and under loads commensurate with its capacity. The load is supplied by four hydraulic friction-brakes of a type devised by Professor Geo. I. Alden, which are keyed on to the shafts of the supporting wheels and interpose a resistance to their motion. Work is thus furnished the locomotive, not in putting a section of track behind it, but in moving the top of the supporting wheels backward, a condition precisely similar in its effect to the load furnished by a train on the road. The maximum capacity of the four brakes is 800 horse-power.

The first effect of the retarding action of the brakes to the motion of the supporting wheels is the tendency of the locomotive to move forward with a force proportional to the retarding action. This forward tendency is opposed by the draw-bar which alone holds the locomotive on the supporting wheels and which is attached to an Emery dynamometer of 30,000 pounds capacity, made by Wm. Sellers & Co. (Fig. 27), which serves to measure the draw-bar pull. Thus the load, and consequently the speed, are very readily controlled by varying the amount of water flowing to the brakes.

The locomotive is fired with coal in the usual way, and is operated from the cab in a manner precisely similar to that employed on the road.

Chicago and Northwestern Railway at their Chicago shops. The general arrangement is similar to that employed in the Purdue plant.

The plant as originally built was destroyed by fire on January 23, 1894. It was immediately rebuilt in a new location with many added improvements, among which may be mentioned the provision for testing any locomotive built, up to eight wheels coupled. The locomotive originally purchased for use on the plant was sold to the Michigan Central Railway in June, 1897, and a new machine, known as Schenectady No. 2, was purchased in its stead. The following are its principal dimensions:

GENERAL DIMENSIONS.

Gage	4′ 8½″.
Fuel	Bituminous coal.
Weight in working order	107,200 lbs.
Weight on drivers	65,700 lbs.
Wheel-base, driving	8′ 6″.
Wheel-base, total	23′ 6″.

CYLINDERS.

Diameter of cylinders—simple	16″; compound, 16″ and 30″.
Stroke of piston	24″.
Diameter of piston-rods	2¾″.
Size of steam-ports	18″ × 1⅝″.
Size of exhaust-ports	18″ × 3″.
Size of bridges	1⅜″.

VALVES.

Kind	Allen-Richardson.
Maximum travel	6″.
Outside lap	1⅛″.
Inside lap	Line and line.

WHEELS AND JOURNALS.

Diameter of drivers, outside tires	69″.
Diameter and length of driving-journal	7½″ × 8½″.

BOILER.

Style	Extended wagon-top.
Outside diameter of first ring	52″.
Working pressure	250 lbs.
Thickness of plates	⅝″, ¾″, 9/16″, and ½″.
Grate-surface	17 sq. ft.
Heating-surface	1322 sq. ft.

160. Method of Testing.—The method of testing employed at Purdue is briefly as follows: The test on the boiler is conducted according to the alternate method prescribed by the A. S. M. E. The duration of the test is, except for very slow speeds, sufficient to give a total run of 100 miles. The water supplied the injectors is measured in carefully-calibrated barrels. The coal is weighed out to the fireman as needed. Two indicator-cards are taken on each cylinder and one on the right steam-chest. The cord-connections are short and the reducing-motion accurate. The draw-bar pull is measured by an Emery hydraulic dynamometer. The speed is measured by a revolution-counter and checked by a Boyer speed-recorder. The boiler and dry-pipe pressures are registered by carefully-calibrated gages, the former being checked by a Bristol recording-gage. The draft is measured by draft-gages and checked by a Bristol gage. A Bristol gage is also employed to record the exhaust-pressure. The quality of the steam is determined by a throttling-calorimeter on the dome, made in accordance with the recommendations of the Committee on Locomotive Testing of the A. S. M. E.

The temperature of the smoke-box gases is determined by two methods, the first making use of a Le Chatelier pyrometer, and the second employing the copper-ball calorimeter described in Section 56. A special device is employed to measure the amount of cinders thrown out of the stack.

Observers.—The plant is manned by a force consisting of one supervisor, one fireman, one assistant fireman, two brake-tenders, and observers to the number of ten. The duties of the latter are as follows:

a. Log and time.

b. Right-head indicator, Boyer recorder, Bristol gages, barometer and temperature of room.

c. Right-crank indicator and dry-pipe pressure.

d. Left-head indicator and draft.

e. Left-crank indicator, steam-pressure, and calorimeter.

f. Steam-chest indicator, counter, and brake-pressures.

g. Weight and temperature of feed-water.

h. Weight of coal.

i. Dynamometer.

j. Temperature of waste gases and weight of stack-cinders.

The following are the observations taken during the test:

Time.
Counter.
Dynamometer.
Brake-pressures.
Boiler-pressure.
Dry-pipe pressure.
Barometer.
Pressure in calorimeter.
Temperature in calorimeter.
Temperature of room.
Temperature of waste gases by calorimeter.
Temperature of waste gases by pyrometer.
Draft, gross.
Draft, net.
Weight of water delivered to injectors.
Overflow loss from injectors.
Temperature of feed.

Height of water in boiler.

Minutes injectors were in action.

Loss of steam by calorimeter.

Position of engine on supporting wheels.

Weight of coal fired.

Weight of stack-cinders.

During the test samples of waste gases and coal are taken for analysis. After the test the weight of cinders in the smoke-box and of the ash is found and a determination of surface-moisture in the coal is made. (See Sec. 111.)

161. Method of Working Up Locomotive Tests.—The method of working up herein described includes those items usually found in the report of an engine and boiler test, with the addition of certain others relating only to the locomotive. The data from the tests are preserved in the form of indicator-cards and running logs, accompanied usually by samples of the coal, ash, cinders, and smoke-box gases. Analyses of the samples are made according to the purpose for which the test was run. The results of the analyses are not included in the following calculations.

The Running, Water, and Coal Logs should first be averaged and all necessary corrections, such as those due to errors of gages, etc., applied. In averaging the columns carry the average to two places of decimals. Then transfer the results to the Summary-sheet.

The cards, except those from the steam-chest, should be treated as explained in Section 130. After the factors are determined and marked on the cards, transfer them to the Card Log. Add and average the columns and enter the results in pencil. In averaging columns carry the average to two places of decimals, except on the Per-cent Log, where they should be carried to three places of decimals. This should be checked. Then transfer to the Summary-sheet.

Fill in all items on the several logs before commencing calculation on the Summary-sheet.

In calculating volumes at the several events of stroke use the piston-displacements as given in the "Commonplace-book" to four places of decimals and express the volumes to four places.

In using the steam tables* carry all interpolations to the number of decimal places given in the table.

In calculating weights of steam, carry the result to four places of decimals.

In calculating horse-power use the H.P. constant to five places of decimals and carry the result to two places.

The calculated results appearing on the Summary-sheet are derived as follows:

1. *Indicated horse-power* is the product of the R.P.M., the indicated horse-power constant, and the M.E.P., the last two being for the cylinder-end in question. The total I.H.P. is the sum of the I.H.P. for the four ends.

2. *Weight of steam per revolution at cut-off* is the sum of the weights (per stroke) for each end at cut-off. The weight for one end is found by multiplying the weight of a cubic foot of steam at the absolute pressure of cut-off by the product of the piston-displacement for that end in cubic feet into the sum of the per cent of cut-off plus the clearance on that end. (See Sec. 133).

* See Peabody's "Tables of Saturated Steam."

3. *Weight of steam per revolution at release* is the sum of the weights for each end at release.

4. *Weight of steam per revolution at compression* is the sum of the weights for each end at compression.

5. *Reevaporation per revolution* is the difference between the weight of steam per revolution at release (3) and the weight of steam per revolution at cut-off (2). In case the reevaporation is negative, change the item to read "Condensation."

6. *Reevaporation per horse-power per hour* is the product of the reevaporation per revolution (5) and the average revolutions per hour, divided by the total horse-power.

7. *Weight of steam per revolution by tank* is the quotient of the total weight of steam used by the engine by the total number of revolutions for the test.

8. *Weight of mixture in cylinder per revolution* is the sum of the weight of steam per revolution by tank (7) and the weight of steam per revolution at compression (4).

9. *Per cent of mixture accounted as steam at cut-off* is one hundred times the weight of steam per revolution at cut-off (2) divided by the weight of mixture in cylinder per revolution (8).

10. *Per cent of mixture accounted as steam at release* is one hundred times the weight of steam per revolution at release (3) divided by the weight of mixture in cylinder per revolution (8).

11. *Pounds of steam per I.H.P. per hour by indicator* is the weight of steam per revolution at release (3) minus the weight of steam per revolution at compression (4) multiplied by the revolutions per hour and divided by the I.H.P.

12. *Pounds of steam per I.H.P. per hour by tank* is the weight of steam used by the engine per hour divided by the I.H.P.

13. *Distance equivalent to total revolutions* is the product of the total number of revolutions by the circumference of the drivers in feet divided by the number of feet per mile.

14. *Miles per hour* is the total miles (13) divided by the duration of the test in hours.

15. *Dynamometer horse-power* is found by multiplying the tractive horse-power constant (circumference of drivers in feet divided by 33000) by the average dynamometer-reading in pounds and by the R.P.M.

16. *Friction of engine in H.P.* is the difference between the I.H.P. and the dynamometer H.P. (15).

17. *Friction of engine in per cent of I.H.P.* is one hundred times the friction H.P. (16) divided by the I.H.P.

18. *Dynamometer work in foot-tons per pound of steam by tank* is found by dividing the distance run in miles (13) by the total weight of steam by tank and multiplying the result by 5280, giving the distance run in feet on one pound of steam by tank. This distance multiplied by the dynamometer-reading in pounds and divided by 2000, the number of pounds per ton, gives the desired result.

19. *Dynamometer work in foot-tons per pound of dry coal* is found as above, using total weight of coal in place of steam.

20. *Equivalent weight of train in tons* is found by dividing the corrected dynamometer-reading in pounds by the number of pounds assumed to be necessary to draw one ton (see Section 185).

21. *Equivalent number of loaded cars* is the total weight of train (20) divided by 33, the assumed weight in tons of a loaded car.

22. *Equivalent ton-miles* is the product of the weight of train in tons (20) and the total miles run (13).

23. *Pounds of coal per I.H.P. per hour* is the total pounds of dry coal fired divided by the product of the I.H.P. and the duration of the test in hours.

24. *Pounds of standard coal per I.H.P. per hour.* Standard coal is by definition a coal containing 12,500 B.T.U. per pound. Therefore pounds standard coal is to pounds actual coal (23) as the number of B.T.U. in a pound of actual coal is to 12,500.

25. *Pounds of coal per I.H.P. per hour per square foot of grate-surface* is found by dividing the pounds of dry coal per I.H.P. per hour (23) by the area of the grate-surface in square feet.

26. *Pounds of coal per dynamometer H.P. per hour* is the total weight of dry coal per hour divided by the dynamometer H.P. (15).

27. *Pounds of coal per mile run* is found by dividing the total pounds of dry coal by the total miles run (13).

28. *Pounds of coal per ton-mile* is the total pounds of dry coal divided by the product of the number of tons (20) and the total miles run (13) or by item (22).

29. *Pounds of water evaporated per hour* is found by dividing the total pounds of water delivered to the boiler by the duration of the test in hours.

30. *Pounds of water evaporated per pound of dry coal* is found by dividing the total pounds of water evaporated by the total pounds of coal fired.

31. *Equivalent evaporation from and at 212° F. per*

pound of dry coal is found by multiplying the actual evaporation (30) by the quotient obtained by dividing the B.T.U. per pound of water evaporated (34) by 965.8, which is the number of B.T.U. per pound of water evaporated from and at 212° F.

32. *Equivalent evaporation from 100° F. into steam at 70 pounds pressure* is found by multiplying the actual evaporation (30) by the quotient obtained by dividing the B.T.U. per pound of water evaporated (34) by 1110.2, which is the B.T.U. per pound of water evaporated under the above conditions.

33. *Equivalent evaporation from 100° F. into steam at 70 pounds, per square foot of heating-surface* is item (32) divided by the area of the heating-surface in square feet.

34. *B.T.U. per pound of water evaporated*, or B.T.U. required to evaporate one pound of water under the conditions of the test, is represented by the expression $x_1 r_1 + q_1 - q_2$, the value of which is found as follows: If the boiler-pressure is p_1 and the temperature of the feed-water is t_2, then the heat necessary to raise a pound of water from temperature t_2 up to and into steam at pressure p_1 will be q_1, which is the heat of the liquid at pressure p_1, minus q_2, which is the heat of the liquid at the temperature t_2, plus x_1 per cent of r_1, the heat required to vaporize one pound of water at the pressure p_1, where x_1 is equal to (1 minus the per cent of moisture in steam). (For values of r_1, q_1, and q_2 see steam tables.)

35. *B.T.U. taken up by boiler per minute* is the B.T.U. per pound of water (34) times the pounds of water evaporated per minute.

36. *B.T.U. taken up by boiler per pound of dry*

coal is 60 times the B.T.U. taken up by boiler per minute (35) divided by the pounds of dry coal fired per hour.

37. *B.T.U. taken up by boiler per pound of combustible* is found by multiplying item (36) by the ratio of coal to combustible.

38. *B.T.U. per I.H.P. per minute* is the B.T.U. taken up by boiler per minute (35) divided by the I.H.P.

39. *Pounds of coal per square foot of grate-surface per hour* is the pounds of dry coal per hour divided by the area of the grate-surface in square feet.

40. *I.H.P. per square foot of grate-surface* is the total I.H.P. divided by the grate-surface in square feet.

41. *Horse-power of boiler* is found by multiplying the B.T.U. per pound of water (34) by the pounds of water evaporated per hour and dividing by (30×1110.2), a H.P. being by definition equivalent to the evaporation of 30 pounds of water per hour at 100° F. into steam at 70 pounds pressure.

162. Test of Combined Engine and Boiler.—This test, embodying the elements of tests of large steam-plants, gives the student practice which will fit him to conduct the more elaborate tests. The plant consists of a small combined engine and boiler, the former provided with friction-brake and indicator-rig and the latter with calibrated feed-barrels and platform scales for weighing coal. A convenient arrangement of feed-barrels is to provide two barrels, one of which receives the supply through a suitable valve. This barrel is provided with a discharge-valve and an overflow-pipe and is calibrated to the top of the overflow. The second barrel fitted, with a gage-glass, is placed under the first barrel and receives its discharge. This barrel supplies the boiler. Since the plant is small, the method of conducting the test should be the Alternate Method prescribed by the American Society of Mechanical Engineers.

Specific Directions.—Two students will be assigned to this test. On the day of the test they will be assigned two assistants, to whom they may detail such observations as they choose. The necessary accessory apparatus is an indicator, speed-counter, thermometers for feed- and room-temperature, and a whistle. In making preparations to start the test the following order of procedure should be observed:

1. Secure the accessory apparatus mentioned above.
2. Prepare blank log.
3. Assign observers according to the schedule given below.
4. Place the indicator in position; fill oil-cups and lubricator, the former with engine-oil, the latter with valve-oil.
5. Determine upon brake load to be carried.
6. Weigh out a box of coal, broken to proper size.
7. Start the test as directed below.

The following list of assignments is recommended:

1. Log, time, and misc. observations } in charge.
2. Fireman }
3. Cards, brake load, and weight of coal.
4. Speed and weight of water.

The Log should contain the following items:

1. Time.
2. R.P.M.
3. Brake load.

4. Boiler-pressure.
5. Barometer.
6. Temperature of feed.
7. Temperature of room.
8. Pounds of water delivered to boiler.
9. Pounds of water lost from boiler (leakage and other loss).
10. Pounds of dry coal fired.

Having the apparatus in good working order, indicator in place, brake adjusted, oil-cups filled, and steam at the working pressure, start the engine, opening the throttle wide after a few minutes' run, and adjust the brake load to the amount previously determined upon. Start the test by taking the time, placing the marker on the water-level in boiler and in lower feed-barrel, and taking all observations except cards. The fireman should begin to fire from weighed coal and should note the depth and general condition of the fire, so that they may be duplicated at the end of the test. He should clean the ash-pan immediately after the start. The feed-measurer should, immediately after the start, fill the upper barrel to the point of overflow before beginning to replenish the lower barrel. During the test he should be careful to drain the upper barrel thoroughly before closing the drain-valve.

The test should be from two to four hours in duration. Observations should be taken every ten minutes and cards every fifteen minutes, the first to be taken five minutes after the start. Keep all conditions as constant as possible during the test. Watch the lubrication carefully and add a little water to the brake-wheel from time to time to supply that lost by evaporation. The fireman should seek to maintain an even steam-pressure and depth of fire and to keep the injector running continuously if possible.

Just before the close of the test see that the condition of the fire is the same as at the start and regulate the injector so that in the remaining minutes the water in the boiler will reach the initial level. Have the level in the lower feed-barrel slightly below the initial level. Stop the test by taking all observations except speed and shutting down the engine. Bring the water-level in the lower feed-barrel back to the starting-point and note the fraction of the contents of the upper barrel which has been used. Start the injector and fill the boiler to the third gage-cock. Clean the ash-pan and weigh the ash collected. Rake down the fire left on the grate into the ash-pan. Return all wrenches and oil-cans to their proper places, fill the feed-barrels, and leave the engine, boiler, and surroundings in good order.

The Report should cover the following:

Constants.

Date of test.

Name of maker of engine.

Diameter of cylinder.

Stroke of piston.

Diameter of piston-rod.

Engine-constant { H.E. / C.E. }

Radius of brake-arm.

Weight of brake-arm.

Diameter of boiler.

Number of tubes.

Diameter of tubes.

Length of tubes.

Distance from grate to lower tube-sheet.

Area of grate-surface.

Area of heating-surface.

Ratio of grate- to heating-surface.

Running Log.—In addition to the items given on page 219 under this head the following:

Quality of steam (assumed 98 per cent dry).

Pounds of water delivered to engine (see note on page 223).

Kind of coal.

Pounds of ash.

Calculated Results.—*a.* Ave. M.E.P., H.E.... C.E....

b. Indicated horse-power. H.E.... C.E.... Total....

c. Brake horse-power.

d. Frictional horse-power.

e. Same in per cent of I.H.P.

f. Pounds dry steam per I.H.P. hour by tank (Section 161, item 12).

g. Pounds of coal per I.H.P. hour (Section 161, item 23).

h. Pounds of water evaporated per pound of coal (Section 161, item 30).

i. Equivalent evaporation from and at 212° F. (Section 161, item 31).

j. Horse-power of boiler (Section 161, item 41).

k. Efficiency of boiler, $\frac{\text{B.T.U. in steam}}{\text{B.T.U. in coal}}$.

l. Efficiency of engine, $\frac{\text{B.T.U. in B.H.P.}}{\text{B.T.U. in steam}}$.

m. Efficiency of plant, $\frac{\text{B.T.U. in B.H.P.}}{\text{B.T.U. in coal}}$.

The report should be accompanied by a sample pair of cards.

The directions for working up the cards for M.E.P. and horse-power will be found in Sections 129 and 131.

The item pounds of water delivered to engine is the pounds delivered to boiler, as shown by the Running Log, minus the loss by leakage and through the calorimeter, if one be used.

CHAPTER XIII.

TESTING OF HYDRAULIC MACHINERY.

163. Tests of Steam-pumps. — The methods of arranging for and conducting tests of steam-pumps vary with the design of the plant and the data which it is desired to obtain. The method here described applies to a comparatively small plant fitted with a condenser.*

Both the steam- and water-cylinders of the pump should be fitted with indicators. If the pump is of the ordinary direct-connected type without fly-wheel, provision should be made to make regular observations of the length of stroke. This may easily be accomplished by fastening a pencil to the cross-head and preparing a board with strips of tough paper of suitable length so that the pencil may draw a line on the paper equal in length to the stroke. Provision must be made for measuring the quantity of water delivered and of regulating and determining the suction- and delivery-heads. The measurement of the water delivered may be accomplished by allowing it to flow over a suitable weir or through an orifice the coefficients of discharge of which are known.

Specific Directions. — The number of observers

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* For directions for conducting elaborate tests see report of committee of A. S. M. E., Trans., vol. XII. p. 530.

needed is eight and they should be distributed as follows:

1. Log and time } in charge.
2. Discharge-head }
3. Speed and length of stroke.
4. Quantity of water delivered (hook-gage).
5. Indicators, steam end.
6. Indicators, water end.
7. Weight of condensed steam.
8. Miscellaneous observations.

The Log should be made out to include the following observations:

1. Time.
2. Speed (double strokes per minute).
3. Length of stroke.
4. Steam-pressure.
5. Barometer.
6. Delivery-head.
7. Suction-head.
8. Temperature of discharge.
9. Temperature of room.
10. Volume of water discharged (hook-gage).
11. Weight of condensed steam.

The test should be at least an hour long, with observations every five minutes. The conditions of the test should be maintained for fifteen or twenty minutes before the test commences. Consult the instructor for conditions of head and speed.

Observe the usual precautions in starting the test. Maintain all conditions as nearly constant as possible during the test.

The Report should include, beside a copy of the Running Log, the following items:

Kind of pump.

Name of maker.

Dimensions and constants.

a. Duration of test.

b. Speed (double strokes per minute), average.

c. Boiler-pressure, average.

d. Delivery-head, average.

e. Suction-head, average.

f. Total head, average.

g. Temperature of delivery, average.

h. Cubic feet of water delivered per second.

i. Gallons delivered per 24 hours.

j. Horse-power delivered as shown by water pumped.

k. Indicated horse-power, steam-cylinder.

l. Indicated horse-power, water-cylinder.

m. Mechanical efficiency, (item $l \div$ item k) $\times$ 100.

n. Ratio of I.H.P. (water end) to delivered H.P., (item $j \div$ item l) $\times$ 100.

o. Steam per I.H.P. per hour.

p. Duty.

q. Slip in per cent of total volume swept through.

r. Sample cards.

The slip is found by deducting the volume of water pumped in a given time from the volume swept through by the pump-plunger in the same time.

The duty is the number of foot-pounds of work delivered by the pump per 1,000,000 B.T.U. supplied or it may be defined as the number of foot-pounds per 100 pounds of coal. Calculate the heat supplied from the amount of steam used by the pump and the heat per pound of steam at boiler-pressure, assuming 2 per cent of moisture, from which should be deducted the heat of the liquid corresponding to the temperature of the condensed steam.

164. Advanced Work on Steam-pumps.—To de-

termine the relation between duty and head with constant steam-pressure, run a series of three tests at constant steam-pressure and throttle-opening and with varying heads.

To determine the relation between duty and steam-pressure, run a series of three tests at constant head and throttle-opening and with steam-pressures ranging from 80 to 150 pounds.

Let the tests be conducted and worked up as specified in the preceding section. The Report should include a statement of the purpose of the tests, a description of the plant, a statement of the constant conditions, a copy of all observed and calculated data, a comparison of results in tabular and graphic form, and conclusions.

165. Tests of Centrifugal Pumps.—The test involves the measurement and comparison of the power supplied the pump and that delivered by the pump. The former quantity may be measured by some form of transmission-dynamometer (see Section 70). The delivered power is computed from the quantity of water delivered and the total head against which the pump works.

Specific Directions.—Provide a suitable dynamometer to measure the power supplied, means for controlling and measuring the head, and a weir-tank to measure the quantity of water delivered. The auxiliary apparatus needed is a whistle, two speed-counters, and a thermometer.

Prepare a Running Log with the following headings:

1. Time.
2. Discharge-head.
3. Suction-head.
4. Dynamometer-reading.

5. Depth of water over weir in feet (hook-gage).
6. Speed of pump.
7. Speed of dynamometer.
8. Temperature of water.

The Log should cover the above observations, together with the discharge-pressure and the position of the discharge-valve, indicated by the number of turns it is open.

The test should be from one hour to one hour and a half in duration, with observations every five minutes. The conditions of the test should be maintained for ten minutes before the test commences. For conditions of head consult the instructor.

The Report should include, beside a copy of the Running Log, the following items:

a. Duration of test.
b. Total head.
c. Average speed of pump.
d. Position of gate-valve.
e. Average temperature of water.
f. Cubic feet of water pumped per second.
g. Gallons pumped per hour.
h. Horse-power delivered by pump.
i. Horse-power supplied.
j. Efficiency of pump.
k. Efficiency of plant.

In case a line of counter-shafting is interposed between the dynamometer and the pump the pump-belt should be thrown off and a friction test made of the power absorbed by the counter-shafting. This should be subtracted from the horse-power as shown by the dynamometer to find that absorbed by the pump (item *i*). In calculating the horse-power delivered by the pump (item *h*) notice should be taken of the temperature of the water as affecting its specific weight.

166. Advanced Work on Centrifugal Pumps.—To investigate the relation of the efficiency of the pump to the head, run a series of three tests, the first to be under as low a head as can be obtained, the third to be under as high a head as can be obtained, and the second to be under a head midway between the first and third.

The tests should be twenty to thirty minutes in duration, the conditions to be maintained for ten minutes before the test begins.

The Report should include a statement of the purpose of the tests, sketch and description of apparatus, a statement of constant conditions, a copy of all observed and calculated data (as per Section 165), a comparison of results, including a curve showing relation between efficiency and total head, and conclusions as to the head at which maximum efficiency is obtained and the delivery of the pump at that head.

167. Tests of Turbine-wheels.—The method of testing prescribed in this section applies to turbine-wheels belonging to the classification known as reaction turbines, in which the system of piping in which the wheel is located is filled completely from high level to low level with water. The test involves the measurement and comparison of the power supplied and that delivered.

In Fig. 55 is shown a well-known form of turbine-wheel with housings.

Specific Directions.—The power supplied is determined from a consideration of the quantity of water used by the wheel and the head under which it operates. Provision should be made in the plant for controlling and measuring the head and a weir-tank

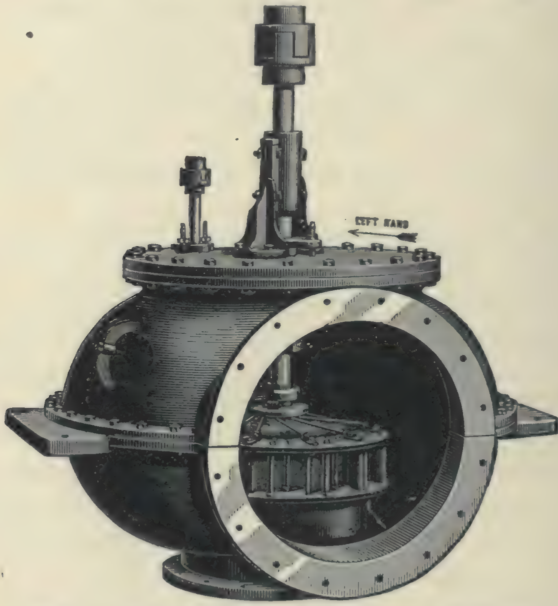

FIG. 55.—LEFFEL TURBINE-WHEEL AND HOUSING.

provided to measure the quantity of water used. The delivered power is measured by a suitable Prony brake. The auxiliary apparatus needed is a whistle, a speed-counter, and a thermometer.

Make out the Running Log to cover the following observations:

1. Time.
2. Head.
3. Speed.
4. Brake load.
5. Hook-gage.

6. Temperature of water.

7. Gate-opening.

The test should be from forty-five minutes to one hour in duration, with observations every five minutes, the conditions of the test to be maintained for ten minutes before the test begins. For conditions of head and load consult the instructor.

The Report should include, beside a copy of the Running Log, the following:

a. Duration of test.

b. Average total head.

c. Average speed.

d. Cubic feet of water used per second.

e. Pounds of water per minute.

f. Horse-power supplied.

g. Horse-power delivered.

h. Mechanical efficiency.

i. Velocity of water due to head.

j. Velocity of periphery of wheel.

Since the turbine receives not only the effect of the pressure-head, measured from the center of the wheel to the level of water in the head-race, but also that of the suction-head, measured from the center of the wheel to the level of water in the tail-race, the total head (item *b*) is the difference of level between the head-race and the tail-race.

In calculating the pounds of water discharged per minute (item *e*) notice should be taken of the temperature of the water as affecting its specific weight.

168. Advanced Work on Turbines.—To investigate the relation of head and speed to efficiency, run three series of tests, the first to be at a low head, the third at a high head, and the second intermediate.

Each series should consist of three tests at different brake loads.

Each test should be of from 20 to 30 minutes' duration, conditions to be maintained for 10 minutes previous to each test.

The Report should include a statement of the purpose of the tests, a sketch and description of the plant, a statement of the constant conditions, a copy of all observed and calculated data (as per Section 167), a comparison of results, including curves showing the relation of efficiency to speed with constant head and to head with constant speed, and conclusions as to conditions of speed and head giving maximum efficiency.

169. Tests of Impulse-wheels. The Pelton Wheel.—The Pelton water-wheel consists of a series of buckets of special form, secured to the periphery of a wheel, and receiving the impact of a jet of water.

FIG. 56.—PELTON BUCKET.

The form of the bucket is shown in Fig. 56, from which it is seen that the jet on striking the bucket is divided by the central rib into two portions, each branch being diverted on curves designed to secure the maximum efficiency of the jet. Fig. 57 shows the wheel with housing removed.

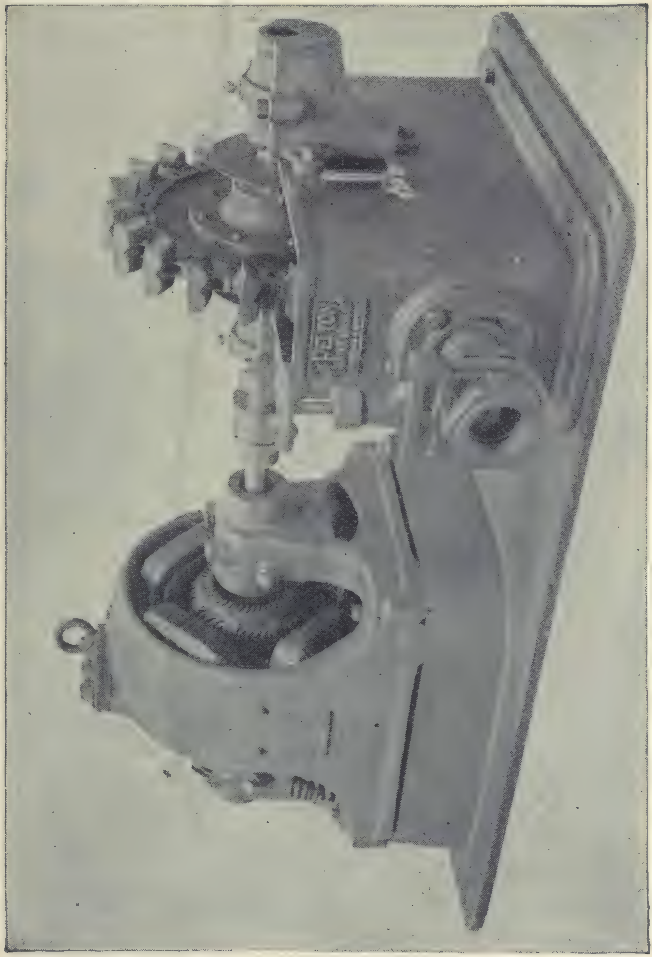

FIG. 57.—PELTON WHEEL WITH HOUSING REMOVED, SHOWING WHEEL AND DIRECT-COUPLED DYNAMO.

In arranging the wheel for testing it should be provided with a suitable brake and means for measuring the head under which the water is delivered. This may be conveniently done by delivering the water into a small stand-pipe from which, by a short connection, the wheel is supplied. The stand-pipe should be arranged with an air-chamber at the top, a gage-glass to show the exact level of the water, and a gage at the top of the air-chamber to measure the pressure at the water-level. A small cock should also be provided to adjust the water-level if necessary by allowing air to escape. The head on the wheel will be the gage-pressure reduced to an equivalent head plus the actual head of water measured from the center of the nozzle to the water-level in the stand-pipe.

Specific Directions.—Run a number of tests at constant head and variable brake load. Let the first load be as light as can be conveniently run. Let the second, third, etc., be under such loads as will successively reduce the speed by steps of 100 revolutions per minute. For conditions of head consult the instructor.

The tests should be of twenty minutes' duration, with observations every two minutes. The observations to be taken are:

1. Log and time.
2. Speed and load.
3. Head.

The Report should include, beside a copy of the Running Log, the following for each test:

a. Duration of test.
b. Effective diameter of bucket-wheel in inches.
c. Effective diameter of brake-wheel in feet.
d. Area of nozzle in square feet.
e. Average height of water in feet.

f. Average pressure on gage.

g. Average total head.

h. Average speed.

i. Average net brake load.

j. Foot-pounds of work delivered per minute.

k. Horse-power.

l. Cubic feet of water used per second.

m. Same in pounds per minute.

n. Foot-pounds of work done by water per minute.

o. Efficiency of motor.

In connection with the Report plot a curve showing the variation of efficiency with speed. The quantity of water used may be found by referring to Section 23, using the proper coefficient of discharge. The efficiency is 100 times the foot-pounds delivered per minute divided by those supplied.

170. Advanced Work.—For a more thorough investigation of the relation of efficiency to head and load the following tests should be run:

To determine the efficiency under different heads, run five series of tests as explained above, at heads of 60, 80, 100, 120, and 140 feet, each series to consist of three tests at different loads. The range of loads for the different series should be constant.

The duration of all tests should be twenty minutes, with observations every two minutes, the conditions of the test to exist five minutes before the test begins.

The Report should include a statement of the purpose of the tests, a sketch and description of the plant, a statement of constant conditions, a copy of all observed and calculated data (see Section 169), and a comparison of results, with curves showing variation of power and efficiency with head and speed.

CHAPTER XIV.

MISCELLANEOUS TESTS.

171. Tests of Internal-combustion Engines.—There are two tests suggested on internal-combustion engines, namely, Friction Tests and Commercial Efficiency Tests. The purpose of the friction test is to determine the relation between indicated horse-power and the mechanical efficiency and frictional horse-power. The commercial efficiency test includes a more elaborate and longer test, from which much information as to the performance of the engine while working under certain conditions of load, gas mixture, ignition, and jacket-temperature may be determined.

SPECIFIC DIRECTIONS FOR STARTING INTERNAL-COMBUSTION ENGINES.—Before giving the directions for taking the observed items, and methods of determining the calculated items, to be included in the report of a friction test or commercial efficiency test, the following instructions are given to aid the student in starting internal-combustion engines.

TO START THE OTTO GAS-ENGINE.

Fill oil-cups and oil all bearings.

See that the battery is in good condition, and test the spark by disconnecting the wires, making and breaking the circuit at their ends. A good, clear spark should result.

Prop up the governor by the small pawl under the governor-arm.

Remove the roller from under the ignitor-rod, letting the rod slide on the pin projecting from the end of the cylinder.

Throw the exhaust cam-lever back (away from the fly-wheel) to give a light compression.

Turn the gas on at the meter and at the engine by opening the mixing-valve.

After seeing that the brake is as loose as possible, turn the engine over by hand. This should result in an explosion which will start the engine.

Throw the exhaust cam-lever to its original position and replace the roller under ignitor-rod. Next, turn on the cooling water, adjust the brake-load at the desired amount, and see that a small amount of cooling water is running into the brake-pulley.

In taking indicator-cards, hold the pencil on the card for at least three explosions.

Note carefully the sequence of the explosions.

At the end of the test throw the battery circuit by means of the switch, shut off the cooling water to the jacket, and drain the jacket. Be sure that all gas- and water-valves are closed, and leave the engine in good condition.

TO START THE MERRIAM-ABBOTT GAS-ENGINE.

Fill oil-cups and oil all bearings, using cup grease in the force feed-cups on the top of cylinders.

Throw in the battery and test the spark.

Notice the air-pressure in reservoir, and, if less than 100 pounds, the air-pumps should be started.

Loosen the thumb-screw on the commutator and rotate the commutator clockwise, so as to make a late ignition.

Turn the sliding and rotating sleeve so as to give the largest opening for admission of air to the mixing-chamber.

Open the compression-valve on gas-cylinder, that is, the right-hand cylinder, and close the compression-valve on the left-hand or air cylinder.

Throw out the gas-admission valve by unscrewing the adjusting-rod with the locked nuts on top of the left-hand cylinder.

Screw down the adjusting-rod on the exhaust-lever of the same cylinder so as to open the exhaust-valve every revolution.

See that the check-valve for the admission of air into the air or left-hand cylinder is free to open. This is done by unscrewing the knurled lock-nut.

Place the cranks a little past the upper dead-center. This can easily be done when it is known that the keys in the shaft to hold the fly-wheels correspond in position to the position of the crank-pins.

Open the gas-valve a little.

Open the air-valve on the pipe between the air-reservoir and the left-hand cylinder. This cylinder should now work as an air-engine, and as soon as the other cylinder, that is the right-hand cylinder, is working satisfactorily as a gas-cylinder, close the compression-valve, shut off the air from the reservoir, and change the left-hand cylinder back to a gas-cylinder. This is accomplished by changing the exhaust-valve so that it is opened but once in two revolutions and by screwing down the adjusting-rod on the gas-admission valve, thus admitting the gas. Turn on the cooling water. Screw down the knurled nut on the check-valve so as to lock the valve shut.

Switch in the sparker, adjust the commutator to give early ignition, and fasten. Adjust the brake to the desired load, at the same time closing the air-valve to the mixing-chamber until the proper mixture is reached.

To stop the engine, close the gas-valve, throw out the switch, and turn off the cooling water to the jackets. Leave the engine in as clean a condition as possible.

TO START THE FAIRBANKS-MORSE ENGINE.

With Gasoline.

Fill oil-cups and oil all bearings.

Set the crank in such a position that the piston is toward the head end of the cylinder, having slightly advanced, say, about one half an inch from the head-end dead-center position. This will put the crank slightly above the dead-center. Care must be taken that this is the stroke which would be the explosion stroke. This can be determined by the location of the exhaust-cam, which should be just above the roller on the end of the exhaust-rod.

See that the air-valve in the pipe leading from the frame of the engine to the mixing-chamber is open.

Throw in the switch so as to furnish current for the ignitor.

The small charging-pump attached to the base of the engine is fitted with a small receptacle which must be filled with gasoline, through the small funnel-shaped opening in the left-hand side.

The next operation is to charge the detonating device which is composed of a round steel plunger, inserted through a screw-plug in the cylinder. By unscrewing the brass disc, the plunger can be withdrawn and the small hole or slotted openings on one side at the end of the plunger charged with a parlor cracking-match. A portion of the wood should be broken off so that only the short head of the match is inserted in the end. Replace the plunger in the cylinder. Screw down the brass disc; open the lever-handled cock interposed in the pipe leading from the self-starter pump to the cylinder.

Now open the gasoline throttle-valve to the point marked (1), which is the starting-point. More may be required if the engine is cold.

Then with the left hand hold the fly-wheel of the engine and give the self-starter pump several full, quick strokes. This should make the engine pull strong on the fly-wheel, and when the power is sufficient so that the engine begins to move slightly, quickly strike the detonator, which will explode the match previously inserted in the cylinder. This fires off the charge which has just been pumped into the cylinder, giving the piston a forward motion with sufficient velocity to draw in a charge through the regular channels and be ignited by means of the permanent igniting-device. Close the stop-cock between the cylinder and the starter-pump.

Turn on the cooling water.

Set the throttle-valve back to the point (2), which has been found to be about the best point for full work. Some judgment must be exercised in turning the throttle-valve to such a point that all ignitions are made, for the point will vary with every load.

With Kerosene.

Oil all bearings and fill oil-cups.

Throw in the battery for the ignitor.

Fill the kerosene-torch heater and pump in air to give pressure on oil in the heater.

To start the engine, first light the heater and set it under the generator, taking care to swing aside the slide which covers an opening in the bottom of the outer casing.

Next take out the plug in the top of the small chamber to which the reservoir is attached, and pour in about one-eighth of a pint of oil and replace the plug. Part of this oil will be highly heated by the heater, which generates a gas, which in turn, when mixed with air, forms an explosive mixture.

The starter-pump and detonating-device are used as in the method just described when using gasoline.

The damper-valve in the top of the generator, with a spring in the back of the handle, regulates the amount of heat given to the generator by the exhaust. Under light loads, the heater must be used continually, but with heavy loads it is needed only long enough to start the engine.

The regulation of the amount of oil by the throttle-valve and the amount of air is very important for good results. The admission of water into the cylinder when the engine is working over three eighths of its rated capacity is also necessary for satisfactory results.

FRICTION TEST. — In the friction test of an internal-combustion engine, the brake load should be increased by equal increments designated by the instructor, from zero to the maximum load that the engine will carry. The test under each load should be of fifteen minutes' duration, great care being exercised that the brake load is held constant during the interval. The following observations should be taken every five minutes:

1. Time.
2. Revolutions per minute.
3. Explosions per minute.
4. Brake load.
5. Indicator-cards.

The report should include all engine constants, a copy of the running log, sample indicator-cards, one from each brake load, and the following items.

1. Duration of tests.
2. Average R.P.M. for each brake-load.
3. Average explosions per minute for each brake-load.
4. Mean effective pressure for each brake-load.
5. Indicated horse-power.
6. Brake horse-power.
7. Friction horse-power.
8. Mechanical efficiency in per cent.

The report should also include curves showing the relation between the indicated horse-power (I.H.P.), plotted as abscissas, and the mechanical efficiency and friction horse-power, plotted as ordinates.

COMMERCIAL EFFICIENCY TEST.—The commercial efficiency test of an internal-combustion engine is much more complete than a friction test, therefore involving many more observations. The test should be one hour in length, with observations taken every five minutes, except cards, which should be taken at ten-minute intervals. All conditions should be maintained as nearly constant as possible throughout the test. The observations should include:

A. When using gas.
   1. Time.
   2. Revolutions per minute.
   3. Explosions per minute.
   4. Brake-load.
   5. Initial temperature of jacket-water.
   6. Final temperature of jacket-water.
   7. Weight of jacket-water.
   8. Sequence of explosions.
   9. Barometer.
   10. Reading of gas-meter.
   11. Difference of meter readings per five minutes.
   12. Pressure of gas.

13. Temperature of gas.
14. Setting of the gas-valve.

B. When using gasoline or kerosene.

Items 1 to 9 as above, together with the following:

10. Reading on the measuring-tank, in pounds or cubic feet.
11. Difference of readings on measuring-tank, in pounds or cubic feet.

The report should include, in addition to the original copy of running logs and sample indicator-cards, all dimensions and constants, the following items:

A. When using gas.

1. Duration of test.
2. Average R.P.M.
3. Average explosions per minute.
4. Ratio of explosions to revolutions.
5. Average initial temperature of jacket-water.
6. Average final temperature of jacket-water.
7. Pounds of jacket-water.
8. Pounds of jacket-water per hour.
9. The setting of the regulating-valve.
10. Average temperature of the gas.
11. Average pressure of the gas.
12. Mean effective pressure.
13. Maximum compression pressure.
14. Maximum pressure of explosion.
15. Indicated horse-power.
16. Brake horse-power.
17. Frictional horse-power.
18. Mechanical efficiency.
19. Cubic feet of gas or pounds of gasoline used.
20. Cubic feet of gas or pounds of gasoline used per hour.

21. Cubic feet of standard gas per hour (see note below).
23. Heat supplied per hour. (See instructor for heat equivalent of 1 cubic foot of gas or pound of gasoline.)
24. Heat equivalent to indicated horse-power in B.T.U. per hour and in per cent of heat supplied.
25. Heat radiated or given to jackets per hour in B.T.U. per hour and in per cent of heat supplied.
26. Heat exhausted in B.T.U. per hour and in per cent of heat supplied.
27. Cubic feet of standard gas or pounds of gasoline per indicated horse-power per hour.
28. Cubic feet of standard gas or pounds of gasoline per brake horse-power per hour.
29. B.T.U. consumed per I.H.P. per minute.
30. B.T.U. consumed per B.H.P. per minute.
31. Thermal efficiency. (Heat equivalent to brake horse-power per hour divided by B.T.U. consumed per hour.)

Note.—Omit items 10, 11, and 12 if engine uses gasoline or kerosene.

Item 21. Standard gas has been assumed at a temperature of 62° F. and a pressure of 14.7 pounds. To convert the gas to the standard condition, let P_1, V_1, and T_1 represent the observed pressure (made absolute), volume, and temperature $(460.7+t_1)$ and P_s, V_s, and T_s the standard conditions. Knowing that $P_1V_1=RT_1$, and also that $P_sV_s=RT_s$, then $V_s=T_sP_1V_1$ divided by P_sT_1.

In calculating items 24, 25, and 26, the method is as follows: Item 23 gives the amount of heat supplied the engine-cylinder per hour. This heat is divided between

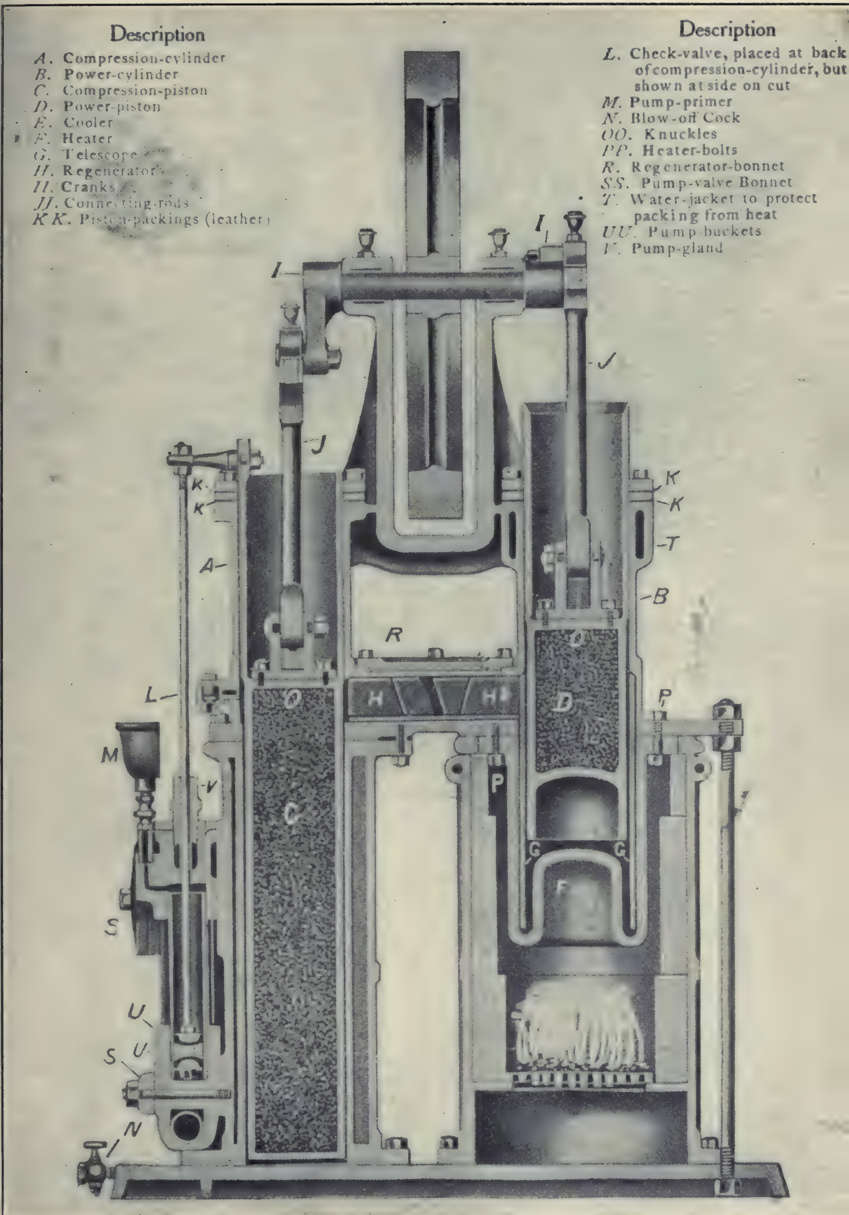

FIG. 57*a*.—SECTIONAL VIEW OF RIDER ENGINE.

the three factors (items 24, 25, and 26), of which 25 may be calculated from the rise in temperature and the weight of water passing the jacket, while 24 may be found from the indicated horse-power (item 15). Item 26 may then be determined from the equation between the four factors (assuming no loss by radiation):

Item 24 + item 25 + item 26 = item 23.

Items 23, 24, and 25 should be expressed as B.T.U. per hour and as per cent of item 23.

THE RIDER-ERICSSON HOT-AIR PUMPING-ENGINE.— The operation of the Rider engine is briefly as follows: The compression-piston, *C*, Fig. 57*a*, first compresses the cold air in the lower part of the compression-cylinder, *A*, into about one third its normal volume, when, by the advancing or upward motion of the power-piston, *D*, and the completion of the down stroke of the compression-piston, *C*, the air is transferred from the compression-cylinder, *A*, through the regenerator, *H*, and into the heater, *F*, without appreciable change of volume. The result is a great increase of pressure, corresponding to the increase of temperature, and this impels the power-piston up to the end of its stroke. The pressure still remaining in the power-cylinder, and reacting on the compression-piston, *C*, forces the latter upward to a point near the top of its stroke, when, by the cooling of the charge of air, the pressure falls to its minimum, the power-piston descends, and the compression again begins.

In the meantime the heated air, in passing through the regenerator, has left the greater portion of its heat in the regenerator-plates, to be picked up and utilized on the return of the air toward the heater.

There are several styles of water-pumps for use in connection with these engines. Generally, however, the engine is placed near the source of water-supply, and is furnished with the Rider Rolling-valve Pump, Fig. 57*b*, bolted to the cooler.

The pump is made in two pieces. The upper or main part contains the delivery-valves, and also the barrel, which is a seamless-drawn brass tube.

The lower chamber, to which the suction-pipe is attached, contains the suction-valves, and is bolted, as shown, to the main part.

The bucket is provided with two reverse cup-leathers; the rod passing upward through the stuffing-box is connected to an arm on the cold piston, as may be seen by referring to the cut of the engine. The pump is held to the cooler by two bolts, which are long enough to go through and secure the bonnets over the valves.

The pump is primed without unscrewing the air-chamber or other fittings. The operation of this device (marked *M* on the sectional cut) requires no explanation, except to state that it is only necessary to pour water into the cup, and turn the cock, thus priming the pump.

DIRECTIONS FOR OPERATING.

Firing.—Before turning on the gas, close the mixer. Apply match to burner at once *after* turning on gas. Close the door and carefully open the gas-gland until the flame is blue.

Oiling.—Fill the oil-cups with machine-oil and never permit them to be empty. Put a few drops into the oil-holes at the lower ends of both connecting-rods. Both pistons should be oiled by applying a small amount of waste saturated with oil to the piston surface.

Too much oil on the piston is injurious.

Starting.—The engine is ready to start when the heater above the gas-burner is a dull cherry-red. Stand at the

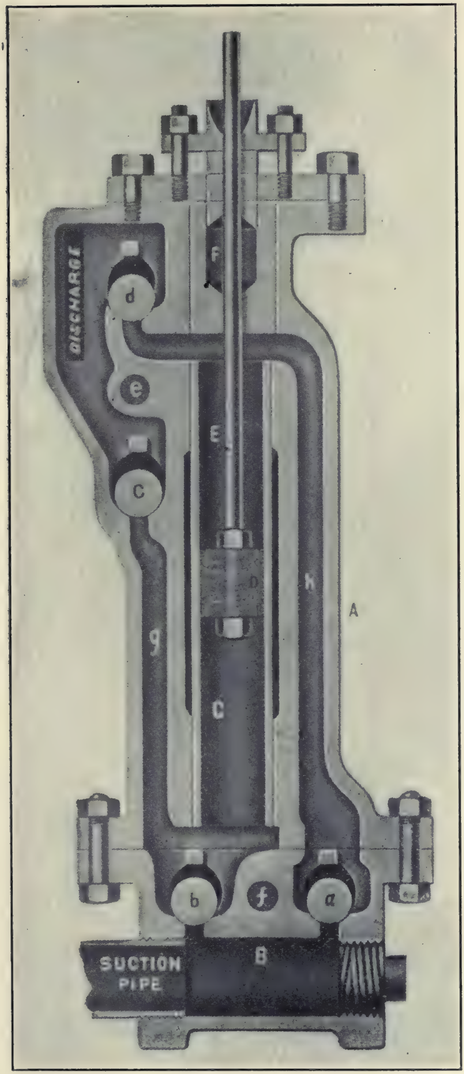

FIG. 57*b*.—DOUBLE-ACTING ROLLING-VALVE PUMP FOR LIGHT SUCTION.

fire-door and pull down on the fly-wheel. If the engine does not start, a little air may be let out by opening the cock at the bottom of the cold cylinder, when the hot piston is nearly at the bottom of its stroke.

Priming.—To start the pump it may be necessary to fill the pump with water. A priming-cup is provided on top of the pump for this purpose. Use the cock under the priming-cup to permit escape of air from the pump if necessary.

Always have water circulating in the jacket above the hot cylinder.

Stopping.—To stop the engine, shut off the gas, close the gas-gland, open the fire-door, and open the cock at the end of the bed-plate under the compression-cylinder.

TEST OF A RIDER-ERICSSON HOT-AIR PUMPING-ENGINE.

Observations.—Test to be of one hour duration, and observations taken every five minutes.

1. Time.
2. Gas-meter reading.
3. Temperature of gas.
4. Pressure of gas.
5. R.P.M.
6. Barometer.
7. Suction-head.
8. Discharge pressure.
9. Weight of water pumped.
10. Temperature of supply-water.
11. Temperature of discharge water.

The report should include all constants of the engine, copy of the running-log, sample-cards, and the following:

1. Duration of tests.
2. Average R.P.M.
3. Average M.E.P.

4. I.H.P.

5. Pounds of water pumped per hour.

6. Cubic feet of water pumped per hour.

7. Gallons of water pumped per 24 hours.

8. Average suction-head.

9. Average discharge pressure.

10. Average total head.

11. Horse-power delivered by the pump.

12. Mechanical efficiency.

13. Cubic feet of gas used per hour.

14. Cubic feet of standard gas (62° F. and 14.7 lbs. pressure) per hour.

15. B.T.U. supplied per hour (1 cubic foot of standard gas = 560 B.T.U.).

16. Cubic feet of standard gas used per I.H.P.H.

17. Cubic feet of standard gas used per H.P. delivered at pump per hour.

18. B.T.U. consumed per I.H.P.H.

19. B.T.U. consumed per H.P. delivered by pump per hour.

20. B.T.U. equivalent to I.H.P. per hour, and per cent which this is of total B.T.U. supplied.

21. Thermal efficiency of plant.

22. Pump-plunger's displacement per hour (cu. ft.).

23. Slip (in per cent of water pumped per hour).

24. Duty (foot-pounds of work delivered at pump per million B.T.U.).

Let the report include a brief description of the Hot-air Engine, and a statement of the principles involved in its operation.

172. Tests of Air-compressors.—The extended use of compressed air for the transmission of power and its exclusive use for special purposes, such as the air-brake, gives frequent occasion for the testing of air-compressing plants of various kinds. These tests are usually to determine the volume of air delivered per pound of steam at various pressures of delivery and the pounds of steam consumed per horse-power of work delivered. To give practice in the testing of compressors working under different conditions, this test may be run either as a *continuous test*, the conditions being those under which compressed-air power-plants operate, or as an *intermittent test*, representing the working conditions of an air-brake pump. The plant consists of the compressor, a surface-condenser which receives the exhaust-steam, a large main receiver into which the air-cylinder discharges, and an auxiliary receiver into which the main receiver leads and which contains an orifice of known diameter for measuring the discharge of air. In Fig. 58 is shown an arrangement of piping which has been used in the Purdue laboratory with satisfactory results.

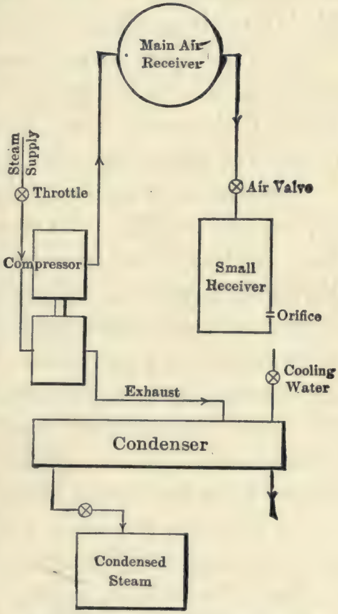

FIG. 58.—ARRANGEMENT OF COMPRESSOR PLANT.

Specific Directions: Continuous Test.—This test should be conducted by two men, to whom two assistants are assigned. The following is a recommended assignment of observers: 1. Log and time in charge. 2. Weight of condensed steam in charge. 3. Speed. 4. Miscellaneous observations.

The Running Log should be drawn up to contain the following items: 1. Time. 2. Steam-pressure. 3. Main-receiver pressure. 4. Auxiliary-receiver pressure. 5. Barometer. 6. Speed of compressor (double strokes). 7. Temperature in auxiliary receiver. 8. Temperature of room. 9. Weight of condensed steam.

In case a speed-recorder is not attached it may be found convenient to keep the record of speed on a separate log-sheet, the observer detailed to count the same making a mark for each double stroke. The speed should be counted continuously for five minutes at a time, beginning at intervals ten minutes apart.

The accessory apparatus needed for the test is a thermometer and a whistle. The test should be one hour in duration and observations should be taken every five minutes.

Conduct the test as follows: Carefully inspect the piping and see that all valves are suitably placed. See that the lubricator is filled and adjusted. Having the Running Log prepared and observers posted, start the compressor and turn cooling water on the condenser, regulating the supply-valve to obtain the amount necessary to prevent the escape of uncondensed steam. See that the weighing-tanks are empty and the discharge-valve open. Secure the desired pressure of delivery in the main receiver by manipulation of the valve between the main and the auxiliary receiver and keep it constant during the test.

Start the test by noting the time, taking all observations, closing the weighing-tank drain-valve, and noting the water-level as shown by the float or gage-glass on the tank. Keep all conditions constant during the test.

Specific Directions: Intermittent Test. — This test should be conducted by two men with two assistants. The following is a recommended assignment of observers:

1. Log and time } in charge.
2. Weight of condensed steam } in charge.
3. Speed.
4. Miscellaneous observations.

The Running Log should be drawn up to cover the following items:

1. Time of starting compressor.
2. Time of stopping compressor.
3. Steam-pressure.
4. Main-receiver pressure, maximum.
5. Main-receiver pressure, minimum.
6. Auxiliary-receiver pressure.
7. Barometer.
8. Speed of compressor (double strokes).
9. Temperature of auxiliary receiver.
10. Temperature of room.
11. Weight of condensed steam.

The test should be one hour in duration, and observations should be taken at the time of starting and stopping the compressor, except in the case of items 3, 6, and 9, which should be taken at intervals while the compressor is at work. The speed (item 6) is determined by counting the number of double strokes for the interval during which the compressor is running.

Conduct the test as follows: Carefully inspect the piping and see that all valves are suitably placed. See that the lubricator is filled and adjusted. Having the Running Log prepared and observers posted, start the compressor and turn cooling water on the condenser, regulating the supply-valve to obtain the amount necessary to prevent the escape of uncondensed steam. See that the weighing-tank is empty and its discharge-valve open. With the throttle-valve wide open, regulate the auxiliary-receiver pressure to give a main-receiver pressure of five pounds in excess of the maximum pressure determined upon. This auxiliary-receiver pressure should be constantly maintained throughout the test by manipulation of the main-receiver discharge-valve. Now stop the compressor and allow the main-receiver pressure to fall. When the pressure has fallen to the predetermined minimum the compressor should be started with wide-open throttle and the test considered as commenced.

The method of procedure now is to allow the compressor to raise the main-receiver pressure to the predetermined maximum, then shut down quickly and allow the pressure to fall to the minimum, always keeping the auxiliary-receiver pressure constant. Then start the compressor and repeat the process throughout the test. The test is to be stopped when, after shutting down the compressor, the main-receiver pressure has fallen to the minimum.

Report of Compressor Test.—The Report should include beside a statement of dimensions, constants, and running conditions, the following:

a. Weight of air escaping per second, in pounds.

$$G = 0.530F\frac{p_1}{\sqrt{T_1}} \quad \text{when} \quad p_1 > 2p_a, \quad . \quad . \quad . \quad (1)$$

$$G = 1.060F\sqrt{\frac{p_a(p_1 - p_a)}{T_1}} \quad \text{when} \quad p_1 < 2p_a, \quad (2)$$

where p_1 is the mean pressure in the small receiver in pounds per square inch absolute, p_a the barometric pressure in pounds per square inch, T_1 the absolute temperature of the air in the small receiver in degrees Fahrenheit, and F the area of the orifice in square inches. Use formula (1) or (2) according as p_1 may be greater or less than $2p_a$.

b. Pounds compressed per minute,

$$P = G \times 60. \quad . \quad . \quad . \quad . \quad . \quad . \qquad (3)$$

c. Total weight compressed,

$$P_1 = P \times \text{no. of minutes of entire test.} \quad . \qquad (4)$$

d. Volume of one pound of atmospheric air in cubic feet,

$$v_a = \frac{53.22\, T_a}{144 p_a}, \quad . \quad . \quad . \quad . \quad . \quad . \qquad (5)$$

where T_a is the absolute temperature of the room in degrees Fahrenheit.

e. Volume compressed per second,

$$V = v_a \times G. \quad . \quad . \quad . \quad . \quad . \quad . \qquad (6)$$

f. Total volume compressed,

$$V_1 = V \times \text{no. of seconds of entire test.} \quad . \qquad (7)$$

g. Work done in compressing one pound of air in foot-pounds,

$$W = 144 p_a v_a \frac{n}{n-1} \left\{ \left(\frac{p_2}{p_a} \right)^{\frac{n-1}{n}} - 1 \right\}, \quad . \quad . \qquad (8)$$

where $n = 1.4$ for dry air, and p_2 is the mean pressure in the main reservoir in pounds per square inch absolute.

h. Horse-power,

$$\text{H.P.} = \frac{W \times P}{33000}; \quad . \quad . \quad . \quad . \quad . \qquad (9)$$

$$\text{H.P.} = \frac{W \times P_1}{33000 \times \text{no. minutes that compressor was working}}. \quad . \qquad (10)$$

Formula (9) should be used for continuous and formula (10) for intermittent running.

i. Steam per H.P. per hour

$$= \frac{\text{steam per hour in lbs.}}{\text{H.P.}} \quad . \quad . \quad . \quad . \quad (11)$$

j. Air compressed per pound of steam in pounds

$$= \frac{P_1}{\text{total steam in lbs.}} \quad . \quad . \quad . \quad . \quad . \quad (12)$$

k. Volume of air compressed per pound of steam

$$= \frac{V_1}{\text{total steam in lbs.}} \quad . \quad . \quad . \quad . \quad . \quad (13)$$

l. Volume of standard air compressed per pound of steam

$$= 12.3909 \times \frac{P_1}{\text{total steam in lbs.}} \quad . \quad . \quad (14)$$

m. Ratio of volume of air compressed to volume swept by piston $= V_1 \div$ (volume swept by pistons in one stroke $\times$ total number of strokes)

$$= \frac{V_1}{C \times \text{no. of strokes}} \quad . \quad . \quad . \quad . \quad (15)$$

The value of the constant C in formula (15) may be had by reference to the laboratory Commonplace-book.

The volume of standard air, that is, air at 32° F. and under atmospheric pressure as given by formula (14), will serve as a basis of comparison between different tests. The constant 12.3909 is derived from formula (5), making $T = 32 + 460.7$ and $p_a = 14.7$.

173. Advanced Work on Air-compressors.—To determine the efficiency under different pressures of delivery, run a series of four tests under constant steam-pressure. Let the conditions be as follows:

1st. Continuous running with air-pressure as high as pump will deliver.

4th. Continuous running with air-pressure as low as can be had without using more steam than can be readily condensed.

2d and 3d. Continuous running with air-pressure intermediate between that of 1st and 4th tests.

All tests should be of 30 minutes' duration, and the conditions should be maintained for 1c minutes before beginning the test. They should be conducted and worked up as explained in Section 172.

The Report should include a statement of the purpose of the test, a sketch and description of the plant, a statement of the constant conditions, a copy of the Running Log, a tabulated summary statement of the calculated results, and a comparison of results, including curves showing the relation of horse-power, steam per horse-power-hour, cubic feet of air pumped per second and per pound of steam to pressure of delivery.

To determine the efficiency under different steam-pressures, run a series of three tests under constant pressure of delivery and with steam-pressures of 60, 120, and 180 pounds. Conduct the tests and make the report as described above.

174. Tests of Injectors.—*Description.*—The injector is an instrument in common use for delivering feed-water to boilers. It is used very generally on locomotive boilers and to a considerable extent in small stationary plants. It is made in two general classes, lifting and non-lifting. In the former class the water-supply is below the level of the injector and work is done in raising the water, in addition to that required to deliver against a pressure. In the latter class the water is delivered to the injector under more or less pressure.

The lifting injectors may be further divided into single- and double-tube injectors. In Fig. 59 is shown a sectional view of the Metropolitan double-tube locomotive injector. Pipe-connection is made at *A* with the steam-supply, at *B* with the water-supply, and at *C* with the delivery-pipe. *D* is the overflow. The tubes *E* are termed the lifting and combining tubes and their function is to lift the water from the source to the forcing-tubes *F*, which deliver it against the desired pressure. Fig. 60 is a sectional view of the Sellers self-acting injector of 1887, a single-tube injector. At 19, 23, 19*a* and 29 are, respectively, the connections for the steam-supply, water-supply, delivery, and overflow. The single set of tubes 3-2-1 performs the function both of lifting and forcing.

Operation of the Injector.—The method of starting the injectors described above, which applies in a general way to many injectors now on the market, is as follows:

Open steam and water-supply valves wide.

Pull starting-lever back a short distance until water appears at the overflow and then continue the movement steadily as far as the lever will go (Metropolitan); or pull the starting-lever back steadily as far as it will go (Sellers).

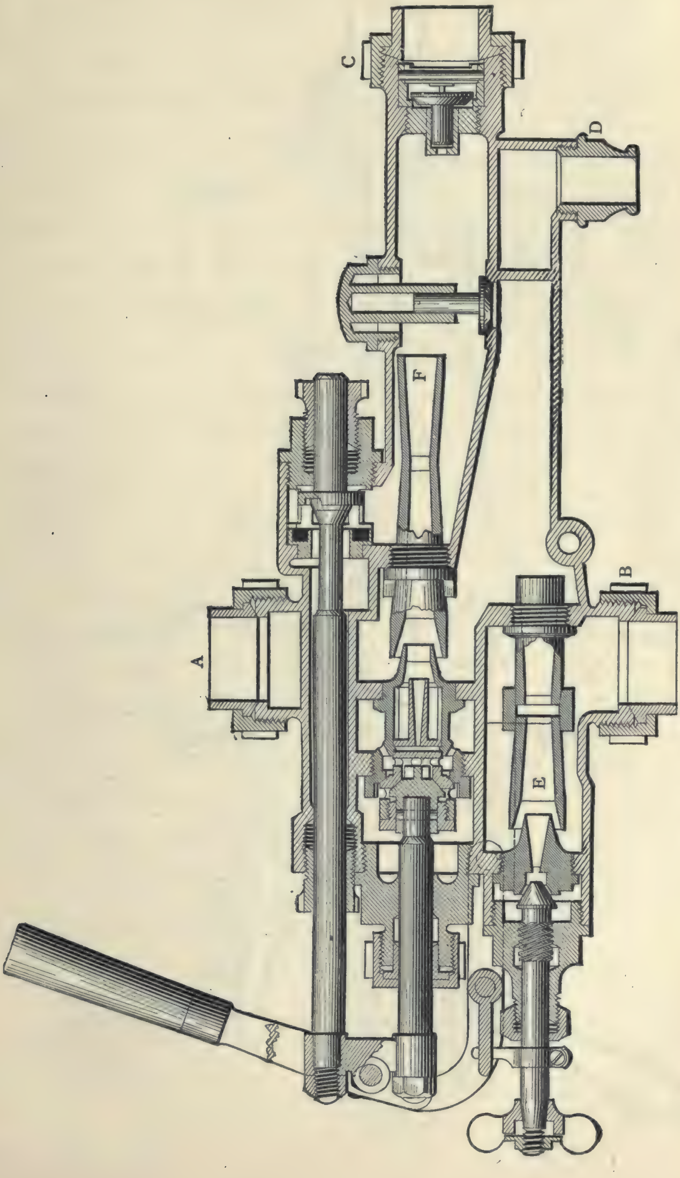

FIG. 59.—METROPOLITAN DOUBLE-TUBE INJECTOR.

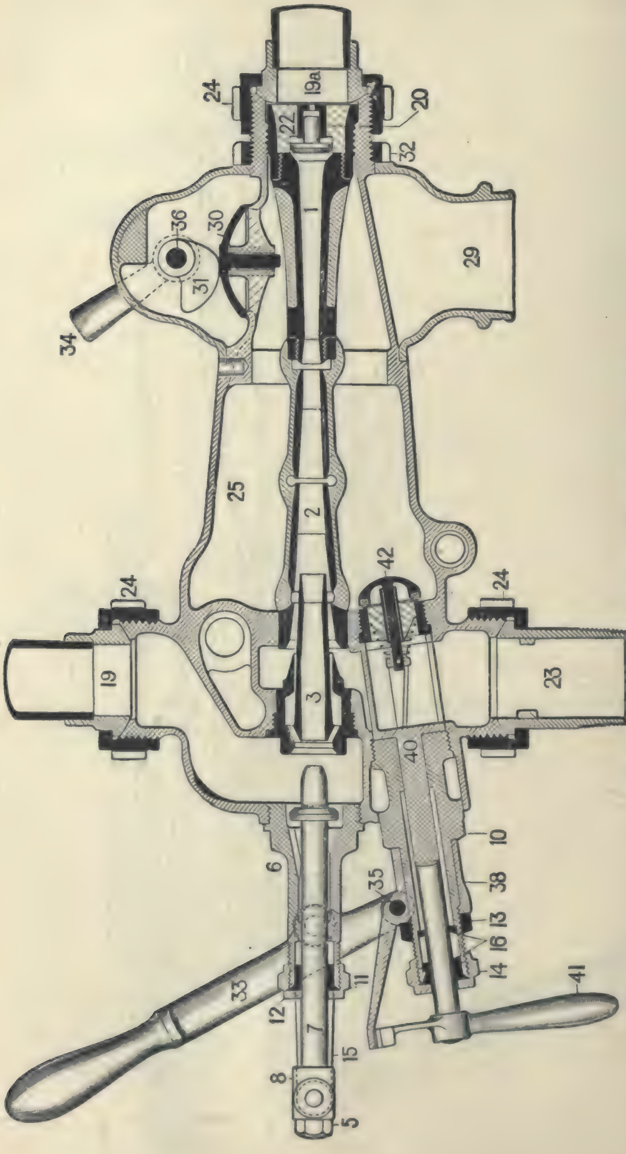

FIG. 60.—SELLERS SINGLE-TUBE INJECTOR.

Regulate the rate of delivery by the water-supply valve.

Method of Testing.—The testing-plant consists of two tanks mounted on scales or fitted with calibrated gage-glasses. The injector draws from one and delivers into the other. In order to begin the test with a flying start, provision is made by which the injector may be started prior to the commencement of the test, drawing from the supply-tank and delivering into a by-pass fitted with a suitable swinging nozzle. The initial level is maintained in the supply-tank by an inlet-pipe controlled by a quick-acting valve whose handle is connected with the swinging nozzle. When the test is begun the supply-valve is closed and at the same time the swinging nozzle turns the delivery from the by-pass into the delivery-tank. Provision is made for producing and measuring the head against which the injector is to work and for measuring the temperatures of supply and delivery. Before beginning the test, place two or three buckets of cold water in the delivery-tank and let the initial balance include the weight of this water. This is to prevent vaporization of the delivery-water.

Specific Directions.—Determine upon the steam-pressure, pressure of delivery, temperature of supply, and rate of delivery under which the test will be made by consultation with the instructor.

Prepare the Running Log, making provision for the following list of observations:

1. Time.
2. Steam-pressure.
3. Delivery-pressure.
4. Suction head.
5. Barometric pressure.
6. Temperature of supply.
7. Temperature of delivery.
8. Temperature of room.
9. Reading of supply-tank.
10. Reading of delivery-tank.

The duration of the test is governed by the capacity of the supply-tank, and will vary with the rate of delivery.

Having the discharge-tank empty, the supply-tank full, and the regulating-valve on discharge-pipe wide open, start the injector, allowing the delivery to flow into the by-pass. Open the supply-tank inlet a sufficient amount to maintain a constant water-level in the supply-tank. When the desired conditions are obtained start the test by shutting off the supply-valve, turning the delivery into the delivery-tank and taking all observations. Take observations at regular intervals during the test and keep all conditions constant. To close the test, stop the injector.

The following is a form of Report to be used in connection with the injector test:

TEST OF INJECTOR.

Observers { ....
.... *Date*........

Make of injector........
Number and style........
Size of connections: steam........in.; water........in.; discharge........in.
Diameter (minimum) of lifting-tube....in.; forcing-tube....in.
a. Duration of test........
b. Steam-pressure (average), pounds gage, p_1........
c. Delivery-pressure (average), pounds gage, p_2........
d. Delivery-head (average), feet, h_1........
e. Suction-head (average), feet, h_2........
f. Temperature of supply (average), t_1........
g. Temperature of delivery (average), t_2........
h. Pounds water supplied per hour, W_1........
i. Pounds water delivered per hour, W_2........
j. Cubic feet of water delivered per hour, c........
k. Wet steam per hour, w_1........

l. Dry steam per hour, w_2........
m. Water delivered per pound wet steam, pounds........
n. Water delivered per pound dry steam, pounds........
o. Velocity of discharge, feet per second, v........
p. Energy delivered, raising injection-water, B.T.U. per hr........
q. Energy delivered, heating injection-water, B.T.U. per hr........
r. Energy delivered, velocity of discharge, B.T.U. per hr..........
s. Total energy delivered, B.T.U. per hour........
t. Energy supplied, B.T.U. per hour........
u. Thermal efficiency........
v. Horse-power........
w. Dry steam per horse-power per hour, pounds........

A constant correction, found in the Commonplace Book, should be made for the volume of the suction-pipe and measuring-stick, and this should be deducted from the reading of the supply-tank.

The wet steam per hour, $w_1 = W_2 - W_1$.

The dry steam per hour, $w_2 = x_1 w_1$, where x_1 is the per cent of dry steam. If this is not measured assume 98 per cent.

The water delivered per pound of wet steam $= W_2 \div w_1$.

The water delivered per pound of dry steam $= W_2 \div w_2$.

The velocity of discharge,

$$v = \frac{\text{(cubic feet delivered per hour)} \times 144}{3600 \times \text{(area discharge end in sq. in.)}}.$$

The energy of raising injection-water $= [W_1(h_1+h_2) + w_1 h_1] \div 778$.

The energy of heating injection-water $= W_1(q_2 - q_1)$, where q_1 and q_2 correspond to t_1 and t_2.

The energy of discharge $= W_2 v^2 \div (2g \times 778)$.

The total energy delivered = item p + item q + item r.

The energy supplied $= w_1(x_1r_1 + q_1 - q_2)$, where r_1 and q_1 correspond to p_1, and q_2 corresponds to t_2.

The thermal efficiency $= 100 \times \frac{\text{item } s}{\text{item } t}$.

The horse-power $= \frac{W_1(h_1 + h_2) + w_1h_1}{60 \times 33000}$.

The dry steam per horse-power per hour $= w_2 \div$ item v.

175. Advanced Work on Injectors.—As topics for advanced study of injectors the following are suggested:

1. Effect of steam-pressure on efficiency and capacity.

Run a series of five tests under the following conditions: steam-pressures of 60, 80, 100, 150, and 200 pounds; rate of discharge minimum, mean, or maximum; feed-temperature constant and delivery-pressure equal to steam-pressure.

2. Effect of temperature of feed on efficiency and capacity.

Run a series of five tests under the following conditions: feed-temperatures of 50, 80, 110, 140, and maximum; steam-pressure constant; mean rate of delivery and delivery-pressure equal to steam-pressure.

3. Effect of delivery-pressure on efficiency.

Run a series of three tests under the following conditions: delivery-pressure 75 and 100 per cent of steam-pressure and maximum; mean rate of delivery; steam-pressure and feed-temperature constant.

4. Maximum starting and working temperatures.

Make an experimental investigation under different steam-pressures.

5. Overflow loss under different steam-pressures.

6. Restarting conditions.

These tests (except under heads 4, 5, and 6) should be run and worked up as described in Section 174. The Report should include a statement of the purpose of the tests, a sketch and description of the plant, a statement of the conditions of the tests, a copy of all observed and calculated data, comparisons of results accompanied by curves, and conclusions.

176. Tests of Steam-turbines. The De Laval Turbine.—The De Laval steam-turbine consists of a wheel provided with buckets, against which act jets of steam delivered from suitable nozzles. The wheel is

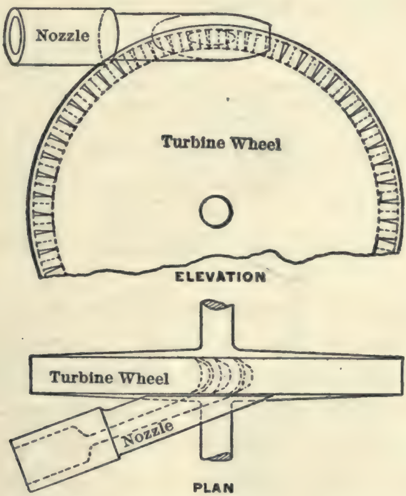

FIG. 61.—DE LAVAL STEAM-TURBINE. ARRANGEMENT OF WHEEL AND NOZZLE.

mounted upon a shaft carrying a small pinion which meshes with a large gear on the driving-shaft, thus reducing the speed at which the power is delivered. The speed is regulated by a throttling-governor.

In Fig. 61 is shown the arrangement of nozzle and wheel, and in Fig. 62 are shown dimensioned drawings of the moving parts of a 10-horse-power turbine. The form of the nozzle is such that the steam in passing through is expanded to atmospheric pressure, while its velocity is correspondingly increased. The energy in the steam is thereby converted into the form most available for impact on the wheel. In the 10-horse-power turbine there are four nozzles, two of which are provided with stop-valves. Nozzles of different sizes are provided for use with different steam-pressures, as follows:

	No. 1.	No. 2.	No. 3.	No. 4.
For 100 lbs. (7 kgm.) use nozzles marked	5 × 7.1 mm. (with stopper).	5 × 7.1 mm. (with stopper).	5 × 7.1 mm.	Blind.
130 lbs. (9.2 kgm.)	4 × 6.3 mm. (with stopper).	6.5 mm. (with reg. spindle).	4 × 6.3 mm.	4 × 6.3 mm.
140 lbs. (9.8 kgm.)	4 × 6.3 mm. (with stopper).	4 × 6.3 mm. (with stopper).	4 × 6.3 mm.	4 × 6.3 mm.
180 lbs. (12.7 kgm.)	3.7 × 6 mm. (with stopper).	3.7 × 6 mm. (with stopper).	3.7 × 6 mm.	Blind.

When using the regulating-spindle with 130 pounds pressure observe the following directions: On the spindle nearest the wheel is the mark 09*k*; here the hand must point when the nozzle is used with 130 pounds pressure. To shut off the nozzle entirely, the hand should point to mark *S*. On the socket of the nozzle and also on the box of the turbine is the mark 1, showing where the socket and nozzle should be placed. In fitting the turbine for testing it should be provided with a suitable brake, and should be in pipe-connection with a surface-condenser.

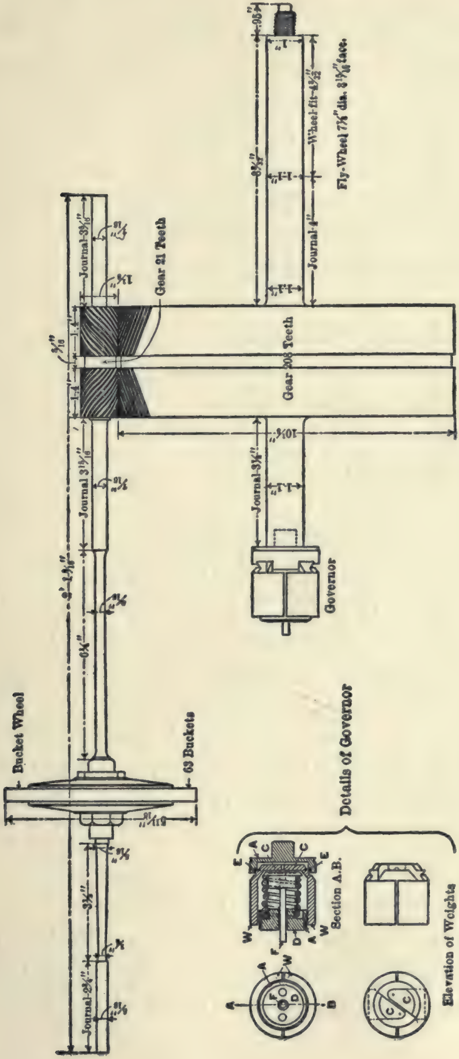

FIG. 62.—DETAILS OF DE LAVAL STEAM-TURBINE.

Specific Directions.—Run three tests at constant steam-pressure and different brake loads to determine the variation in economy. The auxiliary apparatus needed includes a speed-counter and a whistle.

The tests should be of 30 minutes' duration, with observations at five-minute intervals, the turbine to run at least 20 minutes before the first test is commenced, and to run under load conditions of the test for five minutes before taking observations.

The observations are as follows:

1. Initial steam-pressure.
2. Pressure below governor-valve.
3. Exhaust-pressure.
4. Barometer.
5. Brake load, net.
6. Speed.
7. Weight of condensed steam.

After determining the desired brake loads under which the tests are to run calculate from known dimensions of the brake the weight which must be carried on the scale to secure the required power.

The Report should fully state conditions of test, giving number and size of nozzles used, and should include a brief statement of arrangement of plant, a tabulated Running Log, and the following calculated results:

a. Brake H.P.

b. Weight of steam per H.P. per hour.

As subjects for advanced study, investigate the change of efficiency with change of steam-pressure and the effect of varying the number of nozzles in use.

APPENDIX.

177. Circumferences and Areas of Circles.

1 TO 400 ADVANCING BY 10THS FROM 1 TO 50.

(Abridged from Carpenter's "Experimental Engineering.")

Diam.	Circum.	Area.	Diam.	Circum.	Area.	Diam.	Circum.	Area.
1.0	3.142	.7854	6.4	20.106	32.170	11.8	37.071	109.36
1.1	3.456	.9503	6.5	20.420	33.183	11.9	37.385	111.22
1.2	3.770	1.1310	6.6	20.735	34.212	**12.0**	37.699	113.10
1.3	4.804	1.3273	6.7	21.049	35.257	12.1	38.013	114.99
1.4	4.398	1.5394	6.8	21.363	36.317	12.2	38.327	116.90
1.5	4.712	1.7672	6.9	21.677	37.393	12.3	38.642	118.82
1.6	5.027	2.0106	**7.0**	21.991	38.485	12.4	38.956	120.76
1.7	5.241	2.2698	7.1	22.305	39.592	12.5	39.270	122.72
1.8	5.655	2.5447	7.2	22.619	40.715	12.6	39.584	124.69
1.9	5.969	2.8353	7.3	22.934	41.854	12.7	39.898	126.68
2.0	6.283	3.1416	7.4	23.248	43.008	12.8	40.212	128.68
2.1	6.597	3.4636	7.5	23.562	44.179	12.9	40.527	130.70
2.2	6.912	3.8013	7.6	23.876	45.365	**13.0**	40.841	132.73
2.3	7.226	4.1548	7.7	24.190	46.566	13.1	41.155	134.78
2.4	7.540	4.5239	7.8	24.504	47.784	13.2	41.469	136.85
2.5	7.854	4.9087	7.9	24.819	49.017	13.3	41.783	138.93
2.6	8.168	5.3093	**8.0**	25.133	50.266	13.4	42.097	141.03
2.7	8.482	5.7256	8.1	25.447	51.530	13.5	42.412	143.14
2.8	8.797	6.1575	8.2	25.761	52.810	13.6	42.726	145.27
2.9	9.111	6.6052	8.3	26.075	54.106	13.7	43.040	147.41
3.0	9.425	7.0686	8.4	26.389	55.418	13.8	43.354	149.57
3.1	9.739	7.5477	8.5	26.704	56.745	13.9	43.668	151.75
3.2	10.053	8.0425	8.6	27.018	58.088	**14.0**	43.982	153.94
3.3	10.367	8.5530	8.7	27.332	59.447	14.1	44.296	156.15
3.4	10.681	9.0792	8.8	27.646	60.821	14.2	44.611	158.37
3.5	10.996	9.6211	8.9	27.960	62.211	14.3	44.925	160.61
3.6	11.310	10.179	**9.0**	28.274	63.617	14.4	45.239	162.86
3.7	11.624	10.752	9.1	28.588	65.039	14.5	45.553	165.13
3.8	11.938	11.341	9.2	28.903	66.476	14.6	45.867	167.42
3.9	12.252	11.946	9.3	29.217	67.929	14.7	46.181	169.72
4.0	12.566	12.566	9.4	29.531	69.398	14.8	46.496	172.03
4.1	12.881	13.203	9.5	29.845	70.882	14.9	46.810	174.37
4.2	13.195	13.854	9.6	30.159	72.382	**15.0**	47.124	176.72
4.3	13.509	14.522	9.7	30.473	73.898	15.1	47.438	179.08
4.4	13.823	15.205	9.8	30.788	75.430	15.2	47.752	181.46
4.5	14.137	15.904	9.9	31.102	76.977	15.3	48.066	183.85
4.6	14.451	16.619	**10.0**	31.416	78.540	15.4	48.381	186.27
4.7	14.765	17.349	10.1	31.730	80.119	15.5	48.695	188.69
4.8	15.080	18.096	10.2	32.044	81.713	15.6	49.009	191.13
4.9	15.394	18.857	10.3	32.358	83.323	15.7	49.323	193.59
5.0	15.708	19.635	10.4	32.673	84.949	15.8	49.637	196.07
5.1	16.022	20.428	10.5	32.987	86.590	15.9	49.951	198.56
5.2	16.336	21.237	10.6	33.301	88.247	**16.0**	50.265	201.06
5.3	16.650	22.062	10.7	33.615	89.920	16.1	50.580	203.58
5.4	16.965	22.902	10.8	33.929	91.609	16.2	50.894	206.12
5.5	17.279	23.758	10.9	34.243	93.313	16.3	51.208	208.67
5.6	17.593	24.630	**11.0**	34.558	95.033	16.4	51.522	211.24
5.7	17.907	25.518	11.1	34.872	96.769	16.5	51.836	213.83
5.8	18.[illegible]	26.421	11.2	35.186	98.520	16.6	52.150	216.42
5.9	18.535	27.340	11.3	35.500	100.29	16.7	52.465	219.04
6.0	18.850	28.274	11.4	35.814	102.07	16.8	52.779	221.67
6.1	19.164	29.225	11.5	36.128	103.87	16.9	53.093	224.32
6.2	19.478	30.191	11.6	36.442	105.68	**17.0**	53.407	226.98
6.3	19.792	31.173	11.7	36.757	107.51	17.1	53.721	229.66

CIRCUMFERENCES AND AREAS OF CIRCLES.

Diam.	Circum.	Area.	Diam.	Circum.	Area.	Diam.	Circum.	Area.
17.2	54.035	232.35	23.2	72.885	422.73	29.2	91.735	669.66
17.3	54.350	235.06	23.3	73.199	426.39	29.3	92.049	674.26
17.4	54.664	237.79	23.4	73.513	430.05	29.4	92.363	678.87
17.5	54.978	240.53	23.5	73.827	433.74	29.5	92.677	683.49
17.6	55.292	243.29	23.6	74.142	437.44	29.6	92.991	688.13
17.7	55.606	246.06	23.7	74.456	441.15	29.7	93.305	692.79
17.8	55.920	248.85	23.8	74.770	444.88	29.8	93.619	697.47
17.9	56.235	251.65	23.9	75.084	448.63	29.9	93.934	702.15
18.0	56.549	254.47	**24.0**	75.398	452.39	**30.0**	94.248	706.86
18.1	56.863	257.30	24.1	75.712	456.17	30.1	94.562	711.58
18.2	57.177	260.16	24.2	76.027	459.96	30.2	94.876	716.32
18.3	57.491	263.02	24.3	76.341	463.77	30.3	95.190	721.07
18.4	57.805	265.90	24.4	76.655	467.60	30.4	95.505	725.83
18.5	58.119	268.80	24.5	76.969	471.44	30.5	95.819	730.62
18.6	58.434	271.72	24.6	77.283	475.29	30.6	96.133	735.42
18.7	58.748	274.65	24.7	77.597	479.16	30.7	96.447	740.23
18.8	59.062	277.59	24.8	77.911	483.05	30.8	96.761	745.06
18.9	59.376	280.55	24.9	78.226	486.96	30.9	97.075	749.91
19.0	59.690	283.53	**25.0**	78.540	490.87	**31.0**	97.389	754.77
19.1	60.004	286.52	25.1	78.854	494.81	31.1	97.704	759.65
19.2	60.319	289.53	25.2	79.168	498.76	31.2	98.018	764.54
19.3	60.633	292.55	25.3	79.482	502.73	31.3	98.332	769.45
19.4	60.947	295.59	25.4	79.796	506.71	31.4	98.646	774.37
19.5	61.261	298.65	25.5	80.111	510.71	31.5	98.960	779.31
19.6	61.575	301.72	25.6	80.425	514.72	31.6	99.274	784.27
19.7	61.889	304.81	25.7	80.739	518.75	31.7	99.588	789.24
19.8	62.204	307.91	25.8	81.053	522.79	31.8	99.903	794.23
19.9	62.518	311.03	25.9	81.367	526.85	31.9	100.22	799.23
20.0	62.832	314.16	**26.0**	81.681	530.93	**32.0**	100.53	804.25
20.1	63.146	317.31	26.1	81.996	535.02	32.1	100.85	809.28
20.2	63.460	320.47	26.2	82.310	539.13	32.2	101.16	814.33
20.3	63.774	323.66	26.3	82.624	543.25	32.3	101.47	819.40
20.4	64.088	326.85	26.4	82.938	547.39	32.4	101.79	824.48
20.5	64.403	330.06	26.5	83.252	551.55	32.5	102.10	829.58
20.6	64.717	333.29	26.6	83.566	555.72	32.6	102.42	834.69
20.7	65.031	336.54	26.7	83.881	559.90	32.7	102.73	839.82
20.8	65.345	339.80	26.8	84.195	564.10	32.8	103.04	844.96
20.9	65.659	343.07	26.9	84.509	568.32	32.9	103.36	850.12
21.0	65.973	346.36	**27.0**	84.823	572.56	**33.0**	103.67	855.30
21.1	66.288	349.67	27.1	85.137	576.80	33.1	103.99	860.49
21.2	66.602	352.99	27.2	85.451	581.07	33.2	104.30	865.70
21.3	66.916	356.33	27.3	85.765	585.35	33.3	104.62	870.92
21.4	67.230	359.68	27.4	86.080	589.65	33.4	104.93	876.16
21.5	67.544	363.05	27.5	86.394	593.96	33.5	105.24	881.41
21.6	67.858	366.44	27.6	86.708	598.29	33.6	105.56	886.68
21.7	68.173	369.84	27.7	87.022	602.63	33.7	105.87	891.97
21.8	68.487	373.25	27.8	87.336	606.99	33.8	106.19	897.27
21.9	68.801	376.69	27.9	87.650	611.36	33.9	106.50	902.59
22.0	69.115	380.13	**28.0**	87.965	615.75	**34.0**	106.81	907.92
22.1	69.429	383.60	28.1	88.279	620.16	34.1	107.13	913.27
22.2	69.743	387.08	28.2	88.593	624.58	34.2	107.44	918.63
22.3	70.058	390.57	28.3	88.907	629.02	34.3	107.76	924.01
22.4	70.372	394.08	28.4	89.221	633.47	34.4	108.07	929.41
22.5	70.686	397.61	28.5	89.535	637.94	34.5	108.38	934.82
22.6	71.000	401.15	28.6	89.850	642.42	34.6	108.70	940.25
22.7	71.314	404.71	28.7	90.164	646.93	34.7	109.01	945.69
22.8	71.268	408.28	28.8	90.478	651.44	34.8	109.33	951.15
22.9	71.942	411.87	28.9	90.792	655.97	34.9	109.64	956.62
23.0	72.257	415.48	**29.0**	91.106	660.52	**35.0**	109.96	962.11
23.1	72.571	419.10	29.1	91.420	665.08	35.1	110.27	967.62

CIRCUMFERENCES AND AREAS OF CIRCLES.

Diam.	Circum.	Area.	Diam.	Circum.	Area.	Diam.	Circum.	Area.
35.2	110.58	973.14	41.2	129.43	1333.17	47.2	148.28	1749.74
35.3	110.90	978.68	41.3	129.75	1339.65	47.3	148.60	1757.16
35.4	111.21	984.23	41.4	130.06	1346.14	47.4	148.91	1764.60
35.5	111.53	989.80	41.5	130.38	1352.65	47.5	149.23	1772.05
35.6	111.84	995.38	41.6	130.69	1359.18	47.6	149.54	1779.52
35.7	112.15	1000.98	41.7	131.00	1365.72	47.7	149.85	1787.01
35.8	112.47	1006.60	41.8	131.32	1372.28	47.8	150.17	1794.51
35.9	112.78	1012.23	41.9	131.63	1378.85	47.9	150.48	1802.03
36.0	113.10	1017.88	**42.0**	131.95	1385.44	**48.0**	150.80	1809.56
36.1	113.41	1023.54	42.1	132.26	1392.05	48.1	151.11	1817.11
36.2	113.73	1029.22	42.2	132.58	1398.67	48.2	151.42	1824.67
36.3	114.04	1034.91	42.3	132.89	1405.31	48.3	151.74	1832.25
36.4	114.35	1040.62	42.4	133.20	1411.96	48.4	152.05	1839.84
36.5	114.67	1046.35	42.5	133.52	1418.63	48.5	152.37	1847.45
36.6	114.98	1052.09	42.6	133.83	1425.31	48.6	152.68	1855.08
36.7	115.30	1057.84	42.7	134.15	1432.01	48.7	153.00	1862.72
36.8	115.61	1063.62	42.8	134.46	1438.72	48.8	153.31	1870.38
36.9	115.92	1069.41	42.9	134.77	1445.45	48.9	153.62	1878.05
37.0	116.24	1075.21	**43.0**	135.09	1452.20	**49.0**	153.94	1885.74
37.1	116.55	1081.03	43.1	135.40	1458.96	49.1	154.25	1893.45
37.2	116.87	1086.87	43.2	135.72	1465.74	49.2	154.57	1901.17
37.3	117.18	1092.72	43.3	136.03	1472.54	49.3	154.88	1908.90
37.4	117.50	1098.58	43.4	136.35	1479.34	49.4	155.19	1916.65
37.5	117.81	1104.47	43.5	136.66	1486.17	49.5	155.51	1924.42
37.6	118.12	1110.36	43.6	136.97	1493.01	49.6	155.82	1932.21
37.7	118.44	1116.28	43.7	137.29	1499.87	49.7	156.14	1940.00
37.8	118.75	1122.21	43.8	137.60	1506.74	49.8	156.45	1947.82
37.9	119.07	1128.15	43.9	137.92	1513.63	49.9	156.77	1955.65
38.0	119.38	1134.11	**44.0**	138.23	1520.53	**50.0**	157.08	1963.50
38.1	119.69	1140.09	44.1	138.54	1527.45	51	160.22	2042.82
38.2	120.01	1146.08	44.2	138.86	1534.39	52	163.36	2123.72
38.3	120.32	1152.09	44.3	139.17	1541.34	53	166.50	2206.19
38.4	120.64	1158.12	44.4	139.49	1548.30	54	169.64	2290.22
38.5	120.95	1164.16	44.5	139.80	1555.28	55	172.79	2375.83
38.6	121.27	1170.21	44.6	140.12	1562.28	56	175.93	2463.01
38.7	121.58	1176.28	44.7	140.43	1569.30	57	179.07	2551.76
38.8	121.89	1182.37	44.8	140.74	1576.33	58	182.21	2642.08
38.9	122.21	1188.47	44.9	141.06	1583.37	59	185.35	2733.97
39.0	122.52	1194.59	**45.0**	141.37	1590.43	**60**	188.50	2827.44
39.1	122.84	1200.72	45.1	141.69	1597.51	61	191.64	2922.47
39.2	123.15	1206.87	45.2	142.00	1604.60	62	194.78	3019.07
39.3	123.46	1213.04	45.3	142.31	1611.71	63	197.92	3117.25
39.4	123.78	1219.22	45.4	142.63	1618.83	64	201.06	3216.99
39.5	124.09	1225.42	45.5	142.94	1625.97	65	204.20	3318.31
39.6	124.41	1231.63	45.6	143.26	1633.13	66	207.34	3421.19
39.7	124.72	1237.86	45.7	143.57	1640.30	67	210.49	3525.65
39.8	125.04	1244.10	45.8	143.88	1647.48	68	213.63	3631.68
39.9	125.35	1250.36	45.9	144.20	1654.68	69	216.77	3739.28
40.0	125.66	1256.64	**46.0**	144.51	1661.90	**70**	219.91	3848.45
40.1	125.98	1262.93	46.1	144.83	1669.14	71	223.05	3959.19
40.2	126.29	1269.23	46.2	145.14	1676.39	72	226.19	4071.50
40.3	126.61	1275.56	46.3	145.46	1683.65	73	229.34	4185.39
40.4	126.92	1281.90	46.4	145.77	1690.93	74	232.48	4300.84
40.5	127.23	1288.25	46.5	146.08	1698.23	75	235.62	4417.86
40.6	127.55	1294.62	46.6	146.40	1705.54	76	238.76	4536.46
40.7	127.86	1301.00	46.7	146.71	1712.87	77	241.90	4656.63
40.8	128.18	1307.41	46.8	147.03	1720.21	78	245.04	4778.36
40.9	128.49	1313.82	46.9	147.34	1727.57	79	248.19	4901.67
41.0	128.81	1320.25	**47.0**	147.65	1734.94	**80**	251.33	5026.55
41.1	129.12	1326.70	47.1	147.97	1742.34	81	254.47	5153.00

CIRCUMFERENCES AND AREAS OF CIRCLES.

Diam.	Circum.	Area.	Diam.	Circum.	Area.	Diam.	Circum.	Area.
82	257.61	5281.02	142	446.11	15836.77	202	634.60	32047.39
83	260.75	5410.61	143	449.25	16060.61	203	637.74	32365.47
84	263.89	5541.77	144	452.39	16286.02	204	640.88	32685.13
85	267.04	5674.50	145	455.53	16513.00	205	644.03	33006.36
86	270.18	5808.80	146	458.67	16741.55	206	647.17	33329.16
87	273.32	5944.68	147	461.81	16971.67	207	650.31	33653.53
88	276.46	6082.12	148	464.96	17203.36	208	653.45	33979.47
89	279.60	6221.14	149	468.10	17436.62	209	656.59	34306.98
90	282.74	6361.73	**150**	471.24	17671.46	**210**	659.73	34636.06
91	285.88	6503.88	151	474.38	17907.86	211	662.88	34966.71
92	289.03	6647.61	152	477.52	18145.84	212	666.02	35298.94
93	292.17	6792.91	153	480.66	18385.39	213	669.16	35632.73
94	295.31	6939.78	154	483.81	18626.50	214	672.30	35968.09
95	298.45	7088.22	155	486.95	18869.19	215	675.44	36305.03
96	301.59	7238.23	156	490.09	19113.45	216	678.58	36643.54
97	304.73	7389.81	157	493.23	19359.28	217	681.73	36983.61
98	307.88	7542.96	158	496.37	19606.68	218	684.87	37325.26
99	311.02	7697.69	159	499.51	19855.65	219	688.01	37668.48
100	314.16	7853.98	**160**	502.65	20106.19	**220**	691.15	38013.27
101	317.30	8011.85	161	505.80	20358.31	221	694.29	38359.63
102	320.44	8171.28	162	508.94	20611.99	222	697.43	38707.56
103	323.58	8332.29	163	512.08	20867.24	223	700.58	39057.07
104	326.73	8494.87	164	515.22	21124.07	224	703.72	39408.14
105	329.87	8659.01	165	518.36	21382.46	225	706.86	39760.78
106	333.01	8824.73	166	521.50	21642.43	226	710.00	40115.00
107	336.15	8992.02	167	524.65	21903.97	227	713.14	40470.78
108	339.29	9160.88	168	527.79	22167.08	228	716.28	40828.14
109	342.43	9331.32	169	530.93	22431.76	229	719.42	41187.07
110	345.58	9503.32	**170**	534.07	22698.01	**230**	722.57	41547.56
111	348.72	9676.89	171	537.21	22965.83	231	725.71	41909.63
112	351.86	9852.03	172	540.35	23235.22	232	728.85	42273.27
113	355.00	10028.75	173	543.50	23506.18	233	731.99	42638.48
114	358.14	10207.03	174	546.64	23778.71	234	735.13	43005.26
115	361.28	10386.89	175	549.78	24052.82	235	738.27	43373.61
116	364.42	10568.32	176	552.92	24328.49	236	741.42	43743.54
117	367.57	10751.32	177	556.06	24605.74	237	744.56	44115.03
118	370.71	10935.88	178	559.20	24884.56	238	747.70	44488.09
119	373.85	11122.02	179	562.35	25164.94	239	750.84	44862.73
120	376.99	11309.73	**180**	565.49	25446.90	**240**	753.98	45238.93
121	380.13	11499.01	181	568.63	25730.43	241	757.12	45616.71
122	383.27	11689.87	182	571.77	26015.53	242	760.27	45996.06
123	386.42	11882.29	183	574.91	26302.20	243	763.41	46376.98
124	389.56	12076.28	184	578.05	26590.44	244	766.55	46759.47
125	392.70	12271.85	185	581.19	26880.25	245	769.69	47143.52
126	395.84	12468.98	186	584.34	27171.63	246	772.83	47529.16
127	398.98	12667.69	187	587.48	27464.59	247	775.97	47916.36
128	402.12	12867.96	188	590.62	27759.11	248	779.11	48305.13
129	405.27	13069.81	189	593.76	28055.21	249	782.26	48695.47
130	408.41	13273.23	**190**	596.90	28352.87	**250**	785.40	49087.39
131	411.55	13478.22	191	600.04	28652.11	251	788.54	49480.87
132	414.69	13684.78	192	603.19	28952.92	252	791.68	49875.92
133	417.83	13892.91	193	606.33	29255.30	253	794.82	50272.55
134	420.97	14102.61	194	609.47	29559.25	254	797.96	50670.75
135	424.12	14313.88	195	612.61	29864.77	255	801.11	51070.52
136	427.26	14526.72	196	615.75	30171.86	256	804.25	51471.85
137	430.40	14741.14	197	618.89	30480.52	257	807.39	51874.76
138	433.54	14957.12	198	622.04	30790.75	258	810.53	52279.24
139	436.68	15174.68	199	625.18	31102.55	259	813.67	52685.29
140	439.82	15393.80	**200**	628.32	31415.93	**260**	816.81	53092.92
141	442.96	15614.50	201	631.46	31730.87	261	819.96	53502.11

CIRCUMFERENCES AND AREAS OF CIRCLES.

Diam.	Circum.	Area.	Diam.	Circum.	Area.	Diam.	Circum.	Area.
262	823.10	53912.87	309	970.75	74990.60	355	1115.27	98979.80
263	826.24	54325.21	**310**	973.89	75476.76	356	1118.41	99538.22
264	829.38	54739.11	311	977.04	75964.50	357	1121.55	100098.21
265	832.52	55154.59	312	980.18	76453.80	358	1124.69	100659.77
266	835.66	55571.63	313	983.32	76944.67	359	1127.83	101222.90
267	838.81	55990.25	314	986.46	77437.12	**360**	1130.97	101787.60
268	841.95	56410.44	315	989.60	77931.13	361	1134.11	102353.87
269	845.09	56832.20	316	992.74	78426.72	362	1137.26	102921.72
270	848.23	57255.53	317	995.88	78923.88	363	1140.40	103491.13
271	851.37	57680.43	318	999.03	79422.60	364	1143.54	104062.12
272	854.51	58106.90	319	1002.17	79922.90	365	1146.68	104634.67
273	857.65	58534.94	**320**	1005.31	80424.77	366	1149.82	105208.80
274	860.80	58964.55	321	1008.45	80928.21	367	1152.96	105784.49
275	863.94	59395.74	322	1011.59	81433.22	368	1156.11	106361.76
276	867.08	59828.49	323	1014.73	81939.80	369	1159.25	106940.60
277	870.22	60262.82	324	1017.88	82447.96	**370**	1162.39	107521.01
278	873.36	60698.71	325	1021.02	82957.68	371	1165.53	108102.99
279	876.50	61136.18	326	1024.16	83468.98	372	1168.67	108686.54
280	879.65	61575.22	327	1027.30	83981.84	373	1171.81	109271.66
281	882.79	62015.82	328	1030.44	84496.28	374	1174.96	109858.35
282	885.93	62458.00	329	1033.58	85012.28	375	1178.10	110446.62
283	889.07	62901.75	**330**	1036.73	85529.86	376	1181.24	111036.45
284	892.21	63347.07	331	1039.87	86049.01	377	1184.38	111627.86
285	895.35	63793.97	332	1043.01	86569.73	378	1187.52	112220.83
286	898.50	64242.43	333	1046.15	87092.02	379	1190.66	112815.38
287	901.64	64692.46	334	1049.29	87615.88	**380**	1193.81	113411.49
288	904.78	65144.07	335	1052.43	88141.31	381	1196.95	114009.18
289	907.92	65597.24	336	1055.58	88668.31	382	1200.09	114608.44
290	911.06	66051.99	337	1058.72	89196.88	383	1203.23	115209.27
291	914.20	66508.30	338	1061.86	89727.03	384	1206.37	115811.67
292	917.35	66966.19	339	1065.00	90258.74	385	1209.51	116415.64
293	920.49	67425.65	**340**	1068.14	90792.03	386	1212.65	117021.18
294	923.63	67886.68	341	1071.28	91326.88	387	1215.80	117628.30
295	926.77	68349.28	342	1074.42	91863.31	388	1218.94	118236.98
296	929.91	68813.45	343	1077.57	92401.31	389	1222.08	118847.24
297	933.05	69279.19	344	1080.71	92940.88	**390**	1225.22	119459.06
298	936.19	69746.50	345	1083.85	93482.02	391	1228.36	120072.46
299	939.34	70215.38	346	1086.99	94024.73	392	1231.50	120687.42
300	942.48	70685.83	347	1090.13	94569.01	393	1234.65	121303.96
301	945.62	71157.86	348	1093.27	95114.86	394	1237.79	121922.07
302	948.76	71631.45	349	1096.42	95662.28	395	1240.93	122541.75
303	951.90	72106.62	**350**	1099.56	96211.28	396	1244.07	123163.00
304	955.04	72583.36	351	1102.70	96761.84	397	1247.21	123785.82
305	958.19	73061.66	352	1105.84	97313.97	398	1250.35	124410.21
306	961.33	73541.54	353	1108.98	97867.68	399	1253.50	125036.17
307	964.47	74022.99	354	1112.12	98422.96	**400**	1256.64	125663.71
308	967.61	74506.01						

178. Decimal Equivalents.

8ths and 16ths.	32ds.	64ths.	Decimals.	8ths and 16ths.	32ds.	64ths.	Decimals.
		1	.015625	9/16	18	36	.5625
	1	2	.03125			37	.578125
		3	.046875		19	38	.59375
1/16	2	4	.0625			39	.609375
		5	.078125	5/8	20	40	.625
	3	6	.09375			41	.640625
		7	.109375		21	42	.65625
1/8	4	8	.125			43	.671875
		9	.140625	11/16	22	44	.6875
	5	10	.15625			45	.703125
		11	.171875		23	46	.71875
3/16	6	12	.1875			47	.734375
		13	.203125	3/4	24	48	.75
	7	14	.21875			49	.765625
		15	.234375		25	50	.78125
1/4	8	16	.25			51	.796875
		17	.265625	13/16	26	52	.8125
	9	18	.28125			53	.828125
		19	.296875		27	54	.84375
5/16	10	20	.3125			55	.859375
		21	.328125	7/8	28	56	.875
	11	22	.34375			57	.890625
		23	.359375		29	58	.90625
3/8	12	24	.375			59	.921875
		25	.390625	15/16	30	60	.9375
	13	26	.40625			61	.953125
		27	.421875		31	62	.96875
7/16	14	28	.4375			63	.984375
		29	.453125	1	32	64	1.00
	15	30	.46875				
		31	.484375				
1/2	16	32	.5				
		33	.515625				
	17	34	.53125				
		35	.546875				

179. Weights of Various Materials.

Material.	Approx. Sp. Gravity.	Pounds per Cubic Inch.	Pounds per Cubic Foot.	Cubic Feet per Ton (2000).
Cast iron......	7.1	.2607	450	4.44
Wrought iron..	7.7	.281	486	4.11
Soft steel......	7.9	.285	493	4.06
Hard steel.....	7.7	.278	480	4.17
Brass..........	8.4	.304	525	3.81
Lead..........	11.4	.410	709	2.82
Copper—cast..	8.7	.315	543	3.68
Copper—sheet.	8.9	.322	555	3.60
Mercury.......	13.6	.490	847	2.36
Zinc...........	7.1	.253	437	4.58
Tin............	7.3	.263	458	4.37
Timber........	.4 to .8	.0144 to .0289	25 to 50	80 to 40
Stone.........	2.2 to 2 8	.079 to .101	137 to 175	14.6 to 11 4
Brick..........	1.6 to 2.1	.0578 to .0752	100 to 130	20 to 15.4
Mortar........	1.5	.0544	94	21.3
Water.........	1	.036	62.4	32.0

180. Weight of Water.

Temperature. Fahr.	Weight per Cubic Foot. Pounds.	Temperature. Fahr.	Weight per Cubic Foot. Pounds.	Temperature. Fahr.	Weight per Cubic Foot. Pounds.
32	62.42	122	61.70	168	60.81
40	62.42	124	61.67	170	60.77
45	62.42	126	61.63	172	60.73
50	62.41	128	61.60	174	60.68
55	62.39	130	61.56	176	60.64
60	62.37	132	61.52	178	60.59
65	62.34	134	61.49	180	60.55
70	62.31	136	61.45	182	60.50
75	62.27	138	61.41	184	60.46
80	62.23	140	61.37	186	60.41
85	62.18	142	61.34	188	60.37
90	62.13	144	61.30	190	60.32
95	62.04	146	61.26	192	60.27
100	62.02	148	61.22	194	60.22
102	62.00	150	61.18	196	60.17
104	61.97	152	61.14	198	60.12
106	61.95	154	61.10	200	60.07
108	61.92	156	61.06	202	60.02
110	61.89	158	61.02	204	59.97
112	61.86	160	60.98	206	59.92
114	61.83	162	60.94	208	59.87
116	61.80	164	60.90	210	59.82
118	61.77	166	60.85	212	59.76
120	61.74				

COMPARISON OF HEADS.

One foot of water at 50° F.	= 62.41 pounds per sq. ft.
One foot of water at 50° F.	= 0.4334 pounds per sq. in.
One foot of water at 50° F.	= 0.8845 in. mercury at 32° F.
One pound per sq. ft. at 50° F.	= 0.01602 feet of water.
One pound per sq. in. at 50° F.	= 2.308 feet of water.
One inch of mercury at 32° F.	= 1.130 feet of water.
One atmosphere of 29.92 in. of mer.	= 33.80 feet of water.

181. Melting-points of Metals.

Mercury	−38° F.
Tin	442° F.
Bismuth	497° F.
Lead	612° F.
Zinc	773° F.
Antimony	810° F.
Brass	1869° F.
Silver	1874° F.
Copper	1995° F.
Gold	2016° F.
Iron, cast	2780° F.
Platinum	3280° F.

182. Properties of Saturated Steam.

(Abridged from Kent.)

Vacuum-gage. Inches of Mercury.	Absolute Pressure. Lbs. per Sq. In.	Temperature. Fahrenheit.	Heat of the Liquid. *q*.	Heat of Vaporization. *r*.	Weight of 1 Cu. Ft. in Pounds.
29.74	.089	32	0	1091.7	.00030
29.67	.122	40	8	1086.1	.00040
29.56	.176	50	18	1079.2	.00058
29.40	.254	60	28.01	1072.2	.00082
29.19	.359	70	38.02	1065.3	.00115
28.90	.502	80	48.04	1058.3	.00158
28.51	.692	90	58.06	1051.3	.00213
28.00	.943	100	68.08	1044.4	.00286
27.88	1	102.1	70.09	1043.0	.00299
25.85	2	126.3	94.44	1026.0	.00577
23.83	3	141.6	109.9	1015.3	.00848
21.78	4	153.1	121.4	1007.2	.01112
19.74	5	162.3	130.7	1000.7	.01372
17.70	6	170.1	138.6	995.2	.01631
15.67	7	176.9	145.4	990.5	.01887
13.63	8	182.9	155.5	986.2	.02140
11.60	9	188.3	156.9	982.4	.02391
9.56	10	193.2	161.9	979.0	.02641
7.52	11	197.8	166.5	975.8	.02889
5.49	12	202.0	170.7	972.8	.03136
3.45	13	205.9	174.7	970.0	.03381
1.41	14	209.6	178.4	967.4	.03625
Gage-pressure. Lbs. per Sq. In.	14.7	212.0	180.9	965.7	.03794
0.304	15	213.0	181.9	965.0	.03868
1.3	16	216.3	185.3	962.7	.04110
2.3	17	219.4	188.4	960.5	.04352
3.3	18	222.4	191.4	958.3	.04592
4.3	19	225.2	194.3	956.3	.04831
5.3	20	227.9	197.0	954.4	.05070
6.3	21	230.5	199.7	952.6	.05308
7.3	22	233.0	202.2	950.8	.05545
8.3	23	235.4	204.7	949.1	.05782
9.3	24	237.8	207.0	947.4	.06018

PROPERTIES OF SATURATED STEAM.

Gage-pressure. Lbs. per Sq. In.	Absolute Pressure. Lbs. per Sq. In.	Temperature. Fahrenheit.	Heat of the Liquid. q.	Heat of Vaporization. r.	Weight of 1 Cu. Ft. in Pounds.
10.3	25	240.0	209.3	945.8	.06252
11.3	26	242.2	211.5	944.3	.06487
12.3	27	244.3	213.7	942.8	.06721
13.3	28	246.3	215.7	941.3	.06955
14.3	29	248.3	217.8	939.9	.07188
15.3	30	250.2	219.7	938.9	.07420
16.3	31	252.1	221.6	937.2	.07652
17.3	32	254.0	223.5	935.9	.07884
18.3	33	255.7	225.3	934.6	.08115
19.3	34	257.5	227.1	933.4	.08346
20.3	35	259.2	228.8	932.2	.08576
21.3	36	260.8	230.5	931.0	.08806
22.3	37	262.5	232.1	929.8	.09035
23.3	38	264.0	233.8	928.7	.09264
24.3	39	265.6	235.4	927.6	.09493
25.3	40	267.1	236.9	926.5	.09721
26.3	41	268.6	238.5	925.4	.09949
27.3	42	270.1	240.0	924.4	.1018
28.3	43	271.5	241.4	923.3	.1040
29.3	44	272.9	242.9	922.3	.1063
30.3	45	274.3	244.3	921.3	.1086
31.3	46	275.7	245.7	920.4	.1108
32.3	47	277.0	247.0	919.4	.1131
33.3	48	278.3	248.4	918.5	.1153
34.3	49	279.6	249.7	917.5	.1176
35.3	50	280.9	251.0	916.6	.1198
36.3	51	282.1	252.2	915.7	.1221
37.3	52	283.3	253.5	914.9	.1243
38.3	53	284.5	254.7	914.0	.1266
39.3	54	285.7	256.0	913.1	.1288
40.3	55	286.9	257.2	912.3	.1311
41.3	56	288.1	258.3	911.5	.1333
42.3	57	289.1	259.5	910.6	.1355
43.3	58	290.3	260.7	909.8	.1377
44.3	59	291.4	261.8	909.0	.1400
45.3	60	292.5	262.9	908.2	.1422

PROPERTIES OF SATURATED STEAM.

Gage-pressure. Lbs. per Sq. In.	Absolute Pressure. Lbs. per Sq. In.	Temperature. Fahrenheit.	Heat of the Liquid. q.	Heat of Vaporization. r.	Weight of 1 Cu. Ft. in Pounds.
46.3	61	293.6	264.0	907.5	.1444
47.3	62	294.7	265.1	906.7	.1466
48.3	63	295.7	266.2	905.9	.1488
49.3	64	296.8	267.2	905.2	.1511
50.3	65	297.8	268.3	904.5	.1533
51.3	66	298.8	269.3	903.7	.1555
52.3	67	299.8	270.4	903.0	.1577
53.3	68	300.8	271.4	902.3	.1599
54.3	69	301.8	272.4	901.6	.1621
55.3	70	302.7	273.4	900.9	.1643
56.3	71	303.7	274.4	900.2	.1665
57.3	72	304.6	275.3	899.5	.1687
58.3	73	305.6	276.3	898.9	.1709
59.3	74	306.5	277.2	898.2	.1731
60.3	75	307.4	278.2	897.5	.1753
61.3	76	308.3	279.1	896.9	.1775
62.3	77	309.2	280.0	896.2	.1797
63.3	78	310.1	280.9	895.6	.1819
64.3	79	310.9	281.8	895.0	.1840
65.3	80	311.8	282.7	894.3	.1862
66.3	81	312.7	283.6	893.7	.1884
67.3	82	313.5	284.5	893.1	.1906
68.3	83	314.4	285.3	892.5	.1928
69.3	84	315.2	286.2	891.9	.1950
70.3	85	316.0	287.0	891.3	.1971
71.3	86	316.8	287.9	890.7	.1993
72.3	87	317.7	288.7	890.1	.2015
73.3	88	318.5	289.5	889.5	.2036
74.3	89	319.3	290.4	888.9	.2058
75.3	90	320.0	291.2	888.4	.2080
76.3	91	320.8	292.0	887.8	.2102
77.3	92	321.6	292.8	887.2	.2123
78.3	93	322.4	293.6	886.7	.2145
79.3	94	323.1	294.4	886.1	.2166
80.3	95	323.9	295.1	885.6	.2188
81.3	96	324.6	295.9	885.0	.2210

PROPERTIES OF SATURATED STEAM.

Gage-pressure. Lbs. per Sq. In.	Absolute Pressure. Lbs. per Sq. In.	Temperature. Fahrenheit.	Heat of the Liquid. q.	Heat of Vaporization. r.	Weight of 1 Cu. Ft. in Pounds.
82.3	97	325.4	296.7	884.5	.2231
83.3	98	326.1	297.4	884.0	.2253
84.3	99	326.8	298.2	883.4	.2274
85.3	100	327.6	298.9	882.9	.2296
86.3	101	328.3	299.7	882.4	.2317
87.3	102	329.0	300.4	881.9	.2339
88.3	103	329.7	301.1	881.4	.2360
89.3	104	330.4	301.9	880.8	.2382
90.3	105	331.1	302.6	880.3	.2403
91.3	106	331.8	303.3	879.8	.2425
92.3	107	332.5	304.0	879.3	.2446
93.3	108	333.2	304.7	878.8	.2467
94.3	109	333.9	305.4	878.3	.2489
95.3	110	334.5	306.1	877.9	.2510
96.3	111	335.2	306.8	877.4	.2531
97.3	112	335.9	307.5	876.9	.2553
98.3	113	336.5	308.2	876.4	.2574
99.3	114	337.2	308.8	875.9	.2596
100.3	115	337.8	309.5	875.5	.2617
101.3	116	338.5	310.2	875.0	.2638
102.3	117	339.1	310.8	874.5	.2660
103.3	118	339.7	311.5	874.1	.2681
104.3	119	340.4	312.1	873.6	.2703
105.3	120	341.0	312.8	873.2	.2724
106.3	121	341.6	313.4	872.7	.2745
107.3	122	342.2	314.1	872.3	.2766
108.3	123	342.9	314.7	871.8	.2788
109.3	124	343.5	315.3	871.4	.2809
110.3	125	344.1	316.0	870.9	.2830
111.3	126	344.7	316.6	870.5	.2851
112.3	127	345.3	317.2	870.0	.2872
113.3	128	345.9	317.8	869.6	.2894
114.3	129	346.5	318.4	869.2	.2915
115.3	130	347.1	319.1	868.7	.2936
116.3	131	347.6	319.7	868.3	.2957
117.3	132	348.2	320.3	867.9	.2978

PROPERTIES OF SATURATED STEAM.

Gage-pressure. Lbs. per Sq. In.	Absolute Pressure. Lbs. per Sq. In.	Temperature. Fahrenheit.	Heat of the Liquid. q.	Heat of Vaporization. r.	Weight of 1 Cu. Ft. in Pounds.
118.3	133	348.8	320.8	867.5	.3000
119.3	134	349.4	321.5	867.0	.3021
120.3	135	350.0	322.1	866.6	.3042
121.3	136	350.5	322.6	866.2	.3063
122.3	137	351.1	323.2	865.8	.3084
123.3	138	351.8	323.8	865.4	.3105
124.3	139	352.2	324.4	865.0	.3126
125.3	140	352.8	325.0	864.6	.3147
126.3	141	353.3	325.5	864.2	.3169
127.3	142	353.9	326.1	863.8	.3190
128.3	143	354.4	326.7	863.4	.3211
129.3	144	355.0	327.2	863.0	.3232
130.3	145	355.5	327.8	862.6	.3253
131.3	146	356.0	328.4	862.2	.3274
132.3	147	356.6	328.9	861.8	.3295
133.3	148	357.1	329.5	861.4	.3316
134.3	149	357.6	330.0	861.0	.3337
135.3	150	358.2	330.6	860.6	.3358
136.3	151	358.7	331.1	860.2	.3379
137.3	152	359.2	331.6	859.9	.3400
138.3	153	359.7	332.2	859.5	.3421
139.3	154	360.2	332.7	859.1	.3442
140.3	155	360.7	333.2	858.7	.3463
141.3	156	361.3	333.8	858.4	.3483
142.3	157	361.8	334.3	858.0	.3504
143.3	158	362.3	334.8	857.6	.3525
144.3	159	362.8	335.3	857.2	.3546
145.3	160	363.3	335.9	856.9	.3567
146.3	161	363.8	336.4	856.5	.3588
147.3	162	364.3	336.9	856.1	.3609
148.3	163	364.8	337.4	855.8	.3630
149.3	164	365.3	337.9	855.4	.3650
150.3	165	365.7	338.4	855.1	.3671
151.3	166	366.2	338.9	854.7	.3692
152.3	167	366.7	339.4	854.4	.3713
153.3	168	367.2	339.9	854.0	.3734
154.3	169	367.7	340.4	853.6	.3754

PROPERTIES OF SATURATED STEAM.

Gage-pressure. Lbs. per Sq. In.	Absolute Pressure. Lbs. per Sq. In.	Temperature. Fahrenheit.	Heat of the Liquid. q.	Heat of Vaporization. r.	Weight of 1 Cu. Ft. in Pounds.
155.3	170	368.2	340.9	853.3	.3775
156.3	171	368.6	341.4	852.9	.3796
157.3	172	369.1	341.9	852.6	.3817
158.3	173	369.6	342.4	852.3	.3838
159.3	174	370.0	342.9	851.9	.3858
160.3	175	370.5	343.4	851.6	.3879
161.3	176	371.0	343.9	851.2	.3900
162.3	177	371.4	344.3	850.9	.3921
163.3	178	371.9	344.8	850.5	.3942
164.3	179	372.4	345.3	850.2	.3962
165.3	180	372.8	345.8	849.9	.3983
166.3	181	373.3	346.3	849.5	.4004
167.3	182	373.7	346.7	849.2	.4025
168.3	183	374.2	347.2	848.9	.4046
169.3	184	374.6	347.7	848.5	.4066
170.3	185	375.1	348.1	848.2	.4087
171.3	186	375.5	348.6	847.9	.4108
172.3	187	375.9	349.1	847.6	.4129
173.3	188	376.4	349.5	847.2	.4150
174.3	189	376.9	350.0	846.9	.4170
175.3	190	377.3	350.4	846.6	.4191
176.3	191	377.7	350.9	846.3	.4212
177.3	192	378.2	351.3	845.9	.4233
178.3	193	378.6	351.8	845.6	.4254
179.3	194	379.0	352.2	845.3	.4275
180.3	195	379.5	352.7	845.0	.4296
181.3	196	380.0	353.1	844.7	.4317
182.3	197	380.3	353.6	844.4	.4337
183.3	198	380.7	354.0	844.1	.4358
184.3	199	381.2	354.4	843.7	.4379
185.3	200	381.6	354.9	843.4	.4400
186.3	201	382.0	355.3	843.1	.4420
187.3	202	382.4	355.8	842.8	.4441
188.3	203	382.8	356.2	842.5	.4462
189.3	204	383.2	356.6	842.2	.4482
190.3	205	383.7	357.1	841.9	.4503

PROPERTIES OF SATURATED STEAM.

Gage-pressure. Lbs. per Sq. In.	Absolute Pressure. Lbs. per Sq. In.	Temperature. Fahrenheit.	Heat of the Liquid. *q*.	Heat of Vaporization. *r*.	Weight of 1 Cu. Ft. in Pounds.
191.3	206	384.1	357.5	841.6	.4523
192.3	207	384.5	357.9	841.3	.4544
193.3	208	384.9	358.3	841.0	.4564
194.3	209	385.3	358.8	840.7	.4585
195.3	210	385.7	359.2	840.4	.4605
196.3	211	386.1	359.6	840.1	.4626
197.3	212	386.5	360.0	839.8	.4646
198.3	213	386.9	360.4	839.5	.4667
199.3	214	387.3	360.9	839 2	.4687
200.3	215	387.7	361.3	838.9	.4707
201.3	216	388.1	361.7	838.6	.4728
202.3	217	388.5	362.1	838.3	.4748
203.3	218	388.9	362.5	838.1	.4768
204.3	219	389.3	362.9	837.8	.4788
205.3	220	389.7	363.2	837.6	.4808

183. Comparison of Fahrenheit and Centigrade Thermometer Scales.

Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.
212	100.0	169	76.1	126	52.2	83	28.3	40	4.4	−3	−19.4
211	99.4	168	75.5	125	51.6	82	27.7	39	3.8	−4	−20.0
210	98.8	167	75.0	124	51.1	81	27.2	38	3.3	−5	−20.5
209	98.3	166	74.4	123	50.5	80	26.6	37	2.7	−6	−21.1
208	97.7	165	73.8	122	50.0	79	26.1	36	2.2	−7	−21.6
207	97.2	164	73.3	121	49.4	78	25.5	35	1.6	−8	−22.2
206	96.6	163	72.7	120	48.8	77	25.0	34	1.1	−9	−22.7
205	96.1	162	72.2	119	48.3	76	24.4	33	0.5	−10	−23.3
204	95.5	161	71.6	118	47.7	75	23.8	32	0.0	−11	−23.8
203	95.0	160	71.1	117	47.2	74	23.3	31	−0.5	−12	−24.4
202	94.4	159	70.5	116	46.6	73	22.7	30	−1.1	−13	−25.0
201	93.8	158	70.0	115	46.1	72	22.2	29	−1.6	−14	−25.5
200	93.3	157	69.4	114	45.5	71	21.6	28	−2.2	−15	−26.1
199	92.7	156	68.8	113	45.0	70	21.1	27	−2.7	−16	−26.6
198	92.2	155	68.3	112	44.4	69	20.5	26	−3.3	−17	−27.2
197	91.6	154	67.7	111	43.8	68	20.0	25	−3.8	−18	−27.7
196	91.1	153	67.2	110	43.3	67	19.4	24	−4.4	−19	−28.3
195	90.5	152	66.6	109	42.7	66	18.8	23	−5.0	−20	−28.8
194	90.0	151	66.1	108	42.2	65	18.3	22	−5.5	−21	−29.4
193	89.4	150	65.5	107	41.6	64	17.7	21	−6.1	−22	−30.0
192	88.8	149	65.0	106	41.1	63	17.2	20	−6.6	−23	−30.5
191	88.3	148	64.4	105	40.5	62	16.6	19	−7.2	−24	−31.1
190	87.7	147	63.8	104	40.0	61	16.1	18	−7.7	−25	−31.6
189	87.2	146	63.3	103	39.4	60	15.5	17	−8.3	−26	−32.2
188	86.6	145	62.7	102	38.8	59	15.0	16	−8.8	−27	−32.7
187	86.1	144	62.2	101	38.3	58	14.4	15	−9.4	−28	−33.3
186	85.5	143	61.6	100	37.7	57	13.8	14	−10.0	−29	−33.8
185	85.0	142	61.1	99	37.2	56	13.3	13	−10.5	−30	−34.4
184	84.4	141	60.5	98	36.6	55	12.7	12	−11.1		
183	83.8	140	60.0	97	36.1	54	12.2	11	−11.6		
182	83.3	139	59.4	96	35.5	53	11.6	10	−12.2		
181	82.7	138	58.8	95	35.0	52	11.1	9	−12.7		
180	82.2	137	58.3	94	34.4	51	10.5	8	−13.3		
179	81.6	136	57.7	93	33.8	50	10.0	7	−13.8		
178	81.1	135	57.2	92	33.3	49	9.4	6	−14.4		
177	80.5	134	56.6	91	32.7	48	8.8	5	−15.0		
176	80.0	133	56.1	90	32.2	47	8.3	4	−15.5		
175	79.4	132	55.5	89	31.6	46	7.7	3	−16.1		
174	78.8	131	55.0	88	31.1	45	7.2	2	−16.6		
173	78.3	130	54.4	87	30.5	44	6.6	1	−17.2		
172	77.7	129	53.8	86	30.0	43	6.1	0	−17.7		
171	77.2	128	53.3	85	29.4	42	5.5	−1	−18.3		
170	76.6	127	52.7	84	28.8	41	5.0	−2	−18.8		

184. Moments of Inertia.

Section.	Dimensions.	Axis.	Moment of Inertia.
Rectangle...	$b \times h$	On side b	$\frac{bh^3}{3}$
Rectangle...	$b \times h$	Through c. of g., parallel to b	$\frac{bh^3}{12}$
Hollow rectangle	Outside, $b \times h$, inside, $b_1 \times h_1$	Through c. of g., parallel to b	$\frac{bh^3 - b_1h_1^3}{12}$
Triangle..	Base b, alt. h	Through c. of g., parallel to b	$\frac{bh^3}{36}$
Circle.......	d	Through center	$\frac{\pi d^4}{64}$
Hollow circle	Outside d, inside d_1	Through center	$\frac{\pi(d^4 - d_1^4)}{64}$

185. Tractive Force.—The following table gives the tractive force necessary to draw one ton at various speeds under average conditions of railway service:

Speed. Miles per Hour.	Tractive Force per Ton.
15	5.8 pounds.
25	8.3 "
35	10.8 "
45	13.3 "

186. Coefficients of Discharge of Rectangular Overfall Weirs with Full Contraction.

Effective Head in Feet.	Breadth of Weir in Feet.				
	1	1.5	2	3	4
.1	.639	.643	.646	.653	.654
.15	.625	.630	.634	.639	.641
.2	.618	.622	.626	.631	.632
.25	.612	.617	.621	.625	.627
.3	.608	.612	.616	.620	.622
.4	.601	.605	.609	.614	.616
.5	.593	.599	.605	.610	.613
.6	.590	.596	.601	.607	.610
.7	.587	.593	.598	.605	.608
.8	....	.589	.595	.602	.606
.9	....	.585	.592	.600	.605
1.0	....	.583	.590	.598	.604

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