# THE APPLICATION OF HIGHLY SUPERHEATED STEAM TO LOCOMOTIVES

*Robert Garbe*

# THE APPLICATION OF HIGHLY SUPERHEATED STEAM TO LOCOMOTIVES

BEING A REPRINT FROM A SERIES OF ARTICLES APPEARING IN "THE ENGINEER"

BY

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# PREFACE

The continual growth in the weight of modern rolling stock and the call for greater speed and punctuality in service are ever adding to the demands made on locomotives. The restrictions of the permanent way and bridges preclude increasing the axle-load beyond certain limits, and, therefore, the locomotive superintendent is faced with the difficult problem of materially increasing the hauling capacity of his locomotives without, at the same time, adding unduly to their weight.

Further, the enormous sums which have been added of recent years to the coal bill of our leading railway companies must focus the attention of the directors on finding a possible means of obtaining a substantial saving in the cost of fuel.

From the experience of the Prussian State and other railways which have been using highly superheated steam it would appear that its use offers the most feasible and, at the same time, the simplest and least costly means of solving the problem with which modern railways are faced.

A series of articles, which first appeared in *The Engineer*, from the pen of Mr. Garbe, gave, for the first time in English, the reasons for, as well as the results of, the extended adoption of superheated steam that has taken place on the Prussian State railways, of which he is one of the locomotive superintendents. Mr. Garbe's independent testimony is of particular value, as he has, with the collaboration of Dr. Wilhelm Schmidt, of Cassel-Wilhelmshöhe, followed the introduction of superheated steam from its very early stages, and much of the success which has attended its introduction on the Prussian State railways is due to the care and enthusiasm which Mr. Garbe has brought to bear upon his work.

As it was suggested to me that it would be an advantage if these articles were available in book form, I consented to edit the same for publication, and trust that, as now presented, they may be of service to those interested in the introduction of superheated steam. While the text of the articles as they originally appeared in *The Engineer* has been subjected to revision, care has been taken to preserve unaltered the views originally expressed by the author.

I would refer those who are desirous of studying the question in greater detail to the larger German work by Mr. Garbe, entitled "Die Dampflokomotiven der Gegenwart," published by Messrs. Julius Springer, Berlin, in which volume they will find a mass of valuable information and data in regard to the use of superheated steam on locomotives.

My thanks are again due to my chief assistant, Mr. Charles Dresser, for his care and co-operation in the preparation of the present volume, as also to Mr. H. A. Stenning for kindly reading the proofs.

LESLIE S. ROBERTSON.

28, Victoria Street,
Westminster, S.W.,
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# CONTENTS

## CHAPTER I

### GENERATION OF HIGHLY SUPERHEATED STEAM



## CHAPTER II

### SUPERHEATED STEAM AND THE TWO-CYLINDER SIMPLE ENGINE



## CHAPTER III



## CHAPTER IV

### DESIGNS OF LOCOMOTIVE SUPERHEATERS



## CHAPTER V

### DESIGNS OF LOCOMOTIVE SUPERHEATERS (*continued*)

## CHAPTER VI

### CONSTRUCTIVE DETAILS OF LOCOMOTIVES USING HIGHLY SUPERHEATED STEAM



## CHAPTER VII

### EXPERIMENTAL AND WORKING RESULTS WITH SUPERHEATED STEAM LOCOMOTIVES

# LIST OF ILLUSTRATIONS

THE APPLICATION OF

# HIGHLY SUPERHEATED STEAM TO LOCOMOTIVES

## CHAPTER I

### GENERATION OF HIGHLY SUPERHEATED STEAM

Among recent improvements in locomotive construction none has excited greater interest in professional circles than the application of highly superheated steam to present-day locomotive practice. Ten years ago few, even among the most far-seeing of practical locomotive engineers, were willing to admit of the possibility of permanently and regularly producing steam at temperatures of 550° to 650° Fahr. within the restricted capacity of the ordinary locomotive boiler, and of its safe and economical application to the ordinary running of the engine; while at the present time[1] it has been successfully applied to more than two thousand eight hundred locomotives—including in this number those in course of construction as well as those actually running. Dry or moderately superheated steam has been frequently tried in the past, but without any marked economical advantages accruing therefrom. It was not until Dr. William Schmidt, of Cassel, developed, about twenty years ago, practical means of applying highly superheated steam that its use became possible in stationary engines. In the year 1895, the first steps were taken to extend its use to locomotives. In the latter connection special notice must be taken of the services rendered

[1] June, 1908.

by the Prussian State Railway Department, which, on the author's suggestion, was the first body to sanction the trial on a large scale of the Schmidt system upon the locomotives under its control.

From the commencement of these trials it became apparent that an efficient locomotive superheater could only be obtained by making it an integral part of the boiler itself, so as to receive its heat from the live flames of the fire-grate and not from the waste gases or from an independently fired apparatus. This fundamental principle has been retained in all the Schmidt locomotive superheaters, as well as in the numerous modifications derived therefrom, the more important of which will be noticed hereafter.

## (A) PROPERTIES AND ADVANTAGES OF HIGHLY SUPERHEATED STEAM.

*Highly Superheated Steam.*—According to Schmidt, the term "highly superheated steam" is restricted to steam that has been raised to about 100° Cent. (180° Fahr.) above its proper saturation temperature, by subjecting it to further heating in an enclosed vessel—termed a superheater—which, though in communication with the steam space, is isolated from the water in the boiler. The effect of adding this additional heat is to dry the steam and increase its temperature; the volume is at the same time increased, since, being in connection with the steam space, its pressure remains practically constant. The method of producing and using the superheated steam will be better understood if the more important properties in which it differs from saturated steam are briefly reviewed.

*Specific Volume.*—The specific volume, *i.e.* the volume per unit of weight—cubic feet per pound or cubic metre per kilogramme—of saturated steam diminishes with increase of temperature and pressure; while, on the other hand, the volume of superheated steam, increases in nearly direct proportion to the rise in temperature. Thus, for steam of 185 lbs. per square inch pressure (absolute):

| | | | | |
|---|---|---|---|---|
| At ... ... ... | 374° | 482° | 572° | 662° Fahr. |
| The specific volume is | 2·48 | 2·83 | 3·14 | 3·46 cubic feet per lb. |

Or for a superheat of 200° the increase in specific volume is approximately 25 per cent. For the same cut-off in the cylinder, therefore, the weight of steam required is about 25 per cent. less with 200° superheat than with saturated steam of the same pressure.

*Thermal Conductivity of Superheated Steam.*—An advantage to be derived from the use of superheated steam, of even greater importance than the increase of volume, is the prevention of all cylinder condensation, if a sufficiently high degree of superheat be employed. While, in a locomotive working under ordinary average conditions with saturated steam, about 35 per cent. of the total quantity admitted is immediately precipitated without doing any mechanical work, and passes through the engine as suspended water in the steam, superheated steam, on the other hand, may by reason of its reserve heat be reduced considerably in temperature without losing any of its capacity as a working agent. In this direction another important property comes into play, namely, its low thermal conductivity. Highly superheated steam in comparison with saturated steam is a bad conductor of heat. This property, which, on the one hand, is of great value in reducing the loss from condensation in the cylinders, is, on the other hand, an obstacle to the free transmission of heat to the steam in the superheater, and calls for special consideration in the design of the latter.

*Calorific Value.—Total Heat.*—In order to realize the great economical advantages of superheated steam, namely, increased volume and avoidance of cylinder condensation, a certain heat expenditure is required which must be debited against the saving due to the above items.

The heat necessary to raise 1 lb. of saturated steam from its proper temperature $t_s$ to the higher temperature $t$ degrees Fahr., is

$$W_1 = C_p (t - t_s) \text{ B.T.U.}$$

$C_p$ being the specific heat of the superheated steam under constant pressure.

Putting W = to the quantity of heat contained per pound of saturated steam at the particular pressure as given in Regnault's tables, then

$$W_2 = W + W_1 = W + C_p(t - t_s) \text{ B.T.U.}$$

and expresses the heat value of the superheated steam; that is, the total heat contained in 1 lb. of the steam superheated to the temperature $t$.

According to the late researches of Knoblauch and Jakob,[1] the specific heat $C_p$ of steam is not constant, but varies with the temperature and pressure. The mean values for the temperature and pressures current in locomotive practice are contained in the following table:—

MEAN SPECIFIC HEATS FOR SUPERHEATING FROM $t_s$° TO $t$° FAHR.

| | | | | |
|---|---|---|---|---|
| Pressure above atmosphere in lbs. per sq. inch ... ... ... | 128 | 156 | 185 | 213 |
| Temperature of saturated steam $t_s$° in degrees Fahr.... ... ... | 354 | 369 | 381 | 392 |
| SPECIFIC HEATS AT CONSTANT PRESSURE, $C_p$. | | | | |
| | $C_p$. | $C_p$. | $C_p$. | $C_p$. |
| For $t$° = 392° Fahr. ... ... ... | 0·597 | 0·635 | 0·677 | (0·751) |
| " 482° " ... ... ... | 0·552 | 0·570 | 0·588 | 0·609 |
| " 572° " ... ... ... | 0·530 | 0·541 | 0·550 | 0·561 |
| " 662° " ... ... ... | 0·522 | 0·529 | 0·536 | 0·543 |

*Size of Superheaters.*—The heat requirements of the superheater are not limited to the amount, $W_1$, necessary for supplying the actual superheat, but must be supplemented by the quantity required to evaporate the particles of water carried over mechanically into the superheater.

Assuming a degree of humidity in the boiler steam of 7 per cent., which for ordinary locomotive working conditions is certainly not excessive, the heat required to be passed through the heating surfaces of the boiler and superheater in order to produce 1 lb. of steam at 170 lbs. pressure and at a temperature of 572° Fahr. will be respectively as follows:—

[1] "Zeitschrift des Vereines deutscher Ingenieure," 1907, p. 81. "Die Abhängigkeit der spez. Wärme $C_p$ des Wasserdampfes von Druck und Temperatur."

Through the heating surface of the boiler

| | B.T.U. | |
|---|---|---|
| 0·93 lb. dry saturated steam = 0·93 × 1194·3 = | 1111 | |
| 0·07 lb. water at saturation temperature, 0·07 × 340·5 = ... ... ... ... ... | 24 | |
| | | 1135 |
| Through the surface of the superheater | | |
| Evaporation of 0·07 lb. water at 368·3 Fahr., 0·07 × 853·8 ... ... ... ... ... | 60 | |
| Superheating 1 lb. dry steam by 204° Fahr., 0·541 × 204 ... ... ... ... ... | 110 | 170 |
| Total heat required for 1 lb. of superheated steam | | 1305 |

of which 170 B.T.U., or 13 per cent., is required for the superheater.

In the subsequent treatment of this subject only such superheaters as depend upon the utilization of a portion of the tube surface of the boiler will be considered. In the normal locomotive boiler with a narrow and deep fire-box having about 10 per cent. of direct heating surface,[1] about 40 per cent. of the total heat is transmitted in the fire-box and the remaining 60 per cent. in the tubes. The superheater surface therefore must be 13 per cent. of 60, or 22 per cent. of the total tube surface; and when it is further considered that the most efficient part of the latter, namely, that in the neighbourhood of the fire-box tube plate, is unavailable, being employed in raising steam, it will be readily understood that in order to obtain a sufficient degree of superheat, from 25 to 30 per cent. of the total tube surface of the boiler must be appropriated to that use.

From what has gone before it will be evident that the surface required for superheating is not directly proportional to the degree of superheat, as the extra surface required to evaporate the water carried over with the steam has to be taken into account. For instance, to obtain half the amount of superheat in the above example, half the superheater surface would not be sufficient.

## (B) PRODUCTION OF HIGHLY SUPERHEATED STEAM IN LOCOMOTIVE BOILERS.

The property of low thermal conductivity characteristic of highly superheated steam, while of value, interposes an obstacle to its production. Steam with only a moderate superheat is generally mixed with particles of water or wet steam, and the better thermal

[1] This excludes from consideration American forms of boiler, which have, as a rule, only comparatively small direct heating surface.

conductivity of the latter tends to lower the general temperature of the mixture, and this tendency only disappears when the superheat is sufficiently high. It is not sufficient to supply heat in appropriate quantity through the superheater walls, but means must be adopted to ensure that the heat so supplied is brought into contact with the individual particles of the steam current, as they flow through the tubes, until each one is brought from the saturated to the superheated state. To effect this, steam coming in bulk from the boiler must be divided into numerous thin streams and frequently reversed in direction, so as to ensure that the wet and superheated particles shall be thoroughly mixed in their passage through the superheater tubes.

It is further necessary, having regard to the low conductivity of superheated steam, that, in order to effect the requisite transference of heat to the rapidly flowing steam particles in the superheater, the tube walls shall be considerably hotter than the steam: that is, a high temperature of the heating gases is essential.

If the steam is not properly superheated, that is, if it contains unmixed particles of both wet and superheated steam, the temperature indicated by the thermometer will be that of the average of the mixture, but the effect will not be equivalent to a uniform superheat at the temperature. Saturated steam particles, with their tendency to abstract heat from the superheated portions, are still present, and the advantages anticipated from its use can only be partially realized.

According to the author's experience, an average temperature of 570° Fahr. in the slide valve chest must be maintained in order to ensure the homogeneity of the superheated steam or its freedom from intermixed wet or saturated portions; repeated trials having shown that the coal and water consumption are considerably increased whenever the temperature falls to any appreciable extent below that figure.

Having regard to the small available space in the locomotive boiler, successful superheating can only be realized in superheaters complying with the following conditions:—

(1) The employment of gases of a sufficiently high temperature, such temperature increasing as the demand on the engine increases.

(2) The splitting up of the superheating surface as completely as possible, involving the use of thick-walled tubes of small diameter.

(3) The thorough mixing of the steam currents on their way through the tubes and the lengthening of their course, so that they are compelled after passing one set of tubes to return by another.

(4) The proper guidance of the heating gases and regulation of their draught and the provision for shutting them off when the engine is standing or drifting.

Superheaters for locomotive boilers may be classified according to their method of construction into :—

(*a*) Those using only a portion of the heating gases. This includes the Schmidt and similar forms such as the Cole, Vaughan-Horsey, and Notkin superheaters.

(*b*) Those allowing the whole of the gases to pass through the superheater. This class includes the Pielock, Slucki, and Clench forms.

(*c*) Those using the waste flue gases only.

(*d*) Those independently fired.

The direction both of the furnace gases and of the steam to be heated is a matter of primary importance in determining the efficiency of a superheater. As regards the former, care must be taken to protect the tubes from the cutting action of the flame, and as regards the latter the counter current principle of bringing the coolest steam in contact with the hottest portion of the tubes is essential. The question whether the tubes should be arranged transversely or parallel to the current of heating gases cannot be considered to be finally settled; experience obtained with stationary boilers seems to show that the latter is more favourable to regularity of heating.

It is essential that the flow of the gases through the superheater should be so regulated that the intensity of the heating current may be modified according to requirements, and that the gases may be entirely shut off while the engine is standing so as to prevent the tubes from becoming red-hot when the regulator is closed. The shutting off of the gases is particularly necessary in the second of the above classes—(*b*)—where a portion of the ordinary boiler tubes serves as the superheater. Only when the superheater is placed at the smoke-box ends of the tubes can the dampers be dispensed with, but with this construction of superheater an efficient degree of superheat cannot be obtained.

The steam should be made to traverse as great a number of small but thick-walled tubes as possible in order that it may become thoroughly mixed, and care should be taken that the pipes do not come in contact with the saturated steam as happens in the Pielock superheater, where the superheated steam is led through the damp steam space of the boiler, with the result that a considerable portion of the heat acquired by the superheated steam is lost.

The velocity of the steam in the superheater must be tolerably high in order to prevent overheating of the tubes. The upper limit of such velocity is determined by the permissible fall in pressure, and is considerably higher than with saturated steam on account of the increased fluidity, due to the additional heating causing the steam to enter more completely into the gaseous state.

The determination of the thermal efficiency of the superheater is impossible; the humidity of the steam entering the superheater being a variable and unknown quantity, the amount of heat taken up by the superheater cannot be calculated. The combined efficiency, however—that is, the ratio of the heat utilized in the boiler and superheater to the total developed in the fire-box—has been determined by the author from the results of six trials made with superheated steam locomotives. On all these occasions the demand on the boiler was fairly high, the average coal consumption being 107 lbs. per square foot of grate surface, and the evaporation 11·75 lbs. of water per square foot of heating surface, under which conditions the heating efficiency of the boiler worked out to 66·4 per cent., a higher result than could be obtained with a saturated steam boiler under similar conditions.

An objection has frequently been raised to superheating on the ground that the economy in the engine obtained thereby is nullified by the waste in the boiler, the heat of the gases being less perfectly absorbed in the superheater than in the generating tubes, causing a higher smoke-box temperature. Such, however, is not the case when the sections of both systems of tubes are properly proportioned. For the same demand upon the engine the boiler is less pressed than it would be with saturated steam, and the heating efficiency of the superheater boiler is correspondingly improved. The main advantages of superheating are, after all, the elimination of cylinder condensation, the use of a lower boiler pressure and consequent increased life of the boiler.

The estimation of economy upon the basis of the evaporation figure alone is inadmissible, as this leaves the higher temperature of the superheated steam out of consideration. The evaporation figures for boilers generating saturated steam are actually at the highest when working under the most uneconomical conditions —that is, when the boilers are overworked, and consequently priming.

# CHAPTER II

## SUPERHEATED STEAM AND THE TWO-CYLINDER SIMPLE ENGINE

### (A) LOSSES BY CONDENSATION.

DURING the admission period the steam comes in contact with the metal surfaces of the steam passages, cylinder cover, piston, and part of the cylinder wall, which are at a much lower temperature than the steam owing to the cooling influences of the preceding expansion and exhaust periods. The greater the difference of temperature between the cylinder walls and the steam, the larger the proportion which the cooling surface bears to the volume of steam at cut-off; and the higher the thermal conductivity of the steam, the greater is the exchange of heat between the steam and the cylinder walls.

Supposing saturated steam is being employed, this thermal exchange, as already stated, causes condensation, and part of the steam loses its capacity for doing work. The condensation loss, although greatest during the admission period, still continues during expansion, though to a considerably less degree, owing to loss of heat to the cylinder wall. At the end of the latter period re-evaporation commences, and proceeds more actively as the steam pressure falls, and in consequence the temperature of the steam approaches that of the condensed water. The most energetic re-evaporation, however, takes place during the period of exhaust, when the fall in pressure is most rapid. The heat necessary for this change must for the most part be supplied by the heated cylinder walls, with a consequent lowering of their temperature. This cooling of the cylinder gives rise to the admission losses referred to above. The heat-exchange, though very rapid at the beginning of the exhaust, slackens during its progress, a result due to the combined effect of the high thermal requirements of re-evaporation (966 B.T.U. per pound of water) and the low temperature of the condensed water, which is constant. The evaporation, therefore, which is very energetic at first, becomes slower as the difference of temperature diminishes, and, therefore, when the piston speed exceeds a certain limit the exhaust period becomes too short for complete re-evaporation, and water remains behind in the cylinder. This is one of the principal reasons of the unsuitability of high piston speeds for locomotives using saturated steam, the boilers of which, when over-driven, prime heavily. Each new admission when the speed is too high gives rise to increased losses from condensation, as the lowering of the temperature of the cylinder walls during the exhaust period and the difference of temperature between them and that of the entering steam continuously increases until a time is reached when the conditions approximate to those of an engine at first starting, when the condensed water must be blown out by the cylinder drain-cock. The most economical speed of working, therefore, in a saturated steam locomotive is attained when the pressure, temperature, and admission conditions are so adjusted that the whole of the condensed water may be easily re-evaporated during the exhaust period. The loss, however, due to the water so re-evaporated having passed through the cylinder without doing any work, still remains.

When a sufficient degree of superheating is employed the conditions in the cylinder are considerably modified from the foregoing. The heat transferred to the cylinder walls during admission is drawn from the excess of heat above saturation temperature, the steam being somewhat cooled, but not sufficiently so to cause condensation, while the loss of working power owing to the contraction of volume due to such cooling is unimportant. During the exhaust the heat demand on the cylinder walls is comparatively small, especially when a slight superheat still remains, partly because superheated steam is a bad conductor of heat, but more particularly because such heat is directly applied to raise the steam temperature and not to re-evaporate condensed water. The use of superheated steam, therefore, is attended with a much smaller heat interchange than is the case with saturated steam,[1] and the mean temperature of the cylinder walls is kept at a higher point.

It must, however, be borne in mind that it is only by a very high initial degree of superheat that cylinder condensation can be prevented during the entire working stroke, and this has been objected to on the ground that with such an excessive temperature the superheat is not entirely expended, the exhaust passing out of the funnel at an unnecessarily high temperature. Upon these grounds it has been proposed so to limit the degree of superheat that at the end of the expansion the exhaust steam may be in the saturated state.

Having regard, however, to the constantly varying demands upon both engine and boiler of the locomotive, such uniformity in working conditions is impossible, as changes in cut-off and temperature, bad and foaming feed-water, too high a water-level in the boiler, over-forcing of the boiler, unskilful driving and firing, etc., necessitate a considerable margin in the power of the superheater above that calculated as normally requisite.

According to the results of experiments made by Professor Seeman on a stationary engine using superheated steam on the Schmidt system, the heat consumption per indicated horse-power fell continuously as the degree of superheat was raised, notwithstanding the higher temperature of the exhaust, as shown in the following table and in Fig. 1:

| Steam temperature. | Exhaust temperature. | Heat required per I.H.P. | Comparative consumption. | Saving per cent. |
|---|---|---|---|---|
| Deg. Cent. | Deg. Cent. | Cal. | | |
| 209 | 103 | 8126 | 100·0 | — |
| 255 | 109 | 7306 | 89·9 | 10·1 |
| 309 | 128 | 5989 | 73·7 | 26·3 |
| 355 | 156 | 5858 | 72·1 | 27·9 |

Although similar experiments have not been carried out with locomotives using superheated steam, the numerous trials made by the author have shown that the greatest economy is invariably

[1] See also Ripper, "Steam Engine Theory and Practice," p. 133.

obtained with the highest degree of superheat, notwithstanding the increased temperature of the exhaust steam consequent thereon.

In order to utilize to the fullest and most economical extent the increased working power of the boiler obtained by the addition of a superheater, it is not enough, as is maintained by some authorities, merely to increase the length of the admission period above that calculated for saturated steam, as the losses due to insufficient expansion, increased back pressure, and undue forcing of the fires caused by such a change will go far to counterbalance the saving that can be realized by its adoption. It is only by a suitable increase in cylinder diameter that the tractive force, while maintaining an economical figure for the cut-off, can be augmented sufficiently to utilize completely the increased working

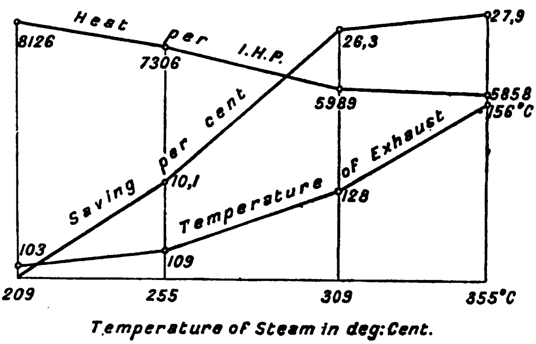



FIG. 1.

capacity of the boiler. To do this the cylinder diameter must be such that the maximum tractive effort at slow speed is obtained with a cut-off of about 45 per cent., and the greatest normal output with 30 per cent. at about 15 lbs. below the normal boiler pressure. For lower and minimum powers the cut-off cannot be indefinitely altered, 20 per cent. admission being the lowest permissible minimum. Below that point the working must be regulated by throttling. That superheated steam can be economically used without giving rise to cylinder condensation when throttled down, depends upon the fact that with the drop in pressure its degree of superheat, and therefore its heat value, increases. For example, steam of 170 lbs. pressure at 575° Fahr. carries 200° of superheat, the saturation temperature being 375°

Fahr.; but when the saturated steam is reduced by throttling to 70 lbs. before entering the superheater, and is then raised to a temperature of 575°, the superheat increases to 575° – 316° = 259°, giving sufficient excess in temperature to prevent cylinder condensation even with the minimum practical cut-off of 20 per cent. With superheated steam, therefore, substantially larger diameters of cylinders can be used than with saturated steam without any fear of losses due to condensation.

The conditions with saturated steam are entirely different. In order to reduce condensation losses the cylinder dimensions must be kept as small as possible, which necessitates a wasteful rate of admission when extra power is required, and it is upon this difference that the superiority of superheated over saturated steam depends. Its recognition as the result of the continuous development in the application of superheating in locomotive construction by the Prussian State Railway Department has led to progressive increases in diameter of the cylinders. The so-called "characteristic C" of the Prussian two-cylinder superheated steam locomotives, given by the following expression:

$$C = \frac{d^2 l}{DR}$$

where $d$ = cylinder diameter in inches,
$l$ = length of stroke in inches,
D = diameter of driving wheels in inches,
R = load on driving axle in tons,

lies between 3·9 and 4·7, or considerably higher than is customary or possible with saturated steam locomotives. The simplification in construction and the increased duty obtained from the working parts, without affecting their durability, notwithstanding the restriction of the axle-load to sixteen tons, will be considered later.

It may not be out of place to mention that trouble in connection with the working parts, anticipated by many railway experts, as likely to arise from the use of highly superheated steam, has not so far been experienced with the locomotives of the Prussian State Railways. More than a thousand of these locomotives are now in use on these lines, and the troubles incidental to the experimental stages have been completely eliminated. Minor defects have been completely overcome, and, over six years ago, forms of pistons, piston valves, and stuffing-boxes were designed, which have proved to be perfectly durable under the highest steam temperatures. Lubrication troubles have also been got over by the use of oils of a sufficiently high flash point, combined with a simple method of oiling under pressure. These details will be more fully considered in a subsequent chapter.

## (B) ECONOMY IN FUEL AND WATER.

The saving in coal, due to the absence of cylinder condensation, in a simple engine using highly superheated steam averages about 25 per cent. when compared with that of a saturated steam locomotive of the same weight, and is in the neighbourhood of 20 per cent. when compared with a two- or four-cylinder compound engine. The saving in water is in most cases considerably larger, because a greater quantity of fuel is required for the production of 1 lb. of superheated than for the same quantity of saturated steam. The greater the amount of moisture in the steam, the larger will be the difference between the saving in fuel and water. The economy due to high superheating admits of running longer distances before taking in water, a point of special importance on long distance express engines. Moreover, boilers require to be less frequently washed out, and the lower working pressure conduces to a longer life and fewer repairs. For the same reason the distances run by the important class of tank engines may be increased to a considerable extent. The figures given above for the saving in fuel and water are low average values. When saturated steam locomotives are forced to do the same work as the superheated steam locomotive, the figures can be considerably increased.

On the other hand, there are conditions under which the economy cited above cannot be reached, but this is only when the drivers are inexperienced in the handling of superheated engines or when the service is such as not to admit of its being realized, as, for instance, in suburban or other local traffic where frequent stoppages occur, but even in such cases the fuel saving may be at least 15 per cent.

In estimating the practical economy of a locomotive the coal consumption figures form the most suitable basis. If the steam consumption alone was relied upon, the variable amount of water present in the saturated steam on the one hand, and the degree of superheat on the other, would be left out of consideration. Such figures would only be of value when expressed in terms of dry saturated steam of a definite fixed pressure; but for this purpose the degree of humidity of the steam must be known, and this cannot be determined on trial runs. The same difficulty is met with when the heat consumption for a particular output, say, one indicated horse-power per hour, is taken as a basis, as it can only be computed for the saturated steam-engine upon the basis of more or less abstract and assumed figures for the humidity, and in the superheated locomotive by the choice of a mean value for $C_p$.

For practical purposes, therefore, comparative coal consumption alone can be relied upon under present conditions. From many sides, rules have been given for determining *à priori* the saving attainable, but these are all based upon the assumption that the saving increases uniformly with the superheat, which, however, is not borne out by the author's experience, as no perceptible saving is realized with less than 100° of superheat, but above that point it increases rapidly.

The essential conditions determining the saving in fuel may be defined as follows:

1. The difference in specific volume between superheated and saturated steam.
2. Their different heat values.
3. The wetness of saturated steam.
4. The reduction in cooling losses in consequence of the higher temperature and lower thermal conductivity of superheated steam.
5. More favourable conditions of firing and use of blower.

Of these points the value of the last two cannot be estimated in actual figures, and therefore must be excluded from the theoretical investigation of possible saving of fuel and feed-water, which involves the following assumptions:—

(*a*) That the boiler efficiency of both engines is the same.

(*b*) That losses due to radiation can be neglected.

(*c*) That the steam from the non-superheated engine is in the dry saturated state.

Theoretical calculations of the thermal economy must be based upon points 1 and 2 given above. The details of such a calculation, which, however, is only of theoretical interest, will be found in the author's lately published work on "The Steam Locomotive of the Future,"[1] p. 226. The results given on p. 229 of this work may be summarized as follows, the steam being superheated to a temperature of 572° Fahr., and the specific heats $C_p$ of superheated steam being taken as 0·48 and 0·6. The table shows the relative economy due to the use of superheated steam over saturated steam, varying with the figure selected for the specific heat $C_p$ of superheated steam.

| Steam pressure above atmosphere. | Theoretical saving. | | |
|---|---|---|---|
| | Water. | Coal. | |
| | | $C_p = 0·48$. | $C_p = 0·6$. |
| Lbs. per sq. inch. | Per cent. | Per cent. | Per cent. |
| 170 | 11·0 | 4·0 | 2·2 |
| 142 | 13·3 | 6·1 | 4·3 |
| 114 | 15·0 | 7·2 | 5·3 |
| 85 | 16·8 | 8·6 | 6·3 |

The principal point of interest in this table is the clear manner in which the value of superheating is brought out, from which it is evident that the highest theoretical saving, both in water and fuel, is obtainable when the highest degree of superheating is combined with the lowest steam pressure, namely, 85 lbs. (572° − 327° = 245° Fahr.).

The actual saving, however, can only be deduced from such theoretical results by introducing corrections for the losses resulting from cylinder condensation and wetness of the steam in an ordinary locomotive cylinder, and as these must be based upon more or less arbitrary assumptions, the practical value of the result is largely vitiated. The practical man, therefore, can only

[1] "Die Dampflokomotiven der Gegenwart," by Robert Garbe (Julius Springer, Berlin).

rely with safety upon the results obtained in properly conducted trials, and results thus obtained will be specially considered in a later chapter.

## (C) TRACTIVE EFFORT OF THE SUPERHEATED STEAM LOCOMOTIVE.

In addition to the saving in fuel and water, a further and more important advantage arising from the use of superheated steam is to be found in the largely increased tractive effort of the engine.

In comparative trials of a four-coupled ten-wheeled four-cylinder compound with a similarly coupled eight-wheeled two-cylinder simple engine, fitted with a Schmidt superheater, and doing the same work, the latter has often shown a saving of about 25 per cent. of coal; and even, when pushed and 40 per cent. more work being got out of it, the consumption was still about 10 per cent. less than that of the compound. From these results the following simple practical conclusions may be deduced:—

Taking a compound engine and a simple superheated engine of equal tractive force, the maximum hauling power of the former corresponding to about the medium power in the latter, and taking the saving in coal in the superheated engine at 20 per cent., the increase in haulage power, due to superheating for equal quantities of fuel burnt under similar conditions, will be $\frac{100 - 80}{80} \times 100$, or an increase of 25 per cent.

As, however, under present working conditions in regard to speed and dimensions in four-cylinder compound express engines, about 40 per cent. of the indicated horse-power developed in the cylinders is consumed in engine and running resistances, it only leaves 60 per cent. for drawbar effort, and therefore the original 25 per cent really becomes $\frac{25 \times 100}{60}$, or an increase of about 40 per cent. at the drawbar, a figure which, as already stated, has repeatedly been obtained in comparative trials. When the comparison is made with a two-cylinder engine of about the same or somewhat larger weight, the advantage in favour of superheating is even still more marked, it being, of course, understood that the dimensions of the cylinders are correctly proportioned for superheating.

We have, therefore, in superheating a means of meeting the ever-growing demand for higher speeds and heavier trains without at the same time having recourse to increasing abnormally the dimensions of locomotive engines and boilers over those now in use.

In ordinary working the saving of coal by superheating is somewhat less than that shown in comparative trials, where the main object is the determination of the maximum tractive power of the engine. When this point, which has been the subject of numerous criticisms in professional circles, as determining the true value of superheating, is considered, it must be remembered that in current working the time-tables are so arranged that the saturated steam locomotives run under conditions at or near their full power, while the more powerful superheated steam locomotive of the same weight would be doing the same work with a considerable reserve of power. When, however, the saturated steam locomotive is pressed beyond its normal power the limit of economical working is soon reached and difficulties are set up which can only be overcome by the use of two engines, or running the train in two portions. Superheating must, therefore, be regarded not merely in the light of a 25 to 30 per cent. saving of coal, but as a means of avoiding the wasteful and objectionable practice of using two engines in front of a train.

The principal advantage of superheating, therefore, can best be realized when heavy loads at very high speeds have to be dealt with. The work consumed in engine and air resistances increases continuously as the speed increases, and the engine resistances are considerably lower in the simple superheated steam engine than in the compound engine.

The marked increase in haulage power, due to superheating, is of much greater importance to the locomotive department than even the largest saving in coal and water. It should be the point of primary consideration, the more so as whether exerting the minimum or maximum power, an increase of haulage capacity would allow of a reduction in the number of different classes of engines in use for different services.

To the practical man the only satisfactory demonstration of the increased haulage capacity of the superheated steam locomotive is that afforded by the results of long-continued working under service conditions. Trials made with superheated locomotives on the Prussian State Railways, leave no doubt as to their superiority over the heavier four-cylinder compounds.

Fig. 2 gives for superheated steam locomotives the maximum

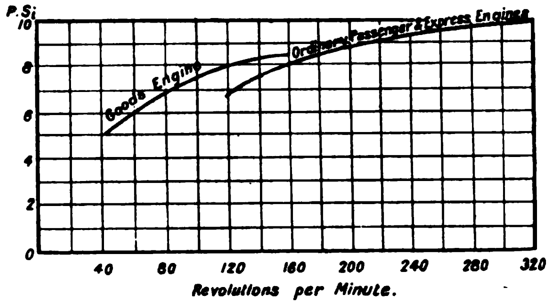



FIG. 2.

sustained I.H.P. per square metre of heating surface for speeds up to 320 revolutions per minute. These results show an increase of 25 to 80 per cent. in the indicated horse-power of superheated steam engines over ordinary engines, according to the class of the latter, whether two-cylinder simple, or two- or four-cylinder compound.

The above remarkable figures establish the superiority of the simple superheated locomotive over the compound engine, and this superiority as regards the pull on the drawbar is the more noteworthy when the simpler construction of the superheated steam engine is taken into consideration.

# CHAPTER III

## COMPOUNDING AND SUPERHEATING

THE use of highly superheated steam in the simple two-cylinder locomotive in its present state of development increases the power of the engine to such an extent that the demand for increased hauling power and speed likely to be called for in the near future can be met without having recourse to four-cylinder compounds, which are both complicated in construction and costly in maintenance. This, in the author's opinion, is one of the greatest advantages of the use of highly superheated steam in locomotive practice, and it has been turned to account in the locomotives on the Prussian State Railways, of which, as stated in the previous chapter, more than a thousand are in service. All of these locomotives are single expansion engines fitted with two high-pressure cylinders, the arrangement of the wheels being kept as simple as possible, no trailing axles being used. The construction of saturated steam four-cylinder compounds has been almost entirely given up on this system. This example has not, however, been followed to the extent which, in the interest of simplicity, economy, and safety in working, is to be desired. Many railway administrations, lacking experience with superheated steam, adhere to the costly and complicated four-cylinder saturated steam locomotive, while others, taking the first steps in superheating, restrict it to moderate superheating in combination with a compound cylinder arrangement. This subject is of great importance as regards the future development of the locomotive, and will, therefore, be more fully discussed in the light of existing experience.

*Losses due to Cylinder Condensation in a Compound Locomotive.*—Compounding and the use of highly superheated steam both have the same object, namely, the diminution or prevention of condensation losses in the cylinders, which in simple saturated steam engines may amount to 35 per cent. and upwards. By compounding these losses may be reduced to 20 or 25 per cent., while with highly superheated steam at 600° to 650° Fahr. they may be entirely prevented, even in the simple two-cylinder engine.

*Compound Working with Initial Superheating.*—Of late years improvements in the compound engine have tended towards the use of higher steam pressures and larger cylinder ratios, thus giving a greater range of expansion, while at the same time a moderate amount of superheat has been employed. The conditions obtaining in the compound locomotive, unlike those in the compound stationary engine, do not in general allow of the use of a high degree of superheat. On long adverse gradients, for instance, a late cut-off up to 60 or 70 per cent. of the stroke may be required continuously for long periods, and this with high superheat would raise the average temperature of the cylinder to such an extent as to cause lubrication troubles or even damage to the cylinder. Only by reducing the ratio of the cylinder volumes could high degrees of superheat be used with compound locomotives, as then an earlier cut-off could be used in the high-pressure cylinder.

The question whether an initial superheat of about 100° Fahr. is sufficient to prevent cylinder condensation has been the subject of investigation by Dr. Schmidt, whose numerous experiments have shown that such a temperature is sufficient if the cut-off is not reduced below 50 per cent. of the stroke. This, however, entirely exhausts the extra heat, so that the subsequent expansion in the low-pressure cylinder is conducted under adverse conditions. Any noticeable saving in steam consumption by the use of superheated steam in compound engines, as against its use in simple engines, could only be effected by avoiding condensation in the low-pressure cylinder as well, but this would involve superheating to 570°. It should be borne in mind that it is matter of indifference whether the steam is expanded in one or two cylinders. For a particular initial pressure and the most suitable exhaust pressure—that is, for a fixed range of expansion—the superheating must in each case be about the same if condensation is to occur at the same point in the expansion curve. For any given initial pressure and degree of superheat there is a corresponding lower pressure where the superheat is expended and condensation begins. In the compound engine, in consequence of the range in temperature being less in each cylinder than in the single cylinder of the simple engine, and owing to the retention by the high-pressure exhaust steam of some of the heat from the cylinder wall, the pressure at which the steam begins to condense is somewhat lower than in simple engines, but only to an unimportant extent.

*Two-stage Superheating.*—Assuming that what has been said above is correct, that the compound engine cannot in general be safely worked with steam at a minimum initial temperature of 570°, the question of intermediate superheating remains to be considered; that is, whether it is economical to superheat the live steam only to such a point as will prevent loss in the high-pressure cylinder, and to add extra heat by a second superheater to the steam entering the low-pressure cylinder. According to the experiments of Dr. Berner,[1] the heat requirements of the engine are considerably higher with two-stage than with single-stage superheating, and Professor Gutermuth found that an intermediate superheating of 108° was insufficient to compensate for a reduction in superheat of 36° in the high-pressure steam. As these results were obtained from condensing engines they are not immediately applicable to the locomotive, where, by reason of the higher receiver pressure, the superheat is conveyed under more favourable conditions; but even here the total heat required will be greater with moderate superheating in two stages than if a higher degree of superheat had been applied to the initial steam and the operation carried out in one stage. Whether this extra demand can be met by more perfect utilization of the heat in the boiler and superheater by the use of waste gases in the second stage could only be determined by exhaustive and difficult experiments. The low-pressure—45 lbs. to 60 lbs.—in the receiver, would,

[1] "Zeitsch. des Vereins deutscher Ingenieure," 1908, p. 784.

however, require a superheat of nearly 200°—a steam temperature of about 470° to 480°—if condensation is to be entirely prevented in the second cylinder. This means a very considerable superheater surface, and, on account of the large volume of low-pressure steam, very large steam passages in the intermediate superheater so as to prevent any undue reduction of pressure in the receiver. Apart from the difficulty of finding room for such a large superheater in the smoke-box, only a very small saving could be effected by such an arrangement, and this would be more than counterbalanced by the increased weight and cost of construction, together with the working difficulties inherent in the injuriously high boiler pressure of 200–225 lbs. per square inch characteristic of the compound system.

Proceeding from the assumption that the principal condensation losses take place in the low-pressure cylinder, and that the economy of the compound engine would be improved by their reduction, it has been proposed to restrict the superheating to the steam in the receiver. At the last exhibition in Liège a four-cylinder compound engine was exhibited by the Cockerill Company of Seraing, with a smoke-tube superheater, which could be used either for high- and low-pressure steam together, or for the latter alone. The results obtained have not been made known, but whatever they may have been, the method cannot be considered as being a satisfactory solution of the problem. To enable superheated steam to be used economically through a considerable range in working conditions, suitable enlargement of the cylinder diameters is necessary. The proper cylinder ratio in a compound engine would be entirely different if superheated steam were used in both high- and low-pressure cylinders from what it would be if restricted to the latter, but experiments under such variable conditions could not be usefully conducted when the cylinder ratio was unchangeable.

As, however, by receiver superheating the conduction losses in the high-pressure cylinder are reduced, but not entirely prevented, this method, even with properly proportioned cylinders, cannot be as economical as superheating the high-pressure steam. As long as this, for practical reasons, is inadmissible in the compound engine, the latter, compared with the simple superheated steam locomotive, must always remain in a position of inferiority as regards steam economy.

*Defects of the Compound Locomotive.* — Supposing highly superheated steam could be advantageously used on a compound locomotive, the fuel economy, as compared with a simple engine using highly superheated steam, would only be small, and would in no way make up for the increased difficulties of construction, cost, and maintenance, and the greater complication in service, difficulty in starting, and general want of adaptability of the compound locomotive. Above all, no notable increase in working capacity can be expected from it, as there is only one most favourable cut-off for any particular set of conditions and degree of superheat. If this is exceeded steam is wasted, and if it is reduced cylinder condensation results, and the economy due to superheating is reduced. This is the reason for the complaints that have been made — often rightly — of the want of adaptability and flexibility of the compound engine on lines with irregular changes of gradients. Taking into consideration the starting difficulties, the increased charge for boiler repairs due to the objectionably high initial pressure of 200 lbs. and more, and the increased capital and maintenance cost, the small saving in fuel is hardly sufficient ground for recommending the adoption of the compound engine. This saving is only realizable under specially favourable conditions, and the adoption of the compound system involves the abandonment of the much greater advantages of the simple two-cylinder arrangement.

The question of the number of cylinders is not included in the above considerations.

*Multiple Cylinder Locomotives.*—As regards the work required from the steam in the cylinder, sufficient power can always in practice be economically and satisfactorily obtained from the simple two-cylinder arrangement, if an adequate degree of superheating be employed. This is admitted by the more moderate advocates of compounding; but it is urged that the compound system has the advantage in that the disturbing influences of the reciprocating parts can be very much reduced, particularly in the case of very fast-running trains. This, however, is only true of very fast and not too heavy trains, and for this class of traffic the multiple cylinder system appears to offer some apparent advantages; certain of the advantages claimed, however, are open to question, while the system undoubtedly has considerable drawbacks.

The principal defects of the three- and four-cylinder compound expansion engines are:—

(*a*) With only a small increase in power over the ordinary eight-wheeled four-coupled simple engine, fifth and sixth axles become necessary, with a corresponding increase in the engine and road resistance.

(*b*) The increase in dimensions is accompanied by a great increase in the weights of the boiler, frames, axles, and cylinders.

(*c*) The necessity of duplicating the driving mechanisms, one of which must be placed between the frames in a position where it is difficult to obtain access for lubrication, cleaning and repairs.

(*d*) Complicated and costly valve gear.

(*e*) The use of expensive crank-axles. Although these are now made of somewhat greater strength than formerly, owing to the employment of tougher steels and stronger binding hoops, it is doubtful whether the increase is sufficient to meet the more exacting requirements of modern traffic, and whether, in spite of improved material, the limitation in dimensions, owing to the contracted space available, has not been attended with corresponding decreased safety in working. Owing to the frequency of hot-running crank-pins, crank-axles must always be more expensive in maintenance and attendance, as well as in workshop repairs, than the more reliable plain driving axles.

(*f*) Increased cost of lubrication, which is nearly double that of a simple engine.

(*g*) The shorter connecting-rods of the inner cylinders, causing greater periodic variations in the load on the driving axles.

In all cases the use of four cylinders is attended with increased initial outlay, greater cost of maintenance in working, and a decidedly higher strain upon the driver and stoker.

With regard to the utilization of heat in the cylinder, it is self-evident that this cannot be better in two smaller steam engines than in a single engine of equal power and size. It is only when the low-pressure cylinder of a two-cylinder compound has attained the maximum permissible limits that the use of four cylinders involving a disproportionately large increase in the weight of the boiler gives some, but only an unimportant, increase in working capacity.

If, on the other hand, better heat utilization is sought by increasing the working pressure from, say, 170 lbs. to 200 or 220 lbs. per square inch—a matter that has nothing to do with the use of four cylinders—the increase in weight and maintenance of the boiler offers serious objections to such a course.

The advantages, therefore, of three and four cylinders are to be sought principally in increased smoothness of running owing to the more even torque and the balancing of the reciprocating masses. The advocates of the three-cylinder engine claim for that form of construction greater ease in starting and reduction of the "nosing" motion, which, however, is attended with an increased tendency to "pound"; while the partisans of the four-cylinder system, aiming at complete suppression of the latter, leave the nosing motion almost undiminished.

An undoubted advantage of the four-cylinder engine is to be found in the four-crank arrangement, which, by lowering the stress on the main axle bearings, reduces the wear on the brasses and prolongs the period of smooth running of the journals in their bearings. Against this it must be borne in mind that the use of inside crank-axles limits the possible length of the main journals for high powers, while a similar difficulty in properly proportioning the size of the journals is not met with in the plain axle.

The three-cylinder arrangement gives bearing pressures similar to those in locomotives of the ordinary type, together with the disadvantages of a racking motion and the use of a crank-axle. The only advantage is the more even turning moment on the cranks.

When it is considered that the pounding action referred to above is not cumulative, and that the equalizing of the reciprocating masses in two-cylinder engines cannot be pushed very far so as to avoid excessive variation in the axle load during the revolution of the wheel, the assumption appears to be justified that the use of more than two cylinders at the highest speeds is not a question of greater safety, but only one of reduced wear on the bearing parts and smoother running of the axle journals in their bearings. It should be borne in mind that two-crank engines run continuously and safely at speeds up to 75 miles per hour, and therefore the use of more than two cylinders is not absolutely necessary to ensure smooth running on the rails. It is a fact well established by practical trials that properly constructed two-cylinder engines in good working condition run perfectly steadily at all speeds generally attainable. Further assistance in this direction has been obtained in the new superheated steam two-cylinder engines of the Prussian State lines by the removal from the driving wheels, on the author's advice, of the counterbalance for the reciprocating parts and the adoption of a rigid tender coupling. By this means one of the greatest advantages claimed for the four-cylinder engine, viz. the reduction of the vertical centrifugal forces and of the destructive hammering action of the driving wheels on the road, is simply and readily effected. The effect of the short connecting-rods of the four-cylinder engine in increasing the vertical pressure on the crosshead, which acts alternately on the bogie frame and the driving axles, is equally as detrimental as the varying centrifugal forces of the counterbalance, and in this respect the simple two-cylinder engine, with its long coupled wheel base, is decidedly superior to the multiple-cylinder form.

By using a tight tender coupling the mass of the tender is utilized to counteract the forces tending to produce swaying. The locomotive cannot have any longitudinal rocking motion relatively to the tender, and therefore the unbalanced forces have to overcome the inertia of both engine and tender before they can cause any longitudinal vibration of the engine. It is necessary, however, that the tender coupling, though tight, shall not be too rigid so as to seriously impair the flexibility of the engine and tender, but it must be made stronger than usual, as the variation in the drawbar pull is larger in the unbalanced engine. The bracing of the frames and the attachment of the cylinders to the frames have to be made stronger so as to withstand the increased stresses thrown upon them by the unbalanced load.

In the author's opinion, at the speeds used at present on the express trains of the Prussian State Railways, it is cheaper to fulfil these requirements on a simple engine, than to introduce four-cylinder balanced engines with the attendant complications and expense.

This being so, the adoption of the simple two-cylinder engine embodying all available methods for preventing premature wear of the bearings is to be strongly recommended, both upon technical and economic grounds. The improvements referred to may best be attained, in combination with a sufficiently long coupled wheel base, by attention to the following simple conditions :—

(*a*) Selection of the best materials for pistons, piston-rods, crossheads, and connecting-rods; these parts, while properly dimensioned, being made as light as possible.

(*b*) Enlargement of the axle journals and crank-pins, and the use of special brasses in three portions for the axle bearings, for the better taking up of the piston pressure and the reduction in wear of the bushes.

(*c*) Proper stiffening of the frames.

(*d*) Choice of the best form and material for the springs.

(*e*) Proper proportioning of compression. In arranging the clearance and compression spaces, considerations of economy must not be pushed too far, having regard to the conditions of quiet running of the moving parts.

(*f*) Improvement of the engine and tender coupling by the use of a strong cross spring and the reduction of the bearing pressure on the coupling pin to prevent rapid wear in the working parts, so that the connection between engine and tender may be as rigid as possible.

(*g*) Reduction of the working pressure in the superheated steam locomotive from, say, 170 to 160 or 140 lbs. per square inch. This would keep the maximum pressure on the bearings at the dead points of the crank circle within reasonable limits, even with greatly increased size of cylinder diameter, and this at the maximum power of the engine.

The above points have been fully considered in the design of the new superheated steam express engines of the Prussian lines, which are all of the simple two-cylinder type.

Should the demand arise upon lines having long level stretches for light express trains of an average speed of 70 miles an hour, corresponding to a maximum of 90 miles per hour, the necessity for four-cylinder engines might be felt. This, however, could be better met by retaining the four-coupled eight-wheel form in combination with four equal sized high-pressure cylinders, and a long wheel base, which for high speed is preferable to the five- or six-axled "Atlantic" type. With the latter form the engine resistances are largely increased and the mobility and safety on curves correspondingly diminished; the engine is too heavy and cannot readily be brought up to a high speed, while the slacking at curves, etc., can only be effected with great loss.

The much simpler 4–4–0 four-cylinder simple engine is certainly preferable both as regards speed and economy to any possible 4–4–2 type for similar driving-wheels, as the latter, with its short connecting-rods, short wheel base, and trailing axles, tends to grip in curves and exercise a destructive action upon the road. Only in the event of the weight of the boiler becoming too great for the 4–4–0 class should a fifth axle be employed, and the addition of this would only be due to the boiler, and not to any requirements of the engine. In such a case it should be placed between the bogie and the driving axles. This axle, of course, is only for bearing purposes, and like the front coupled axle must not be leading in the rails, the guiding being restricted to the bogie and rear axle only. To effect this the wheel flanges of the third and fourth axles would be made thinner than those of the other axles.

This (4 + 2)–4–0 type will then have in its relation to the rails all the advantages of the best high-speed engine type, *i.e.* the 4–4–0 engine with a very long rigid wheel-base.

# CHAPTER IV

## DESIGNS OF LOCOMOTIVE SUPERHEATERS

GENERALLY speaking, locomotive superheaters may be divided, as already mentioned, into the following classes :—

(*a*) Those abstracting a large amount of heat from a portion of the live gases of the fire-box—smoke-tube superheaters.

(*b*) Those abstracting a small amount of heat from the whole body of the fire gases—boiler-tube or boiler barrel superheaters.

(*c*) Those heated by waste gases only — smoke-box superheaters.

A fourth class, where the superheating is obtained by use of an independent furnace, although in use in stationary steam plant and marine practice, has not been applied to locomotives, and will not, therefore, be considered. In the following pages some forms of the three preceding types which have been adopted in practice will be noticed in detail.

### (A) SMOKE-TUBE SUPERHEATERS.

The smoke-tube superheater owes its development largely to Dr. Schmidt, of Cassel, who has invented two principal modifications of it.

(1) *Schmidt Fire-Tube Superheater.*—The Schmidt fire-tube superheater dates from 1897, when it was applied to two engines of the Prussian State Railways, which, it may be remarked, are still working satisfactorily. It consists of a single 18-inch tube running through the whole length of the boiler barrel, having the U-shaped superheater tubes arranged in a circle within it. This, although of fundamental importance—it having served as

the starting-point for the later developments by the inventor and the author—is now only of historical interest.

(2) *The Schmidt Smoke-Tube Superheater.*—This is represented in its latest form in Figs. 3 and 4. In it the ordinary small tubes in the upper part of the body of the boiler are replaced by two or three rows of larger size. In the figures there are three rows of eight tubes of 124 mm. ($4\frac{7}{8}$ in.) internal and 133 mm. ($5\frac{7}{32}$ in.) external diameter. Within each of these are four smaller tubes spaced at equal distances, connected

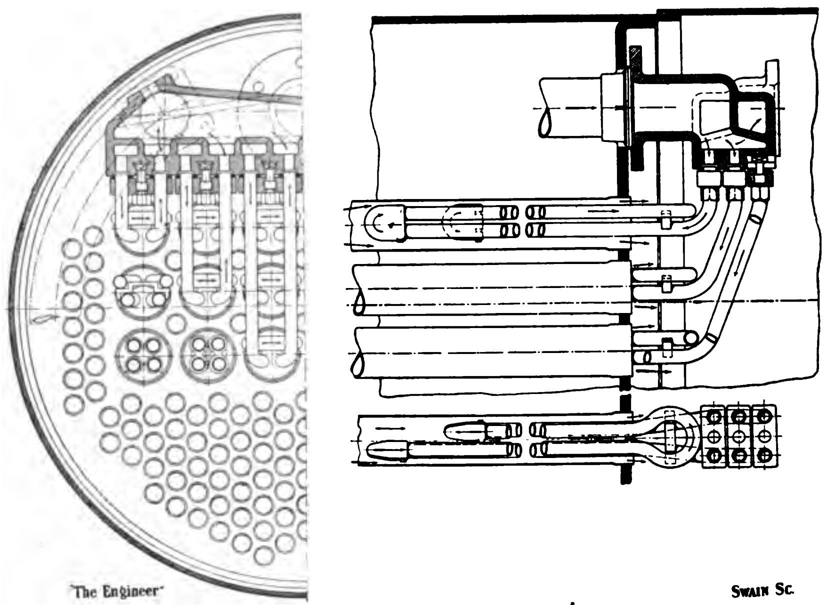
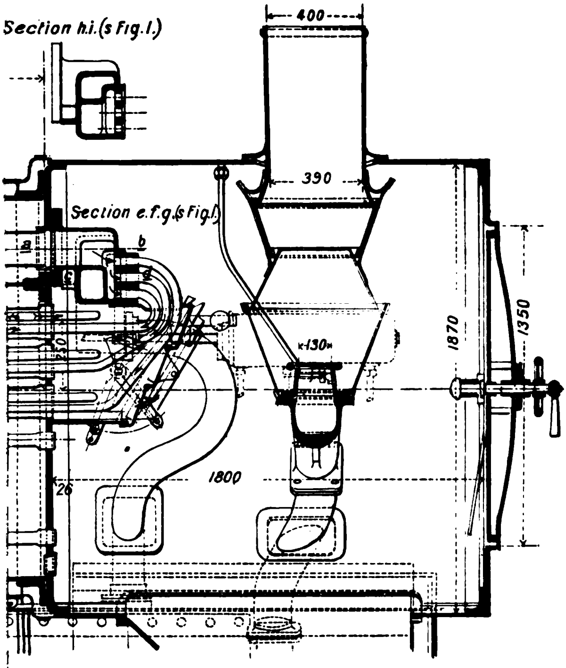
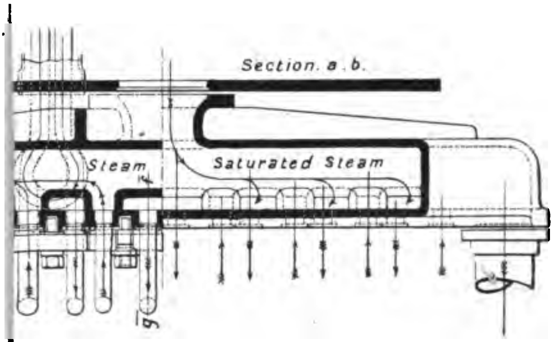



FIG. 4.—Schmidt Locomotive Superheater.

together at their fire-box ends by cast-steel return bends to form a single continuous passage, so that the steam passes four times along the length of the superheater tubes. Near the fire-box the outer tubes are contracted to 114 mm. ($4\frac{15}{32}$ ins.) to allow of a freer movement of the water near the tube plates, into which they are expanded in a special way. The ends of each group of superheater elements on the smoke-box side are expanded into flanges, which are connected to the steam collecting-box by screwed joints arranged either horizontally as

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in Fig. 3, or vertically, Fig. 4; the joint being made tight by a copper asbestos packing ring. The former arrangement, involving a semicircular return bend for the superheater tubes, has the disadvantage of requiring an extra long smoke-box, but as it causes a better utilization of the heat it has been retained on the Prussian lines up to the present.

The second form of construction—Fig. 4—has the advantage of only requiring rectangular connecting bends, and gives the possibility of an easier arrangement of the self-closing damper doors. In another early form, which also proved satisfactory, each of the superheater elements was made up of two independent U-tubes, so that the steam only passed once backwards and forwards through it.

In the new form with the double-looped arrangement the steam passes through at a much higher rate of speed, whereby a better heat abstraction, and consequently a longer life of the tube, is obtained. An advantage of greater importance lies in the better form of connection between the tubes and the header. Each superheater element is independently secured by a single screw.

The cast-iron collector for the superheated steam, which is made of the same metal as the engine cylinders, is so divided and connected with the boiler and valve chest that the steam from the former must pass through the whole of the superheater system before reaching the cylinders.

The fire gases being divided between the lower normally arranged boiler tubes and the larger upper tubes containing the superheaters give up their heat partly to the surrounding boiler water, and partly to the steam circulating in the superheater. The regulation of the flow of the gases through the superheater is effected by a system of dampers, which are kept open by steam power as long as the regulator is open, but are closed either by a spring or a counterweight directly the regulator is shut. When the engine is standing or running without steam the flame is entirely diverted from the superheater tubes, which would otherwise become red-hot. The position of the dampers can also be varied while the engine is under steam by a hand wheel and rod on the driver's platform, so that the superheating may be regulated independently of the automatic arrangement. The latter, placed outside the smoke-box, on the left-hand, or fireman's, side, is a small steam cylinder whose piston is connected by levers with the damper doors. There is a pipe connection between the back of the piston and the valve chest, so that when the regulator is open and steam is admitted to the cylinders the piston travels forward, opening the dampers, which are closed by the counterpoise as soon as the pressure is taken off by the closing of the regulator.

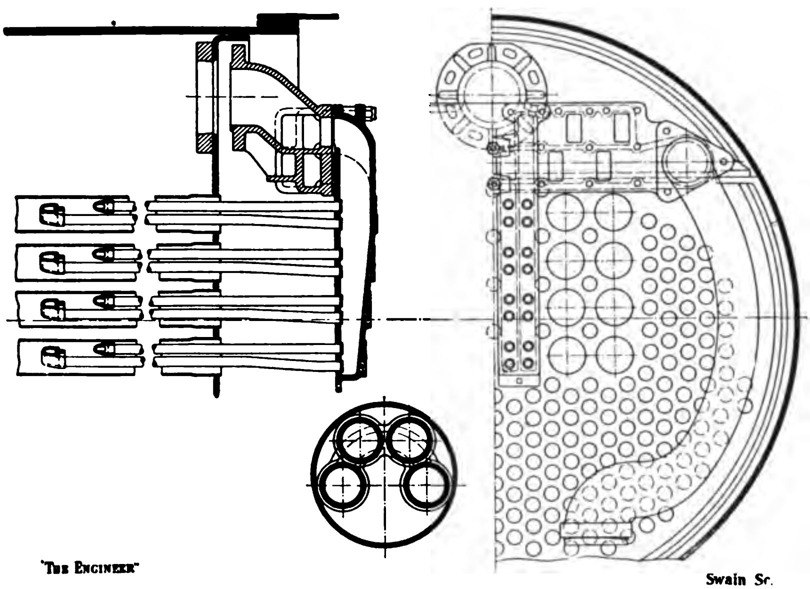
The removal of soot and ashes from the large smoke-tubes may be most readily effected by steam or compressed air either from the fire-box or the smoke-box, but preferably from the former. As a rule, air at a pressure of about 140 lbs. per square inch is the best cleaning agent both for these and the ordinary boiler tubes. If steam is used the cleaning should be done while the boiler is still hot. The particular advantages of this form of superheater are to be found in the readily interchangeable character of its parts, as each element of the tube system being secured by a single screw needs only to be unscrewed to release it without interfering with the remaining parts, and also with the accessibility of each element and the smoke-tubes.

The important advantages that have been realized by the Schmidt smoke-tube superheater have been followed by the introduction of numerous other forms based upon the same general idea, some of which will next be noticed.

(3) *The Schenectady Superheater.*—The Schenectady superheater of F. C. Cole, the chief engineer of the American Locomotive Company, is represented in one of its newer forms in Fig. 5. When first introduced in 1904 the "Field" principle was adopted for the circulating tubes, which, however, had the fundamental defect that the wet steam in the inner tube flowed in the reverse direction to the superheated steam in the outer tube, and so exerted a cooling influence on the latter, with the result that only a slight degree of superheat could be realized.

In the later forms, therefore, the "Field" tube has been given up in favour of the U-tube. The only remaining difference is in the pipe connections at the smoke-box end, a series of rectangular collecting headers being used instead of the curved bends employed by Schmidt. This difference, however, is not regarded by the author as an improvement, as the box ends block up the ends of the front tube plate of the boiler, making the smoke-tubes difficult of access for cleaning and caulking, besides prejudicially affecting the flow of the heating gases. The number of apertures, requiring to be kept tight and of screwed joints is also much larger in the Cole than in the Schmidt construction.

(4) *The Vaughan-Horsey Superheater.*—Up to the end of 1903 a large number of highly superheated steam locomotives with



"THE ENGINEER" Swain Sc.

FIG. 5.—Schenectady Locomotive Superheater.

Schmidt superheaters had been adopted by the Canadian-Pacific Railway Company, and at a later date a modified construction was introduced by Messrs. Vaughan and Horsey, the former being the superintendent of motive power, and the latter the mechanical engineer to the company. In this superheater (Fig. 6) the elements are 5-inch tubes, each having two superheating U-tubes. The saturated steam supply and the collecting box for the superheated steam are, however, completely separated. From the latter, which are placed below, small finger-like headers are carried upwards, and into them are screwed four tube struts, which are connected to the superheated steam ends of the superheater tubes by twelve large coupling nuts. The saturated steam passes from the large steam collecting box by similar small channels placed alternately with those conveying the superheated steam, but in a downward direction. The channels are

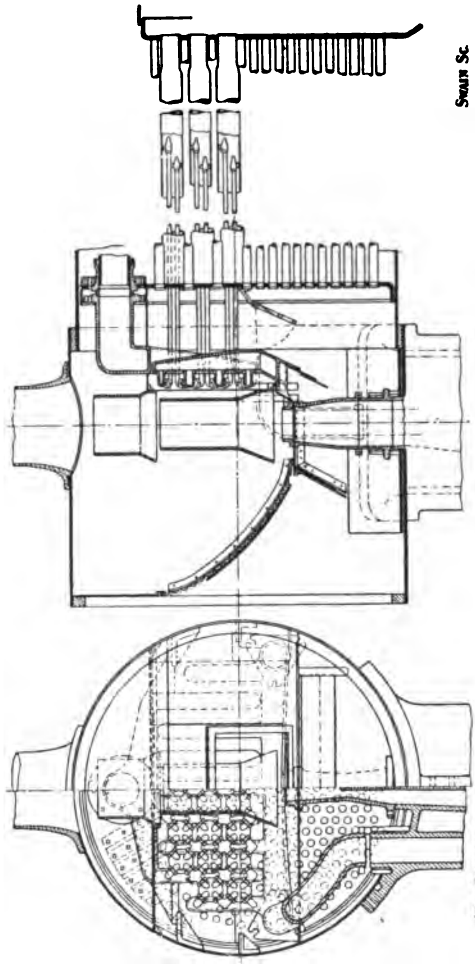
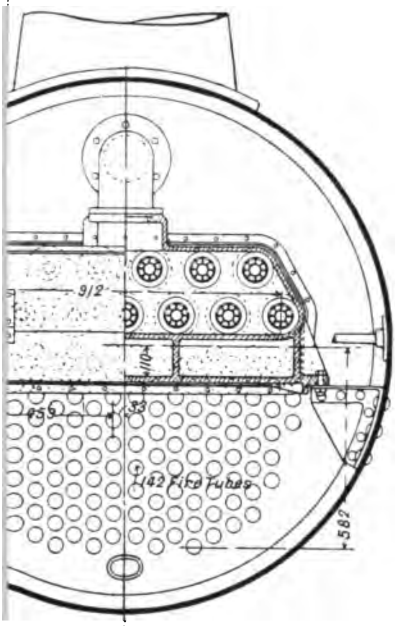
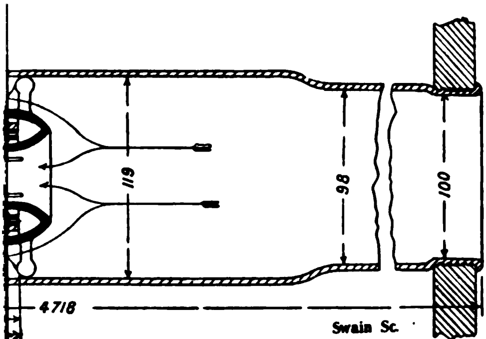



FIG. 6.—Vaughan-Horsey Locomotive Superheater.

secured by struts and screwed collar connections similar to those previously described. The four steam circulating tubes, therefore, in each of the heating tubes on the Vaughan construction, involve four screwed joints of 45 mm. ($1\frac{3}{4}$ ins.) diameter, an arrangement which certainly does not facilitate the removal of the element in









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the Vaughan arrangement. The Cole and the Vaughan superheater have, in the author's opinion, the common disadvantage that they do not allow the tubes of each superheater element to expand independently; the tubes need freedom of expansion on account of the temperature of the steam in the single tubes of each element being different. In the Schmidt design this is obtained by the pipe bends in the smoke-box, whereas in the Cole and Vaughan designs all pipes are straight and rigidly connected. This is the principal reason for the defects the Vaughan superheater has shown in service. (Compare H. H. Vaughan, before the Am. Mast. Mech. Assoc., 1907, *American Engineer*, p. 322.)

(5) *The Notkin Superheater.*—Fig. 7 shows a new form of this superheater. Originally the "Field" type of circulating tube was adopted, but this has been abandoned in favour of the arrangement shown in Fig. 7, where a 31 mm. ($1\frac{7}{32}$ in.) tube is used centrally with a Serve tube, the eight spaces between the ribs of the latter forming the steam passages. The wet steam entering below passes along the four passages below the horizontal plane, and returns, in the reverse direction, along the upper passages to the saturated steam collector. The difficulty of making and maintaining the joint between the ribs of the Serve tube and the inner steam pipe, the stiffness of the connections of the superheater pipes at both ends, and the inaccessibility of the superheater elements are the most serious objections to this design.

# CHAPTER V

## DESIGNS OF LOCOMOTIVE SUPERHEATERS—*Continued*

### (B) BOILER-TUBE OR BOILER-BARREL SUPERHEATERS

In this class, for part of their length, the ordinary tubes of the boiler are utilized for superheating the steam.

(6) *The Pielock Superheater* (Fig. 8).—The principal feature of this superheater consists of a box of nearly cubical form, enclosing a part of the length of the tubes through the water space of the boiler, the tubes being slightly expanded into the plates on either side. The tube holes in one plate are made slightly larger than those in the other plate, being smallest at the fire-box and largest at the smoke-box end, so that defective tubes may be drawn and replaced through the smoke-box plate, an operation usually of great difficulty on account of the scale on the superheater tubes. The steam chest is divided by diaphragm plates, which originally were placed transversely to the tubes; but in the latest modification, in order to facilitate construction and erection, a parallel arrangement is adopted, and the wet steam entering from above passes by a circuitous passage several times round the heating tubes. The fundamental principle, that the entering steam should be divided into a number of thin streams, is not fulfilled, and the heavy flow of wet steam from the dome being led through in a single stream, sufficiently close contact between the steam and the heating surface of the tubes cannot be secured.

In principle, moreover, the use of the ordinary boiler tubes for superheating is fundamentally wrong, having regard to their function as stays between the tube plates, as owing to irregular heating of the tubes, undue longitudinal stresses will be set up in the boiler barrel. As these tubes are thin, the danger of their becoming red-hot in the superheating-box is not impossible, especially as no means exist of shutting off the superheater when the engine is not using steam. Another danger in the same direction is the weakening of the tubes when under strong tensile stress at a "blue" heat—a temperature which must be realized, even if only momentarily, at every stoppage, and also

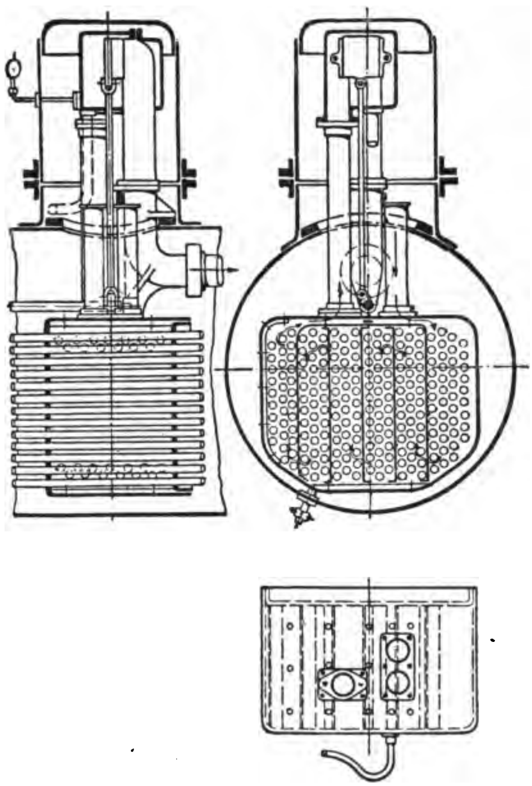


FIG. 8.—Pielock Locomotive Superheater.

when the blower is in use. The expanding of the joints in the tube plates must be done with the greatest possible care, and may require to be frequently repeated. Leakages cannot be traced, the superheater being inaccessible.

Only a very moderate degree of superheat can be obtained by this system, as the heating surface available must be comparatively small, and to enlarge it sufficiently would trench upon the water space, and, consequently, upon the steaming power of the boiler, whereby the working capacity, especially on rising gradients, would be lowered instead of raised. The attainment of a high degree of heat by placing the superheater nearer to the fire-box is inadmissible on account of the increased danger to the tubes from overheating.

The steam temperature, which is given at 535° Fahr. to 570° Fahr. at the dome, is reduced considerably in its passage to the engine as the steam, after leaving the superheater, is led through the water space of the boiler; the fall in temperature, as determined in the experimental plant at Saint Louis, amounted to 140° Fahr., so that the amount of superheat in the steam on admission to the cylinders is very materially reduced.

There is, however, one advantage in the system, namely, that the lost superheat in the steam is reabsorbed by the water, and, therefore, is not lost to the boiler as it would be if the drop in temperature was due to radiation.

As a result of the author's long experience with superheated steam, he feels it necessary at this point to state decidedly that any superheater depending upon thin tubes, and without automatic means of shutting off the heating gases when the steam supply is stopped, is essentially dangerous in work. As far as his information goes, collapse of the tubes from becoming red-hot in the superheating space has occurred in two locomotives of this class, and although these accidents were accounted for by defective construction, they serve to indicate the serious danger that may, under certain circumstances, arise with this class of superheater.

In order to meet dangerous weakening of the tubes by rusting, the parts within the superheater have lately been jacketed with metal, and provision has been made for filling the superheater box with water while the engine is standing, which must be emptied again before starting, and, therefore, imposes an additional duty upon the driver and fireman not likely to be conducive to rapidity in the long run.

(7) *The Clench Superheater* (Fig. 9).—Clench makes use of the smoke-box ends of the boiler tubes, C, for superheating by shutting off a portion of the front of the boiler barrel with a

second plate, $B_1$, within which the wet steam entering from above is made to circulate by diaphragm plates across the tubes, as shown in Fig. 9. This form of superheater, from its position at the cooler end of the boiler, may be regarded as a connecting link with the waste gas superheater, and can only have a low heating effect. As compared with the Pielock superheater, it has the advantage of requiring only one additional tube plate, and the temperature of the heating gases being low

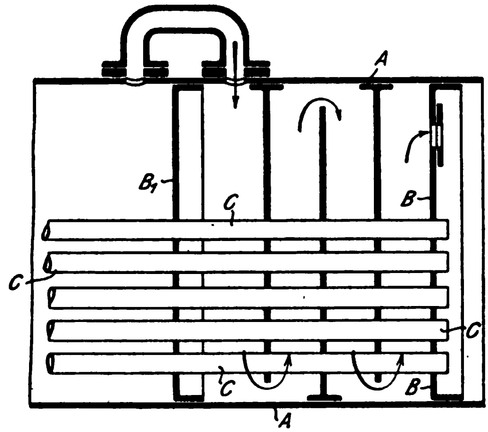



FIG. 9.—Clench Locomotive Superheater.

there is no danger of the tubes becoming red-hot when the regulator is closed. Under the latter condition, however, the inner tube plate is subjected to pressure from the boiler side only, which makes it difficult to prevent leakage around the tubes. This defect is said to have been met in a newer form, which gives a permanent communication between boiler and superheater, with the regulator placed behind the latter. The difficulty from rusting is, however, the same as in the Pielock form of construction. So far as the author knows, only a very moderate degree of superheat has been obtained with this arrangement in practice, which can scarcely compensate for the loss of heating surface and water space in the boiler, and the increased cost of construction and repairs involved in its use.

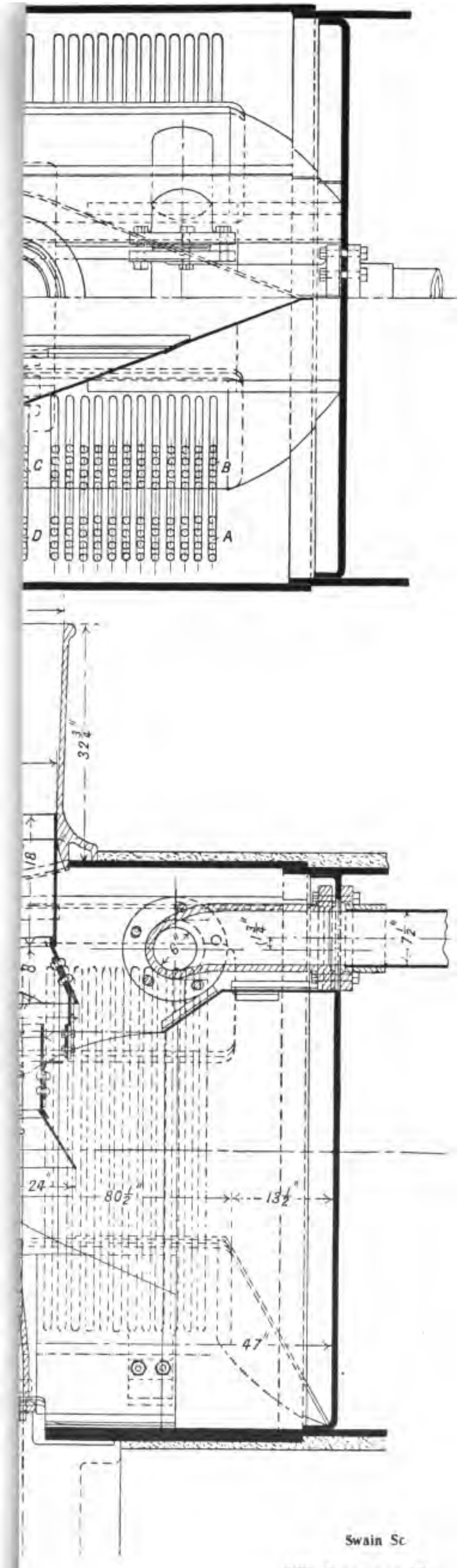
### (C) WASTE GAS SUPERHEATERS.

Waste gas superheaters are all based upon the principle of utilizing the waste gases from the boiler tubes, which are sometimes made shorter than in the ordinary locomotive, for the purposes of superheating in the smoke-box. The low temperature of the smoke-box, however, is against the possibility of obtaining any notable heating effect by this means, the action being rather that of drying than superheating the steam, and the saving is too small to cover the cost of providing and maintaining such superheaters. It is only by employing the most highly heated gases of the fire that a really useful locomotive superheater can be obtained.

As the numerous examples of superheaters of the class under consideration differ from each other principally in minor details of construction, their general characters may be sufficiently illustrated by the discussion of a single example.

(8) *The Baldwin Superheater* (Fig. 10).—This superheater has lately been applied by the Baldwin Locomotive Works in Philadelphia to two heavy American goods engines. It is made up of groups of curved tubes connected with cast-steel steam collectors above and below, which are placed in the smoke-box on each side of the engine. The tubes are arranged in five groups, with corresponding divisions in the steam collectors, so that the steam must pass through all five successively on its way to the cylinders. The superheater tubes are expanded at both ends into tube plates, which are bolted on to the steam collectors, the joint being secured by copper gasket packing. The maintenance of a steam-tight joint over these large surfaces in the smoke-box is one of the most difficult problems accompanying this form of construction.

With the first superheaters of this class the average heat added to the steam was 20° to 30° Fahr., or scarcely a drying heat, and there was no serious attempt made to develop the peculiar gas-like properties of highly superheated steam. Nevertheless, the builders thought it would allow of the use of greatly enlarged cylinders with correspondingly reduced steam pressures.

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In the first engine to which it was applied, a heavy 2-10-2 locomotive, the cylinders were 32 inches diameter and stroke, and steam at only 130 lbs. was used, the small superheat being expected to allow of reduced pressure and consequent saving in boiler repairs. Later the pressure was raised to 150 lbs., notwithstanding the size of the cylinders, in order to obtain the necessary duty. In a later engine the cylinders have been reduced to 28 inches, with 32-inch stroke, and the initial pressure has been raised to 160 lbs. What results have been attained with this engine the author is unable to say; but, whatever they may have been, a marked increase in saving and efficiency is not to be obtained by such a method. This is proved by the numerous experiments of different railway systems with similar waste heat superheaters which have always ultimately had to be abandoned, as the results obtained stand in no relation to the extra trouble and cost involved in their adoption.

The blocking up of the smoke-box and the tube plate on the smoke-box side is an objectionable feature in superheaters of this type, and the author can hardly believe that this form of superheater will find friends, especially in America.

In the preceding pages a few only out of a very great number of different systems of superheater construction have been considered, to enable those interested in the matter to estimate the value of the existing forms, and to facilitate further development of these much discussed contrivances.

## CHAPTER VI

### CONSTRUCTIVE DETAILS OF LOCOMOTIVES USING HIGHLY SUPERHEATED STEAM.

For the use of highly superheated steam it is essential that all parts of the engine with which it is brought in contact, such as cylinders, pistons, stuffing-boxes, slide valves, etc., should be constructed in such a manner as to suit the special properties of that medium. As in the case of other improvements, particularly in locomotives, the introduction of highly superheated steam was at first attended with considerable difficulties, but these have now been surmounted.

### (A) CYLINDERS AND PISTONS.

In the design of the cylinders for use with superheated steam particular care must be taken to avoid all sudden alterations of section of the metal which, due to the hot steam, are likely to cause irregular expansion of the structure; and the body of the chest valve must be kept entirely separate from the cylinder casting, so that the parts of the latter nearest the admission ports may not become more highly heated than those in the neighbourhood of the exhaust ports.

After a long and troublesome series of experiments, with a view to obtaining a tight working piston as nearly frictionless as possible, a simple modification of the well-known Swedish piston has been arrived at by Dr. Schmidt—shown in Fig. 11—and has given extremely satisfactory results.

This success is due to the fact that the three light packing rings bear none of the weight of the body of the piston, their function being merely to form a steam-tight joint, and this is effected through the combination of their elasticity and the small pressure acting behind them. Three rings are used in order that the middle one may never be subjected to any back pressure. Each of the rings is perforated radially by six holes

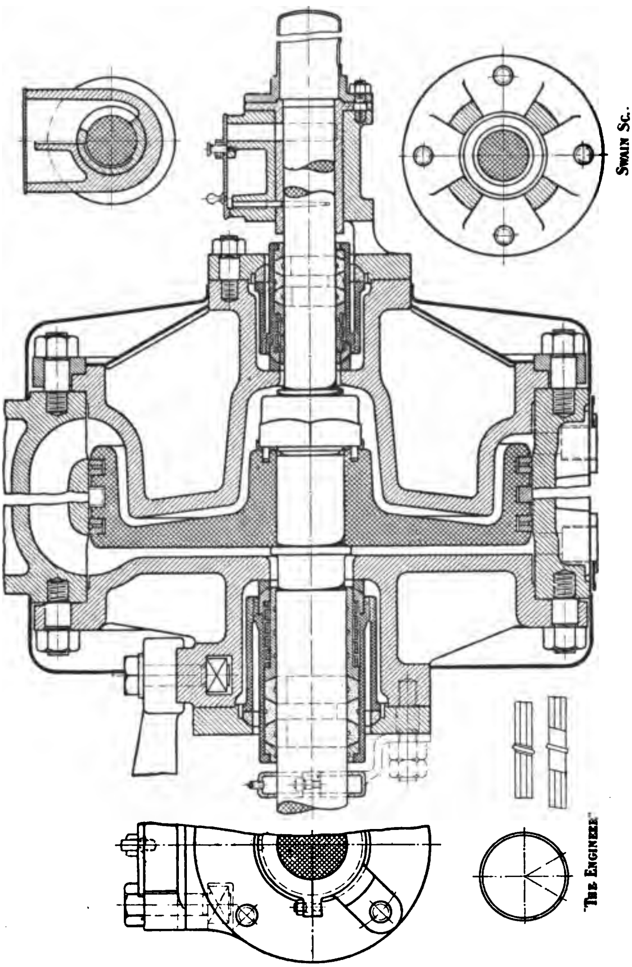



Fig. 11.—Piston and Stuffing-boxes for Superheated Steam.

3 mm. ($\frac{1}{8}$ in.) in diameter, spaced at equal distances apart, and opening into a shallow groove turned in the outer surface, thus forming a series of passages from the front to the back of the ring. When, therefore, at the beginning of the stroke, the first or third ring is driven by the compression out of

contact with the cylinder, steam makes its way behind it through the small exposed passage and presses it back, a too sudden restoration of the contact being prevented by the reflex action of part of the steam flowing back into the groove and cushioning the blow. Furthermore, a small amount of the steam finds its way between the ends of the second and third rings and their seats on the piston, relieving the pressure sufficiently to ensure merely a light contact with the surface of the cylinder.

The body of the piston, composed of the highest quality of cast-steel, is made as light as possible. Both the outer and

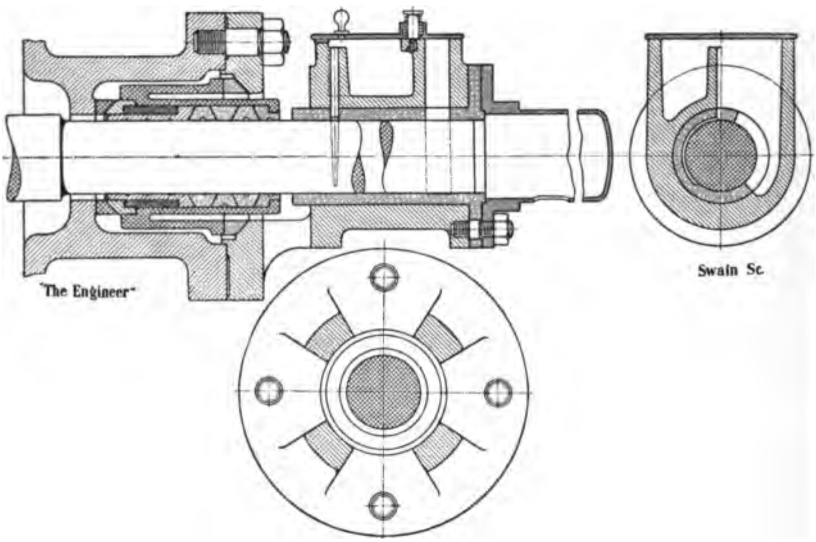



**Fig. 12.—Stuffing-box for Superheated Steam.**

inner edges of the grooves for the ring seats are rounded, the former somewhat more than the latter, to facilitate distribution of the lubricating oil. The diameter is made about 3 mm. ($\frac{1}{8}$ in.) less than that of the cylinder to prevent cutting during withdrawal, and also when from wear in the stuffing-boxes the piston is no longer perfectly central. Neither the cylinder barrel nor the stuffing-boxes must at any time carry any part of the weight of the piston. The piston-rod has a special guide in front, and is carried behind by the crosshead, so that the piston is kept nearly floating in the cylinder.

## (B) PISTON-ROD STUFFING-BOXES.

With highly superheated steam the use of a metallic packing allowing of free lateral motion for the piston-rod is essential. A packing, which has proved very successful, is shown in detail in Figs. 12 and 13.

If the piston is maintained as closely as possible central by keeping the crosshead slipper properly packed and by timely renewal of the forward guide-bars, which precautions

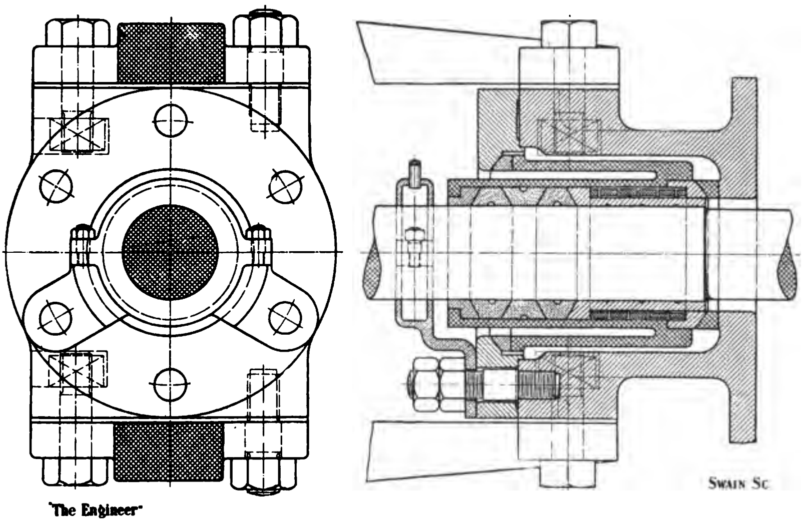



FIG. 13.—Stuffing-box for Superheated Steam.

are absolutely necessary for proper and regular working, the stuffing-box packings will run for years with extremely little wear in any of their parts.

## (C) PISTON-VALVES.

[1] [In all locomotives using highly superheated steam piston-valves must be employed, preferably with inside admission. This does away with the necessity of stuffing-boxes for the valve

[1] The following matter included between brackets did not form part of the original articles in *The Engineer* (L.S.R.).

rod, as the outsides of the valve are only under the low pressure of the exhaust steam which is gradually taken up by a long sleeve packing.

Dr. Schmidt has introduced two distinct patterns with inside admission specially designed by him for use in superheater locomotives. These types are:

(1) Piston valve with steam jacketed casing, double admission and solid piston rings.

(2) Piston-valve with balanced split-rings, and valve cover pressed on by steam.

The first-mentioned design, the construction of which requires up-to-date shop machinery, and particularly exact workmanship, has been principally used by the Prussian State Railways, whereas the second pattern has been adopted by most of the other railways.

### (1) PISTON-VALVE WITH STEAM JACKETED CASING, DOUBLE ADMISSION, AND SOLID RINGS.

In this valve the rings are undivided and are closely fitted to the valve chest liner by grinding to gauge. The difference in diameter between ring and liner should not be more than 0·002 inch in order to avoid excessive leakage, and to attain this exact workmanship is required. Such valves, as long as they are maintained in good working condition, require very little power to drive them on account of their small weight and their frictionless character, and consequently all parts of the valve gear can be kept comparatively light. Due to the small weight of the reciprocating parts of the valve, the wear and tear of all parts of the valve gear is exceptionally low.

As at first constructed, difficulties were experienced from irregular expansion between liner and valve. This has been overcome by using double admission ports and reducing the diameter of the valve, and the valve chest has been jacketed and heated with live steam. These modifications have made it possible to adopt a single size of valve, 150 mm. ($5\frac{29}{32}$ in.) in diameter, for all the superheated steam locomotives of the Prussian State Railways. The advantage arising from the adoption of a single standard size of valve for all classes of engines will be apparent without further comment.

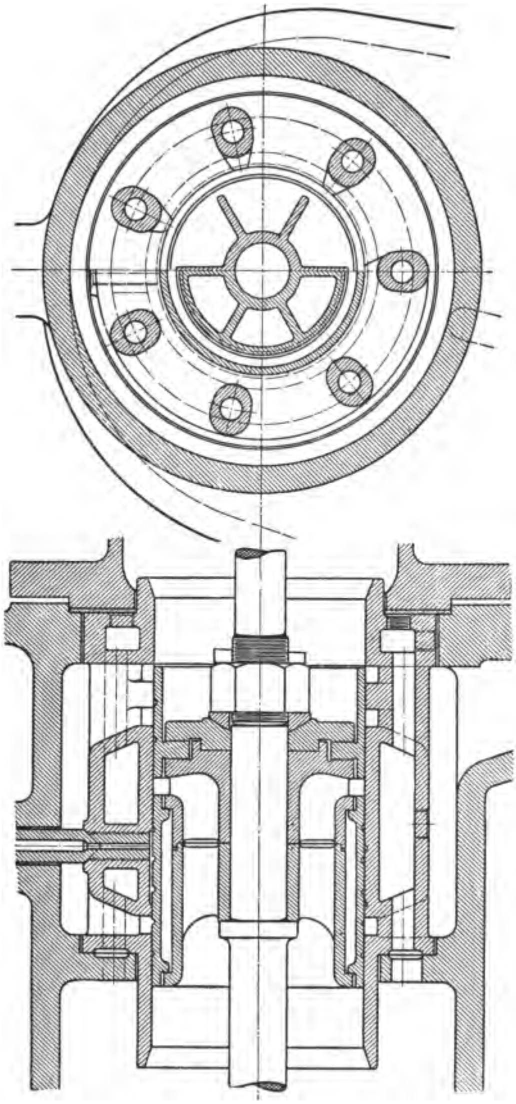


FIG. 14.—Piston-valve.

With regard to the objection raised by many authorities to valves of the construction described above, on the ground of leakage, it must be remarked that the loss of steam measured when at rest is no measure of that taking place when running.

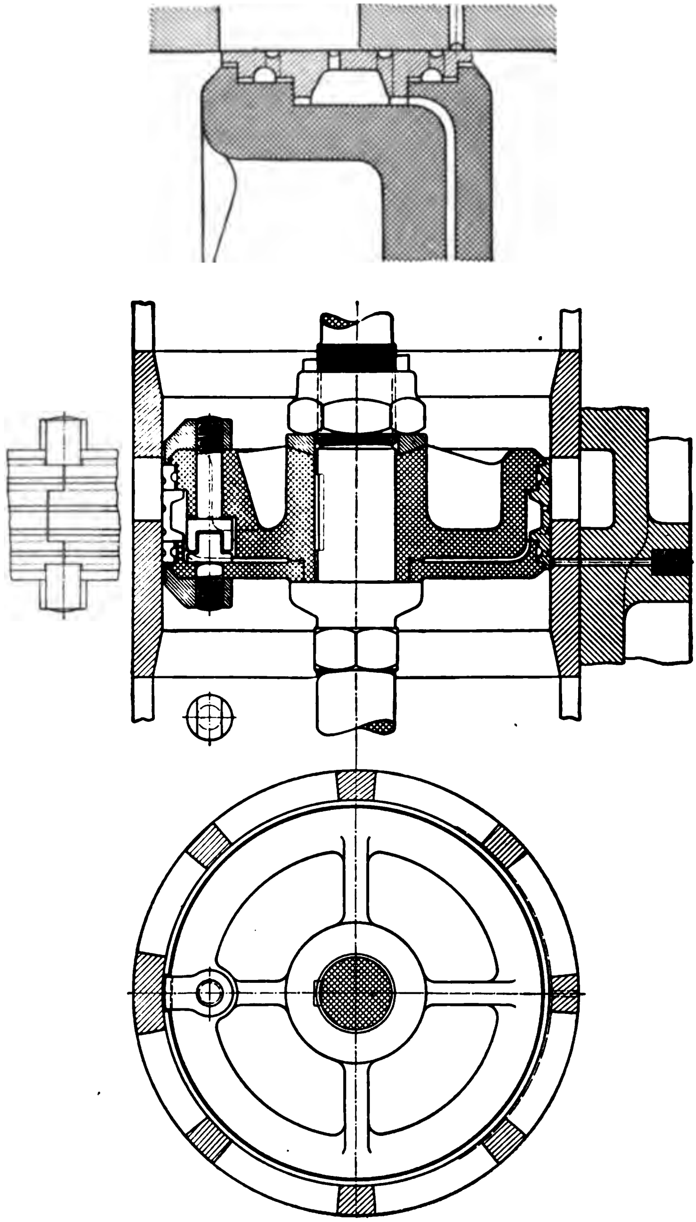


Fig. 15.—Piston-valve for Single Admission.

The long solid rings necessarily allow a considerable amount of steam to pass as a condition of maintaining their frictionless floating character when at rest, but such leakage decreases with increase of speed when in motion. A thin film of oil works into the clearance space between the valve and casing forming a sufficiently satisfactory packing. The small amount of power lost from this cause bears no relation to the much greater amount required to work large flat valves or heavy piston valves with *unbalanced* split-rings, to say nothing of the much greater wear and tear of the latter.

### (2) PISTON-VALVE WITH BALANCED SPLIT-RINGS AND VALVE COVERS PRESSED ON BY STEAM.

(*a*) *For Single Admission* (Fig. 15).—Although good results have been obtained with the form of piston-valve just described, the success of this type depends largely upon very exact workmanship in the rings and liner and in the careful maintenance of these parts in service. Another form of piston-valve has therefore been designed by Dr. Schmidt which is equally suited for use with highly superheated steam; it is at the same time more steam-tight, but does not require such accuracy in its manufacture.

In this type (see Fig. 15) wide rings are employed in place of the narrow split-rings generally adopted. The latter have the well-known objection that they wear out the bridges in the steam-ports of the liner quicker than the remaining portion, and, consequently, they are more likely to seize and break. Experience has proved that narrow rings are not to be recommended for use with highly superheated steam. Wide rings of the usual kind overcome this difficulty, though they have other disadvantages. By the steam leaking behind the rings, the latter are forced with great pressure against the liner and excessive wear soon takes place; on the other hand, during compression, they are unable to withstand the excessive pressure on the outer surfaces; they are forced inwards and leakage occurs. In this new type of valve, the advantages of the wide ring are retained, but the valve is constructed in such a manner as to overcome the aforesaid drawbacks, and also to prevent the inner, or outer, pressure seriously affecting the rings. This result has been achieved by providing several steam-tight spaces on the inside of each ring, which communicate with the steam-port by means of radial holes about $\frac{3}{16}$ inch diameter, arranged circumferentially round the ring. Thus the pressure on both sides of the ring is equalized, so that the ring is only pressed against the liner by its own tension which is sufficient to secure steam-tightness.

In order to secure a good fit between the valve-end and the ring, and between the ring and the valve-body, and that without jamming the ring between the two, the valve-end is made with a certain amount of elasticity, and is only screwed up against the valve-body at the centre, leaving the outer periphery to be pressed on by the steam.

The steam pressure in the valve-chest is thus made to ensure the tightness of the rings, while at the same time the elasticity of the cover gives the ring sufficient freedom for expansion. As, during admission, the pressure on both sides of the cover is the same, the ring adjusts itself independently of the valve end or cover.

During exhaust, however, the ring is held in position by the cover, till readmission takes place. Excessive outward pressure of the ring against the liner, and, consequently, excessive friction is thus prevented, although at this point of the stroke a perfect balance between the pressure on both sides of the ring may not instantly occur.

The resistance to motion of this type of piston-valve is very small, and the wear of the rings is almost infinitesimal.

As compared with the solid-ring type of valve, this modified type has the advantage of remaining absolutely steam-tight so long as there is any elasticity in the rings. The split or cut in the rings must always be placed opposite the broad bridge of the liner, so as to prevent leakage through the cut. The cut in the ring is protected on the outside by a cover, which is fixed respectively to the valve-body and to the valve-end or cover. The screws holding the split covers prevent the rings from turning. Hence, in cases where the split covers are cast on, special set-screws must be provided for this purpose.

These piston-valves, with split-rings, have been in use for a number of years with marked success, and have been adopted by the majority of railways using superheated steam.

(*b*) *For Double Admission* (" *Trick*" *Channel*).—The "Trick" channel has the well-known advantage of offering larger port openings for the entering steam, and for this reason it has been very generally applied to flat slide-valves. On piston-valves with split-rings the arrangement of the "Trick" channel, however, causes some difficulties, in cases where wide valve rings are used, because the spaces on the inside of the two rings are

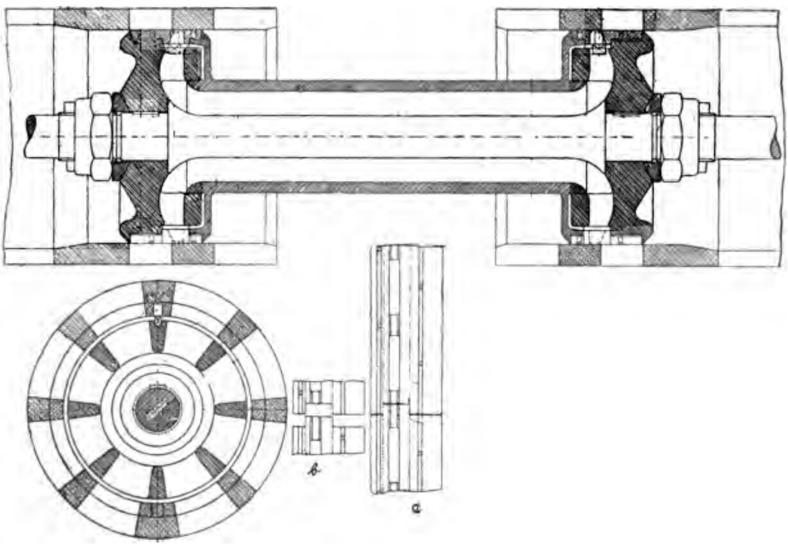


FIG. 16.—Piston-valve for Double Admission ("Trick" Channel).
*a*, Rings closed. *b*, Rings open.

in communication through the "Trick" channel, and thus the varying pressure in the latter works on the full steam-tight inside surface of the ring. When the valve is in such a position that the inside pressure in the "Trick" channel is greater than the outside pressure on the ring, the latter is forced with great pressure against the liner, and causes excessive wear; on the other hand, when the position of the valve is such that the inside pressure on the ring is the smaller, the latter is forced inwards, and considerable leakage occurs. In the improved design shown in Fig. 16, the space behind each ring is separated into three steam-tight compartments of which only the middle one communicates with the "Trick" channel; the outer and inner compartments are not influenced by the pressure in this channel. Hence this pressure can only work on a small part of the inside width of the ring, and does not give rise to the above-mentioned difficulties.

In all other respects the valve is designed on the same principles as that shown in Fig. 15, *i.e.* with radial balancing holes in the rings, and flexible valve-covers pressed on by

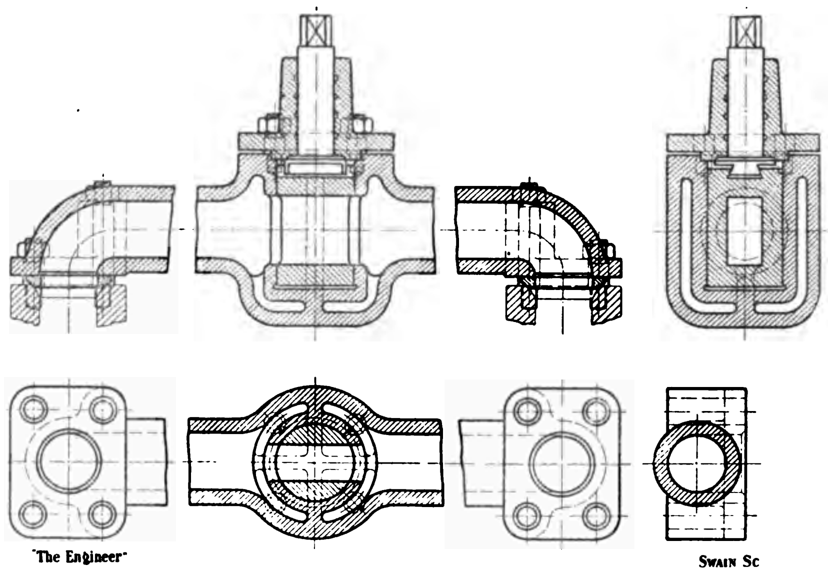



Fig. 17.—Pressure Equalizing Pipe.

steam. This new type offers, of course, the further advantage —that on account of the double admission the diameter of the valve, and consequently its weight, can be decreased.]

### (D) PRESSURE EQUALIZING ARRANGEMENT (FIG. 17).

Piston valves have the defect that, unlike flat slide valves, they cannot lift from their seats should the compression, when the engine is drifting, become too high. To avoid the injurious shocks to the rods and motion due to this cause, superheated steam locomotives are frequently provided with the contrivance shown in Fig. 17. This consists of a bye-pass tube 60 mm. ($2\frac{11}{32}$ in.) bore, connecting the two ends of the cylinder with a cock in the centre. When the steam regulator is closed this is opened, and the pressure on both sides is equalized. The cock is steam-heated, and, to prevent it becoming fixed on its seat, it is only made a loose fit, the steam pressure from either side keeping it tight in its place during running. The valve stem is connected with the cock by a grooved and dovetailed piston and the grooves turned in the outer guide enable a stuffing-box to be dispensed with. The cock is worked by hand with a key on the square end of the stem. The driver has to open the cock immediately on closing the regulator and must shut it again before re-admitting steam to the cylinder. In addition to the bye-pass arrangement, snifting valves must be fitted as in an ordinary locomotive.

## (E) LUBRICATION.

A matter of primary importance in the use of highly superheated steam in locomotives is the provision of suitable lubrication for the parts working under steam—the piston and piston valves—and this calls for special care in the choice of material and necessitates certain modifications in the details of their arrangement.

The high temperature makes it necessary to use only pure mineral oils having a particularly high flash point, and a definite quantity of the lubricant must be supplied to the rubbing surfaces, the amount being determined by the speed, *i.e.* the revolutions of the driving wheels. The oil must be prevented from becoming mixed with water, or heated and decomposed by steam, both of which effects are more or less likely to occur with drop or sight-feed lubricators. The access of water to the surfaces to be lubricated is injurious to the working parts, and is a cause of waste through the condensed steam carrying finely divided oil to parts not requiring to be lubricated.

A further objection to drop lubricators when superheated steam is used is to be found in their inflexibility, the oil being distributed by a continuous flow from one or other end of the supply pipe in the direction of lower pressures, irrespective of the requirements of the surfaces. Now, for successful lubrication, it is essential that it shall be possible to meet all variations of pressure on the rubbing surfaces by varying the supply of oil as the necessities of the case demand. These considerations have led to the exclusive adoption in the author's practice of forced lubrication. As the oil has to be supplied to three places on either side of the engine (two valve pistons and one cylinder piston) the oil presses must be fitted with six cylinders, and the communication pipes must be kept constantly filled and under pressure, with suitable return valves at the distributing points. The return valves, or oil savers, are important features in the arrangement, preventing irregularity of flow due to changes of pressure in the places to be lubricated, and waste of oil from the supply pipes when the engine is standing or running without steam for any length of time.

The oil presses are placed on the left-hand, or fireman's side of the cab, and are generally driven by a hanging rod receiving motion from the rear driving wheel, so that they are only at work while the engine is running. The regulation of the oil supply is controlled by varying the effective length of the rod.

Oil presses by the following makers are adopted on the Prussian railways: Ritter, of Altona; Michalk, of Deuben, near Dresden; and Dicke and Warneburg, of Halle; while in Austria the Friedmann oil pump is generally used. These have proved to be thoroughly efficient in use, and allow of any desired rate of consumption being attained with ease and certainty. It is, however, essential that they should always be tested before starting by means of the small test-cocks placed below the return valves to ascertain that they are in proper working order.

### (F) SPECIAL FITTINGS FOR SUPERHEATED STEAM LOCOMOTIVES.

In addition to the items described above, certain special fittings are required for the superheated steam locomotive. These include a pyrometer and a pressure gauge for determining respectively the superheat and pressure at the valve chest, a vacuum gauge for the smoke-box, a hand rod for the pressure equalizer, placed near the hand wheel of the valve gear and safety valves in the cylinder covers. The handle for regulating the superheater dampers is placed on the left-hand side of the fire-box.

### (G) SPECIAL WORKING REGULATIONS FOR SUPERHEATED STEAM LOCOMOTIVES ON THE PRUSSIAN STATE LINES.

I. *Before Starting.*—(1) The oil presses, which, in accordance with the instructions supplied, are to be filled with oil at the end of the run, must invariably be tested as to their working condition before starting on a new journey. The strainer in the feed vessel must be cleaned out at short intervals, and the presses must be kept scrupulously clean.

(2) The self-acting valves of the smoke-tube superheaters must be kept clean and completely shut while the engine is firing up or standing, and their adjustment to the working position must only be done when the regulator is opened and in accordance with the directions of the indicator plate.

(3) It is of great importance that the smoke-box be kept tight. All leakages in the door, the covering plates, and the flange of the ash-pan must be very carefully stopped, as such leakages have a very prejudicial influence on the working of the superheater.

(4). When first starting up the cylinder drain cocks must be opened, and remain so until the pyrometer shows a temperature of 400° Fahr. or more, after which they may remain shut even at restarting, but they must be immediately opened when any sudden fall takes place in the superheat, to prevent the chance of water being carried over into the cylinder.

II. *During the Journey.*—(1) *Position of Valve Gear and Regulator.*—At starting the regulator must only be opened gradually, and even under the heaviest load it must be kept in such a position that the pressure in the valve chest is not more than about 7 lbs. below that in the boiler, so as to prevent water passing over into the cylinders.

To avoid slipping at starting the valve motion should be linked up, and the starting be controlled principally by it. This can be readily done on account of the ease of movement of the different parts by hand allowing the cut-off to be rapidly varied, so as to prevent slipping while maintaining a powerful starting pull.

The cut-off in the cylinder is never to be reduced below one-fifth of the stroke. When lower powers are required the steam pressure must be throttled down from 20 to 30 lbs., keeping the valve gear sufficiently forward to ensure easy running.

To prevent jamming and cutting of the valves the motion must not be immediately put in full gear directly the regulator is shut. In all cases, however, when coming out of the sheds the gear must be put full forward to ensure the proper distribution of the lubricating oil over the surface of the slide, as well as for the purpose of blowing out dirt and coagulated oil.

The pressure equalizer on the driver's side must always be opened immediately after closing the regulator, and when the engine is standing, being immediately shut again on starting.

(2) *Firing and Superheating.*—The average amount of superheat must be kept as nearly as possible at 600° Fahr., and must not exceed 660° Fahr., the temperature being ascertained from the pyrometer. When the highest limit is reached the temperature must be reduced by closing the damper of the superheater tubes.

Under ordinary working conditions sufficient superheat cannot be obtained with a heavy smoky fire or with too thin a fire on the grate, because the tubes are cooled by the excess of air passing in with the gases. Other causes tending to inefficiency are, too high a water-level in the boiler and dirty superheater tubes.

In order, therefore, to obtain the desired temperature of 600° Fahr. the firing must be very carefully done, keeping a well-ignited body of fuel on the grate and adding fresh coal by a few shovelfuls at a time, making the largest additions at the back and to the under corners of the fire-box and below the fire-door. It is necessary that the boiler should be fired more frequently than with compound engines, care being taken that the fire never becomes thin enough to allow air to penetrate through bare spaces on the grate, and, as a rule, the injectors should be started after each firing.

A sudden drop in temperature is always experienced when the steam carries much water over into the superheater, which often happens with turbid and dirty feed-water. This can only be remedied by thoroughly washing out the boiler. With a proper use of the regulator the flow of steam may be so arranged as to deliver it as dry as possible to the superheater. The correct degree of throttling for this purpose is ascertained from the gauge indicating the pressure in the valve chest.

III. *After the Journey.*—The superheater tubes are to be cleaned from soot and ashes by introducing the nozzle of a hose connected with a steam or air pipe among the superheater tubes from the back. The cleaning may be done either with steam from the boiler or compressed air from a special supply at 150 lbs. pressure, that from the reservoirs of the Westinghouse brakes not being high enough. When the boiler is cold, compressed air only must be used, as the condensation of steam on the cold tubes is likely to rust them. The interval which elapses between cleaning depends entirely on the quality of the coal. Whenever the boiler is washed out any accumulations of slag that may have formed on the back ends of the superheater tubes are to be cleared out from the fire-box side, and the spark arrester is to be taken out in order to see if any incrustation of soot has formed on the rim of the blast pipe. If this is the case the lubrication is too heavy, and the delivery of the oil pumps must be proportionately reduced. Washing out or sprinkling the superheater, as it leads to rusting, must be absolutely avoided.

| No. | Railway. | Description of Locomotives. Type of Locomotive. | Number of Locomotives. | Wheel arrangement. | Cylinder arrangement. | Cyl. dia. × Stroke / Dia. of Driving Wheels. | Weight of Locomotive. |
|---|---|---|---|---|---|---|---|
| | | | | | | Inches. | Tons. |
| 1 | Prussian State Railways (Berlin District). | Saturated Steam Loco. | 3 | 2–6–0 T. | Simple. | 18·9 × 24·8 / 59 | 58·8 |
| | | Superheated Steam Loco. | 3 | 2–6–0 T. | Simple. | 21·3 × 24·8 / 59 | 60·5 |
| 2 | Ditto (Breslau District). | Saturated Steam Loco. | 1 | 0–10–0 T. | Simple. | 20·5 × 24·8 / 47·2 | 70·1 |
| | | Superheated Steam Loco. | 1 | 0–10–0 T. | Simple. | 24 × 26 / 53·2 | 72·4 |
| 3 | Aussig-Teplitzer Ry. Co. (Austria). | Saturated Steam Loco. | 1 | 4–6–0 | Simple. | 19·7 × 25·6 / 65 | 59·4 |
| | | Superheated Steam Loco. | 1 | 2–6–2 | Simple. | 21·3 × 24·8 / 63·8 | 65·0 |
| 4 | Northern Bohemian Railway. | Saturated Steam Loco. | — | 4–4–0 | Simple. | 16·7 × 19·7 / 68·1 | 42·6 |
| | | Superheated Steam Loco. | 2 | 2–6–0 | Simple. | 19·7 × 23·6 / 59·8 | 47·0 |
| 5 | Bergslagermas Railway (Sweden). | Saturated Steam Loco. | 3 | 4–4–0 | Simple. | 17 × 24 / 66·9 | 35·4 |
| | | Superheated Steam Loco. | 1 | 4–4–0 | Simple. | 18·5 × 24 / 66·9 | 38·8 |
| 6 | Belgian State Railways. | Saturated Steam Loco. | — | 4–6–0 | Simple. | 20·5 × 26 / 66·9 | — |
| | | Superheated Steam Loco. | — | 4–6–0 | Simple. | 20·5 × 26 / 66·9 | 69·1 |
| 7 | Belgian State Railways. | Saturated Steam Loco. | — | 0–6–0 | Simple. | 18·5 × 26 / 59·8 | 43·8 |
| | | Superheated Steam Loco. | — | 0–6–0 | Simple. | 19·7 × 26 / 59·8 | 47·6 |

COMPARATIVE TRIALS OF SUPERHEATED STEAM SIMPLE

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 8 | Prussian State Railways (Breslau District). | Saturated Steam Loco. | 1 | 4–4–2 | 4-Cylinder Compound. | 2 (13·4+22) × 25·2 / 78 | 62·7 |
| | | Superheated Steam Loco. | 1 | 4–4–0 | Simple. | 21·3 × 23·6 / 78 | 54·5 |
| 9 | Canadian-Pacific Railway. | Saturated Steam Loco. | 12 | 2–8–0 | 2-Cylinder Compound. | (22 + 35) × 28 / 57 | 72·3 |
| | | Superheated Steam Loco. | 6 | 2–8–0 | Simple. | 21 × 28 / 57 | 83·1 |
| 10 | Ditto. | Saturated Steam Loco. | 41 | 2–8–0 | 2-Cylinder Compound. | (22 + 35) × 28 / 57 | 72·3 |
| | | Superheated Steam Loco. | 20 | 2–8–0 | Simple. | 21 × 28 / 57 | 83·1 |

| Heating Surface of Boiler + Superheater (fire side). | Grate Area. | Type of Super-heater. | Trial or Service Test. | Date of Test. | Economy of Superheated Steam Loco. | | Reference. |
|---|---|---|---|---|---|---|---|
| | | | | | Coal. | Water. | |
| Sq. ft. | Sq. ft. | | | | Per cent. | Per cent. | |
| 1297 | 18·3 | — | 2 Months' Service, Berlin Suburban Railway. | May and June, 1905. | — | — | Garbe, "Dampflok. der Gegenwart," p. 415. |
| 1113 + 318 | 18·3 | Smoke-box. | | | 19·7 | 39·3 | |
| 1480 | 25·5 | — | Service. | — | — | — | Schwartzkopff Locomotive Works, Berlin. |
| 1417 + 341 | 24·2 | Smoke-box. | | | 25 | 39 | |
| 1889 | 31·2 | — | 5 Months' Service. | 1906. | — | — | Aussig-Teplitzer Railway Co. |
| 2179 + 512 | 39·5 | Smoke-tube. | | | 20 | — | |
| 1256 | 21·6 | — | Service. | 1907. | — | — | |
| 1166 + 275 | 25·3 | Smoke-tube. | | | 25·4 | — | |
| 996 | 16·1 | — | Service. | August to December, 1905. | — | — | *Die Lokomotive*, August, 1906, p. 146. |
| 969 + 183 | 17·8 | Smoke-tube. | | | 26·7 | — | |
| 1864 | 30·6 | — | Numerous Service Runs. | 1905. | — | — | Garbe, "Dampflok. der Gegenwart," p. 424. |
| 1561 + 356 | 30·6 | Smoke-tube. | | | 27 | 24 | |
| 1242 | 27·1 | — | A number of Service Runs. | April, 1906. | — | — | |
| 1034 + 231 | 27·1 | Smoke-tube. | | | 32 | 28·5 | |

LOCOMOTIVES AND SATURATED STEAM COMPOUND LOCOMOTIVES.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1927 | 27·9 | — | 212 Miles' Service. | — | — | — | Garbe, "Dampflok. der Gegenwart," p. 375. |
| 1095 + 331 | 24·4 | Smoke-box. | | — | 21·1 | 36·7 | |
| 1991 | 43·6 | — | 4 Months' Service. | January to April, 1905. | — | — | Master Mechanics' Association, 1905. |
| 2143 + 375 | 43·6 | Smoke-tube. | | | 14·5 | — | |
| 1991 | 43·6 | — | 7 Months' Service. | May to October, 1905. | — | — | New York Railway Club, April, 1906. |
| 2143 + 375 | 43·6 | Smoke-tube. | | | 17·8 | — | |

# CHAPTER VII

## EXPERIMENTAL AND WORKING RESULTS WITH SUPERHEATED STEAM LOCOMOTIVES

FROM the large amount of experience which has been accumulated from trial runs and from ordinary working with superheated steam locomotives, only a few important points will be selected.

### (A) SAVING OF COAL AND WATER WITH SUPERHEATED STEAM LOCOMOTIVES.

In the table on pp. 60 and 61 particulars are given of the resulting saving in coal and water in locomotives fitted with Schmidt superheaters computed from figures communicated by different railway authorities. The figures have chiefly been obtained from comparative trials under similar conditions of superheated steam locomotives and ordinary locomotives, extending over several months. From the results of ordinary working alone it is not, however, easy to form a correct opinion as to the actual economy in consumption, as in many cases both the handling and maintenance of superheated steam locomotives leave much to be desired. The much more favourable results obtained on trial runs must be regarded as the best attainable. The fact that these are not realized in continuous working is to be attributed to the circumstance that the size of the trains and the running times are arranged to meet the conditions suited to the best and most economical working of the ordinary saturated steam locomotives, and are not those best suited to the much higher capacity of superheated steam locomotives. Notwithstanding these drawbacks, the average saving of coal in practical working with superheated steam is from 25 to 30 per cent. of the consumption of simple and 15 to 20 per cent. of that of compound engines using saturated steam.

## (B) INCREASED WORKING CAPACITY OF THE SUPERHEATED STEAM ENGINE.

As the above point was theoretically considered in Chapter II. it will only be necessary to illustrate it further by a series of examples of practical results. These are partly taken from the author's work on "The Steam Locomotive of the Future."[1]

In Figs. 18–22 the working results of superheated steam locomotives on the Prussian and Belgian State lines are represented graphically. They are selected from such parts of trial runs as show most clearly the extraordinary working capabilities of the Schmidt system. In Figs. 18, 19, 20, and 22 the times are shown as abscissæ, which departure from the usual practice gives a distorted outline to the section, but as the individual gradients are given this will not be found to be an inconvenience, as the curve shows the work done and the period of its duration simultaneously, so that the average duty can be easily deduced. In Fig. 21, referring to the Belgian State lines, this method could not be used, and the distances have been given as abscissæ.

The brilliant results obtained are so clearly indicated in the figures that further comment is superfluous. Similar results have never been obtained with saturated steam in engines of the same weight and number of axles, and when it is remembered that these have been accompanied by very considerable saving in coal and water, it can no longer be doubted that the adoption of highly superheated steam in the simple two-cylinder locomotive affords the best means of increasing the power of the locomotive while retaining simplicity of construction.

## (C) COST OF CONSTRUCTION AND MAINTENANCE.

The undoubted advantages of the system having been demonstrated, the objections made on the ground of greater costliness remain to be considered. The extra cost due to the superheater, and to the increased size of some of the working parts, is comparatively small, when the advantages previously cited and the practical abolition of double heading are taken into account. The standardization of the details, and their production on a

[1] "Die Dampflokomotiven der Gegenwart" (Julius Springer, Berlin).

large scale, are likely still further to reduce the extra cost. In the author's opinion, the practical abolition of double heading due to the increase in power obtainable when a superheater is fitted, more than compensates for the increased initial cost, and therefore the saving in coal and water may be considered net profit.

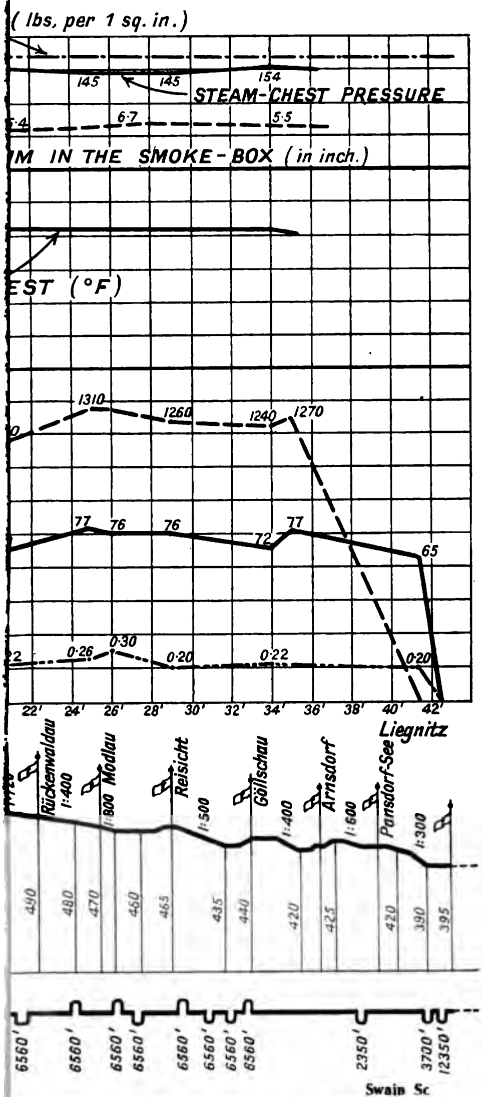
It will be easily understood that during the experimental period many mistakes were made. Every new type of locomotive brought its own problems with it, and the experience gained with each has been utilized in its successor, so that at the present time it may be fairly claimed that the requisite simplification has been attained. The experience accumulated as to the durability of the superheater and the other details of the system, and the cost of upkeep of the same, is of a uniformly favourable nature.

As regards the cost of maintenance, the experience with the Schmidt smoke-tube superheaters on the Prussian State Railways, as compared with the smoke-box superheaters, extends over too short a period to allow of an absolutely final estimate being formed, but the excellent behaviour of the former type in current work, together with the much larger experience of foreign railway companies with this particular type, justifies the opinion that no difficulties are to be anticipated on this ground.

It is, however, essential that the regulations for tube-cleaning must be rigorously observed, as if this is not done thoroughly, deposits accumulate in the tubes, diminishing the free draught of the heating gases, with a corresponding lowering of their heating power.

As has already been stated, in the earlier superheated steam locomotives the working parts were not strengthened sufficiently to meet the increase of power, and the new form of piston-valve caused some difficulties. These, however, have been completely overcome, and it may be confidently stated that the cost of maintenance of the newest engines is in no way higher than that of the simple two-cylinder engines, and considerably below that of the four-cylinder compound engines.

Evidence of this is given by the working results of the 2-6-0 tank engines put into service in February and March, 1905, for heavy suburban passenger traffic, which ran for




...st, 1906, *from Sommerfeld to Liegnitz*

| | | |
|---|---|---|
| engine in working order | ... ... | 56·7 tons |
| tender ,, ,, | ... .. | 78·1 ,, |
| ... ... ... ... | ... ... | 5 ,, |
| ... ... ... ... | ... ... | 4730 gals. |

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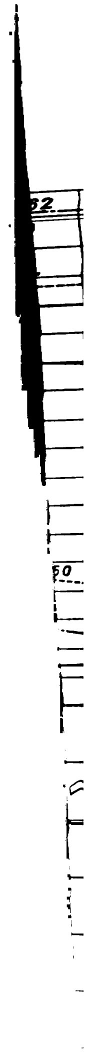

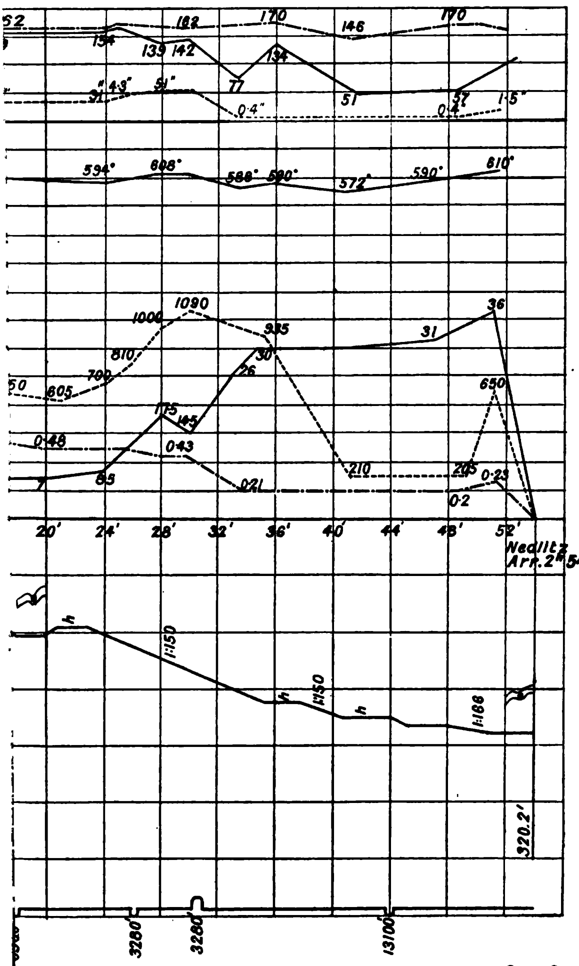


SWAIN Sc

ox *Superheater, on June 29th,* 1905,

| | |
|---|---|
| Grate area ... ... ... ... ... ... | 24·2 sq. ft. |
| Weight of engine in working order ... ... | 72·4 tons. |
| Coal ... ... ... ... ... ... ... | 2 „ |
| Water ... ... ... ... ... ... | 1540 gals. |

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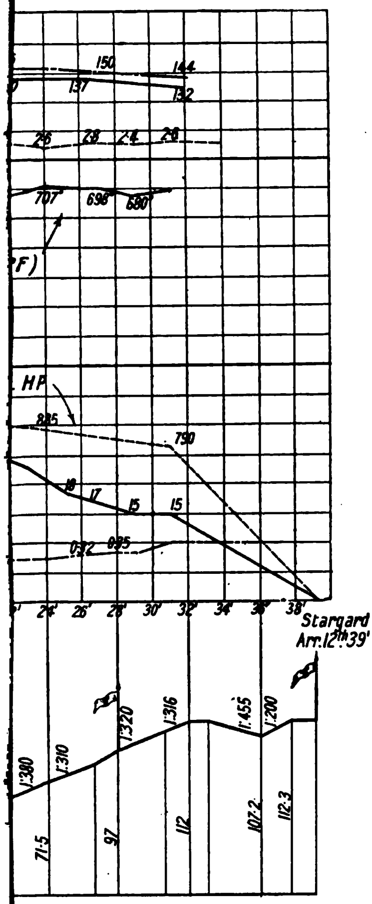



*ke-box Superheater, on January* 13*th,*
*lways*).

09 tons.

| | | | | | |
|---|---|---|---|---|---|
| eater | ... | ... | ... | 341·2 sq. ft. | |
| ... | ... | ... | ... | 1764·8 | „ |
| ... | ... | ... | ... | 24·1 | „ |
| els | ... | ... | ... | 55·1 tons | |
| rking order | ... | ... | | 55·1 | „ |
| „ | „ | ... | ... | 42·3 | „ |
| ... | ... | ... | ... | 5·6 | „ |
| ... | ... | ... | ... | 3520 gals. | |

[*To face page* 64.

eighteen months, covering from 62,000 to 73,000 train-miles before returning to the shops for complete overhaul, when it was found that the wear of the axles and other moving parts was only of the ordinary amount, and no special difficulties had arisen with the superheater and cylinders.

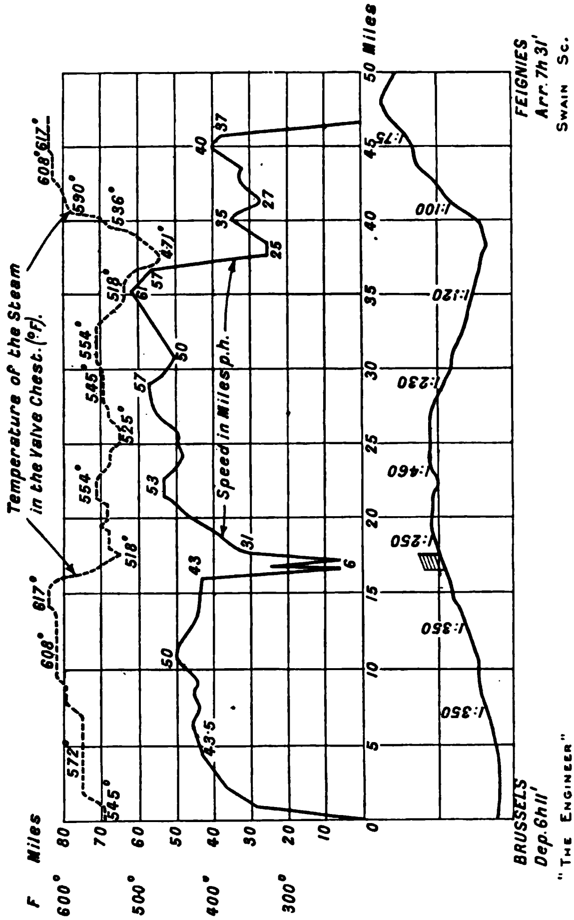



FIG. 21.—*Trial Run of 4-6-0 Superheated Steam Locomotive with Schmidt Smoke-tube Superheater, on July 6th, 1905, from Brussels to Feignies (50 miles—Belgian State Railways).*

Weight of Carriages 350 tons.

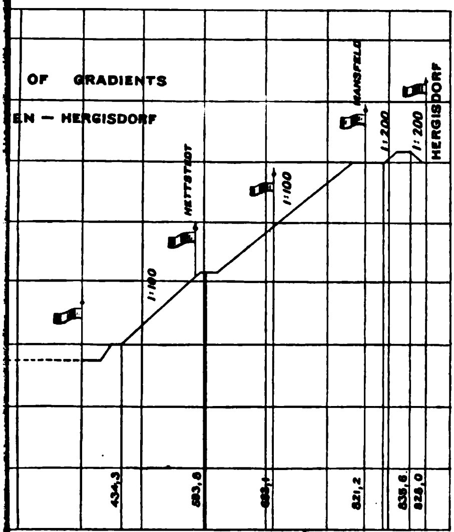
| | |
|---|---|
| Type of engine ... ... | 4-6-0 |
| Superheater ... ... | Schmidt smoke-tube |
| Diameter of cylinders ... | 20·5 ins. |
| Stroke ... ... ... | 26 " |
| Diameter of driving-wheels | 66·9 " |
| Boiler pressure ... ... | 200 lbs. per sq. in. |
| Heating surface, fire-box ... | 160·4 sq. ft. |
| Heating surface, tubes ... ... | 1399·4 sq. ft. |
| " " superheater ... | 356·3 " |
| " " total ... ... | 1916·7 " |
| Grate area ... ... ... | 30·6 " |
| Weight on driving wheels ... ... | 51·8 tons |
| " of engine in working order | 69·1 " |

Mr. H. H. Vaughan, of the Canadian-Pacific Railway, at the meeting of the Master Mechanics' Association in 1905, stated that, "Speaking generally, the maintenance cost of a superheated steam locomotive is not necessarily greater than that of an ordinary engine of the same size, for although certain supplementary costs are incurred, they are compensated by savings in other directions, so that there is no very great difference in the total. If this be so, the value of the superheater only depends upon the relation between the first extra outlay and the saving effected, and as the first cost at present is about 1000 dols., with the probability of a considerable future reduction, the provision of a superheater seems to be a very advantageous capital investment." Under American conditions, Mr. Vaughan considers that the cost of the superheater will be covered by the saving in two years.

M. Flamme, Inspector-General of the Belgian State lines, at the Liège meeting of the Institution of Mechanical Engineers in 1905, stated in regard to the superheated steam locomotive, type 35, that no particular difficulties had been experienced with it during one and a half year's regular working, and that, in consequence of the favourable results obtained, the Belgian Government had decided to extend the use of superheaters very considerably.

The Bohemian Northern Railway Company, in a letter to the author of April 24, 1907, write as follows:—"The two superheated steam locomotives supplied in the year 1905 were sent after a year's working to the shops for general overhaul, when it was found that no appreciable wear had taken place in the pistons and the piston valves, which, after cleaning, were replaced in the same condition. In the same way no defects were found in the superheater itself, and the total cost of the first overhaul was not higher than that of ordinary locomotives after doing the same amount of work." The experience of other lines leads to the same conclusion as that above stated.

Care, however, must be taken in the driving of superheated steam locomotives that the prescribed regulations are exactly and intelligently followed. It is, therefore, necessary that men should not be put in charge of these engines until they have been thoroughly instructed how to handle them by properly qualified instructors. The proper personal instruction of the drivers and firemen is of the greatest importance if the increased usefulness which may rightly be expected from superheating is to be realized.




*August* 1*st*, 1906.

| | |
|---|---|
| riving-wheels ... ... ... ... | 46·9 tons |
| gine in working order ... ... | 68·5 „ |
| nder „ „ ... ... | 49·1 „ |

[*To face page* 66.

# INDEX

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