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Experimental Locomotives

by F. Ya. Slavgorodskiy

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F. Ya. SLAVGORODSKIY

EXPERIMENTAL LOCOMOTIVES

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This book gives a comprehensive description of the most interesting experimental locomotives that have been built or designed during the past two decades in the USSR and abroad.

The book is addressed to engineer, technical and practical workers in the locomotive field.

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PREFACE

From the very first days of public railroads down to the end of the past century, the steam locomotive in all countries of the world was the only type of railroad motive equipment. During that period and the following period, down to our own times, it has undergone substantial changes in design and proportions (weight, power, speed, etc). The modern steam locomotive has lost all resemblance to the first locomotives like the Cherepanov type, the Stephenson "Locomotion", "Rocket", etc, although the principle of construction has remained unchanged.

During the first years of the present century, the monopoly of the steam locomotive came to an end. A more modern and more efficient locomotive than the steam locomotive appeared on the scene: the electric locomotive. This was without doubt the greatest forward stride ever taken in the field of technical progress in train traction throughout the entire history of railroading.

During two decades, transport machine construction gained yet another major victory. A locomotive form was created that in tractive properties yielded but little to the electric locomotive. We refer, as the reader must have already guessed, to the internal combustion locomotive. During the relatively short period of 15-20 years, the internal combustion locomotive has gained a very considerable degree of acceptance both in the USSR and in other countries, and its relative participation in railroad transportation, especially in passenger service, is growing rapidly and steadily.

Nevertheless the steam locomotive still continues in its predominant role, and is the most widely employed form of railroad motive power in use in the USSR and most other countries of the world.

This is mainly due to the fact that locomotive construction technology, for its part, has also achieved brilliant results during this same period in improving the design of the standard types of steam locomotive. It is precisely because of this that the steam locomotive has always been able, up to now, to compete successfully with both electric and internal combustion locomotives.

But does this imply that the steam locomotive completely satisfies all the requirements of modern railway operation and that today there are no longer any problems of steam traction?

By no means! Even in its most up-to-date design the steam locomotive has still not freed itself of the essential shortcomings that will be discussed in their proper place in this book and to which the highly developed transport of today is less than ever inclined to resign itself.

It is precisely for this reason that scientific and technological thinking in the USSR and the other countries of the world has been, and still is, constantly and energetically working towards further improvement of the steam locomotive and also towards the creation of fundamentally new types and designs of steam and other locomotives.

It is hard to overestimate the results of this work, especially during the past two decades. Thousands of steam locomotives have been modernized or structurally improved (to one degree or another), many hundreds of designs have been drawn, many tens of experimental locomotives of various new types (steam, electric, internal combustion, steam-turbine, gas-turbine locomotives) have been built and tested in trial operation, and have often deviated basically in design from the existing standard locomotives.

These results have not been accidental. The entire preceding course of development of transport technology has served to prepare for them, as has the prolonged and steadfast labor of the creative thought of scholars, engineers, technicians, designers and inventors.

The transport technology of our country before the October Revolution, and especially after it, and its best representatives of past and present generations, occupies one of the foremost positions in this respect among the other countries. The outstanding position of our science and technology in the development and realization of many technical improvements in rolling stock, maintenance of ways, operation, etc, is definitely established today. Let us illustrate this by only a few generally known examples relating to train traction and locomotive construction.

Experimental work on the use of superheated steam in locomotives -- this, the most effective method of improving the tractive and thermal performance of a locomotive -- was first initiated in our country, and it was here, in Russia, that experimental locomotives using superheated steam appeared before they did in England or the United States.

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The method of experimental study of the tractive characteristics of the steam locomotive under stationary conditions was first developed by Russian traction specialists, and was borrowed from us by foreign railroads, while a stationary locomotive-testing laboratory was set up by the Russian engineer A. P. Borodin at the Kiev railway shops as early as the beginning of the 80's of the past century, at a time when not a single other country had such a laboratory.

The Series E steam locomotive built in 1912 by the Lugansk plant was the best locomotive of its day in its economy, reliability of operation, and simplicity of maintenance and repair, as compared to all other series of locomotives then in use on European and American railways.

All this speaks for the capacities and talent of the representatives of Russian transport technology in the field of train traction. Even under the musty and suffocating environment and conditions of prerevolutionary Russia they were able to overcome the sluggishness of the dignified railway bureaucracy and to advance the cause of Russian transport technology. The names of such scientists and traction specialists of the prerevolutionary period as N. P. Petrov, A. P. Borodin, N. Ye. Zhukovskiy, A. N. Krylov, Ye. Ye. Nol'teyn, and others, will not be forgotten in the chronicles of our transportation.

As for our achievements in the postrevolutionary period, these are very well known, not alone in the USSR but also abroad. It will be enough if we point in this place to these models of

Soviet locomotive construction which are unsurpassed throughout all of Europe: the FD and IS steam locomotives; to the powerful main-line internal combustion locomotives that we built and put into service when they still existed neither in Europe or America; to the rapidly introduced series construction of electric locomotives of first-class design, and particularly to the powerful two-voltage electric locomotives and motorcar sections, first in the world.

Generally known, too, are the roles played and services rendered by Soviet scientists and highly qualified traction specialists (steam, electric and internal combustion locomotive men). It would be impossible to refer to them all by name here, for we have many hundreds of them. S. P. Syromyatnikov, D. A. Shtange, N. I. Belokon', N. I. Kartashev, O. N. Isaakyan, K. A. Shishkin, Ya. M. Gakkel', A. N. Shelest, V. F. Yegorchenko, V. B. Medel', P. V. Yakobson, L. S. Lebedyanskiy, A. A. Poydo, A. A. Chirkov, I. V. Pirin, P. K. Konakov, L. M. Mayzel, B. D. Podshivalov, A. M. Babichkov, A. M. Slomyanskiy, P. A. Gurskiy -- these are only a few of those whom I directly recall. All of them, each in their own field, together with, and on a parity with, the other Soviet traction specialists I have not named, have placed, and still continue to place, their creative powers and abilities at the service of the progress of our transport technology in the train-traction field, and of the cause of improving the existing locomotives and creating new and more perfected ones.

Disposing as we do of such forces, and of so intensively ramified a system of research institutes and enterprises both in the transport system and that of the transport industry, we possess all the prerequisites for creating, during the next few years, even more efficient and perfected locomotives both of standard models and of radically new types and designs.

But as we solve this problem, we would be guilty of the grossest error if we were to neglect and leave without proper appreciation the creative energies of the collective, many thousands strong, of our engineering and technical workers, inventors and practical traction specialists who are scattered over all the huge railway~~s~~ system of the USSR. Armed with knowledge and rich in productive experience, they as well can and do make their own essential contribution to this cause. It is only necessary to assure conditions under which this collective shall at all times be abreast of the accomplishments of their own national transport technology in the field of experimental locomotive construction, and of the accomplishments of foreign technology in that respect as well. This goal can be attained by the regular exposition of technical information addressed to a wide circle of readers, and consequently in popular form, in the shape of appropriate magazine articles, pamphlets and books.

When such information does appear in the USSR, however, it is as a general rule in unsystematized form, scattered among various journals, often either over the heads of this circle of readers or, on the contrary, unduly oversimplified, and thus in either case useless. In consequence this collective of engineering and technical workers, which numbers no few talented inventors, is deprived of the possibility of keeping track of the rapid development of technology in this field, and as a reult its members remain passive, possess all the prerequisites for creating, during the next few years, even more efficient and perfected locomotives both of standard models and of radically new types and designs.

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In writing this book the author aimed to fill in, to some slight extent, this gap in our technical railway literature.

In conclusion it still remains for me to say a few words on the substance of this book and the form in which it is set forth.

To mirror all the achievements of modern transport technology (at home and abroad) in the construction of experimental locomotives would mean describing scores if not hundreds of modernized, improved-design and radically new types and designs of locomotives, both those actually built and those still on the drawing-boards.

Such an objective involved peculiar difficulties. It became necessary to choose: either to increase the volume of the book many times over, or to confine oneself for each separate object to only short data of handbook character, shorn of the necessary detail and elucidation. The first alternative would hardly have been expedient, given the original specialized purpose of the book. And to adopt the second alternative would turn the book into a peculiar, dry-as-dust, official reference book and would not at all have made it a repository of the effective technical information of which we were speaking.

I was therefore left no choice but to reject both alternatives and choose instead the middle road of illustrating these accomplishments only by single examples of greatest demonstrative force.

This book has therefore included only experimental locomotives of more or less original or radically novel types. As for those locomotives which have merely been modernized, or improved in design (in greater or lesser degree), only a few USSR examples have been described by way of exceptions.

In spite of this enforced restriction in scope, the reader will nevertheless be enabled to become acquainted with all the new ideas and current tendencies in experimental locomotive construction, and consequently it seems to me that this book has fulfilled its specific purpose.

Finally one more remark should be made.

It has not proved possible in this book to elucidate a good number of major projects carried out in the USSR on the design and experimental study of equipment for the new, high-efficiency locomotives of original design.

F. Ya. Slavgorodskiy

INTRODUCTION

The extraordinary multiplicity in the types and designs of the experimental locomotives actually constructed or merely designed during the past one and a half or two decades in many countries of the world, including our own USSR, is by no means the result of chance, nor does it by any means depend on the personal "tendencies" of one designer or the next. It is based on motives of profoundly practical and utilitarian character. Any one of these locomotives is one of the variants of the solution of the problem of completely or partially eliminating certain of the shortcomings in design and operating characteristics of the existing locomotive types.

It is the steam locomotive that has the most substantial of these shortcomings. Much is often spoken of these shortcomings; much is often written about them in books and journals. And the question very naturally arises: is their complete elimination possible in the process of further improvement of this type of locomotive if the basic principle of its design is still to be followed?

It goes without saying, of course, that a completely definite positive or negative answer can hardly be given to this question. The only statement that does seem indisputable is that during the entire course of the very protracted period that has gone before -- and this is particularly true of the last three or four decades, which have been most fruitful of all in improvements of design -- it has not been possible to succeed in doing this. Plainly this accounts too for the current tendencies in the construction of experimental locomotives to abandon the orthodox Stephenson pattern and seek out radically new forms of design for the steam locomotive. To a certain extent as well, analogous tendencies are observed in experimental construction of internal combustion and electric locomotives.

Current experimental-locomotive construction is proceeding mainly along the following paths:

Improvement of the tractive and thermal performance of the steam locomotive by increasing the temperature of the superheated steam, by maximum utilization of the heat of the exhaust steam and gases for preheating the feedwater and the air drawn into the firebox, by various improvements in the exhaust nozzle or its replacement by the more efficient exhaust fan, by various modifications in the design of the locomotive engine itself, and of the boiler, and by a good number of other improvements, without encroaching on the principle of locomotive design as a whole, as represented by the standard locomotive that exists at the present day.

Attainment of better tractive thermal properties and operating characteristics of locomotives by the use of new types of boilers and engines and also by introducing variations in the design of their individual components.

Production of high-pressure steam locomotives and use of high superheat temperatures.

Employment of the steam turbine or a combination of steam turbine and steam engine for tractive purposes, for steam at low or high pressure, with or without condensation, and using electric or hydraulic transmission.

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Adaptation of existing locomotives to operate on gaseous fuel, or the design and construction of new gas-generator or gas-holder locomotives.

Simplification of internal combustion locomotive design by eliminating intermediate links in the power transmission system, and also by reducing their weight, first cost and operating cost.

Employment of the gas turbine as the tractive engine, using electric or hydraulic drive.

Design and construction of electric locomotives with transformers to take current at industrial frequency (50 cycles) to simplify the stationary installations and reduce their cost.

All of the material descriptive of the individual locomotives or plans for them that have appeared during the past two decades, have been arranged by us into Parts in roughly the above sequence.

So as to make it easier for the reader to evaluate critically the accomplishments in design and operating characteristics of any one of the experimental locomotives described, each Part begins with a short introduction under the heading "General information", explaining the motivations for, and the practical meaning of, deviation from the old standards and norms in locomotive construction and of the transition to the new.

PART ONE

MODERNIZED STEAM LOCOMOTIVES

GENERAL INFORMATION

The modern technology of locomotive construction disposes of a wide range of methods and means for improving, to varying extents, the tractive-thermal chatacteristics of the existing standard types of steam locomotives. The most efficient of these are:

Increasing the superheat temperature;
Preheating the feedwater;
Preheating the air delivered to the firebox;
Introduction of pulverized-coal burning;
Replacing the exhaust nozzle by exhaust fans.

The improvement or modernization of a locomotive by any of these methods is customarily termed thermal modernization, and may yield very considerable concrete results. Thus, for instance, with respect to fuel economy, increasing the superheat may under certain conditions reduce fuel consumption as much as 15 percent, feedwater preheating by as much as 8-10 percent, air preheating by up to 8 percent, pulverized-coal firing by up to 20 percent, an exhaust fan by up to 5 percent, and even more than that.

It is entirely obvious that the application of all these methods of modernization as a unit, or as it is called, multiple modernization of a locomotive, is in a position to yield even more noticeable results. This statement has already been confirmed by practical experience. A locomotive of the E series that had undergone multiple modernization showed an average fuel saving in 1942 test operation, in the USSR, amounting to 20 percent. On the basis of this experience it was calculated that the capital expense of modernizing our entire locomotive stock in this way would be repaid by the fuel savings in about half a year.

The question very naturally arises: why are so effective methods of modernizing locomotives not used on a large scale?

There are various reasons, both technical and economic, for this.

In the first place, the modernization of the entire locomotive stock would require the expenditure of large sums and the consumption of much metal, labor power, etc.

In the second place, any form of such modernization would involve complication (often a very serious one) in the design of the locomotive as a whole, which would be a very serious drawback under the specific conditions of railway service; and under certain conditions this disadvantage might wipe out all of the gains from the use of the modernization in question.

Finally the faults of design and the imperfections of components of the equipment is a substantial factor that operates to retard such modernization -- whether such faults and imperfections concern the feedwater heaters, air preheaters, steam superheaters or smoke-suction installation connected with such modernization. Such faults will be discussed in their proper place, but at this time we may merely point out that the creative thought of the engineer, designer and inventor must search for, and will undoubtedly find, methods of overcoming and eliminating them. When they do, the problem of producing a high-efficiency locomotive with respect to tractive effort per unit of fuel consumed will thereby be completely solved.

Before we proceed to the description of the various modernized locomotives, let us consider very briefly the essential nature and the practical meaning of the performance, on a locomotive, of each of the above enumerated methods of modernization.

The raising of the superheat temperature by the installation of a fire-tube superheater was the first practised towards the end of the last century. Next to the application of the compound principle, it was the most effective method of improving the thermal efficiency. The consumption of fuel in modern locomotives with superheated steam is about 70 percent that of locomotives running on saturated steam.

So significant an economy is explained first by the fact that each unit of steam by weight (let us say a kilogram), contains a larger amount of heat (in calories) in the superheated state than the same unit of saturated steam, and, secondly, the thermal process itself (the work done by steam) in the engine cylinders is accomplished more economically. Let us explain briefly what is meant.

According to the first law of thermodynamics there is a very definite relation, or what is termed an equivalent, between heat and mechanical work: 1 kcal. = 427 kg. The more the heat, the more, in consequence, will be the mechanical work. This means that a unit by weight of superheated steam (a kilogram) is able to perform more work than a kilogram of saturated steam.

In addition to this, steam also acquires other valuable properties in the process of being superheated, namely, as its temperature rises its specific volume continually increases, while its thermal conductivity falls. In practice this means first that each stroke of the piston uses up less steam by weight, and secondly that the losses by heat-exchange between the steam and the cylinder walls are reduced to a minimum, while when saturated or only slightly superheated steam is used these losses amount to 20 percent or 30 percent of total engine heat output.

It is true that some additional fuel must be used to increase superheat temperature, but this expenditure is more than made up by the advantage gained through the more economical march of the thermal process in the engine cylinders under these conditions.

For this reason it is obvious that increase in the superheat temperature is a substantial condition for the further improvement in the thermal efficiency of a locomotive. It must be kept in mind in this connection, that the utilization of high-superheat steam (over 400 degrees) involves serious difficulties, mainly because of the injurious action of high temperatures on metals and lubricants. These difficultires are gradually being overcome, and the temperature limits for the possible employment of superheated steam will, it must be assumed, considerably widen.

Our Soviet locomotive construction industry has already registered notable achievements in the field of high-temperature superheated steam. Thus we have the FD and 2-3-2 locomotives with the L-40 superheater, which assures for instance a superheat of 430 - 450 degrees. The problem of highly superheated steam cannot, however, be considered completely solved. The point is that the superheat temperature in fire-tube superheaters varies with the degree of forcing, increasing at high forcing and falling at low forcing.

One of the variant solutions to the problem of obtaining high and yet stable superheat is the use of the so-called chamber superheater. This idea was born in our country. As early as 1916 attempts were made (at the suggestion of Pokrzhevnitskiy) to design such a superheater and put it into practical operation. Fifteen years afterwards (in 1931), the problem again occupied the attention of our Soviet engineer I. V. Pirin, who proposed his own design of a chamber superheater.

The fundamental and valuable idea about this superheater is that it assures high superheat of the steam independently of the degree of forcing of the boiler.

In 1935 one of the series E^f locomotives (described in this Part) was equipped with this superheater. Tests of the locomotive showed that the fuel economy attributable to the high superheat amounted to 15-17 degrees.

Feedwater heating on the locomotive. The idea of using the heat of the exhaust steam to preheat feed water on the locomotive is almost a hundred years old. But only during the last two decades has it been successfully put into practice. The practical meaning of feedwater heating on the locomotive is as follows.

The feedwater usually has a temperature of 10-15 degrees (on the average) as it enters the boiler. Before it begins to turn into steam, a certain amount of heat (fuel) must be consumed to bring it up to the temperature at which steam is generated at the given pressure in the boiler. It is not hard to understand that if this water is preheated by using, let us say, the heat of the exhaust steam from the cylinders (which usually enters the smokestack at a temperature of 105-150 degrees) to the temperature of around 95 degrees (it is explained on page 25 why preheating beyond this temperature is practically inexpedient), 80-85 kcal of heat per kilogram of its weight can be saved.

The economy of fuel (in percent) through the use of feedwater heating on a locomotive may be easily calculated, by the approximate formula:

$$\text{Э}_m = \frac{t_K - t_m - b_n\,(i_n - t_K - t_m)}{i_n - t_m} \times 100$$

Here t_k is the temperature of the heated water as it enters the boiler; its heat content in calories is taken for simplicity as equal to its temperature in degrees;

t_m is the temperature of the water in the tender, which may be taken as equal to 10 degrees, and its heat content to 10 kcal per kilogram;

i_n is the heat content of the saturated steam in the boiler, which may on the average be taken as 655 kcal/kg;

i_n is the heat content of superheated steam, which may be taken on the average to equal 745 kcal/kg;

b_n is the consumption of steam by the admission stroke of the piston, which according to the data of operating practice (on SO^k locomotives) amounts to 0.02 kg per kg of feedwater delivered.

On substituting the above values in the formula, we obtain, for the amount of fuel saving:

$$\frac{95 - 10 - 0.02\,(655 - 95 - 10)}{745 - 10} \times 100 \cong 10\%$$

In addition to this, the heating of water on the locomotive by the so-called method of mixture with the waste steam also assures a certain economy of water by the condensation of this steam into water.

Feedwater heating on the locomotive likewise helps to lengthen the useful life of the boiler, mainly because:

It eliminates the sharp temperature fluctuations which are unavoidable when cold water is fed into a boiler and thus eliminates the attendant extraordinary stresses set up in the metal;

It reduces the rusting of the boiler plate, because air is eliminated from the water along with the carbon dioxide (in a feedwater heater that uses open-type mixing).

The cost of boiler maintenance and repair is also considerably reduced by feedwater heating, since the formation of scale in the boiler is reduced (the temporary hardness-forming salts being precipitated out to a considerable extent in the feedwater heater itself), which in turn makes it possible to increase the length of the runs between boiler washings.

The exhaust-steam injector is still the most prevalent method of feedwater heating. It is fairly simple in design and is fairly compact, and the economic effect of its use is also relatively slight -- 3 - 3.5 percent fuel economy.

In operating practice throughout the world today there are very many different systems used to heat the feedwater on locomotives. They may be divided into three main groups:

(1) steam feedwater heaters that use the heat of the exhaust steam;

(2) gas feedwater heaters, that use the heat of the combustion gases;

(3) combination feedwater heaters that simultaneously use the heat from both gases and exhaust steam.

Systems of the second and third groups are nowhere in use today, on account of their complicated design and bulkiness.

Systems of the first group are widely employed. They may be subdivided, according to the type of heat-exchanger used, into the following two groups:

(1) surface or contact water-heaters;

(2) mixing water-heaters.

In surface water-heaters, the heat is transmitted from steam to water through the walls of the pipe, while in mixing water-heaters the feedwater is heated by having exhaust steam mixed with it.

The following are surface heaters:

The S~~i~~oviet "Borets" feedwater heater

The French low-pressure Kayl'-Ponon'e [Quaille-Ponongo] open-type feedwater heater (the exhaust steam from the heat-exchanger being discharged directly into the atmosphere)

The German high-pressure Knopp feedwater heater (the water in the heat-exchanger being maintained at boiler pressure);

The American closed-type Elesco-Coffin feedwater heater, (with the condensate from the heat exchanger being returned to the boiler).

The mixing water-heaters include:

The Soviet "Krasniy Putilovets" feedwater heaters and TsT NKPS of the Koloma plant;

The American Worthington and Wilson feedwater heaters, the British ACFI feedwater heater, and the Czechoslovak "Dabeg".

In this part, three systems of feedwater heating are described: the open-type mixing heater (the TsT system of the NKPS), the Worthington closed-type heater (since this system is incorporated in a few series E^m locomotives coming on our lines), and the Italian Franco locomotive, as an original type of locomotive with a combination feedwater heater.

The preheating of air on the locomotive. The combustion in the firebox is essentially a chemical reaction between the burning components of the fuel and the oxygen of the air. If combustion is to proceed with maximum intensity, a certain amount of air must be introduced into the firebox. If this air, however, is cold, it takes up a certain amount of heat (obtained as a result of the combustion) in order to heat it (the air) up to the combustion temperature, which of course increases total fuel consumption and thus reduces boiler efficiency.

This was the origin of the idea of preheating the air by using the heat of the exhaust steam or that of the combustion gases. In the former case the object is achieved by the installation of sectional radiators [rib-type] (resembling the cooling condenser t tubes on locomotives with steam condensation) by means of which the air can be preheated to 60 - 80 degrees Centigrade and 4 - 5 percent of fuel saved as a result. In the latter case, the air is preheated, as shown by experiments, to 110 - 130 degrees Centigrade and fuel consumption consequently reduced by 8 - 10 percent.

In the USSR for test purposes, a certain number of locomotives (series S^{um}) have been equipped with air-preheating installations using steam, and a certain number (series E and S^{u}(with heaters using combustion gases.

Pulverized-coal firing. Pulverized-coal firing of locomotives is an extremely effective measure both from the technical and national economic points of view.

The technical and economic advantages of pulverized-coal firing have been sufficiently confirmed by the experience in stationary thermal electric power stations. At the present time the design of powerful stationary installations is mostly based on the firing of pulverized coal.

Pulverized-coal firing consists essentially in blowing coal, reduced to the finest powder, through special devices (forced-draft fans) into the firebox, where it arrives in a state of suspension, is mixed with air and is completely consumed. As a result the losses from incomplete combustion, unburned fuel, etc, inevitably associated with the firing of lump coal, are completely absent. Thus locomotive boiler efficiency for coal firing reaches 75 - 80 percent (i.e. the same levels as that for oil-firing boilers) as against the usual 60 - 65 percent when firing lump coal. Besides this, firing a locomotive boiler with pulverized coal also assures a series of other very substantial advantages:

it simplifies to a minimum the regulation of the processes in the firebox;

it eliminates sparks from the smokestack;

it reduces the time for getting up steam to a minimum (about an hour as compared to 2.5 to 3.5 hours for ordinary coal firing) and this operation requires no firewood;

it makes it possible to burn low-grade fuels (brown coals, shales, etc) and culm at high efficiency.

The saving of fuel from pulverized-coal firing may reach 15 - 20 percent.

Attempts to fire locomotives with pulverized coal date back for half a century. In a number of countries (Sweden, Great Britain, United States, Germany, Italy, Holland, etc) individual locomotives were experimentally remodeled, but the results of their trial operation proved unsatisfactory, mainly on account of the imperfections in the design of the pulverized-coal firing systems as a whole.

In the USSR the pulverized-coal firing of locomotives started to occupy those concerned literally during the first months of Soviet power. Tests of the first coal-fired locomotive were made during the period 1920-1925, but it proved unsuccessful. The main trouble in the operation of the installation on this locomotive was the clogging of the tubes by cinders, involving interruption of combustion.

In 1930 the experiments on firing locomotives with pulverized coal were resumed, at first under laboratory conditions, and then, from 1934 on, in locomotives of series E^u 701-80 and FD 20-400, in actual service. The designing of individual coal-pulverizing installations on the E^m and FD series of locomotives was based on the results of these experiments. The first experimental locomotive of the E^u series was equipped for this purpose in 1938. The Voronezh plant was subsequently equipped according to the plans for the NIIZhT locomotive of series FD for pulverized-coal firing (which is described in this Part), while in 1940 the first pulverized-coal fired FD locomotive of this system was turned out by the Voroshilovgrad plant. Four other FD locomotives and 24 E^m locomotives were also equipped to fire pul~~p~~verized coal. It is evident from a simple enumeration of the objects of research that work on pulverized-coal firing for locomotives was carried out in the USSR on an especially large scale, and that in this respect we left the other countries far behind us. The war interrupted all the work in this field, but it is now being resumed with renewed vigor.

Forced fan-draft. The nozzle draft now used in world operating practice originated during the first years of the railroads' existence. Its principal accomplishment is the automatic regulation of the draft: as forcing increases the draft also increases, and conversely, thereby assuring the proper combustion regime.

The principle of the nozzle exhaust system is that the exhaust steam from the engine cylinders passes through the nozzle into the smokestack and in this way creates a certain amount of vacuum (rarefaction) in the smokebox, which helps to develop a draft through the boiler.

The exhaust nozzle, however, also possesses a number of substantial faults.

It builds up a certain amount of back pressure in the engine cylinders, thereby reducing the power developed by the engine and consequently also reducing the economy of locomotive operation.

It is responsible for a non-uniform (pulsating) draft through the boiler, with the frequency of the pulsation depending on clyinder exhaust-frequency, or in other words on locomotive speed; as a result the suction of air into the firebox is interrupted during the interval between two exhaust strokes, and it is as though the process of combustion itself were suspended. This has an unfavorable effect on the intensity of combustion and consequently on the generation of steam in the boiler as well.

As the vacuum in the smokebox is increased, it draws out an increasing amount of unburned fuel, thereby still more reducing the economy of boiler operation (boiler efficiency).

The fan exhaust is free of these faults. Moreover, since it is more powerful and more uniform, it assures more complete combustion even of low-grade coal, and allows getting up boiler pressure far more rapidly, making longer runs between firebox cleanings possible. Experiments with the Su locomotives, equipped with exhaust fans, have shown that when boiler pressure accidentally falls, it can be brought back to the norm much more quickly than when using the exhaust nozzle.

It must, however, be pointed out that the exhaust fan installation, with which some S^u and SO non-condensing locomotives are equipped, suffers from a number of substantial defects as well. The principal one of these is the rapid and uneven wear on the vanes of the smoke-exhaust fan caused by the impact of solid particles of unburned fuel carried along with the draft. Depending on the quality of the material from which the vanes are made, their configuration, the kind of fuel used, etc, the useful life of the vanes are limited to 40,000-45,000 kilometers of running, and this is reduced to 12,000-15,000 kilometers by the use of coal with admixture of fine anthracites. Cementation and weld-seaming build-up of the vanes did not lengthen their useful life.

The smoke-exhaust wheels designed by Comrade Krasil'nikov (of the Omsk locomotive depot(without side discs, proved more durable. Their useful life on the SO steam condensation locomotives was almost double. However, since they were of high power, they created a vacuum in the smokebox 10 - 12 percent higher than the ordinary wheels, resulting in higher fuel consumption.

The smoke-exhaust wheel of lighter design proposed by Comrade Savinov (of the depot of the Omsk-Petropavlovsk railroad) likewise assured long service of the vanes, but in contrast to Comrade Krasil'nikov's wheel it did not produce a proper vacuum in the smokebox and therefore could not assure the necessary volume of draft air. Consequently boiler power was impaired, and the design had to be given up.

It must be noted that the use of smoke-exhaust wheels of lighter construction gave excellent results on non-condensing locomotives both in length of service and fuel economy.

Besides these faults, a smoke-exhaust fan making 4,000 revolutions per minute causes a considerable increase in the temperature of the oil in the bearings. As a result the oil, which is sometimes brought up to the boiling point, loses its lubricant properties, in turn contributing to wear on the bearings. There have been cases in which such wear of the smoke exhaust fan has been accompanied by serious accidents.

THE E^p_f LOCOMOTIVE WITH CHAMBER SUPERHEATER (USSR)

(The rebuilding of the series E^p_f locomotives and installation of the chamber superheater system of I. V. Pirin was carried out at the Dnepropetrovsk Locomotive Repair Plant in 1935)

The basic and essential distinction between this locomotive and ordinary locomotives is its superheating system. Steam is usually superheated in locomotive boilers by means of superheaters located inside the flues. It is far from being an easy task to reach higher superheat temperatures in such superheaters. Usually boiler diameter must be increased (while increasing superheater surface), and this in turn results in ~~complicating the~~ design of the boiler, increasing its weight, etc.

Moreover, there are certain conditions under which high grade superheats in fire-tube superheaters fail to give the thermal efficiency counted on from the increase in superheat. This is because a flue superheater, being located in a stream moving parallel to both evaporative and superheat surfaces requires higher temperatures of the gases inside the tube if high superheat temperatures are to be obtained. However, under these conditions, the exhaust gases are discharged into the atmosphere at high temperatures, thus reducing boiler efficiency. The essential fault of the flue superheater is likewise the dependence of the superheat temperature on boiler forcing; at high forcing it is increased, and conversely.

The chamber superheater of I. V. Pirin assures, as we shall see presently, a more rational solution from the technical and economic point of view, of the problem of increasing the superheat temperature.

Its fundamental distinction from the widely employed flue superheaters is in that it is located apart from the boiler, namely beneath the boiler barrel, and symmetrically with respect to the longitudinal axis of the locomotive, as shown by Figures 1 and 2.

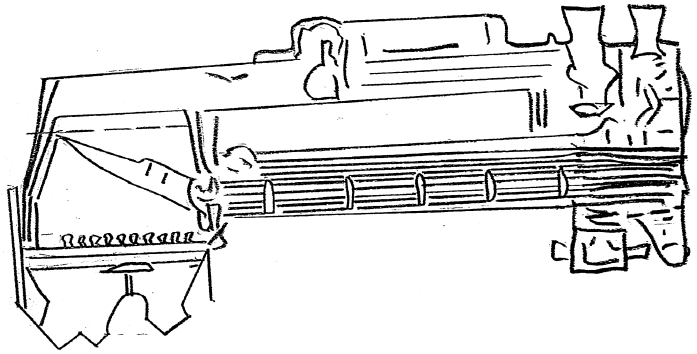

Figure 1. Longitudinal section of boiler of Locomotive E_f^p.

The chambers consist of two tubes of peculiar form and cross-section, consisting of a rigid frame work covered by sheet-iron panels 5 millimeters thick and suspended by their ends under the boiler. In the chambers elements (tubes) of two kinds are arranged in a definite order (Figure 2): peripheral tubes along the inner walls of the chamber and central or internal tubes.

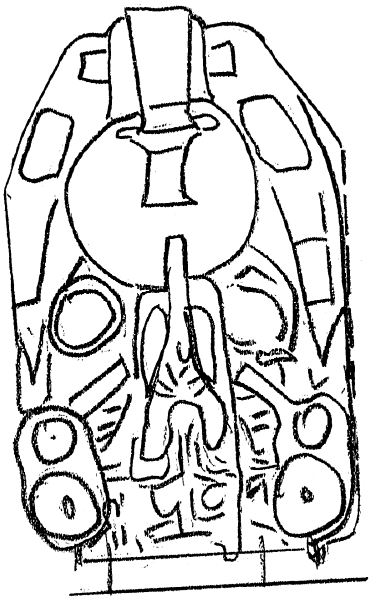

Figure 2. Transverse section of Locomotive E^{p}_{f}.

The elements are connected between themselves through their respective collectors: internal and external. The latter in turn are connected between themselves by steam ducts.

Steam is superheated in the chamber superheater by means of the hot firebox gases, which are divided into two streams, one of which is directed into the flues and the other into the superheater chambers. Both gas streams are discharged into the atmosphere after giving up their heat, the former through the rear smokebox and its (rear) smokestack, and the latter through its own (front) stack.

The working cycle occurs in the following manner: the steam from the boiler passes through the inside valve of the peripheral collector, makes its first round of the peripheral elements and is returned with a slight degree of superheat to the peripheral collector. It then passes through the internal collector, makes its second round of the inside elements and is delivered to the cylinders through the superheated steam valve. After it has done its work in the cylinders, the steam is divided into two streams, one of which is directed into the rear exhaust nozzle and the other into the front one, producing the appropriate vacuum, i.e. boiler draft, in each of the smokeboxes. There is a damper between the front and rear exhaust nozzles by which the distribution of steam between the two nozzles can be regulated from the cab. This or that position of the damper determines the degree of vacuum in the smokebox of the superheater and consequently also the coefficient of distribution of the gas stream and the degree of superheat.

A very major remodeling of the series E^f and E^p_f locomotives was required in connection with the installation of the chamber superheaters and the resultant very substantial changes in the thermal-efficiency and weight parameters of the locomotives. The boilers had to be raised almost 700 millimeters to install the superheater tubes, and in consequence the longitudinal axis of the boiler was now located at a height of 3600 millimeters above the railhead level. The firebox was lowered by 550 millimeters and the number of fire-tubes increased to 322 from 195 before the remodeling. An additional smokebox was installed to serve the superheater. To secure maximum utilization of the heat transfer the cylinder diameter was increased from 635 millimeters to 710 millimeters while keeping the original piston stroke of 711.6 millimeters, and the diameter of the common valve was increased from 305 to 375 millimeters.

The installation of the chamber superheater increased the total weight of the locomotive from 88 to 103.8 tons, and the adhesive weight from 77 to 91.8 tons; accordingly the modulus of tractive force was increased from 26,770 to 31,000 kilograms; and the total calculated weight of the locomotive with tender, together with water and coal supplies was increased from 135 to 160 tons.

An outside view of the locomotive E^p_f is shown by Figure 3.

The locomotive with chamber superheater was given a thermal efficiency test on the test track of the Railway Transportation Research Institute. The tests comprised two stages: (1) study of locomotive performance at three different positions of the regulator damper so that the degree of superheat could be established at various distributions of the gas stream, as well as the influence of the degree of superheat on heat consumed per unit of power; (2) study of the boiler and superheater so as to determine the efficiency of the former and the thermal properties of the latter.

The detailed material (both figures and graphic) obtained from these tests was published at the time and the interested reader may refer to it for all details. (Cf. N. S. Sedov and A. S. Burov, Rezul'taty ispytaniy parovoza s kamernym peregrevatelem I. V. Pirin [Results of the tests on a locomotive with the superheater of I. V. Pirin], TRANSZhELDORIZDAT, 1939.)

Figure 3. Outside view of Locomotive E^{p}_{f}. [PHOTO]

The conclusions based on the analysis of this material reduce in general to the following: 450 degrees to 500 degrees of superheat is entirely attainable in the chamber superheater, regardless of the degree of forcing; such temperatures are more advantageous than the 360 degrees 380 degrees ordinarily employed; and the fuel saving to be expected from the use of the chamber superheater amounts roughly to 15 percent-17 percent as compared to fuel consumption on E^{f} and E^{r} locomotives.

Together with this, however, the Pirin chamber superheater showed also revealed a number of substantial defects in design, and as a result the locomotive E^{p}_{f} 127 was completely unable to operate under normal operating conditions after the tests. Thus, for instance, the steam collectors burst at the places where they had been welded to the interior elements of the superheater, the conic plugs became "burned" and lost steam from their threads, suction from the outer air was observed in the superheater chamber at the points of union between the split details of the casing, and there was a systematic weakening of the attachment of the cylinders to the frame, as a result of which the cylinder bolts were snapped off, with subsequent cracking of the engine block, etc. (This defect, however, had nothing to do with the installation of the Pirin superheater but was caused by weakness in the construction of the underframe of the EF locomotive. The strength of the latter proved all the more inadequate after installation of the Pirin superheater, since the thickness of the locomotive was considerably increased in connection therewith.)

In 1946 I. V. Pirin worked out an improved variant in the design of the chamber superheater for the series L locomotive. In the near future a number of such experimental locomotives will be built and subjected to the appropriate tests.

Without going into any details whatever on the design of this variant of the chamber-superheater locomotive, we confine ourselves here to presenting a few data, published at the time in our literature, to give the reader some opportunity of getting an idea, though in the most general terms of this very interesting locomotive.

The skeleton diagram of the new chamber superheater follows that of the old one, but the changes in the design of its individual details, introduced to eliminate all the faults noted, are very considerable. The boiler was also modified in certain respects, as a result of which its weight and dimensions were considerably reduced, while its thermal characteristics were substantially improved.

The elements in the new steam superheater are arranged somewhat differently along the cross section than in the preceding design; and their number is also different. They have two turns, which assures greater flexibility and consequently avoids the possibility of the steam collectors snapping off.

The exhaust nozzle installation has also been modernized, and in its operation the maintenance of constant back pressure in the nozzle (at given cut-off and speed) is assured, regardless of the magnitude of the gas stream branching off to the chamber.

The plans and the calculations performed on them show that the series L locomotive of type 1-5-0, with the new Pirin superheater, has a higher thermal efficiency than the series locomotive with the ordinary fire-tube type of superheater. The saving of fuel, according to the power developed, ranges from 12 percent to 30 percent.

LOCOMOTIVES WITH TsT MPS SYSTEM MIXER FEEDWATER HEATER (USSR)

A skeleton diagram of the feed water heater on the TsT MPS system is shown in Figure 4, while Figure 5 shows the arrangement of all the equipment and mechanisms on the locomotive.

The basic equipment for the feed water heater system consists of a mixing chamber, ejector-heaters (jet heat-exchangers) ejector apparatus, and a turbine pump (a turbine operating on live steam, and a centrifugal water pump).

The tender is divided (diagram in Figure 4) by a deep partition into two parts or compartments, one a cold-water compartment OXB occupying 2/3 of the tender volume, and a hot-water compartment OGB occupying the remaining third; OGB in turn is subdivided by the partition 21 and the filter 22 into two chambers: a mixing chamber and a chamber for filtered hot water holding about 1 cubic meter.

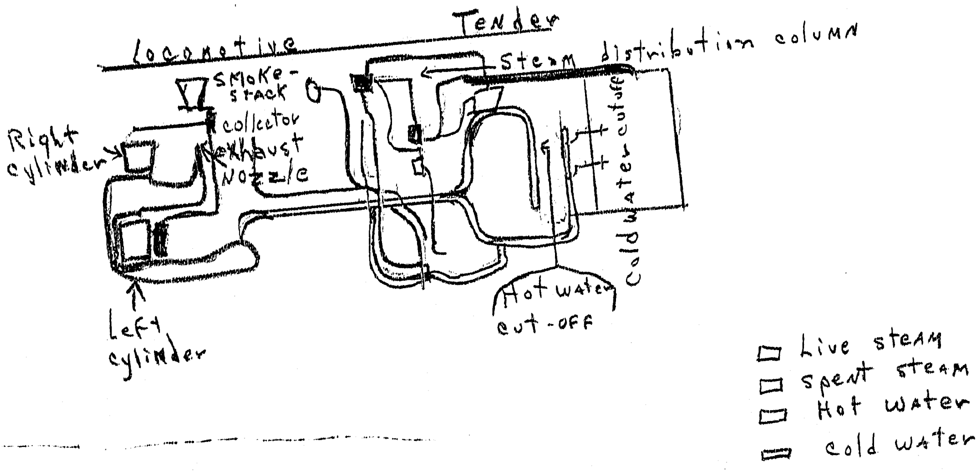

Figure 4. Diagram of TsT MPS feedwater-heating system on locomotive.

The mixing chamber is equipped with a float to indicate the water-level and an air thermometer placed in the tender cabin which enables the engineman to observe the temperature of the water in OGB.

When the locomotive is running with open throttle, the installation operates as follows.

The exhaust steam from the cylinders passes through the pipes 1, 2, 3 and the ball coupling 4. Part of it enters the ejector-heaters (steam-mixers) 7 through pipe 5 and part of it enters the forcing-ejectors 8 through pipe 7. The amount of steam to enter the steam-mixers and forcing ejectors, respectively, and consequently also the temperature and level of the water in OGB is regulated manually by the valve 15. When the water-level drops in OGB, for instance, the engineman sets the valve so that the steam entering the forcing ejectors is increased, thus increasing the pumping of water from OXB to OGB, and conversely, when the temperature of the water in OGB drops below normal, the valve is set so as to increase the flow of steam into the steam-mixers.

During the process of preheating, the feed water continually circulates through heater-ejectors, while the preheat of the water must not exceed 95 degrees for the reason that at a higher temperature than this the turbine pump stops working and the normal functioning of the system is thus disturbed. The purpose of the filter 22 is to free the water from the oil that gets into it in the tender.

The hot water from OGB flows by gravity through the water-cock 23, the pipe 24 and the rubber hose 25 to the pump 10. The pump then delivers it through the pipe 26 and the feedwater valve 27 to the boiler.

The steam exhausted in the turbine pump is conducted through pipe 11 into the exhaust-steam main. The exhaust steam from the turbogenerator 12 is conducted to the same main through pipe 13.

The bypass 9 is installed on pipe 3. It is controlled from the cab by the drive 39 and serves to open and close the exhaust bleeder from the engine cylinders. The valve 14 is installed on the exhaust pipe 13 and serves to shut off the turbine drive when the turbogenerator is not running.

The 3-inch bypass valve 36 is installed in the deep compartment 20, and is used to release water as it collects on the tender. The control rod for the valve is brought to the outside of the tender.

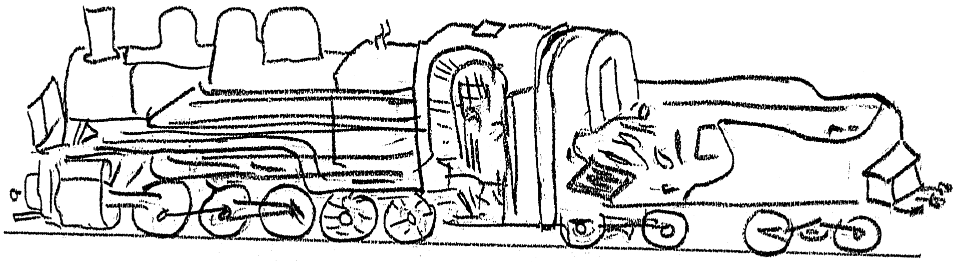

Figure 5. Arrangement of feedwater-heating equipment and mechanisms on Series E Locomotive

To prevent the freezing of the turbine pump and the pipes, the circulation pipe 32 is provided. It has the valve 33, controlled from the cab. When the pump stops delivering water, the engineman cuts in the circulation pipe by opening the valve, thus connecting it into the turbine duct system, and then starts the turbine pump, which starts to pump water through the closed system. The turbine pump is started by the drive 41.

Besides the turbine pump there are also two Friedman RS-11 injectors. The right injector 28 is always turned on and aspirates water from OXB, while the left injector 31 remains as a reserve for use in the time when the water-heater installation is being gotten under control. In case of need (for instance if the turbine pump should go out of action) it is then connected up by the flexible hose 25 and the turbine duct 24.

To prevent suction of the water from the tender into the engine cylinders (which may happen while running with closed throttle when a vacuum is built up in the exhaust steam pipe), a safety air-valve is installed near the bypass. If the pressure in the turbine duct for exhaust steam should drop, the safety valve will open and admit the outside air.

The ball coupling 4, which consists of three joints, assures the free displacement of the pipes, and consequently their safety, in the event of a mutual displacement of locomotive and tender during travel.

The live-steam mixer 19 is provided for heating the feed water while the locomotive is standing (and there is thus no exhaust steam). This mixer is fed from the bleeder line through the turbine duct 16, the ball coupling 17 and the turbine duct 18.

The type 1-TH turbine pump consists of three principal parts: the stator or nozzle, the rotor and the regulator. The latter stops the turbine automatically if the prescribed number of revolutions (6300-6500 rpm) is exceeded. At 6000 rpm the turbine develops 55 HP, can pump 34.6 tons of feed water per hour at 95 degrees water temperature and develops a pressure head of 19.1 atmospheres.

The feed water heater likewise assures thermal treatment of the water in OGB, which constitutes its advantage. Together with this, however, the system also has its faults. Here are the most substantial of them:

While the steam engine is running at low cut-offs, the exhaust steam is unable to overcome the hydraulic resistance of the turbine duct for exhaust steam or the hydrostatic pressure in the pipe that conducts the steam to the forcing ejector. In consequence the water is not heated and the boiler is not supplied with the necessary amount of preheated feed water.

If the normal temperature in OGB (93 degrees-95 degrees) is exceeded (which is far from being out of the question when manual regulation is used, especially at high forced draft) it involves doing without the operation of the turbine pump, which means disturbing the normal functioning of the system.

The feed water in OGB must first be preheated to a certain temperature by live steam before the system starts to operate, which considerably lowers the operating economy of the system.

The design is complicated and the installation as a whole bulky and very heavy.

When the locomotive is being prepared for a run, and also under way, the installation requires attentive and qualified treatment and service, and unless it gets it, disturbance of its normal operation is inevitable.

The 1-TN turbine pump is unreliable and uneconomical in operation, and is frequently out of commission.

For all these reasons the preheating of feedwater by open-type mixing in the tender, by the TsT system, did not receive widespread acceptance. At the present time other systems of feedwater mixing-preheating are being considered and tried out.

LOCOMOTIVES WITH THE NIIZhT AIR-PREHEATING SYSTEM (USSR)

The air preheater (air economizer) consists of a welded shell of the same diameter as the smoke box. The shell has two gratings and is filled with lengths of fire-tubes.

The shell with its bank of tubes is fastened by bolts to a special flange on the front of the firebox, and constitutes the natural prolongation thereof. The arrangement of the air-preheater on a series S^u locomotive is shown in Figure 6.

The front of the economizer is closed by a normal front plate (with a small port). At the bottom of the drum, between the front tube plate the front plate, there is a special bunker for cinders, which is provided under the removable damper.

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To assure the possibility of repairing the fittings, and of replacing elements and tubes, the bank is also fastened to special loops that allow it to be opened in a manner similar to that in which the front plate is opened.

The shell has a slot on top to admit the outside air into the economizer. A second slot is provided on the bottom to connect the air duct with the hermetically closed ash-box.

The smokebox is divided into two parts, a lower and an upper, by a removable diaphragm. The forced-draft nozzle leads into the upper part of the smokebox. The diaphragm has a valve through which (if necessary) part of the gases may be diverted into the smokebox without passing through the air-preheater bank. The same valve permits inspection of the nozzle syphon and the steam exhaust pipes with closed air-preheater.

A manhole is provided for inspecting the smokebox with the air preheater bank closed, and also to afford entrance to the smokebox during washing-out.

The blow-offs of the air preheater bank and of the boiler barrel are performed by means of two steam soot-blowers located in the first chamber of the smokebox. They are placed symmetrically with respect to the two sides of the smokebox and are installed in such a way as to allow the nozzle to be turned through a full 360 degrees.

Besides the movable soot-blowers in the upper ejection chamber, there is also a fixed jet for blowing off the horizontal part of the diaphragm.

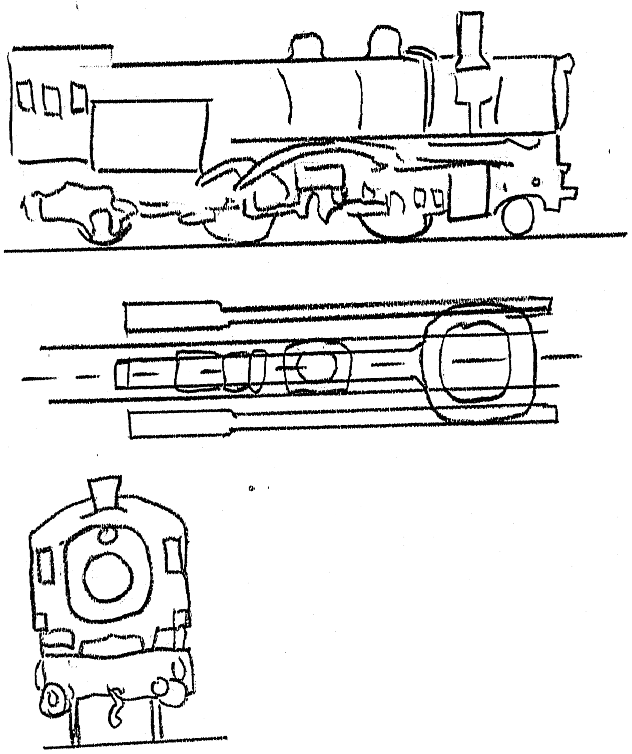


Figure 6. Scheme of NIIZhT air-preheating system on Series S Locomotive

The air-preheater operates as follows. The gases emerging from the boiler barrel are directed through the first (upper) chamber of the smokebox into the lower part of the bank of tubes, and after passage through the tubes turn into the forward chamber of the bank. They then pass through the tubes of the upper part of the bank and are discharged into the atmosphere through the ejection chamber.

The outside air is sucked (owing to the reduced pressure in the firebox, airducts and tube-banks) into the upper slit, bathes the external surfaces of the tubes, and passes through the lower slit into the air-duct and then into the ash pan.

Table 1 gives the design characteristics of the air-preheater for locomotives S^u and E^m.

TABLE 1

	Locomotive	
	S^u	E^m
Diameter of air-preheater bank in mm	1,736	1,810
Diameter of preheater tubes in mm	51/46	51/46
Number of preheater tubes	600	740
Distance between tube plates in mm	1,180	620
Heating surface (air) in sq. m	115.6	75.6
Cross-section of gas (tube) part in sq. m	0.498	0.615
Mean air cross-section in sq. m	0.398	0.179
Weight of bank in kg	3,392	2,316
Total weight of installation in kg	3,635	2,424

The installation of the air-preheater thus increases the total weight of the S^u locomotive by about 4 tons, and that of the E^m by about 3 tons.

During 1940, S^u and E^m locomotives equipped with this air-preheater were given thermal tests on a testing rack. The results of these tests were published at that time. (Cf. Parovoznoye i vagonnoye Khozyaistvo [The Locomotive and Car World], 1941, No 1, pp. 6-19. Therefore we shall limit ourselves here to giving a few figures that characterize the operation of the air-preheaters, and also give generalized conclusions.

The degree of preheat of the air in the economizer, which is an index of the completeness of utilization of the heat in the exhaust gases ranges from 100 degrees to 170 degrees for S^u locomotive, and from 116 degrees to 190 degrees Centigrade for the E^m. The corresponding reduction of the heat loss from the exhaust gases is 5-10 percent and 9-12 percent respectively.

The use of the air-preheater assures more efficient firebox combustion even with lower coefficients of excess air.

Heat losses in the refuse at heat output of the grate of the order of 2,500 kcal/sq.m per hour, for various mixtures, range from 3.41 percent to 8.76 percent as against 3.54 to 11.32 percent for locomotives without air preheating.

Thus air preheating improves the termal process in the firebox not only by recuperating the heat of the flue gases but also by modifying the firebox process itself.

Depending on the kind of coal mixture burned, the fuel saving at the forced combustion rate of 50 kg/sq.m per hour was 12 to 14 percent for the S^u locomotive, and 15 percent for the E^m.

The average fuel saving through heat recuperation and increased firebox efficiency amount to 11-12 percent when air preheated to 100-170 degrees was introduced into the firebox.

The real fuel saving resulting from air preheating is somewhat less, however. The reason for this is that the hydraulic resistance of the gas-air tract is increased by the introduction of the air heating equipment into the system. Depending on the degree of the boiler forcing, the value of the total resistance of the air preheater (gas and air combined) has been shown by experiment to range from 8 mm of water with $Z_k = 10$ kg/sq. m per hour to 100 mm of water with $Z_k \doteq 70 \text{kg/m}^2$ - hour.

The capacity of the exhaust nozzle must be increased to overcome these additional resistances. This increase may be achieved by reducing nozzle cross-section. But this produces increased back pressure in the cylinders, and this in turn reduces engine power. Air preheating also results in a certain reduction of superheat temperature, which also reduces the economy of engine operation.

In determining the required capacity of the exhaust nozzle however, the factors that facilitate nozzle operation when the firebox air is preheated are also taken into account. They are that the gases discharged into the economizer pass into the tube at a lower temperature than in locomotives without air preheating (roughly 165-200 degrees as against 350-380 degrees), and their specific volume is therefore lower (on account of their increased specific gravity), and consequently the necessary ejection capacity of the nozzle is also reduced. Besides this, the volume of gas to be ejected is likewise reduced on account of the increased boiler efficiency, than in locomotives without air-preheating since less fuel must be burned to generate the same amount of steam that passes, after doing its work, into the exhaust nozzle.

Thus the required nozzle capacity is determined in the last analysis by the relation between the value of the resistance of the gas-air tract, that of the increase in boiler efficiency, and that of the change in the specific volume of the gases resulting from the lowering of their temperature at the nozzle.

Special tests made on locomotive S^u 207-76 with various sizes of exhaust nozzles established that a reduction of 5.45 percent in nozzle cross-section area was required to increase nozzle capacity by 10 percent at forced draft fuel consumption of 50 kg/m^2-hour, which reduction resulted in 1.45 percent loss of locomotive power, while the increase in fuel consumption, at equal locomotive power, after allowing for boiler efficiency, did not exceed 2.1 percent.

Thus a fuel saving of about 9-10 percent is possible by using air-preheating. This system of air preheating, however, is also not free from defaults, of which the most substantial are as follows:

The horizontal position of the tubes of the bank, resultle~~ing~~ in easy deposition of cinders; and unless timely measures are taken the preheater clogs up rapidly; the prescribed devices for cleaning steam superiors [SUPER'YERY] for blowing off -- are not efficient enough to prevent clogging, since they function poorly and demand constant attention and handling from the locomotive crew, to the detriment of their primary duties; the direct result of clogging is to increase the hydraulic resistance of the gas-air tract, which at a certain level the discharge nozzle becomes unable to overcome, and the locomotive "runs out of steam"; besides this cinders are the primary reason for disturbance of the normal operation of an air preheater, and also of frequent damage to the installation; the massive bank of the air-preheater is suspended on the loops and front part of the smokebox and makes it very inconvenient to open or close the smokebox, this operation often requiring the use of a jack or even a hoisting crane; the main load of the air-preheater is placed on the front axle, which is already overloaded even without this extra weight, thus causing hot journals cracks in the springs, and uneven wear on the tires. For these reasons this draft-air preheater design has not gained wide acceptance.

THE PULVERIZED COAL-FIRED FD LOCOMOTIVE (USSR)

(Equipped by the Voronezh Locomotive Repair Plant according to NIIZyT plans.)

Before taking up the equipment and installations on this locomotive, the essential features of pulverized coal firing will be briefly explained, together with the practical meaning of its introduction on locomotives in general.

The process of combustion proceeds most intensively when a sufficient quantity of atmospheric oxygen is conducted to the surface of each particle of the burning material. When 1 kg of coal in lump form is burned, for example, the area of its surface coming in contact with the oxygen of the air is about 0.01 m^2. If the same lump, however, is converted into pulverized coal, then the total surface area of the separate particles amounts to about 500 m^2, i.e. 50,000 times as great as in the lump of coal. It is therefore easy to understand how much more favorable the conditions are for burning pulverized coal. Moreover, the pulverized coal is fed together with air which is carefully mixed with it. The ratio between the volume of each coal particle and its share of the air is about 1:1500, or in other words about 1500 cubic meters of air are delivered to the firebox, on the average, for every cubic meter of pulverized coal delivered to it. Thus what enters the firebox is really air saturated with pulverized coal.

The air entering the firebox under forced draft, together with the pulverized coal, is customarily known as primary air, while that entering by means of the exhaust-nozzle of exhaust-blower draft is called secondary air. Since pulverized coal burns in a state of suspension (in air), the locomotive boiler grate becomes superfluous, and the ashpit is used for additional firebox volume.

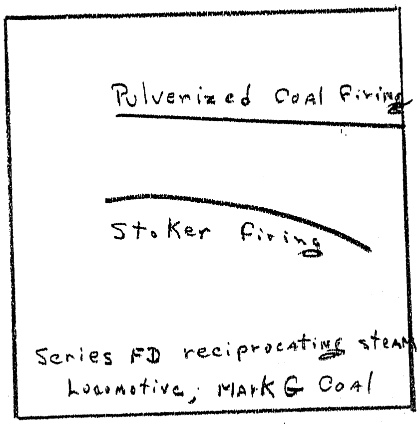


Figure 7. Relationship between boiler efficiency and boiler forcing, expressed in normal steam.

The experimental research into the pulverized-coal firing of locomotive boilers, conducted in the USSR and abroad, testifies to the great economy of the thermal process. When the boiler is handled properly its efficiency is equivalent to that of an oil-fired boiler, no matter what the quality of the coal from which the pulverized fuel has been prepared. This is very graphically illustrated by the diagram of Figure 7 which shows the relationship between boiler efficiency M_k and degree of forced draft, expressed in normal steam Z_{kn}, for series FD boilers respectively firing pulverized coal and stoker coal of the identical grade (mark G).

The flexibility and ease of control of the combustion in the firebox, according to the amount of steam required, is a characteristic and extremely valuable feature of pulverized-coal firing. After long standing with the fires out in the firebox, steam can be raised to normal pressure in the boiler inside of a few minutes. In case of need the combustion in the firebox can be stopped in a moment.

The principal equipment for preparing pulverized coal on the locomotive is located on the tender and consists of:

a coal pulverizing mill;

a coal conveyor with trough, crusher and reducer;

a stoker steam engine with a winch [sharnirniy val] for turning the conveyor;

a pulverized-coal bunker with two conveyers;

a stoker steam engine with drives for turning the pulverized-coal conveyors;

a turbine blower fan for feeding air to the entire system;

a gas-air duct with a carburetor head that connects the firebox installation with the suction-inlet connecting branch of the fan;

pulverized-coal ducts that connect the mill through the blast fans and the pulverized-coal mixing box or carburetor with the forced-draft inlets;

steam supply pipes for feeding the mill, turbine fan and donkey engine with steam.

The mill (Figure 8) consists of two parts, a lower part in which the coal is ground, and an upper part, where the ready pulverized coal is separated from the unground pieces of coal.

The mill acts as follows. The coal entering the lower part of the mill through the inlet connecting branch 4, falls on the steam jet 7, is taken up by a high-velocity jet of superheated steam and carried upwards to the steam diffuser 5.

In their movement through the diffuser the lumps of coal collide with each other and are broken up. On leaving the diffuser they move forward and encounter in their path the baffle plate 3, which they strike with great force and are converted partly to dust and partly to finely-divided coal.

After striking the plate the stream of coal fragments and steam makes a sharp 90 degree turn and then moves parallel to the baffle plate towards the walls of the mill housing. In the course of its motion the stream of coal and steam is traversed by the hot mixture of gas and air issuing from the gas-air line 9, which takes up the finished coal-dust and fine grains and carries them down with it, while the stream of coal and steam comes once more to the jet.

In its further journey upwards through the ducts of separator 1, the velocity of the stream continually falls on account of the increasing sectional area of the passage. As a result the larger particles of coal continue to settle and thus leave the stream.

On its arrival at the upper part of the separator, the stream is directed inside the separator funnel where it passes between the rotating vanes (by which the direction of the dust-air stream is changed) and the coal-dust outlet connecting-branch of the mill. During this course the velocity of the stream is sharply reduced on account of the larger area of the passage, while centrifugal forces are also generated by the stream being directed by the vanes along tangents to the circumference.

Thus the final separation of the finished coal-dust from the incompletely ground coal particles is effected; the finished coal-dust fuel is directed together with the gas-air stream into the bunker or firebox, while the incompletely ground particles settle out on the bottom of the separator funnel and enter the steam jet again. The fineness of grind is adjusted by changing the position of the vanes.

[See following page for Figure 8]

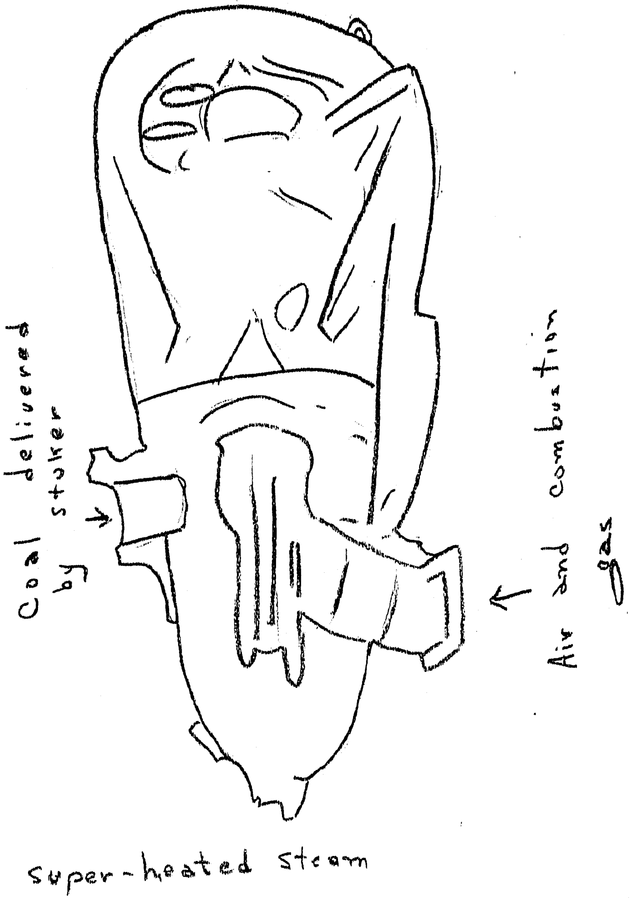


Figure 8. Coal-pulverizing mill for FD Locomotive.

1-Separator; 2-Body of mill; 3-baffle plate; 4-stoker inlet connecting branch; 5-steam diffuser; 6-trap for cleaning mill; 7-steam jet; 8-fan inlet connecting branch; 9-gas-air pipe; 10-protective netting; 11-manhole; 12-return hose for coarse coal-dust; 13-bracket and supporting guide pipe for separator; 14-drive for separator vanes; 15-lug of delivery part; 16-delivery part of mill; 17-lug for lifting mill; 18-flange of connection to distributing box of multicyclone

The quality of the milling also depends on the moisture content of the coal. The drier the coal is, the better the milling will be, and the higher will be the productivity of the mill. For this reason the heat from the gas-air mixture and from the steam is used for drying out the product during the grinding. According to experimental data about 500 kg of steam are used for milling one ton of coal. The pulverized-coal bunker (Figure 9) serves to store the supplies of pulverized coal required to keep up the first during standing, for getting up steam in a cold locomotive, and for use when the mill is out of order. The amount of pulverized coal in the bunker is enough for the normal operation of the boiler for 1 hour without being replenished from the mill.

The bunker is of welded metal, rectangular in shape, and divided into two pockets on the bottom. Two troughs fastened to the bottom are connected by connecting branches to the dust-mixing boxes or carburetors. Each trough has a pulverized-coal conveyor to feed the fuel to the carburetors.

Under the bunker, beneath the fuel conveyors, air-jets connected with the main air-reservoir are installed. These jets serve to break up accumulations of pulverized coal that may form beneath the conveyors.

There are two inspection hatches in the upper roof of the bunker, and also a large manhole, all of them wither hermetically closing covers.

Special devices called cyclone fans or multicyclones are installed on the roof of the bunker. They serve to remove the pulverized coal from the gas-air stream from the mill, and thus to assure a constant supply of pulverized coal to the bunker. The multicyclones ordinarily catch from 75 percent to 80 percent of all the coal-dust in the stream, while the remaining 15-25 percent is carried with the air into the firebox.

Special float indicators are provided to show the amount of coal-dust in the bunker. The inside walls of the bunker and of the fuel ducts are built without having any projections whatever, since long-continued stoppages or obstructions at any point in the flow of the fuel may result in its spontaneous combustion.

The pulverized-coal conveyors are lighter than those used for ordinary coal. They are driven from the donkey engine by one cylindrical reduction-drive 7 and two conical reducers 10 and 14. The conveyors are started and stopped by the lever 16.

For normal operation of the pulverized-coal firebox, firstly, combustion must be completely finished by the time the gases arrive in the tubular part of the boiler, and, in the second place, the temperature of the gases at the tube plate must be lower than the melting point of ash. Unless it is, molten cinder deposits will form on the tube plate and the caps of the superheater elements.

[See following pages for Figures 9 and 10]

In order to reduce the rate of heat liberation as much as possible, the volume of the firebox is made as large as possible usually at the expense of the ashpan by removing the grates. Even

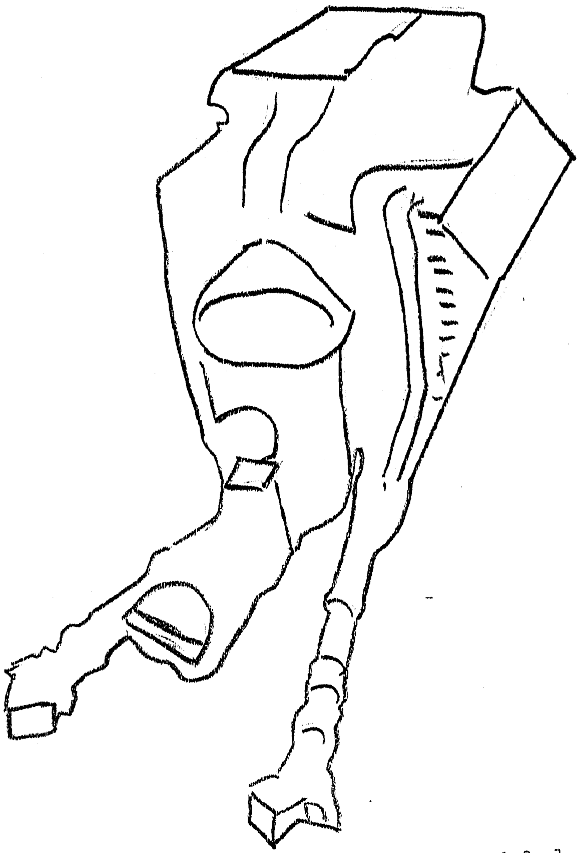
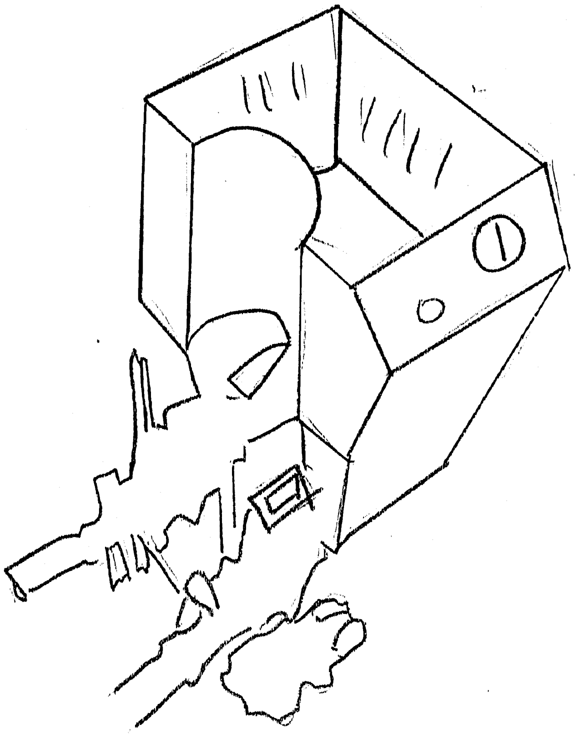
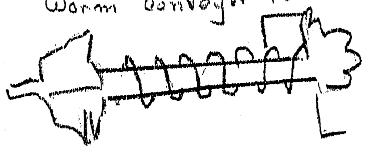


Figure 9. Bunker with pulverized-fuel ducts for FD Locomotive

1-bunker; 2-small safety valve; 3-manhole; 4 multicyclone; 5-safety valve; 6-distribution box; 7-valve handles; 8-valve handles; 9-pulverized-fuel duct; 10-mill; 11-inspection trap of mill; 12-turbo-blower; 13-ball coupling of pulverized-fuel duct; 14-flanges of compensator; 15-ball coupling of pulverized-fuel duct; 16-fuel-jet holder; 17-fuel-jet or burner; 18-gas-mixer head; 19-ball coupling of gas-mixer head on locomotive; 20-ball coupling on tender; 21-handle of test-rod; 22 feed of pulverized-fuel duct.





Worm Conveyor for Pulverized Coal

Figure 10. . Drive for pulverized-fuel worm conveyor on FD Locomotive

1-bunker; 2-rear bearing; 3-fuel-conveyor; 4-guide tube of fuel-conveyer; 5-feed of fuel-duct; 6-donkey engine; 7-cylindrical reducer; 8-fuel duct; 9-clutch; 10-conical reducer; 11-shaft; 12-clutch; 13-front bearing of fuel-conveyer; 14-conical reducer; 15-post of shifting lever; 16-engaging lever of fuel-conveyer clutch; 17-clutch of fuel conveyor; 18-safety stop.

when this is done, however, the heat liberated in the locomotive firebox reaches 1.2 to 1.5 million kcal/m^8 per hour (as against the usual 200,000-300,000 in the stationary boiler) which creates certain operating difficulties. To safeguard the walls of the ashpit and firebox frame from the action of high temperatures, they are lined with firebrick. The secondary air is introduced into the firebox through a hatch in the front wall of the ashpan.

In the rear wall of the ashpan beneath the fuel-jets, there is a second valve for induction of air. Two vents are provided in the bottom of the ashpit for the removal of ash and cinder.

Under the firebox frame, over the fuel-jets, is the gas-mixing cap through which the gases are drawn from the firebox to heat the air that enters the mill.

The arrangement of the firebox is shown in Figure 11. The fuel-jets are located at the rear corners of the ashpit, under the firebox frame, and send their jets of fuel obliquely to intersect at about the center of the part of the firebox under the fire arch.

A turbo blower fan serves to feed the system with air and is located under the floor of the cab. The number of revolutions per minute is regulated by changing the steam pressure by a valve in the cab. Its capacity is up to 10000 m^3 per hour.

Figure 12 is a schematic representation of the whole pulverized-coal firing system. The operating cycle proceeds in the following sequence.

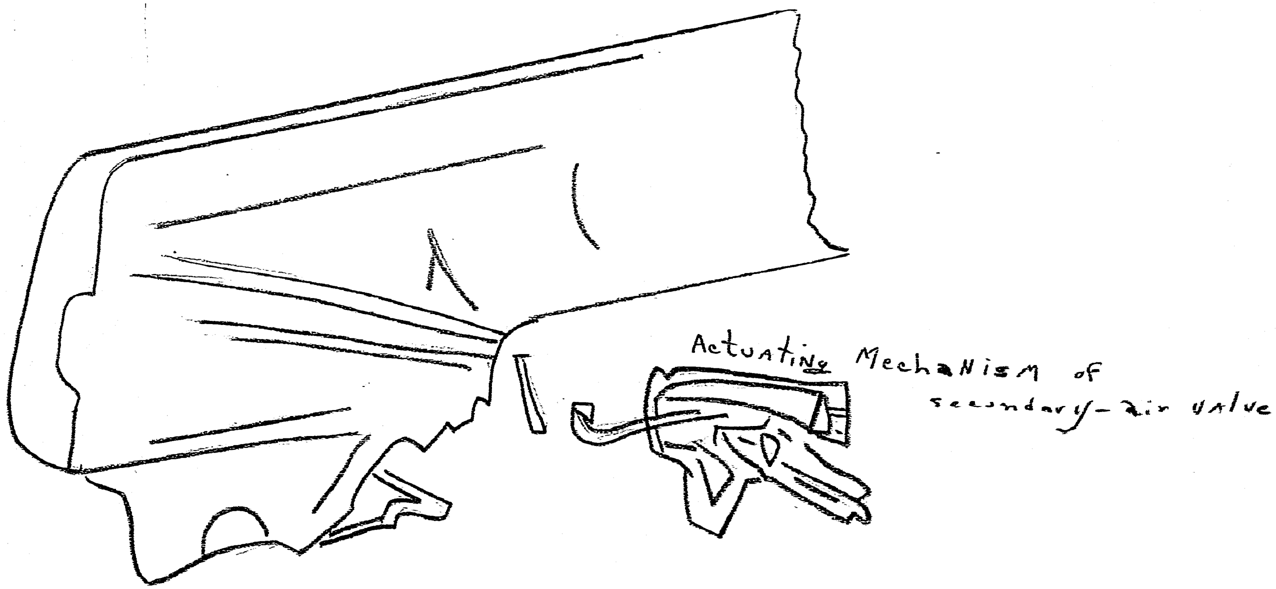


Figure 11. Pulverized-coal firebox of series FD Locomotive.

1-fuel-jet; 2-lining of side firebox walls; 3-ashpan; 4-valves of ashpan bunker; 5-actuating mechanism for ashpan-bunker valves; 6-lining of ashpan; 7-threshold; 8-actuating mechanism of front valve; 9-secondary-air-duct valve (front valve); 10-boiler arch

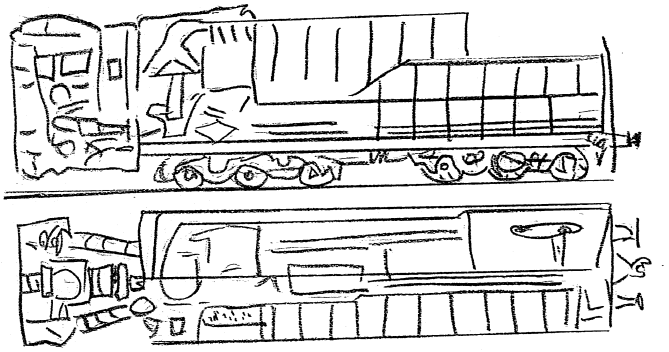


Figure 12. Installation of pulverized-coal equipment on series FD Locomotive. 1-jet for pulverized coal; 2-gas-mixer head; 3-ball coupling of fuel duct; 4-ball coupling of gas duct; 5-telescopic joint of fuel duct; 6-telescopic joint of gas duct; 7-turbo-blower; 8-steam mill; 9-steam jet of mill; 10-distributor head; 11-multicyclone; 12-pulverized-coal bunker; 13-safety valve; 14-stoker to deliver coal to mill; 15-reducer of stoker; 16-Cardan shaft of stoker; 17-guide tube for Cardan shaft of stoker; 18-donkey engine for stoker; 19-conical reducer for fuel conveyors; 20-cylindrical reducer; 21-clutch for fuel conveyors; 22-donkey engine for fuel conveyors; 23-reversing valve for fuel-conveyor donkey engine; 24-feeder of fuel-duct; 25-reversing valve of stoker donkey engine; 26-fuel conveyor

[Note: "Fuel" here means only pulverized coal].

From the tender, coal is delivered to the mill by the stoker (conveyer) 8. In the mill it is simultaneously dried out and ground. The finished fuel, together with air and steam, is conducted from the mill through the tube duct into the multicyclone, where the pulverized coal is separated from the air. The former falls into the bunker, while the coaldust-free air is drawn up through the inner tube of the multicyclone and is led off through the fuel duct to the fuel-jets. In the course of this movement the air encounters on its path the pulverized coal delivered from the bunker by the conveyer, and carries that coal through the fuel-jets into the firebox.

The air conducted into the mill to dry out the coal is preheated by means of the hot gases drawn from the firebox, which are mixed in the gas-mixing cap with air arriving through the damper from the outside atmosphere. The temperature of the gas-air mixture is regulated by using the air-damper.

The control system consists of four valves installed in the cab, by means of which steam is admitted to the mill, the turbine blower fan, and the donkey engines for driving the coal and pulverized-coal conveyors.

One of the faults of the installation is the necessity of limiting the temperature of the gas mixture to 300 degrees Centigrade since increase beyond that point involves danger to the operation of the fan through which this mixture passes, while a higher temperature (450-500 degrees Centigrade) is required for handling coal with higher moisture content. Besides this, the existence of a partial vacuum between the firebox and the suction inlet connecting branch, while there is a certain amount of pressure between the delivery connecting branch of the fan and the fuel-jet (pressure created by the air delivered by the fan) makes it necessary to have all joints and seams of the mill, bunker and pulverized-coal ducts carefully packed if diffusion of coaldust is to be avoided.

These shortcomings are completely eliminated by the new scheme (Figure 13) proposed by Engineer Tsygankov. Its basic difference from that installed on the FD locomotive is that the mill, bunker, cyclone and most of the fuel ducts operate under a partial vacuum, thereby eliminating the possibility of dust diffusion. This is accomplished by placing the turbine fan in the cab and connecting its suction-inlet connecting branch to the fuel ducts from the delivery connecting branches of the cyclones. The presence of an inlet connecting branch (for drawing in fresh air, which enters the fan directly and avoids the bunker and cyclones) reduces the temperature of the gas-air mixture at the fan to 60 degrees-70 degrees, as against temperatures running up to 600 degrees before the mill. Thanks to the increase in the temperature of the gas-air mixture, it becomes possible to transfer the mill to operation on the exhaust steam from the turbine blower fan.

The working cycle in the new scheme is as follows. The gas-air mixture enters the mill at a temperature running up to 600 degrees. In the mill, after the coal has been dried out and warmed, the mixture is cooled down to 100-120 degrees. From the mill the mixture then proceeds, together with the coaldust fuel, to the cyclone, where the fuel dust is separated from the gases. From the cyclone the coaldust-free air is drawn by the blower fan and is mixed with pure air conducted into that fan through a special inlet connecting branch, as a result of which the temperature of the air is lowered to 60 degrees before it enters the blower fan. Thence the air is forced through the pipe duct where it takes up on its way the coal-dust fuel delivered by the conveyers and blows that fuel through the fuel jets into the firebox.

An experimental check of the scheme has confirmed its superiority.

Steam in a cold locomotive is raised by using pulverized coal. To put the turbine blower fan and the donkey engines into operation, and also to start the syphone when getting up steam, a supply of steam from an independent source (such as another locomotive, a stationary boiler, etc), is required.

The mill is started only after the firebox has been well heated by the operation of the fuel-jet on the finished coaldust fuel in the bunker.

Although considerable achievements have already been registered in the field of practical utilization of pulverized coal for firing locomotives, this problem is still far from being solved.

The existing systems of pulverized coal firing, besides requiring complicated and bulky equipment and installations, do not even assure fuel savings, as has been shown by operating experience with the series E^m and FD locomotives. As a general rule, to the cyclone, where the fuel dust is separated from the gases. From the cyclone the coaldust-free air is drawn by the blower fan and is mixed with pure air conducted into that fan through a special inlet connecting branch, as a result of which the temperature of the air is lowered to 60 degrees before it enters the blower fan. Thence the air is forced through the pipe duct where it takes up on its way the coal-dust fuel delivered by the conveyers and blows that fuel through the fuel jets into the firebox.

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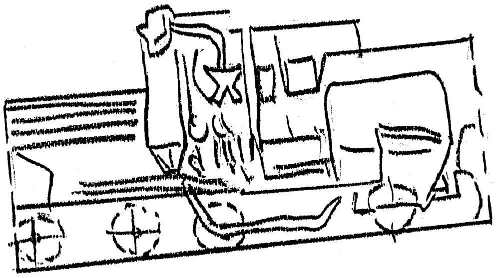

Figure 13. Scheme of Engineer Tsygankov's system of pulverized-coal firing. 1-firebox; 2-gas-mixer head; 3-air-damper; 4-ball-telescopic joint of gas-air duct; 5-mill; 6-fuel-duct from mill to cyclones; 7-cyclone; 8-pulverized coal bunker; 9-suction duct for pulverized coal; 10-air inlet connecting branch; 11-turbo-blower; 12-pressure duct for pulverized coal; 13-ball-telescopic joint of fuel duct; 14-fuel jet; 15-front valve for admitting air to firebox; 16-grate for admitting air to firebox; 17-rear valve for admitting air to firebox; 18-steam admission pipe for mill; 19-conveyor for returning coal; 20-coal conveyor; 21-reducer for coal conveyor.

these locomotives often needed repairs and thus interrupted normal movement of trains. As a result a prejudice grew up among many traction workers against pulverized-coal firing in general, which they considered an inefficient and unpromising method. This of course is not true.

The research work which has been done on systems of pulverized-coal firing has shown that the productivity of the mill on the FD locomotive does not exceed 2000 kg/hour, while 3500-4000 kg/hour of pulverized coal are required; and with this the quality of the fuel obtained was very poor, and the overconsumption of fuel on this locomotive reaches as much as 100 percent above the norm. The main reason for this is the unsuccessful design of the steam-air mill (especially on the FD locomotives), and likewise of the fuel-jets themselves that serve to inject the air-fuel mixture into the firebox of the boiler. Unskillful handling of the mill by locomotive crews also plays a not unimportant part in the deterioration of its operation.

It has likewise been established that the mill on the E^m locomotive is better in all respects than that on the FD model. This is explained by the more successful design of the jet and ejector. The productivity of this mill, when properly regulated, is sufficient to supply the normal operation of the boiler. Thus for instance, with a steam pressure of 13.9 atmospheres before the jet, it produces up to 2770 kg/hour of pulverized coal, while at 7 atmospheres it produces only 1265 kg/hour, which of course is very far from being sufficient.

Other factors that militate to the disadvantage of the pulverized-fuel firing system are the relatively high cost of preparing, transporting and storing pulverized coal, and also the necessity for strict observation of the safety conditions prescribed by the regulations, since under certain conditions spontaneous combustion or even explosion may occur in pulverized coal.

In view of all that has been presented above, it is not hard to understand why pulverized-coal firing, down to the present time, has not emerged from the stage of experimentation either in the USSR or abroad.

THE E^{km} LOCOMOTIVE (USSR)

(The plans for the modernization of two Series E^{m} locomotives by a combined (complex) scheme (whence the designation E^{km}) were worked out and performed by the Locomotive Department of the MEMIIT, headed by Academician S. P. Syromyatnikov. One of these locomotives -- E^{km} 707-32--was tested under operating conditions on the Tomsk Railway in 1942-1943.))

Some types of locomotive modernization, when performed separately, on a non-combined basis, have only a very slight effect, ~~since even if the~~ thermal efficiency of the locomotive as a whole may be improved, it is only to a very insignificant extent. It has been established, for instance, that feedwater and draft air preheating result in a fairly perceptible reduction of the superheat temperature. Thus the plus signs from this really very useful measure are to a certain extent cancelled out by the minus signs from the reduction of the superheat.

This phenomenon is the direct result of a peculiar disruption of the normal thermal balance in the boiler. Academician S. P. Syromyatnikov explains it in this way. The introduction of feed water heating on a locomotive, other things being equal, increases the amount by weight of the steam generated. But since the temperature regime in the boiler, or to put it differently, the thermal work of the gas stream that bathes the superheater elements, remains quantitatively unchanged, each unit of steam by weight (say a kilogram) consequently receives a smaller share of heat for superheat, and the superheat accordingly falls.

To a certain extent the same thesis is applicable to the preheating of draft air. True, the (thermal) effect of the gases is considerably increased by the delivery of hot air to the firebox, but, as has been shown by tests made on locomotives with draft-air preheating, the additional heat is almost entirely transferred in the boiler to heating the surface of the firebox itself. The temperature of the gases as they emerge into the tube of the boiler is therefore relatively little increased, namely, by only some 30-50 degrees when the draft air is preheated by 150 degrees. And it follows that each unit by weight of the steam in the superheater likewise receives only a small accession of heat.

In his theoretical studies in this field, Academician Syromyatkov points out the necessity for taking measures to prevent lowering of the degree of superheat simultaneously with the introduction of preheating feedwater and draft air.

Starting out from this position, the Locomotive Department of MEMIIT performed the modernization of two series E^m locomotives by a multiple method, i.e. by making appropriate improvements in the fire-tube superheater, parallel with the installation of feed-water and draft-air preheating systems. The locomotives so modernized were given the designation E^{km}.

One of these locomotives (E^{km} 707-40) was equipped with a draft air preheating installation of the NIIZhT system, but with certain variations in design. Particularly, to reduce the hydraulic resistance and promote uniform distribution of the gas-air stream over the entire cross-section in the air-intake and air-outlet boxes, and likewise in the gas deflection chamber, Prandtl' directing vanes are installed.

The presence of Prandtl' vanes, an improved gas-air tract, a more rational (rhombic-circular) layout, and the proper disposition of the tubes assured the possibility of obtaining from the installation the equivalent of the thermal effect from a typical draft-air preheater, in spite of the reduction in the number of tubes (to 420 instead of 740).

To obtain the proper thermal balance in the boiler, the superheater was placed in 46 fire-tubes, instead of 32 in the series locomotive. Under these conditions only 71 fire-tubes could be placed in the tube plate (instead of 147 in the series locomotive E^{m}).

The fire-tubes are arranged in six vertical rows (Figure 14). In view of the impossibility of placing the usual type of six-row collector in the smokebox of this locomotive (since its dimensions are too great), the collector is filled in three chambers and four rows according to the scheme shown in Figure 15.

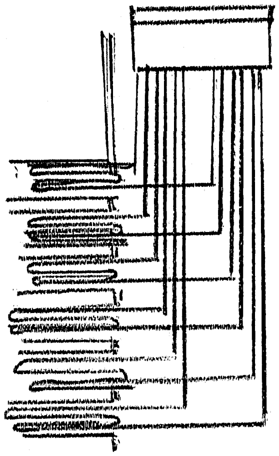

Figure 14. Usual arrangement of superheater elements in boiler flues.

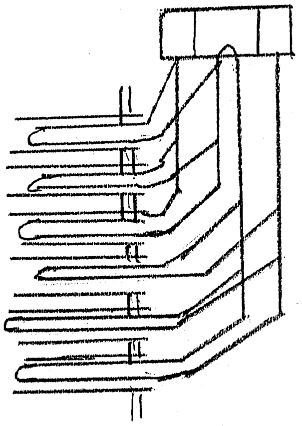

Figure 15. Modified scheme of conducting steam to superheater elements on E^{km} Locomotives.

The difference between this superheater and the ordinary kind consists in the fact that the four-course, two-reversal elements are doubled and placed not in a single fire-tube, but consecutively in two. The central chamber of the collector replaces the reversed loops of the customary two-reversal elements.

The reduced and lightened construction of the draft-air preheater described above nonetheless kept the shortcomings inherent in that design, which were listed in their place during our description of this type of air-heater.

For this reason, in modernizing the locomotive E^{km} 707-32, a new design, free from the enumerated faults, was worked out.

The draft-air preheater consists (Figure 16 and 17) of four separate banks placed in a niche of the smokebox. The niches are made of boiler-plate 10 millimeters thick and are set up by welding to an opening cut into the smokebox wall autogenously for this purpose.

The banks consist of lengths of fire-tubes arranged vertically and welded into honeycomb-type sections. The tubes terminate above and below in pockets of 3 millimeter sheet iron, which are intended to separate the gas stream from the air stream. The tubes are surrounded by a casing, and the bank suspended and fastened to the niche by means of the flanges of this casing. The niches terminate in wide bunkers in which cinders collect. The two air-duct sleeves from the bank join into a single sleeve at the front of the boiler, which union sleeve conducts the preheated draft-air to the ashpit. The smokebox is divided into two parts by a baffle plate.

The gases from the fire-tubes pass under the baffle plate and through the opening, or "window", in the lower part of the smokebox, and then enter the gas pockets, whence they pass through the tubes of all four banks. They then rise above the banks, and emerge through the upper gas pockets into the part of the firebox above the baffle plate, whence they are discharged through the smokestack into the atmosphere. Thanks to the fact that the gas jet makes an abrupt turn as it enters the lower pockets of the bank-tubes, a considerable percentage of the cinders settle out and fall into the bunkers.

The air drawn from the sides through the upper pockets passes down between the tubes, and enters the air duct through the lower air pockets, whence it goes to the ashpit.

The boiler in locomotive E^{km} 707-32 is moved backwards on the frame by 375 millimeters. This made it possible to lighten the load on the forward axles and distribute the boiler weight more uniformly on all the axles. Moving back the boiler in turn assured a greater length for the smokebox, thereby making convenient placement of the air-heater bank possible, and also making it possible to assure the interchangeability of the ordinary Schmidt type of superheater with the six-row collector.

The superheater box is of welded construction of channels and fire tubes and is mounted on a slab 32 millimeters thick. Six rows of superheater element tubes are attached to it on Ryazantsev cones.

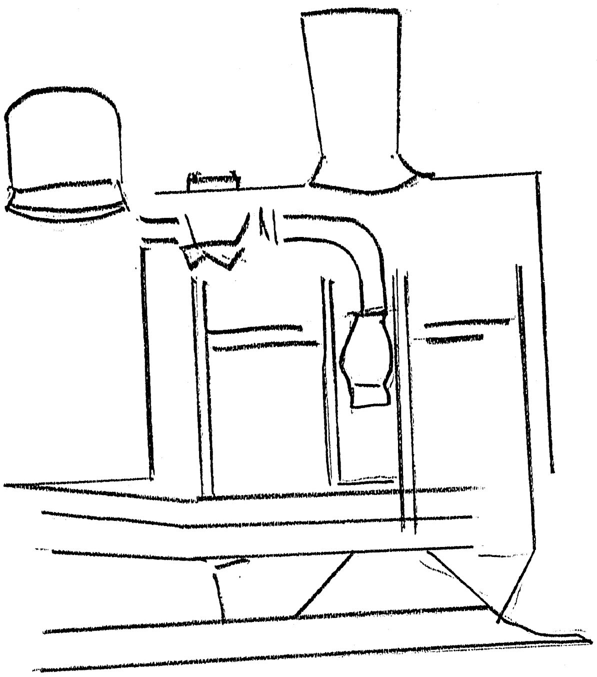

Figure 16. MEMIIT-system air-preheater on E^{km} locomotive 707-32

(side view)

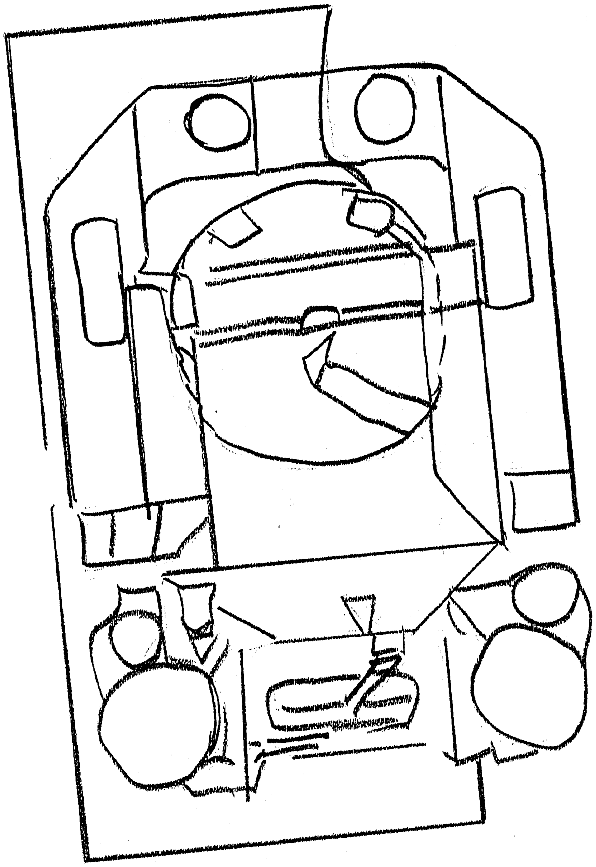

Figure 17. MEMIIT-system air-preheater on E^{km} locomotive 707-32

(front view)

The following Table 2 gives the basic boiler dimensions for locomotive E^{km} 707-32, and, for purposes of comparison, those of the series E^{m} locomotive.

TABLE 2

Name of Elements	Locomotive E^{km} 707-32	E^{m}
Area of grate R, in sq. m	4.46	4.46
Heating surface of firebox H_m in sq m	18.08	18.08
Volume of firebox V_m in cubic m	7.39	7.39
Number and diameter of firetubes, n_d, d_d	172 x 46/51	157 x 46/51
Number and diameter of flue, n_f, d_f	46 x 125/133	32 x 125/133
Evaporative water-surface of firetubes, H_d in sq. m	53.45	115.6
Same for flues, H_f in sq. m	88.91	61.50
Total Evaporative heating surface of boiler, H_k in sq. m	160.44	195.25
Heating surface of superheater, H_n in sq. m	86.54	60.20
Total heating surface of boiler and superheater, H in sq. m	246.98	255.45
Flame heating surface of firetubes, Hd in sq. m	47.80	105.70
Same for flues up to beginning of superheater H_f in sq m.	9.01	6.27
Same for firetubes in region of superheater, H''_f in sq. m	75.02	52.19

The modernized locomotive E^{km} 707-32 was given a road test under operating conditions during 1942 and 1943 with dynamometer cars on sections of varying profile and with varying trains on the Tomsk Railway. The series locomotive E^{m} 726-70 was given parallel tests for the purpose of comparison.

A detailed analysis of the results of these tests has been published, and those interested may learn all the details from it. (See Transactions of MEMIIT Kompleksnaya modernizatsiya i sovremennyye metody rascheta parovozov [Combined modernization and modern methods of locomotive calculation] -- Transzheldorizdat, 1945, Jubilee Issue.)

It must here be borne in mind that this locomotive was tested with an inoperative feedwater heater (out of order) and that the superheat temperature could not be brought up to the proper level.

The tests showed that the modernized locomotive was not only more economical to operate but had also acquired a number of what were in a certain sense, new properties, namely:

the most advantageous utilization of the locomotive (minimum ordinate of the curves) lay within the limits of higher forcing than the ordinary ones;

The economy of operation of the modernized locomotive is more stable within the limits of a wide range of train speed-ups than the ordinary ones;

These properties possess a very important practical meaning under current operating conditions, since they assure more complete utilization of the tractive resources possessed by the locomotive, and at the same time they do not reduce its thermal economy, as is usually the case with the standard types of locomotives.

It must be remembered however that this locomotive was not subjected to experimental study on the test track of the TsNII of the MPS, and that, accordingly, the accuracy of all the above data on its resulting results has not been verified. At the present time this locomotive is now being tested on the test track we have just mentioned.

LOCOMOTIVE 1-5-0 FIRING PULVERIZED COAL FROM A CENTRAL STATIONARY PLANT (Constructed in 1936) (GERMANY)

Figure 18 shows the equipment scheme of this locomotive, while Figure 19 gives a general view of it.

The pulverized coal is drawn into a welded metal bunker, set up on the tender, through three upper ports with covers flush with the sides. Two troughs with the conveyors 1 are attached to the lower part of the bunker, and are used for delivering fuel to the firebox. The troughs end in front in the inlet connecting branch 2, into which the conveyor runs, thereby eliminating the chance of losing fuel from the bunker. At a certain distance from its bottom, the lower part of the trough is surrounded by a second wall so as to form the crescent-shaped air-passage 3.

In the first part of the trough the passage traverses the annular section 4 which surrounds the conveyor of the inlet connecting branch, and terminates in a flange to connect with the fuel duct 5 running to the fuel-jet 6.

The air-passage is connected in the rear by the tube-duct 7 to the delivery connecting branch of the blower fan 8, which is installed on the water tank and leads from the turbine. Pulverized coal conveyors also lead from the same turbine (through the vertical shaft 9 and the reducer with conical gears). A 1.5 HP steam engine is used on some locomotives to drive the conveyors. The conveyor shafts have clutches with lever actuation, so that each conveyor can be started or stopped according to conditions. As it rotates, the conveyor worm takes hold of the pulverized coal from the bunker and delivers it to the annular section through the inlet connecting branch in the front of the trough. Air from the blower fan is forced through the annular section with a velocity of 30 m/sec, taking up the pulverized coal delivered by the conveyors and blowing it through the fuel-jets into the firebox.

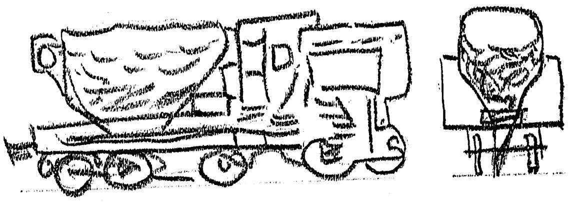

Figure 18. Scheme of equipment of German locomotive firing pulverized coal prepared at central stationary installation.

The amount of fuel delivered to the firebox is regulated either by changing the speed of the conveyors or by turning one of them on or off.

Together with its advantage (with respect to simplicity of equipment and ease of servicing), the firing of pulverized coal prepared at a central installation also has very substantial shortcomings:

Figure 19. General view of German locomotive firing pulverized coal prepared at central stationary installation [PHOTO]

The locomotive can be operated only on railway sections having stationary coal-pulverizing installations;

large capital expenditures are required to equip pulverizing plants at the depots, and large amounts of electric power are used in grinding, amounting on the average to 30-35 kwh per ton of coal;

the bulky pulverized-coal bunker on the tender reduces the supply of water that can be carried in the tank;

the complexity of the operations involved in loading the pulverized coal into the bunker and the resultant increase of locomotive standing time for taking on fuel.

It is precisely for these reasons that all our efforts in the experimental work in the USSR have been concentrated on individual coal-pulverizing on the locomotive.

THE WORTHINGTON SA MIXING FEEDWATER HEATER (UNITED STATES)

The principal equipment of this system of feedwater heating consists (see diagram of Figure 20) of the mixing chamber 3, the hot-water piston pump 12 and the cold-water turbine pump 22, operated by live steam.

The mixing chamber is directly connected with the steam chests of the cylinders through the return valve chest 1. These valves assure supply to replace that from the steam supply pipe if the delivery of exhaust steam should be cut off or the pressure be insufficient.

The installation operates as follows when the locomotive is running with open throttle.

Cold water from the tender is drawn by the turbine pump through the pipe duct 21 and is forced through the pipe-duct 17 and the atomizing valve 7 into the chamber 3. The water in spray form is heated instantaneously on contact with the exhaust steam inducted into the chamber, and the gases so released are discharged into the atmosphere through the air-vent 6. The temporary hardness salts are precipitated out and remain in chamber 3.

The operation of the turbine pump is controlled automatically by the float 2. When the water level rises above normal, the float displaces the valve, thus closing the admission port of the pipe duct that supplies steam to the turbine pump, and the latter stops. The exhaust steam from the turbine passes into the atmosphere through the pipe duct 19.

The heated feedwater from the mixing chamber enters the pipe-duct 10 and is pumped by the pump 12 through the pipe duct 9 and the return valve 25 into the boiler. As the pump operates, the water-level in the chamber will continually drop, and the float with it. When it reaches a predetermined limit, the float actuates a lever to open the valve, which again admits steam to the turbine pump, and the pump starts to pump in water again.

The mixing chamber 3 is cast of iron with a considerable admixture of steel. The return valves, of which the numbers and dimensions are determined by the delivery capacity, prevent the possible access of water into the steam cylinders. They are made of rustless steel and are surface ground.

The float is made of red copper and the other details of the float mechanism, of bronze and steel.

The oil gaining entrance with the exhaust steam and accumulating on the surface of the water "splashes out" through the so-called annular aperture for the discharge of air. This takes place at moments of sharp reduction of pressure in the chamber when the regulating valve is closed, when the level of the water instantly rises owing to energetic boiling.

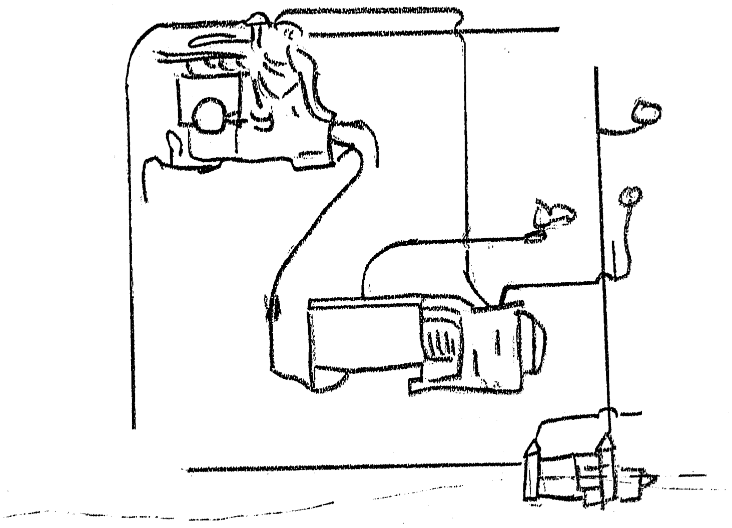

Figure 20. Scheme of Worthington system of feedwater heating.

To eliminate the danger of oil being deposited on the walls of the boiler heating surface during periods when all the water has been emptied from the boiler (for instance when it is being washed out), the manufacturer recommends the use of hot water with caustic soda for washing out the boiler, and the setting of the pressure lubricators of the steam engine and pump for minimum delivery of oil.

The steam section of the hot-water pump is a steam cylinder with an automatic-action valve of steel. The pump has four pressure and four suction valves, which are forged of rustless steel.

The pump is lubricated either by the hydrostatic lubricator in the cab or by the general forced-lubrication system, or, finally, by a small individual pump connected to the steam cylinder. The superiority of the latter method is that lubricant is delivered only while the pump is operating.

The capacity of the hot-water pump is from 20,000 to 50,000 liters per hour, according to the type of pump.

The turbine pump is a combination of a steam turbine and a pump. At full speed the turbine makes 3,600 rpm.

To prevent the turbine from exceeding this maximum allowable speed, there is a special brake disc with four shoes rotating inside a brake drum. When the number of revolutions per minute reaches a predetermined maximum, the discs begin to touch the inner walls of the drum and thus prevent further increase ~~in~~ the speed of rotation.

In delivering water to the feedwater heater, the pump must overcome: (a) the resistance arising from the difference of level between the water in the heater chamber and that in the tender; (b) the resistance of the pressure pipe, including that of the return and atomizing valves; and (c) the resistance caused by the back pressure of the exhaust steam in the heater chamber. The pressure in the force pipe, measured by a manometer set up in it, is usually 0.3 to 0.8 atmosphere higher than that of the exhaust steam.

The manufacturer recommends that the capacity of the feedwater heater should be roughly 25 percent higher than the maximum capacity of the boiler. This makes it possible, when running through rolling country, to build up a supply of water in the boiler on the up-grades so as to make it unnecessary to use the injector when coasting with closed throttle on the down-grades.

The temperature of the heated feedwater entering the boiler (according to the manufacturer) is 5 degrees to 8 degrees Centigrade lower than that of the exhaust steam. Thus, for instance, with the pressure of the exhaust steam at about 0.7 atmosphere, the feedwater temperature is 110 degrees Centigrade. On this basis, and also allowing for the possibility, in the first place, of returning about 14 percent of the spent steam to the boiler in the form of condensate, and, in the second place, of somewhat increasing the boiler efficiency on account of the reduced intensity of combustion at a given rate of steam generation, the manufacturer considers that the economy of operation of a locomotive equipped with the Worthington feedwater heater is increased by not less than 12 percent.

The firm considers that there is no ground for the objections that the reduction in the intensity of combustion at a given level of steam generation would probably involve reducing the degree of superheat and consequently also the operating economy of the locomotive. This reduction in economy, in its opinion, is completely offset by the reduction in the back pressure of the exhaust, since when the intensity of combustion is reduced, the draft in the boiler will be sufficient without reducing the exhaust cross-section of the nozzle.

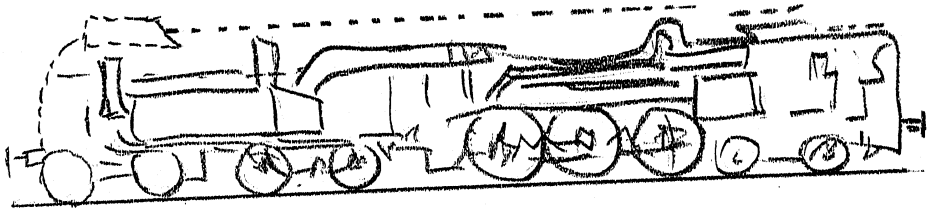

Figure 21. Scheme of Franco-system locomotive.

But there can be no doubt that the above data on the economy of locomotive operation with the Worthington feedwater heater are very much exaggerated. This statement is confirmed by the operating experience on our own lines of a number of E^m locomotives equipped with this system of feedwater heater. The fuel saving amounted here to about 7-8 percent.

While this system has a number of advantages (compactness, light weight, simplicity of control and of servicing), it is nevertheless not free from faults, of which the principal one is a certain complexity of design (the existence of two pumps working on different principles).

THE FRANCO SYSTEM LOCOMOTIVE (ITALY) (Built in 1937).

The scheme of the locomotive built on Professor Franco's system is given in Figure 21. Its essential feature is that it has a second boiler in addition to the ordinary, ~~of~~ or somewhat modified, standard type of boiler, the so-called steam generator. This second boiler, termed the preliminary-heating boiler, is set up on the tender and represents a peculiar economizer of immense size, in which the feedwater is preheated to a temperature not far from that of steam generation (up to about 147 degrees Centigrade). Flexible steam, water, and gas ducts connect the two boilers. The exhaust steam from the engine cylinders and the exhausted firebox gases are utilized for preheating the water. The dimensions and shape of the preliminary heating boiler as well as the method of conducting the gas and steam to it are so chosen that the heating takes place as the result of direct contact between the entire water surface of the boiler and the hot gases. The entire surface of the steam generator is in turn bathed by exhaust gases at a high temperature -- about 400 degrees Centigrade -- thanks to which there is a very intensive generation of steam.

The operation of the boiler is more flexible under this system than is usually the case. Practically all salts contained in the water are precipitated on the bottom of the preliminary heating boiler, whence they may easily be removed. Very favorable conditions for the operation of the steam generator are thus created. Specifically the formation of scale is prevented and its evaporative capacity is thereby increased.

The presence of flexible connections -- the steam, water and gas ducts -- does introduce certain complications of design, but according to the conclusions of the commission that accepted delivery of the locomotive after trial operation, these connections do not significantly increase operating cost and function very reliably.

To study the thermal efficiency of this locomotive, it was given an experimental run with a train on the Ancona-Bologna section of the Italian railways, which is 203 kilometers long. A conventional standard locomotive was given a run over the same section a few days later, under completely identical conditions and with a train of the same weight. An average speed of about 60 kilometers hour was maintained in both cases. Ruhr coal of a heating value of 8394 and 8135 kcal/kg was used as fuel.

The locomotive operation heat balances for the experimental runs are given in Table 3.

[See following page for Table 3]

Indices	Locomotive	
	Franco	Standard
Heat of exhaust gases (temperature of exhaust gases)	7.73 (173)	15.35 (306)
Latent heat of exhaust gases	3.78	5.91
Stack, losses of combustible through grates, and radiation losses	4.16	4.28
Radiation losses from gas feedwater heater	0.26	-
Total losses in steam generation, in percent	15.93	25.34
Boiler efficiency	81.48	71.68
Heat recuperated from steam used to heat feedwater (heating in feedwater heater)	(from 24° to 65°)	-
Heat losses on condenser of steam feedwater heater	0.82	-
Radiation losses and conduction losses from feedwater heating by steam	0.17	-
Heat consumed by pump	3.68	-
Other heat losses	2.40	1.17
Heat losses in injectors	-	0.40
Heat delivered to cylinders	74.41	70.11
Heat lost in exhaust steam	63.95	61.41
Frictional and air resistance to locomotive movement	1.80	2.30
Heat expended for useful work of locomotive at drawbar	8.16	6.90

The heat for the feedwater comes to a small extent (40 percent) from the steam, while the rest of the heat comes from the exhaust gases. The average efficiency of the Franco system boiler is 81 percent at 70 km/hour and 80 percent at 80 km/hour, as against 71 percent and 70 percent, respectively, for the ordinary boiler. The fuel saving at these speeds was 17.8 percent and 14.5 percent.

On account of its complex design, however, this locomotive was never put into series production.

PART II

ORIGINAL LOCOMOTIVE TYPES AND DESIGNS

GENERAL INFORMATION

The reciprocating steam locomotive as a machine possesses a number of very substantial defects. Of these, the principal ones are the following:

the masses performing reciprocal motion in the underframe are insufficiently balanced, thereby producing a harmful and under certain circumstances even a dangerous action on the railroad tracks;

thermal efficiency is extraordinarily low -- the total efficiency of even the most recent designs being only 6-8 percent;

the steam locomotive's coefficient of availability is low, being on the average of the order of 70-75 percent, the remaining 25-30 percent of the time being taken up by periodic inspections, capital and intermediate repairs, etc.; while this coefficient for electric locomotives and motor locomotives is 97-98 percent and 95-97 percent respectively.

One of the faults of the steam locomotive which is of no little importance is its high unit weight, which amounts even in the most recent designs to 70-80 kg/HP. (The unit weight, i.e. the weight per unit power (H.P.) is a very important index for any machine, and especially for the locomotive. The lower it is, the higher is the performance of the locomotive from the technical operating point of view.

The unit weight of the latest models of electric locomotives, steam-turbine locomotives and gas-turbine locomotives, is of the order of 50-55 kg/HP and even lower.

Unit power is the reciprocal of unit weight. The higher it is, the higher the locomotive performance from the above-mentioned point of view.)

Finally, the basic element in locomotive equipment -- the boiler -- is also far from satisfying all modern demands of operation. Before we enumerate the shortcomings of the boiler, a few words must be said of its achievements.

As is commonly known, the modern locomotive boiler has retained all of the basic features of the Stephenson boiler, which was incorporated 120 years into his "Rocket" locomotive. This speaks for the view that this very principle of boiler design was profoundly and thoroughly thought out at the time, or it would long since have been displaced, as locomotive technology developed, by some other radically new and more improved type of boiler.

(This does not, of course, by any means imply that a sign of equality may be placed between them. With respect to its external form, working parameters, dimensions, technical equipment and thermal properties, the modern locomotive boiler has lost almost all resemblance to Stephenson's.)

The existing standard type of locomotive boiler is in fact the most productive of all steam generating apparatus per unit of weight and volume. The intensity of combustion in modern boilers reaches 400-500 kilogram of fuel per square meter of grate surface per hour, and in some cases goes as high as 800-1,000 kilogram; boiler efficiency for coal firing reaches 75 percent, or 80 percent using order of 50-55 kg/HP and even lower.

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With all of these achievements, the standard type of locomotive boiler does have a series of substantial shortcomings, as follows:

The limiting maximum working pressure is around 21-25 atmospheres, not without danger; and this limits the possibility of improving the locomotive's thermal efficiency;

the presence of a large mass of water (8-10 tons) makes it necessary to spend a long time (about 4 hours) in bringing the locomotive from a "cold" condition into operating condition; while the heat losses due to the interruption of combustion, even when the locomotive is not operating (when raising steam, at stops, while being held in reserve, etc.), are very considerable in amount;

it takes high qualifications and the skill of a craftsman to fire a boiler, or its thermal efficiency will be badly impaired;

boiler stresses due to temperature changes and the deformations thereby produced (especially in the fire part) and the presence of firebox stay bolts constitute a prime cause of various types of disturbance in its normal operation;

boiler repair and maintenance involves considerable operating expense, especially on lines where the quality of the water is poor.

This is why engineers, designers and inventors are persistently trying to improve the existing and designs of locomotives and especially of locomotive boilers, as well as to create radically new ones, free from these shortcomings.

During the last years before the Second World War, plans of various and often very original locomotive types and designs were developed and to a considerable extent also actually constructed, both in the USSR and abroad. Thus for example the USSR built the motor-steam locomotive of Engineer L.M. Mayzel, the locomotive with the Volskiy system boiler, etc. In Germany a number of passenger locomotives were built with the La Mont system boiler, and plans were also drawn for a single-cylinder passenger locomotive. A considerable number of locomotives deviating radically from standard design were also built in France. In the United States a locomotive with the Emerson water-tube boiler and an individual drive to each axle was built, together with a number of others.

In this part the most interesting of these locomotives will be described.

2-7-2 LOCOMOTIVE (USSR)

(Built in 1934 at the Voroshilovgrad locomotive construction plant.)

One of the effective methods for increasing the hauling capacity of the main railway lines and simultaneously reducing the cost of transportation is to lift the weight norms for trains. This makes it necessary to increase the tractive force of the locomotive, which in turn requires its adhesive weight to be increased, with consequent increase of axle load (for a given number of axles).

There are however a number of obstacles in the way of increasing these locomotive parameters. Such obstacles are at best difficult to overcome (and under certain circumstances cannot be overcome). The first of these is the screw coupling of cars, which today is being rapidly displaced by the automatic coupling, but has still not been entirely replaced. The screw coupling allows a tractive force of not over 20,000 kilograms to be applied to the drawbar of the tender. The second obstacle is the type of rail and the condition of the roadbed and structures on the section, line or main route. For example, P-38 type rails allow an axle load no higher than 18 tons, P-43 take 20 tons. And at the same time it must be taken into account that in drawing plans for a new locomotive it is usually necessary to figure on a lighter type of rail so that it can "run anywhere".

It is, of course, possible to find a way out by distributing the weight of the locomotive over a greater number of coupled axles. In this case the axle load not only does not increase but may even under certain conditions decrease. However, for reasons related purely to design and the track profile conditions (curves), the possibility of increasing the number of coupled axles to a single rigid locomotive frame is sharply limited. It is precisely for this reason that up to now only a few locomotives have been built with six coupled axles on a single rigid frame (type 1-6-0 in Germany and type 2-6-1 in the United States). As a general rule the number of coupled axles on the locomotives in service in both USSR and abroad does not exceed five.

It is true that the locomotive-construction industry of today is able to furnish locomotives with tractive force of 30,000-40,000 kilogram and over, without exceeding the allowable limits of axle load and without prejudice to safety in taking curves. We refer to the semi-articulated and articulated locomotives of Mallet and Garrat types, which at one time were operated on our own lines and are still operating on the roads of the United States and a few other countries. Articulated locomotives, however, possess their own shortcomings -- primarily their complicated design -- and never became very popular.

Meanwhile the measures of reconstruction for strengthening the superstructure of the ways being put into effect at a rapid pace, and the gradual re-equipment of the rolling stock with automatic couplings, create the necessary conditions for the introduction of more and more powerful locomotives.

It is entirely natural that engineering and designing thought should seek for ways to solve the problem of increasing tractive force by turning its attention in the first place to increasing the number of axles in a single rigid frame. At the beginning of the 30's, Soviet engineers and designers worked out plans for a locomotive with seven driving axles, of type 2-7-2, which was then also constructed by the Voroshilovgrad Locomotive-Building Plant.

As will be seen from the following description, serious difficulties of construction had to be overcome in designing and building the 2-7-2 locomotive.

The following were the principal technical conditions that were laid down for the designers:

the tractive force of the locomotive was to be 40 percent greater than that of the ordinary locomotives with five pairs of coupled drivers;

the complexity of the locomotive design was not to exceed that of a locomotive with six pairs of coupled drivers;

the firebox was to be adapted to the firing of low-grade slow-burning coals;

the dynamic action on the roadbed and track was to be at a minimum, and was to take into account the possibility of serving lines with light rails and at high speeds;

underframe and running parts were to be designed with the curves on the USSR railway system in mind.

The original variants, of wheel-formula 1-7-1, and then 1-7-2 showed that the required weight could not be distributed on the locomotive while also assuring the most favorable conditions for taking curves. It was therefore decided to settle on 2-7-2.

Figure 22 is a general view of this locomotive, which is the only one of its kind in the world.

At first glance the eye is struck by the strongly developed boiler, for which the principal dimensions and operating parameters are as follows.

Over-all length	17,871 mm
Weight without equipment and fittings	60 tons
Number of fire-tubes	138
Number of flues	48
Length of fire-tubes and flues between tube-sheets	7,000 mm
Number of water tubes	4
Evaporative heating surface of firebox	38.56 square meter

Evaporative heating surface of chamber	11.81	square	meter
Evaporative heating surface of water-tubes	4.85	"	"
Evaporative heating surface of flues	180	"	"
Evaporative heating surface of firetubes	212.3	"	"
Total evaporative heating surface (water)	448.64	"	"
Heating surfaceof superheater	174.0	"	"
Total heating surface	662.04	"	"
Grate area	12	"	"
Height of boiler axis above railhead	3,650	"	"

The firebox together with the extended combustion [Kamera Dogoraniya] chamber take up more than half the length of the boiler barrel (7.3 meter) and have a volume of 24.5 cubic meter; and it is large enought to hold the entire boiler of the S^v locomotive.

FIGURE 22

[Photograph]

General view of 2-7-2 Locomotive

It may be inferred from these data on the principal dimensons of boiler and firebox that the rated power of 3500 HP is very reliably assured, and can even be exceeded under certain conditions. This was confirmed when the locomotive made its first trip.

The two-cylinder, single-expansion steam engine has a cylinder diameter of 740 millimeters and a piston stroke of 810 millimeters, with Walschaert valve gear. The common valve is 330 millimeters in diameter and has a maximum stroke of 198 millimeters, steam lap 50 millimeters, exhaust lap 0 millimeter, and linear advance of admission 8 millimeter.

The superheater is the Chusov system, and has six flues, one-round, with increased element diameter (24/30) to eliminate the possibility of rapid incrustation of the flue elements.

The principal proportions of the locomotive are as follows:

Steam pressure in boiler (by manometer)	17 kg/cm^2
Modulus of tractive force	47,127 kg
Adhesive weight	140 tons
Weight empty	184.3 tons
weight loaded	208 tons
Calculated wieght of engine with six-axle tender from ED locomotive	310 tons
Diameter of drivers	1,600 mm
Diameter of wheels of front truck	760 mm
Diameter of wheels of back truck	1,050 mm
Rigid wheel base	5,025 mm
Coupled wheel base	10,050 mm
Total wheel base	17,320 mm
Total length of locomotive at buffers	20,410 mm
Total tender wheel base	9,603 mm
Length of tender between buffers	13,090 mm
Total length of locomotive with tender	33,745 mm

According to calculated data, at the maximum possible tractive effort at the coupling F_k = 30,000 kilogram, the locomotive is able to pull a train of 2,500 tons up a 0.8 percent grade at 24 kilometer/hour.

The firebox and shell are of the radial type, all-welded construction, reinforced by rigid and expansion staybolts. The front and rear tube-plates are also welded.

Intensive water circulation in the boiler is assured by means of four circulation-pipes installed in the firebox, which also serve to support the brick arch.

Because of the great length of the tubes between the tube-plates and the resultant necessity of preventing their buckling or obstruction, with consequent increase in the resistance to the passage of gases, the diameter of the firetubes and flues is somewhat larger than usual, namely:

Flues	163/171 mm
Fire-tubes	65/70 mm
Superheater tubes.	24/30 mm

The boiler barrel, as originally designed, consisted of three drums, but in view of the impossibility of obtaining the necessary dimensions of rolled sheet, it was constructed out of four drums instead. These were connected by two rows of transverse telescopic joints. The connection with the shell of the extended combustion chamber, however, had four rows of joints.

The boiler is fed with water by two exhaust-steam injectors of 360-380 liters/minute capacity and two ordinary live-steam injectors. The regulator is of the multi-valve type (seven valves located in the collector, beyond the superheater).

The boiler is stoker-fired. The shaking grates have one manual shaker and also a mechanical drive from a special machine operated by compressed air or steam.

It was extremely difficult for the designers, architects and builders to make sure that the locomotive would take curves well and also to observe the norms assigned by the technical conditions with respect to the dynamic load on the rails. The first of these problems was solved during planning of the locomotive underframe, and the second while drawing the plans for the locomotive engine.

In usual locomotive construction practice, when building the underframe of a locomotive with many coupled drivers, one modification and additional adjustment or the other is made to assure safety and proper behavior when taking curves. Thus, for instance, the rim of the flange may be trimmed for a short distance (8-10 mm), or rimless widened tire extension axles with lateral displacement, trucks with lateral deviations etc. may be used.

Depending on the number of coupled drivers, the design of the locomotive, and other conditions, one of these methods may be used, either alone or in combination with others.

The lateral displacement of the axles is generally limited (under the conditions of connecting-rod operation) to 25-30 mm., though in locomotives with connecting rods [coupling rods?] constructed on the Gelsford principle, lateral displacements of the axle reach 45 mm and even 50 mm. Lateral displacement of the truck, as a general rule, do not exceed 100-110-mm, and only on the American 2-6-1 locomotive mentioned above does the leading truck have a deviation of ±150 mm.

After careful study and calculation, the following construction was decided on for the under-frame of the locomotive:

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After careful study and calculation, the following construction was decided on for the under-frame of the locomotive:

Leading truck to have lateral deviation of ±145 mm;

I and II coupled axles to have lateral displacement of ±27 mm;

III, IV and V coupled axles, rimless tires, 175 mm wide;

VI, axles with rim, rigid;

VII axle, with lateral displacement of ±35 mm;

trailing truck of two-axle Bissel type with lateral deviation of ±265 mm, while the first axle has a lateral displacement of ±35 mm.

The leading truck consists of two longitudinal equalizers forming axle-boxes at the ends (Figure 23). Two springs leading into the inner space of each equalizer rest on the body of the equalizer. A moveable frame pushes with its over-hang-bracket against the central part of each spring. A supporting frame -- the lower free plate [Katkovaya Plita] -- The later has four inclined planes, arranged in pairs on each side of the middle of the truck. A cylindrical roller may roll along each pair of inclined planes.

A moveable bolt moving in one direction is set in a spherical recess in the upper part of the upper free plate. The bolt is made fast to the lower part of a cylindrical casting.

The load stress is transmitted to the bolt, then to the upper free plate, to the movable frame and, through the brackets to the springs; from the springs to the equalizers and thence to the axle-boxes and axles.

The employment of inclined planes with rollers as a centering mechanism also assures the above-mentioned limits of lateral displacement for the truck, while the centering force equal to 8,250 kilogram is constant and does not depend on the lateral deviation of the truck.

The lateral displacements of the coupled axles I, II and VII is accomplsiehd by means of the play between the axle-box and the cover plate, while the axle-box for axle VII is suspended on two Mayatnikov type suspension arms from the spring. These suspension arms, constituting a centering mechanism, give a varying return force according to the magnitude of the displacement, with an initial value of 1,500 kilogram and a final value of 2,000 kilogram.

The centering mechanism on the VII coupled axle is necessary when the locomotive is moving backwards, at the same time it increases the resistance to "wobbling".

The trailing two-axle Bissel truck (Of the sector type with two low points of support) under the firebox of the boiler has a centering mechanism III that exerts a constant force of 1,600 kilogram. This is the minimum that is necessary for reverse motion, and is chosen so as not to impair the conditions of forward motion too much.

The frame, as on the FD locomotive, is of the bar type, but is not rolled but cast, since the necessary dimensions of rolled material could not be obtained.

The pring suspension of the locomotive is effected by a scheme of three separate groups, located at three points. The first group consists of the springs of the leading truck of coupled axles I, II, III and IV, mutually balanced by longitudinal equalizers and giving a single point. The ball pivot andthe upper free plate of the leading truck serve as the transverse equalizer for this group. The remaining two groups consist of the separate springs of the right and left sides of the V, VI and VII coupled axles and of the trailing truck, connected on each side by longitudinal equalizers. This scheme of spring suspension gives a statically determinate system.

FIGURE 24

Principal proportions and construction of underframe of 2-7-2 locomotive

[Photograph]

In spite of the increased pressure on the axle, in comparison to the series E locomotives, (20 tons as against 16 tons), the static load on the springs of locomotive 2-7-2 is only slightly higher than in the E series (7,700 kilogram as against 6,770 kilogram). This is explained by the fact that the increase in axle pressure is mainly due to the weight of the wheel pairs and the parts suspended on them.

In order to reduce the dynamic action of the roadbed and tracks, the rigidity of the springs of the leading axle is reduced to 82 kilogram/millimeter; the rigidity of the coupled-axle springs is 97 kilogram/millimeter.

The locomotive is equipped with the Kazantsev brake. In view of the great deviations of ~~the displaced axles~~, only ~~axles III~~, IV, ~~V and~~ VI, and also the six-axle tender, are subjected to braking.

The wheel-formula, the great adhesive weight, and the peculiarities of the underframe construction of this locomotive made it very hard to draw plans for the engine, mainly in connection with the changes in cylinder clearance, as well as in the driving pins and fly cranks.

The cylinders could be placed in the clear. The axis of the cylinders was raised by only 20 millimeter above the axle. The IV axle (Figure 24) was taken as the leading axle. The fly connecting-rod is arranged in tandem type. It was thus placed to clear the driving pin and at the same time it proved possible to obtain sufficient dimensions for the driving and central parts of the pin.

FIGURE 23

Front truck of 2-7-2 locomotive

[Photograph]

The crosshead was double. The main one was of multistage type, connected to the connecting rod, and an extra one in front, sliding along a small parallel and serving only for an additional guide and junction with the piston rod.

These complications were introduced in the interest of reducing the diameter of the piston rod. The point is that without the extra crosshead the diameter of the piston rod, under the conditions of buckling, would have to be made considerably larger, and this in turn would lead to increasing the weight of the reciprocating parts and also to impairment of the operation of the rear cylinder stuffing-box.

The piston has Shtarev rings and is equipped with a counter-rod [offset rod?]. The common valves also have offset rods [?] while the installation of fly cranks on the V driving coupled axle was responsible for the relatively great length of the valve rod. To prevent the latter from bending, an intermediate guide in the form of a bronze brush had to be installed.

The design of the internal steam distribution mechanism was also complicated by the installation of fly ranks on the V axle. An intermediate Tya a [arm?] had to be installed for the link and also an extra link lever. In this way a peculiar tandem link was obtained. Thanks to this complication it proved possible to shorten the eccentric rod and thereby to reduce its vibration during locomotive operation to a minimum.

To assure proper operation of the connecting rods when the axles are displaced as the locomotive takes a curve, the first and second coupling rods are mutually connected by a vertical and horizontal roller. Ball bearings to assure the possibility of the coupling rods turning are provided for the pins of the I and II coupled axles.

All of the connecting and coupling and coupling rods have round heads with floating bushings and are adapted for both heavy and light lubricants.

The system of transmitting the torque to the driving axles has certain distinctions from that used in existing locomotives. While in the latter the center crank pin of the leading axle is joined by coupling rods to the crank-pins of all the other driving axles, in the 2-7-2 locomotive it is joined only to the crank-pins of the I, II and III driving axles, while the rear driving axles are connected to the V axle. The latter, just like the leading axle, has a pin with a double crank: a center one, connected by coupling rods to axles VI and VII, and a leading one, connected to the leading crank-pin of axle IV by a special coupling rod, the so-called tandem coupling rod.

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The tandem coupling rod is joined to the connecting rod in the following way. The front end of the tandem coupling rod enters the bifurcated crankhead of the connecting rod and rotates about the central part of the tapered steel bushing. The latter is pressed with its extreme parts against the side of the stub-end, and, together with the "floating" bronze bushing on it, slips onto the driving pin of the driving (IV) axle.

The operating conditions for the driving pin are substantially improved by the existence of the tandem-coupling-rod, since not all the force acting along the axis of the connecting rod axis is transmitted to it, but only a part of it, while the rest of the force necessary to turn the back driving axles, (together with the tandem axle), is transmitted through the tapered bushing directly to the tandem connecting rod.

The great weight of the moving parts of the engine (the driving connecting rod weights weighs 730 kilogram, while the piston, piston-rod and crosshead together weigh 1,127 kilogram), and also the high rate-speed of the locomotive, made careful balancing of all rotating parts necessary, and of part of the reciprocating masses as well. This problem, as will be seen from the data given below, was solved in very satisfactory fashion: the equilibrium of the inertia of the horizontal forces of the masses moving with a reciprocating motion was 57.77 percent, the amplitude of recoiling motion was 4.32 millimeter, the equilibrium of moments of influence [?] was 36.5 percent, and the amplitude of hunting 0.00032.

Calculations of the dynamic action of the locomotive on the rails, made for the dynamic certificate, showed that it did not exceed the allowable limits. At the maximum (design) speed the dynamic coefficient of the driving axle and the other (coupled) axles ranged from 1.5 to 1.6.

This locomotive, however, proved unable to meet all the requirements of operation, especially with respect to taking curves, and did not go into series production.

MOTOR-STEAM LOCOMOTIVE (USSR)

(Designer, Engineer L.M. Mayzel. The working plans were drawn and construction carried out by the Voroshilovgrad Locomotive Building Plant in 1939-1941).

The basic distinction between this locomotive and the standard steam locomotive is in the employment of a special type and design for the engine, in which a steam engine and an internal combustion engine are structurally combined in a single unit.

The idea of the practical utilization of such a combined engine is fairly old, and the foreign literature has also paid great attention to it. Until very recently, however, no concrete steps in this direction were taken. At the end of the 30's our Soviet engineer L.M. Mayzel occupied himself with this problem, and his appropriately grouped proposals formed the basis for the working plans of this locomotive, termed a motor-steam locomotive (Teploparovoz).

What is the practical meaning of the creation of the motor-steam locomotive?

As is commonly known, one of the advantages of the piston steam-engine is its ability to develop a high torque, starting from zero velocity, i.e. when the locomotive commences to get under way and accelerate. On the other hand, this engine also possesses a serious fault, its low thermal efficiency, which amounts to about 13-14 percent. For its part, the internal-combustion engine has a substantial advantage in economy of operation, but because of the specific features of its construction it cannot take on a load before reaching a certain number of revolutions. In other words, it is unable by itself to start from rest and accelarate. Thence the logical conclusion is to unite or combine in a single engine the valuable properties of both, so that the locomotive can start from rest at any moment and develop the speed of an ordinary locomotive, while operating like a motor-locomotive at medium and high speeds. Such a locomotive is the steam-motor locomotive.

Let us see how this is accomplished.

The motor-steam engine of the locomotive consists of two cylinders, one on each side, located in the center of the frame. The cylinders are designed in the form of a separate block (Figure 25) straddling the frame and acting at the same time as an inter-frame reinforcement and a base for the boiler support. The cylinder diameter is 430 millimeter and the piston stroke 770 millimeter. Two opposing pistons operate in each cylinder, thus forming three spaces: the middle one, between the pistons, which is termed the Diesel part, and two outer spaces, between the pistons, and the front and back covers respectively, which are termed the steam part.

FIGURE 25

Cylinder block of motor-steam locomotive

[Photograph]

When the locomotive starts to move, steam appears in all three spaces of each cylinder. When a speed of 12-15 kilometer/hour has been reached, the admission of steam into the Diesel spaces is cut off, and liquid fuel is injected into them by a pump with an Arshaulov gas-plunger. The middle spaces then operate as a two-cycle internal-combustion engine as blast-air commences to be delivered to them by a special turbine air-blower.

The piston bosses of the Diesel portion of the cylinders are cooled by water circulating around the walls in a closed cycle, and the heat of this water is used on the tender to heat the boiler feedwater.

The piston-head has an oil-filled chamber of 22 liters capacity. This assures intensive heat transfer through the ring and piston boss to the water cooling the boss, and thereby prevents excessive temperatures in the bottom, and also prevents the piston-rings from taking fire. [?]

The boiler is analogous to that in the S^u locomotive and differs from the latter only in its higher pressure (20 atmospheres) and use of a radial firebox instead of one with a flat crown.

The admission and release of steam was at first effected by a Lenz-type cam gear. It did not prove rational, however, and was replaced by a positive valve gear.

Boiler draft is supplied by an exhaust fan operating on spent steam.

The torque is transmitted to the wheel pairs by two gear-shafts located respectively in front of the pairs and behind them.

The existence of opposing pistons made it necessary to place the pins of the connecting rod and the coupling rod on the front gear shaft at an angle of 180 degrees, thereby assuring the proper connection between the front and back gear shafts. The right and left cranks on each gear shaft are mutually displaced by 90 degree. The heads of the coupling and piston connecting rods on the back gear shaft are placed on the same axis, and are therefore counterbalanced.

The wheel-pairs, coupling rods and frame assembly are analogous to those on the series IS locomotives.

The existence of pistons with contrary motions and of gear shafts assured good equilibrium, which in turn permits an increased static load on the axles.

All of this taken as a whole made it possible to bring the rated power of the locomotive, with a wheel formula of 1-4-1, up to 3,000 HP, and its speed up to 130 kilometer/hour.

The motor-steam locomotive received its preliminary tests in 1940 on the test track of the All-Union Rail Transport Research Institute, and then had its operating tests in 1941-42 on various lines and main routes of the Soviet railways. It was subseqently put into trial operation on the October Railway. Figure 26 gives an external view of this locomotive.

According to the data of the operating tests, its efficiency was 11.4 percent, and the length of a run without taking on water was 350 kilometer. It was also established that with a wheel diameter of 1,850 millimeter, the internal-combustion engine picked up the load at a speed as low as 12 kilometer/hour, while acceleration to a speed at which that engine could be placed in service took place in only 100-250 meter of travel.

In 1943 substantial improvements were made in the design of the motor-steam locomotive, allowing operation on a so-called mixed cycle. This consists essentially in the introduction of a predetermined amount of steam, by means of special equipment, into the middle space of the cylinder while it is running on the Diesel cycle. In this way the mean indicated pressure could be raised to 9.3 kilogram/centimeter^2, or in other words the power of the locomotive was considerably increased.

The indicator diagrams taken during the trial runs are shown in Figure 27, 28 and 29. The first diagram characterizes the performance of the locomotive on starting to move (i.e. when working the middle cylinder spaces on steam), the second when working the middle cylinder spaces as an internal combustion engine, and the third when working on a mixed cycle.

FIGURE 26

Outside view of passenger motor-steam locomotive

[Photograph]

The consumption of fuel per unit (10,000 ton-kilometer), according to the average monthly data, is 50-60 percent of that consumed by an IS locomotive of equivalent power. The locomotive's train speed on the October Railway reached 130 kilometer/hour. Working the Diesel cycle, the locomotive developed its peak power of 3,000 HP at 78-80 kilometer/hour. The wear on the tires was about 2 millimeter after 30,000 kilometer of running.

At a speed of 60 kilometer/hour the dynamic coefficient did not exceed 1.7, according to the test data, as against 2.15 for the IS locomotive.

But the Mayzel motor-steam locomotive, like any other new machine, is not free of certain more or less substantial faults of design, which do not permit putting it into regular service. Our best designers are energetically working with the designer of the locomotive to eliminate these defects.

At the present time the Voroshilovgrad plant is completing the construction of an analogous locomotive of type 1-5-1 of 3,200 HP, intended for freight train service. All the faults of design revealed by the trial operation of the passenger motor-steam locomotive have been taken into account.

This motor-steam locomotive was designed to work on a mixed steam-gas cycle, which afforded still more opportunity for simplifying the engine and improving its tractive-thermal characteristics. In contrast to the passenger locomotive, the freight motor-steam locomotive has a four-cylinder engine with two opposing pistons in each cylinder. The pistons are connected to the gear shaft and drivers by means of connecting rods and driving connecting rods. The coupling rods that join the wheels and the gear shaft act at the same time as piston-synchronizers.

Starting from zero velocity (i.e. at the time the locomotive starts to move) and up to 10 kilometer/hour, the locomotive engine operates as a unaflow steam engine with opposing pistons, but from

10 kilometer/hour on, its operation is automatically shifted to the steam-gas cycle. The engine operates as follows: as the pistons separate, the space between them is filled by blast air, which is compressed as the pistons again approach each other. As the pistons arrive at dead center, fuel is injected into the chamber by the fuel pump. This fuel ignites, producing pressure in the cylinder, and the pistons again begin to separate; at the moment when the pressure in the cylinder becomes equal to that in the boiler, steam is automatically admitted into the chamber by a valve gear, following the line of gas expansion, with the cut-off, set by the reverse, regulating the amount of such steam. The steam mixes with the gases, is superheated to 600 degrees-700 degrees centigrade and by acting on the pistons jointly with the gases brings them to the extreme dead centers, after which the exhaust occurs.

As the load is reduced, for instance when the locomotive runs over an easier profile, it becomes possible to diminish the cut-off or pass over entirely to the gas cycle. In the latter case a tractive force of roughly 10,000-12,000 kilogram is supplied.

With these peculiarities of design a motor-steam locomotive is able to develop more power than a steam locomotive with equivalent boiler, since the work of the steam is supplemented by that of the gas; while the reduction in the dimensions of the boiler in turn makes it possible to do without a mechanical stoker and (Dogoraniya) extended combustion chamber; thus reducing the amount of metal that must be used in the locomotive per unit of power, etc. All these factors, taken as a whole, should reduce the operating costs of maintenance and care for the locomotive. This locomotive will shortly leave the plant for its trial operation.

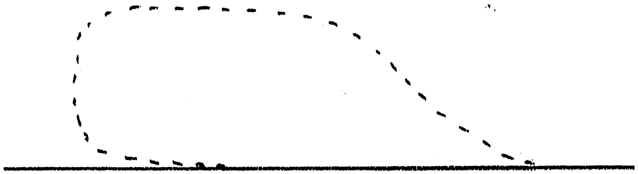


FIGURE 27

Indicator diagram on starting and working middle cylinder-chamber on steam

FIGURE 28

Indicator diagram when locomotive is operating as a motor-locomotive

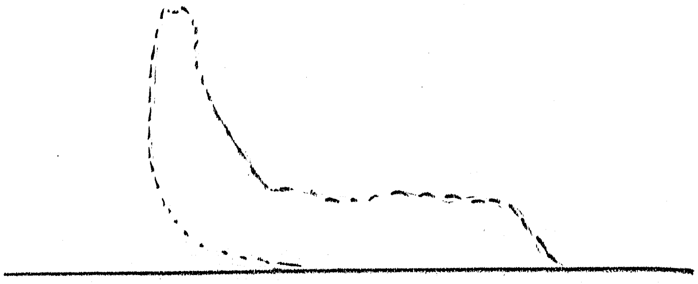


FIGURE 29

Indicator diagram on operation under mixed cycle

LOCOMOTIVE WITH VOLSKIY BOILER (USSR)

(The reader can only get a certain general idea, from this description, of the principle on which the Volskiy boiler is constructed. It is still not possible to give details, or concrete data on the results of the tests of the locomotive with Volskiy boiler on the Experimental Track, or its subsequent trial operation on the October railroad.)

Long study of the reasons for the occurance of cracks and leaks in the tube-plates of firetube boilers, and also the experimental studies of the deformation of the boiler material on firing the boilers, which were made at one time by the Gor'kiy river navigation company, yielded material of considerable value. It was established that cracks, both large and small, were due to the temperature difference between the fire-parts and the boiler barrel, and not to the pressure of steam, as had been previously assumed; that a transverse seam is dangerous, but not a longitudinal one; and that leaks in the tube-plates are likewise produced by the differences intemperature between the firing parts of the boiler and the barrel, and not by the variation of temperature in the firebox space.

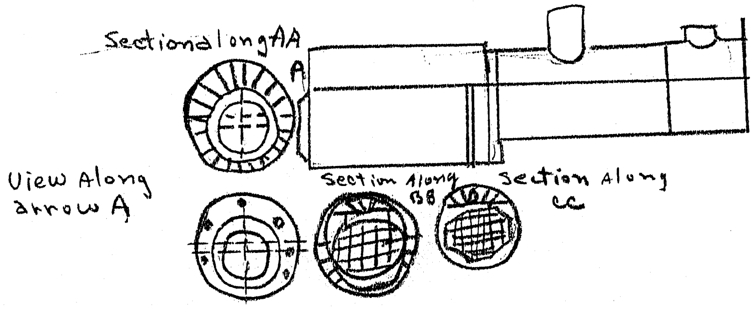
It was also established that the stresses in the transverse sections of badly encrusted boilers may go as high as 2,700 kilogram/centimeter^2 during firing, and that the factor of safety falls in some cases to one and a half times the stress, and sometimes even to the value of the stress itself, while in technology throughout the world the factor of safety is usually taken as five times; the amount of deformation of the boiler barrel along the horizontal diameter, in getting up steam, is increased to 6.5 millimeter at

2 atmospheres pressure, and falls to 2.5 millimeter at 8 atmospheres; and when firing is started, there is a downward bulge of 2-3 millimeters along the vertical diameter, but that, as the pressure increases, there is an upward bulge amounting to as much as 6 millimeter.

A boiler design with gasket reinforcement of the flues was worked out on the basis of these results of the studies and experimental observations. This design completely eliminates the temperature stresses in the boiler caused by the difference between firebox and boiler-barrel temperature, since the firetube, being lengthened more than the barrel, may freely pass out through the gasket. The gasket is protected from the action of the high temperature developed in the firebox by a special waterjacket through which cooling water circulates. Firebox stays are entirely done away with, thereby assuring full freedom of deformation to the fire portions, which are built up by welding. In this way the fire portions of the boiler are completely freed from the influence of the deformations of the outer shell.

FIGURE 30

Volskiy locomotive boiler



Three such boilers, built for the steamers "Plekhanov" and "Krasniy Transportnik" have been giving reliable service, one of them for ten years, and the other two for six.

Considering marine boilers of the proletniy type to have much in common with the locomotive boiler, Professor Volkkiy, one of the specialists of the Gor'kiy steamship line, worked out a few variants of the plans for locomotive boilers with a gasket firebox, and no firebox stays. One of these variants was approved by the MPS, and the locomotive No. 1690, series Shch, was placed at the designer's disposition for installation of a boiler according to that variant.

The boiler of this system, shown in Figure 30, was built at the "Teplokhod" plant in the city of Gorkiy, and then installed on the locomotive frame at the depot of Gorkiy passenger station.

The modernized locomotive received the designation of Shch^V, and was tested on the Test Track, after which it was placed in trial operation on the October Railway. The results of these tests and of the trial operation proved entirely satisfactory.

The merits and expected advantages of the Vol'skiy boiler consists in the fact that the very principle of its design assures: firstly an increase in the factor of safety, and consequently also enhanced safety (with respect to explosions); secondly, lengthening of the useful life, since the causes for the formation of cracks are eliminated; and, thirdly, in reducing its first cost, use of metal in construction, and operating expenses for maintenance and repairs.

Among its defects much be counted the existence of a gasket of large diameter, which requires a great amount of attention to keep tight, and also the increased weight of the boiler in operating condition (filled with water).

LOCOMOTIVE WITH VELOX BOILER (FRANCE)

The principle of the construction and operation of the Velox system boiler, of which a schematic sketch is shown in Figure 31, is as follows.

In a closed chamber in which fuel (fuel oil) is burned, the pressure is maintained at 2.5 atmospheres (by manometer). Thanks to this, the intensity of combustion per unit of volume reaches a very high value -- about 7-8 million kilocalories per square meter per hour at full boiler load.

On emerging from the chamber into a more rarefied space, the gases acquire an immense velocity -- about 200 m/sec, and, expanding in all directions, bathe the evaporative surface of the boiler, and the superheater. The evaporative surface and the superheater are separate elements, which are located around the combustion chamber (so as to minimize the heat losses).

Owing to the high velocity with which they move, the gases possess not only thermal energy, but a considerable kinetic energy as well, which is converted (on contact with the surfaces) into thermal energy and is likewise utilized for superheating. As a result, the coefficient of heat transfer is 10 times as high as in the ordinary boiler, thereby making it possible to reduce the evaporative surface of the boiler, and the superheater surface, to a tenth.

The air for the combustion chamber is delivered by an axial compressor. This consists of a turbine which is operated by the exhaust gases after they have passed through the superheater, which assures highly economical operation of the boiler installation as a whole. The forced circulation of water through the system is maintained by a pump driven by a steam turbine. For starting up (firing) the boiler, there is a special Diesel-generator installation on the tender. This feeds an electric motor which drives the compressor and circulating pump until the boiler pressure rises to the rated level.

Thanks to the slight thermal capacity of the boiler, steam is brought up to operating condition in 15 minutes after firing (20 atmospheres with a superheat temperature of 380 degrees), and after standing for a few hours the boiler only takes 5-6 minutes for this operation.

The operation of the boiler is made completely automatic by means of three controls:

A pressure control, which acts on the delivery of fuel to the chamber and thus assures a constant pressure of steam (after the superheater) regardless of engine load;

a combustion-mixture control, which acts on the speed with which the turbo-compressor runs and thus assures the proper ratio between the quantity of fuel and that of the air entering the combustion chamber;

a water-level control, which acts on the feed valve and thus assures the proper amount of water in the system.

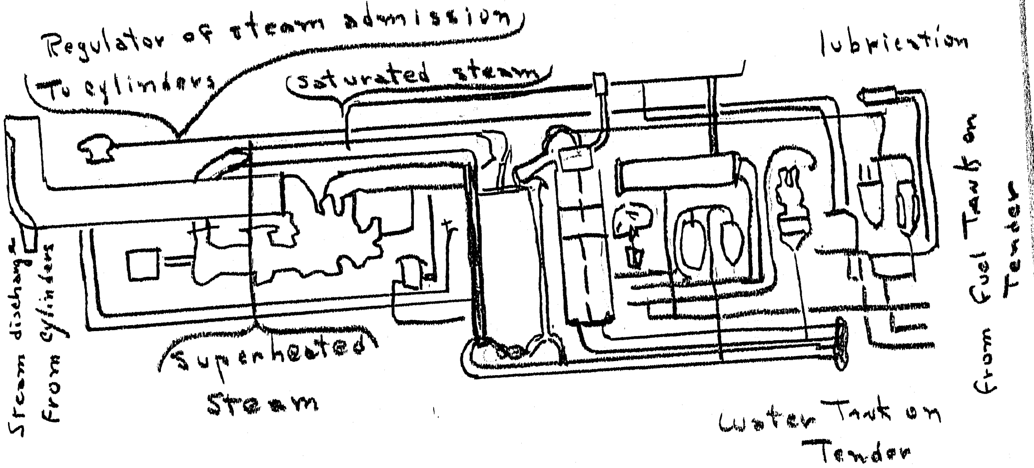


FIGURE 31

Scheme of Velox steam-generating installation

1 combustion chamber; 2 evaporating tubes; 3 water-separator; 4 superheater elements; 5 superheated-steam collector; 6 fuel-oil burner; 7 steam turbine; 8 gas turbine; 9 compressor; 10 starting motor; 11 steam turbine; 12 geared transmission; 13 first stage feed pump; 14 second stage feed pump; 15 circulating pump; 16 fuel pump; 17 lubricant pump; 18 starting motor; 19 primary filters; 20 preheaters and secondary filter; 21 air-fuel-mixture control; 22 lubricating oil cooler; 23 condensor for auxiliary equipment; 24 air-prehater; 25 regulating valve; 26 return-flow apparatus; 27 blow-off cock.

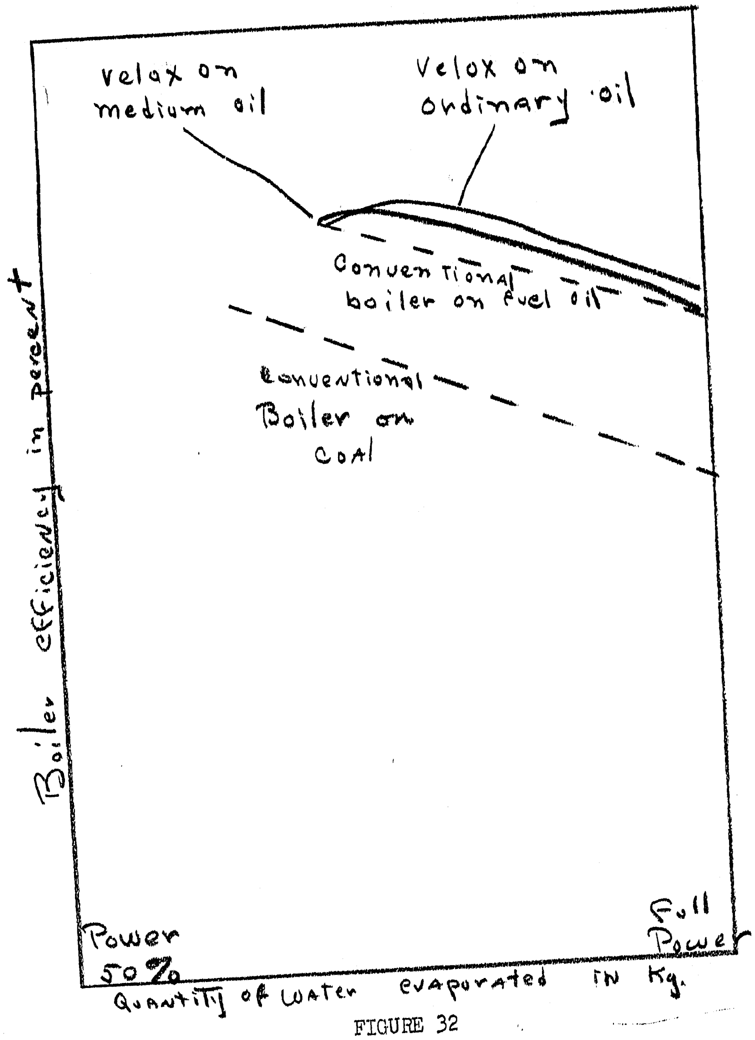


FIGURE 32

Efficiency curves of Velox boiler and of conventional boiler of standard type

FIGURE 33

Boiler installation on locomotive frame (view from right side)

[Photo]

1 boiler; 2 gas turbine; 3 air compressor; 4 suction chamber of compressor; 5 air duct for delivering compressed air to combustion chamber; 6 mud cocks; 7 device for introducing phosphate; 8 condenser for auxiliary equipment; 9 economizer; 10 starting motor for compressor; 11 admission pipes; 12 regulating mechanism; 13 column of reversing lever; 14 braking compressor; 15 sand box; 16 smokestack.

FIGURE 34

Outside view of locomotive with Velox boiler

[Photo]

FIGURE 35

Inside view of engineroom on locomotive with Velox boiler

[Photo]

The installation is mounted in the center of the locomotive body. On the sides there are corridors affording easy and convenient access to all parts and details of the locomotive power plant.

FIGURE 36

Cab (in front of locomotive)

[Photo]

1 throttle lever; 2 electric drive for reverser; 3 horn; 4 repeaters of signal indications

FIGURE 37

Water-tube marine-type boiler installed on experimental locomotive

[Photo]

[redacted] STAT

Figure 32 gives the thermal efficiency curves for the boiler, obtained from stand tests, and for comparison there are plotted on the same diagram the efficiency curves of a standard "Pacific" type locomotive boiler with a grate area of 4.25 square meter and a steam generating capacity ranging from 8 tons per hour at 50 percent load to 17 tons per hour at full load.

As will be seen from the diagram, the efficiency of the Velox boiler on half load, using ordinary fuel oil, is 86 percent, and at full load 84 percent. When medium fuel oil is burned instead, the corresponding values for the efficiency are 86 percent and 81 percent.

The corresponding values of the efficiency for the standard boiler, burning coal are 80 percent and 65 percent, but when fuel oil is burned, however, the efficiency curve almost coincides with that for the Velox boiler. It must, however, be borne in mind that the curves presented for the ordinary boiler do not accurately reflect its relation to the Velox boiler. The point is that the Velox boiler curves give the "net" efficiency, i.e. after deducting the energy consumed in providing the draft for the boiler, while the curves for the ordinary boiler also include this part of the steam energy.

Moreover, the back pressure in the engine cylinders is considerably lower with a Velox boiler than in the ordinary locomotive, and this means that a locomotive with the Velox boiler is able to develop a higher useful power with the same steam consumption as an ordinary locomotive. For instance, the back pressure in the engine cylinders of a locomotive with the Velox boiler, at an indicator power of 1800 HP, is only 0.010 to 0.020 kg/cm^2, while it amounts to 0.330 kg/cm^2 in the cylinders of an engine with an ordinary boiler, under the best possible exhaust conditions. As a result the engine with the Velox boiler assures an advantage in power amounting to about 100 HP at a speed of 90 kilometer/hour and 170 HP at 120 kilometer/hour.

The whole boiler installation weighs 18 tons and is mounted on the frame as shown in Figure 33.

This type of boiler gave the locomotive a most unusual outward appearance, which remainds one of the streamlined motor-locomotive (Figure 34) with a convenient passage with servicing the engine (Figure 35), and the cab (Figure 36) at its head.

The locomotive develops 1800 HP at the drawbar. The fact that it did not go into series production is evidence that its design and operating characteristics do not meet the present-day requirements of the railways.

THE 2-3-2 LOCOMOTIVE WITH WATER-TUBE MARINE-TYPE BOILER AND INDIVIDUAL DRIVE (FRANCE)

(Built in 1938)

This locomotive differs radically from the standard types not only in its drive, but also in its boiler installation, the working parameters of the steam, and the type of prime mover used.

The boiler, of which Figure 37 gives a general view, is of the water-tube type used on ocean steamers, and consists of two continuously interconnected parts: the feedwater heater and cleaner (designed for a pressure of 20 atmospheres) and the boiler proper, in which the steam is generated under the working pressure of 60 atmospheres. The feedwater first enters the first part, where it is brought to a predetermined temperature and freed of impurities, and is then transferred by pumps to the second part of the boiler.

Six low-power, very compact piston steam-engines of 500 HP each (Figure 38 shows one of them) are used as the prime mover. They are located over each driving axle, on each side of the locomotive (photograph on Figure 39), and are connected to the axles by a system of gears and a hollow shaft, usually used on electric locomotives. Thus the torque of two engines with a total of 1,000 HP is transmitted to each axle.

The engines are of the three-cylinder, unaflow type, i.e. having the release of the exhaust steam take place through a special passage of which the port opens at the end of the piston stroke. This prevents steam from condensing in the cylinders and avoids losses due to it. The cylinders are 150 millimeter in diameter, and the piston stroke is 255 millimeter. The engine does 1,000 revolutions per minute. Draft is provided by an exhaust nozzle. The boiler is coal-fired. The diameter of the drivers is 1,550 millimeter, and the locomotive develops 3,000 HP.

THE 16-CYLINDER 2-4-2 LOCOMOTIVE (UNITED STATES)

(Plans)

The locomotive of which Figure 40 is a schematic diagram, is designed to pull heavy 14-car passenger expresses at a speed of up to 160 kilometer/hour, and develops 5,000 HP.

FIGURE 38

One of the steam engines

[Photo]

Its essential peculiarity is the individual drive provided for each of the four driving axles from a separate Besslor 4-cylinder steam engine through a gear drive. This method of transmission makes it possible to transmit a power of up to 1,500 HP to each axle.

In addition to this, an ideal uniformity of torque is assured, since 32 impulses of the torque of 16 cylinders act in unbroken sequence on the axles for each revolution of the wheels. The gear drive and all moving parts of the steam engines are enclosed in a gearbox to which abundant lubrication is supplied under pressure by a special pump.

The admission of steam into the cylinder valve gears, as well as the reversing of the locomotive, is accomplished automatically from the cab by an electropneumatic controller. The diameter of each cylinder is 240 millimeter, and the piston stroke is 178 millimeter.

The watertube type boiler has a steam generating capacity of 36,000 kilogram/hour at a working pressure of 24.6 atmospheres.

FIGURE 39

Outside view of El'zass Company Locomotive [Societe d'Alsace ?]

[Photo]

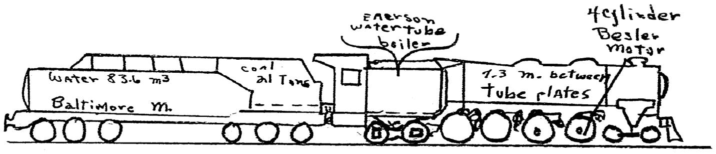
The steam generating capacity can be increased by 15 percent. The boiler heating surface is distributed as follows:

Fire box	72 square meter
Tubes	468 " "
Superheater	144 " "
Total with superheater	684 " "
Grate area	7.44 " "

The superheater also has elements for feedwater heating. The guaranteed steam consumption in the engines is 6.35 kilogram per HP per hour. When the locomotive develops its full 5,000 HP, the water consumption does not exceed 31,750 liters of water per hour.

Thaks to the fact that the frame, springs, and axle-boxes are located on the outside, while each of the power equipment units and its corresponding pair of wheels constitute a single assembly, all of the equipment can easily be dismantled or its separate parts or details replaced where necessary by merely rolling out the wheel-pair in question into the repair-pit.

The all-over length of the locomotive between buffers is 34,700 millimeter. The total weight is 162 tons, of which 105 tons is imposed on the driving axles. The tender weighs 142 tons and holds 83.6 cubic meter of water and 21 tons of coal. The tractive force at starting, with a coefficient of friction of 0.28, is 30,000 kilogram. Taking the uniform torque of the drivers into consideration, the realization of so high a coefficient of friction is considered entirely practicable.



Total weight of locomotive and Tender - 304 Tons.

Figure 40

16-Cylinder locomotive with water-tube boiler and individual drive

To reduce the loss of power in overcoming wind resistance, at high speeds, the locomotive and tender are enclosed in a streamlined shell.

CRANKSHAFT LOCOMOTIVE (FRANCE)

(Built in 1938)

This locomotive is designed to haul light three-car high-speed passenger trains in interurban service. It develops 2,000 HP and has a rated speed of 150 km/hour.

It bears a certain resemblance in design to that of an automobile. Its power equipment consists of 8 steam engines, a watertube boiler, superheater, draft-air heater and other devices and apparatus.

The steam engines have 8 cylinders, with gasoline-engine-type valve gears, and each engine develops 250 HP.

The watertube boiler has one upper and one lower steam collector. It is oil-fired and has a working pressure of 50 atmospheres.

The total weight of the locomotive is 80 tons, all of which is distributed on the two four-axle leading trucks. Wheel diameter is 760 millimeter.

The torque from each steam engine is directly transmitted to the corresponding driving axle. There is no gear drive between engine shaft and axle. Each leading axle is constructed in the form of a crankshaft that takes up the reciprocating motion of the connecting rod and transforms it into rotary motion. The crankshaft is in turn connected with the wheel discs not rigidly but through a system of springs that serve as shock-absorbers or amortizers, to absorb the shocks and vibration during the running of the locomotive. Thus a constant ratio is maintained, throughout the entire range of speeds, between the revolutions of the steam engines and the speed of the rotating wheels.

Another locomotive of entirely analogous design, but developing 1,000 HP, has been constructed by the same firm. It differs from the one described only in having 4 engines instead of 8. Moreover, the torque from these four engines is transmitted to four axles, while the remaining four act as free axles. Accordingly the adhesive weight of the locomotive is 40 tons.

LOCOMOTIVE WITH LONGITUDINAL-SHAFT DRIVE (FRANCE)

(Built in 1938)

This locomotive, like that described above, is designed to service light-weight passenger trains.

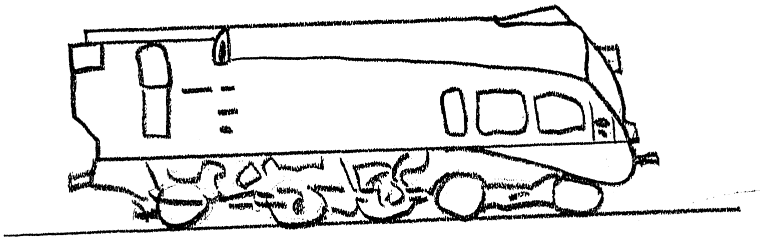


FIGURE 41

Locomotive with longitudinal-shaft transmission

The wheel formula of the locomotive is 2-3-0. Its engine is of 16-cylinder unaflow type, with 1,000 r.p.m., and a V-shaped cylinder arrangement, with 8 in each group, located in the front of the locomotive.

The torque of the shaft, moving longitudinally along the axis of the locomotive, is transmitted to the two driving axles by worm gears and hollow shafts. The design of the transmission bears a certain resemblance to that of an automobile (its oil-filled crankcase design), and, the designer claims, should result in considerable savings in maintenance and care of the locomotive. The motor is capable of developing 1,200 HP at a pressure of 20 atmospheres, 50 percent cut-off and 1,000 r.p.m.

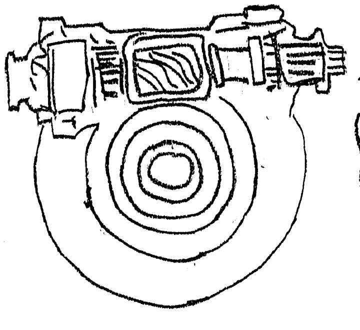


fig. 42

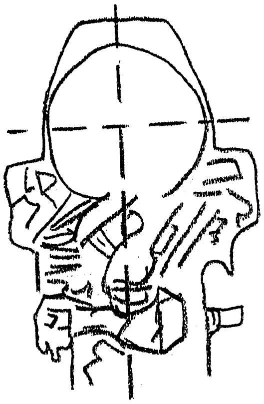


Fig. 43
(caption next page)

FIGURE 42

Engaging mechanism of one of the driving axles drawing on preceding page

FIGURE 43

Section of V-shaped engine-cylinder

Figure 42 shows the mechanism for engaging one of the driving axles of the locomotive, and Figure 43 gives a cross-section of the locomotive along the V-shaped engine cylinders.

SINGLE-CYLINDER TANK LOCOMOTIVE (GERMANY)

(Plans)

This locomotive was planned with its possible use to replace the fast railway motor-cars, hauling fast trains, in mind. These conditions thus determined its specific design peculiarities.

The point of using steam locomotives for this service is that they can burn any heavy fuel, while railway motor-cars require high-grade liquid fuel.

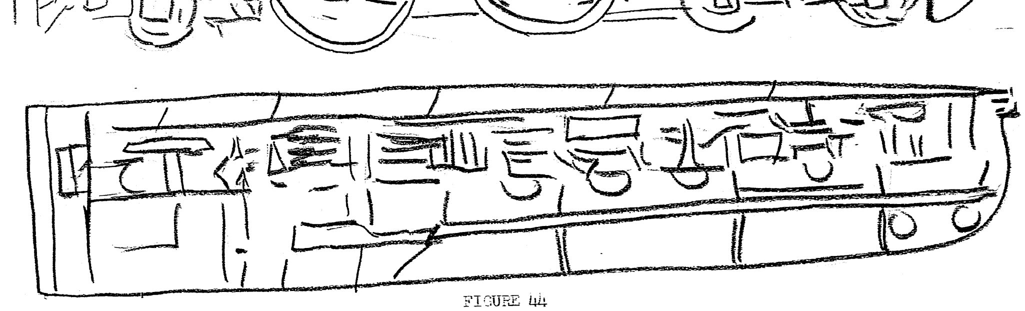


FIGURE 44

Longitudinal and horizontal sections of single-cylinder locomotive

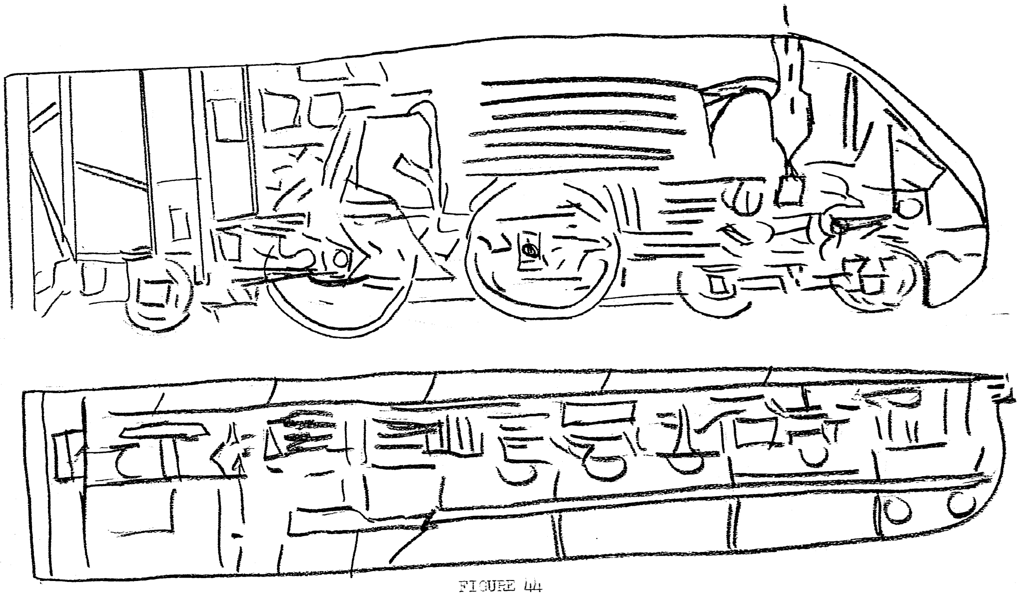


FIGURE 44

Longitudinal and horizontal sections of single-cylinder locomotive

The peculiarity of this locomotive is in its use of a single inside cylinder which is thermally protected in position and has two common valves, and an admission and an exhaust valve, each actuated by its own link. Figure 44 gives a longitudinal and a horizontal section of the locomotive.

The principal advantage of such a locomotive over the ordinary standard two-cylinder locomotives is claimed by the designer to reside in its higher thermal efficiency and lower unit weight per unit of power.

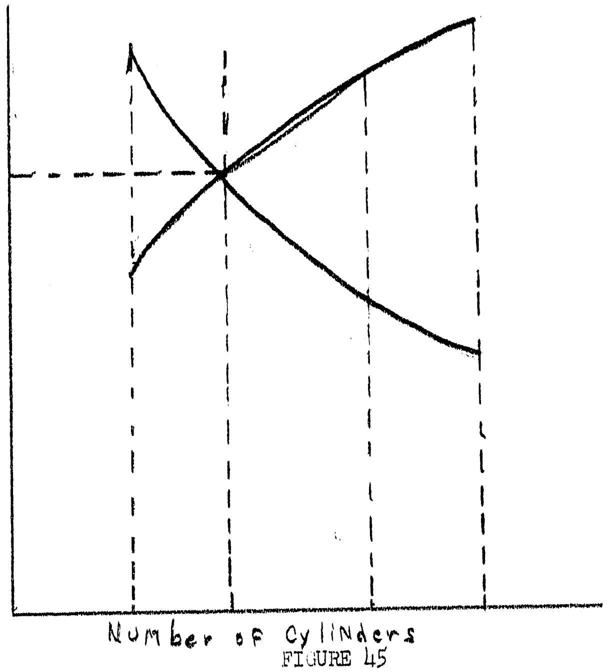


FIGURE 45

Ratios between cylinder diameter (curve 1), ratio of cylinder-surface to working volume of cylinder (curve 2) and number of cylinders, (curve3) of various engines, with same working volume and length of piston stroke, that of the two-cylinder machine being taken as 100 percent.

Curve 1 is plotted for cylinder diameter of 400 millimeter for the two-cylinder engine, and piston stroke of 660 millimeter. Curve 2 is for all conditions.

Its steam consumption per HP/hour is 90 percent of that in a two-cylinder steam locomotive of equivalent power. In determining the saving in steam consumption for this locomotive, the designer proceeds from the following considerations.

To obtain an equal amount of work from two engines - a single-cylinder and a two-cylinder engine -- having the same length of piston stroke, the diameter of the single cylinder must be 1.41 times that of the double cylinders. In other words, if the cylinder diameter of the two-cylinder engine is taken as 100 percent, then it must be 141.4 percent for the single-cylinder engine. This relation is represented graphically by curve 1 of Figure 45. It will be seen from it that this ratio is 81.5 percent for a 3-cylinder engine and 70.7 percent for one with four cylinders.

On the other hand, the ratio between cylinder area and working volume exerts a strong influence on the unit consumption of steam. The higher this ratio, the higher the steam consumption, and conversely. The value of the ratio bears a definite relation to the number of cylinders. If the ratio is taken as 100 for a 2-cylinder engine, it is 77.5 (curve 2, Figure 45) for a single-cylinder engine, 117.1 for three cylinders, and 131.7 for four.

In addition, the position of the cylinder, as it is on all sides, assures a supplementary saving of steam amounting to at least another another 5 percent. Thus the single-cylinder locomotive consumes roughly 10 percent less team than one with two cylinders.

The advantage with respect to design and weight proportions also remains with the single-cylinder locomotive, as is shown by the following table 4.

Table 4

Indices [1]	Locomotive Single-cylinder [2]	 Two-cylinder Henschel [3]
Diameter of cylinders in millimeter	1 x 600	2 x 380
Piston stroke in millimeter	660	660
Diameter of drivers in millimeter	2,300	2,300
Total length between buffers in millimeter	14,000	15,000
Rigid wheel base in millimeter	2,700	3,000
Total locomotive base in millimeter	10,500	10,825
Steam pressure in boiler, atmospheres	16	20
Evaporative surface in direct contact with flames, in square meter	90	105.2
Heating surface of firebox in square meter	8.1	9.5
Heating surface of tubes in square meter	81.9	95.7
Heating surface of superheater in square meter	35	36.1
Grate area in square meter	1.75	2.04
Adhesive weight in tons	36	40
Weight of locomotive in operating condition in tons	80	89.3
Weight of locomotive, empty, in tons	57	64.5

[1]	[2]	[3]
Water supply in cubic meter	15	15
Coal supply in tons	4	4.5
Normal speed in km/hour	150	150
Maximum speed in km/hour	160	160

The running qualities of the single-cylinder locomotive likewise should be superior to the 2-cylinder type. The reciprocating masses of the former can be better balanced (roughly three times as well), since the single-cylinder locomotive has twice the number of wheel discs on which counterweights may be placed. Thus the amplitude of the recoiling motion of the locomotive can be reduced from 3.1 millimeter to 2.5 millimeter.

Besides this the "hunting", or snaky motion of the locomotive about its vertical axis, is absent, since when there is only a single cylinder, disposed along the central longitudinal axis of the locomotive, the moment of sinuosity is zero; and similarly the single-cylinder locomotive eliminates the lateral swaying [Kachka] which is unavoidable in the two-cylinder locomotive and results from the periodically changing pressure against the side rods.

It follows from all of this that the single-cylinder locomotive is better adapted for high-speed movement than the two-cylinder.

The presence of two separate common valves, one admission and one exhaust, affords the following advantages:

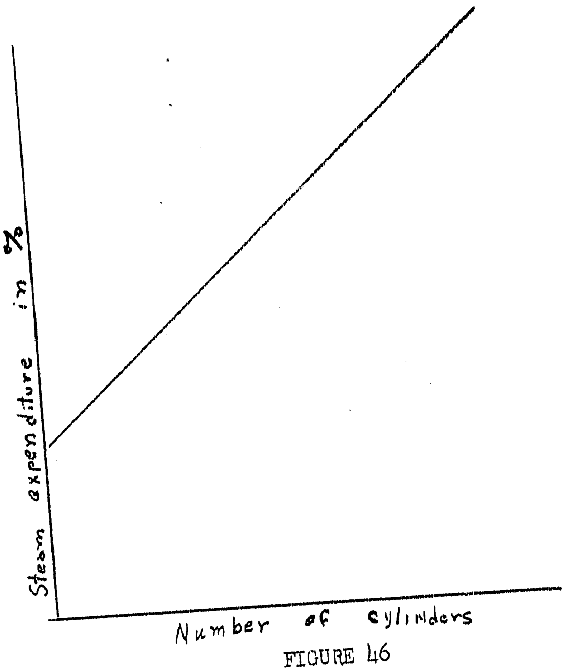


FIGURE 46

Effect of number of cylinders on the steam rate

thermally, the complete separation of the "warm" from the "cold" considerally reduces the losses from cooling;

the internal admission and exhaust makes it possible to use a valve gear without a stuffing box, thus eliminating the steam losses in the part;

it is possible to increase the cross-section of the exhaust and thus to diminish the back pressure;

device for equalizing cylinder pressure (while the locomotive is running without steam) may be placed, if the transverse section of the exhaust port is large, in the steam admission valve.

What is termed a starting mechanism is one peculiar feature in the design of the single-cylinder locomotive. It is provided for the case when the crank is ± 10 percent off dead center when the locomotive comes to a stop, in which case a maximum of half a crank turn is required.

This device is provided in two variants by the plans:

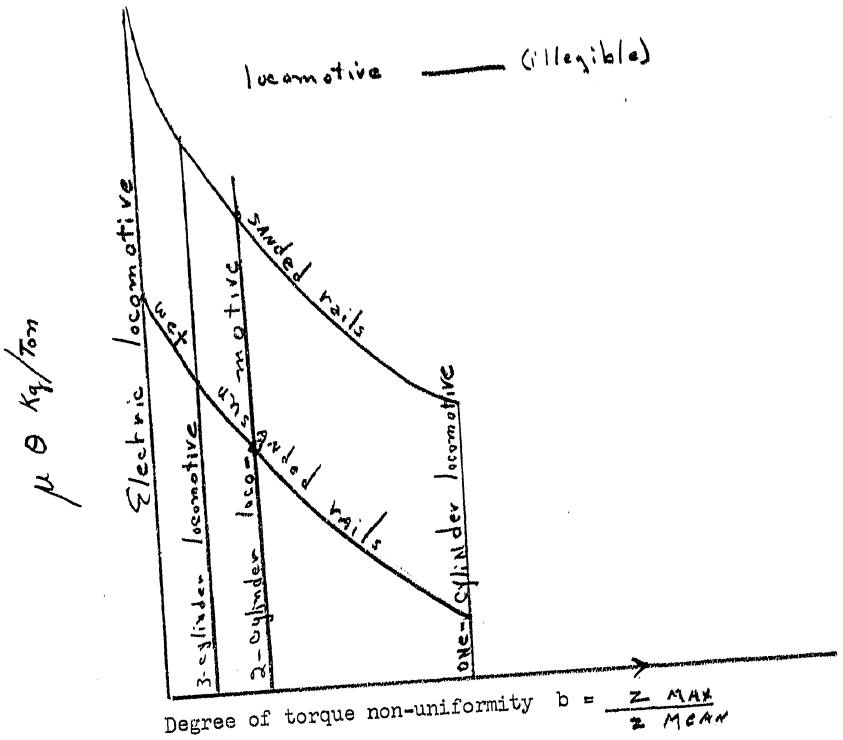
(1) starting from rest by means of a parasitic gear and a swinging steam cylinder; in this case the cylinder, fed by live steam, serves to actuate the driving parasitic gear which is engaged with a toothed disc, flange-coupled to the driving wheel;

(2) starting from rest by using a 6 HP electric starting motor (of the Bosch type, with a sliding rotor), fed by a 5 kw. turbo generator installed on the locomotive and ordinarily used for lighting the locomotive and the train. When the need arises, the motor is connected up to the generator circuit and transmits torque through a double gear drive and the above-mentioned toothed disc to the driving axle. After a half-turn, the crank of the motor is automatically disconnected by the action of a special spring.

The acceleration of the locomotive from the instant of starting up to the maximum speed (150-160 km/hour) takes place in exactly the same way as with the two-cylinder locomotive. The only difference is that the track must be sanded until 40 km/hour is attained. Unless this is done, the one-cylinder locomotive, by virtue of its inherently high degree of non-uniformity, would be unable to start from rest and pick up speed without strong throttling of the steam pressure, which would in practice mean cutting down its thermal efficiency. The diagram of Figure 47 very graphically

[Figure 47 on the following page]

illustrates this, and at the same time explains the causes that are responsible for it.



Reliable Coefficient of friction used, in relation to the degree of non-uniformity of the torque $\sigma = \frac{Z_i \ MAX}{Z_i \ MEAN}$

It will be seen from the diagram that the reliably utilized traction coefficient for the single-cylinder locomotive reaches roughly the same value as for the two-cylinder locomotive only when the tracks are sanded. This circumstance is not a substantial factor for this locomotive, however, given the specific nature of the service for which it is designed -- to haul high-speed trains that only make a few stops at intermediate stations during the whole run.

LOCOMOTIVE WITH PISTON ENGINE AND EXHAUST STEAM TURBINE (UNITED STATES)

(Plans)

This locomotive differs from the standard locomotive mainly in having, in addition to its single-expansion steam engine, a low-pressure steam turbine mounted on a welded saddle of special construction.

The torque is transmitted from the turbine shaft to one of the coupled axles through a hydraulic clutch, a hollow shaft, and flexible cup-drive elements. The latter amortize (absorb) all lateral and vertical shocks and vibration caused by the unevenness of the roadbed and track and thus assure reliable functioning of the whole transmission system.

Figure 48 gives a longitudinal section and plan of the exhaust steam turbine and a transverse section of the hydraulic clutch.

Under normal locomotive operating conditions, the exhaust steam from the cylinders of the steam engine enters the low pressure turbine, and after giving up its energy to turning the rotor, is exhausted to the outside air. Other combinations of the work of the prime movers of the locomotive are also possible. For instance, in hauling a light (or empty) train the locomotive can operate more economically (especially at high speeds) on the turbine alone. In this case the engineman closes the throttle, thus cutting the steam engine out of operation, while the steam from the boiler then enters the turbine directly, after first passing

[Figure 48 on the following page]

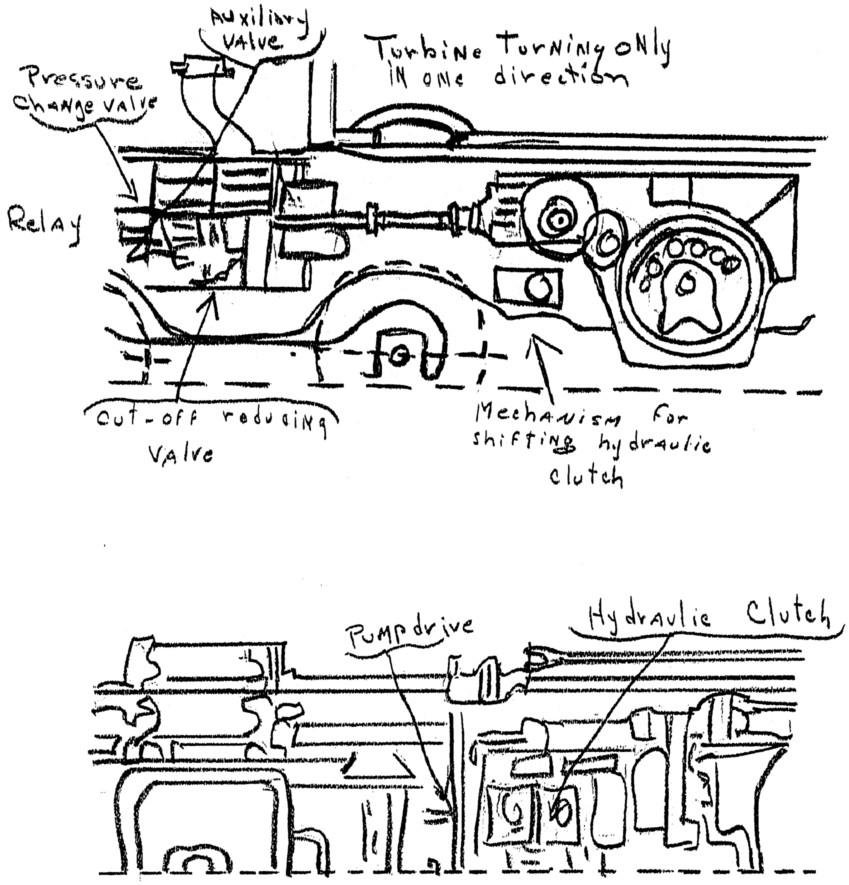


FIGURE 48

Longitudinal section and plan of exhaust-steam turbine, and transverse section of hydraulic clutch through the reducing valve. When the maximum power is desired from the locomotive, the turbine is likewise switched over to direct steam feed from the boiler, it first being throttled, while the exhaust steam from the cylinders is passed out through the exhaust nozzle and thus intensifies the draft through the boiler. The turbine may be turned on and off at any moment, and at whatever speed the locomotive may be traveling.

The system of devices for controlling the locomotive consists of a set of steam admission valves regulated by a cam roller, an auxiliary valve for controlling the intercepting valve, a combination shut-off and reduction valve, and hydraulic clutches which are engaged by the action of a steam-actuated relay or the valve of the hydraulic drive.

The function of the intercepting valve is to draw off the spent steam from the cylinders either into the receiver that feeds the turbine or into the exhaust nozzle; the auxiliary valve serves to feed the turbine with steam (before or after it has entered the throttle, so that the turbine can operate with the throttle closed; the shut-off-reducing valve is designed to perform two functions, first to feed the turbine with live steam through the auxiliary valve, in which case it acts as a throttle; and then to cut off the delivery of live steam to the receiver.

If under the operating conditions for which the locomotive is designed the use of the turbine is required only for a single direction of travel -- for instance when the locomotive is running forward -- then only a single hydraulic clutch is provided. When the turbine is needed for both forward and backward motion, two hydraulic clutches are required, and the transmision system as a through the reducing valve. When the maximum power is desired from the locomotive, the turbine is likewise switched over to direct steam feed from the boiler, it first being throttled, while the exhaust steam from the cylinders is passed out through the exhaust nozzle and thus intensifies the draft through the boiler. The turbine may be turned on and off at any moment, and at whatever speed the locomotive may be traveling.

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If under the operating conditions for which the locomotive is designed the use of the turbine is required only for a single direction of travel -- for instance when the locomotive is running forward -- then only a single hydraulic clutch is provided. When the turbine is needed for both forward and backward motion, two hydraulic clutches are required, and the transmision system as a whole is thereby somewhat complicated.

The mechanism for shifting the turbine from forward to reverse operation, and vice versa, is interlocked with the normal reversing mechanism and the hand lever for controlling the turbine. The latter lever makes it possible to effectuate the various combinations of the work of the prime movers that have already been mentioned.

The fuel saving, according to the estimates of the plans, will amount to 20 percent to 25 percent in comparison with the conventional reciprocating steam locomotive.

PART THREE

HIGH PRESSURE LOCOMOTIVE

GENERAL INFORMATION

High pressures and high superheat temperatures have already gained widespread acceptance in stationary installations.

The attempts to employ them in locomotive installations as well date back to around the middle of the 20's.

What is the basis for this tendency towards high pressures in steam-power installations in general, and in locomotive installations in particular?

As is generally known, the amount of work that can be obtained from the same weight of steam is determined by the limits of its expansion in the engine cylinders, i.e. by the difference between its initial and final pressures. As this difference increases, the fuel consumption per unit of work (HP-hour) proportionately declines. Calculations show that the fuel consumption in a steam power installation with aworking boiler pressure of 140 atmosphers and atmospheric back pressure in the cylinders is about 70 percent of that required at the ordinary pressure of 14 atmospheres, at a given temperature. It is easy to understand in view of this why it is so important (from the practical point of view) to increase pressures and superheat temperatures.

But the solution of this problem in locomotive installations comes up against a whole string of serious difficulties that have to do only with matters of design. Let us enumerate the principal ones:

pressures above 25 atmospheres demand the use of watertube boilers; in turn the clearance and weight limitations imposed on locomotives create serious obstacles to the design of watertube boilers that would satisfy all operating requirements (simplicity of design, safety and durability, low cost maintenance and upkeep, etc.);

special valves and valve-accesories are required to withstand the great compressive stresses and abrasive action of steam at high pressures;

in view of the peculiarities of its construction, the watertube boiler cannot serve as an element that, like the ordinary locomotive boiler, assures the safety of the locomotive;

when watertube boilers having boiler barrels are used, it is difficult to maintain the proper water-level on the upgrades; pure feedwater (without impurities) is required, and since forced circulation is necessary, the pumps must be very reliable;

the superheater elements must be manufactured out of special materials;

it is difficult to reserve enough steam to handle peak loads of short duration;

complete combustion in the firebox is required, or high losses in the exhaust gases will be unavoidable;

the question as to what type of prime mover (whether direct-acting, or compound steam engine, or turbine) would be most rational for high-pressure locomotives from the technical-economic point of view has still been insufficiently investigated, and similarly the question of the most advantageous level of steam pressure still remains controversial, taking due account of the fact that the curve of thermal efficiency rises steeply only to pressures of 45-50 atmospheres, and then flattens out more and more.

It is precisely for these reasons that the experimental medium and high pressure locomotive (25-60 and 100-120 atmospheres respectively) constructed in the USSR and in a number of foreign countries (England, Germany, France, the United States, Switzerland) have been unable to meet all modern requirements of operation and were not accepted for series production.

Nevertheless the problem of the transition to high pressures in locomotive installations has not been removed from the order of the day, and the scientific and technical and inventive thought of the world continues to work intensively towards its solution.

The following description of three high-pressure locomotives which have already been built and tested, and of three others for which the plans have been drawn, will illustrate different variants for the solution of this exceedingly difficult problem.

2-4-1 6--ATMOSPHERE LOCOMOTIVE (USSR)

(These plans were worked out in 1932 by NIS LIIZhT. In 1935 this institution, jointly with the TsKKB, completed working plans for the construction of an analogous high-pressure locomotive, but this time with the wheel formula 1-4-2 instead.)

The plans provided for the principal items of equipment of this locomotive to consist of:

a high-pressure boiler with two superheaters, one high-pressure and the other intermediate to low-pressure;

a low-pressure boiler;

a two-cylinder compound engine;

an economizer;

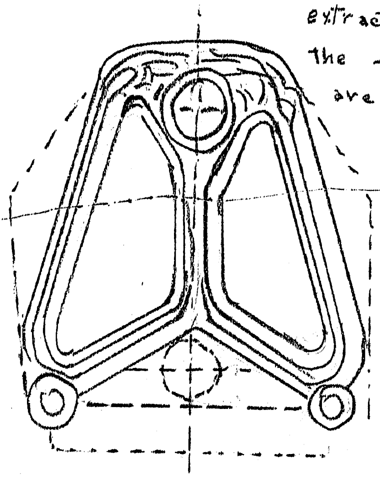
two feedwater heaters, one high pressure and the other low pressure;

a draft-air preheater;

high pressure and low pressure pumps;

a permutit water-treatment tank (on the tender) with filters, for chemical treatment of the feedwater.

The high pressure boiler is of watertube type, with four drums (Figure 49 and 50). The upper drum is entirely forged out of chrome-molybdenum steel with an inside diameter of 600 millimeter. The lower drums are made of the same steel, with diameter of 450 millimeter for the front drum and 300 millimeter for the two back drums. The external surface of the boiler tubes actually heated is 98.4 square meters. The grate area R = 4.4 square meters. The firebox volume



Note: to make it possible to extract the superheater the —— and the ——— are fixed on bolts [?]

FIGURE 49

Transverse section of water-2 boiler

V = 19 cubic meter, and the ratio V:R = 4.3.

The high pressure superheater is of radial type and consists of two loops placed between the water-tubes. [KIPYATEL'NAYA TRUBA, a large water column, not to be confused with the VODOTRUBA or small water tubes, through which water passes and is heated, and which give the name to the "watertube boiler" in distinction to the firetube boiler.] The latter connect the large upper drum with the two lower drum of smaller diameter between the second and third ports. The superheater tubes, 38/32 millimeter in diameter, are made of molybdenum steel. The area of the superheater heating surface is 26 square meter.

The low pressure superheater consists of flat sections placed between the tubes that connect the upper large central drum with the two lower drums in the front of the boiler. The sections are made of seamless tubing 38/32 millimeter in diameter, with horizontal coils, electrically butt-welded at the ends. The area of the superheater heating surface is 30 square meter.

The low-pressure boiler is welded, and consists of a single drum 1850 millimeter in diameter, with walls 16 millimeter thick (Figure 50 and 51). The 392 firetubes have the normal diameter of 51/46 millimeter, and extend 2150 millimeter between the tube-plates. The total heating surface of this boiler is 135 square meters. It functions as a thermal accumulator under the variable regime of boiler operation, furnishing low-pressure steam to supply its own needs, and also playing a role as a mud drum or sedimentation tank for the feedwater, in addition, the process of steam generation that takes place in it favors the partial separation of the sulfates, and particularly of the air and gases contained in the feedwater.

V = 19 cubic meter, and the ratio V:R = 4.3.

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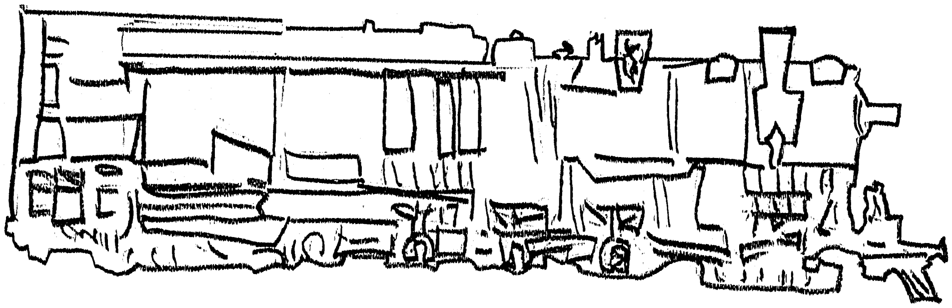

FIGURE 50

Longitudinal section of high-pressure boiler

The two-cylinder engine is selected with the thought of reducing to a minimum the number of stuffing-boxes and valves, and also of making it possible to utilize the running parts of the series IS locomotives. The diameter of the high-pressure cylinder is 365 millimeter, that of the low-pressure cylinder is 610 millimeter, and the piston stroke is 760 millimeter.

The economizer has a heating surface of 30 square meters and is constructed in the form of flat coils, rolled into four collectors and located at the corners of the unaflow part of the gas-passage between the high-and low-pressure boilers.

The feedwater heaters are placed above, in the smokebox. One of them, the high pressure, is heated by steam bled from the high-pressure cylinder, while the other, the low pressure, workds on the spent steam from the low-pressure cylinder.

The draft-air heater has a heating surface of 95 square meter and uses the heat of the exhaust gases at temperatures ranging from 300 degrees down to 220 degrees centigrade, thus preheating the draft air to 80 degrees centigrade. The temperature of the exhaust gases is thus reduced to 220 degrees centigrade (instead of the usual 350 degrees-300 degrees centigrade), thereby reducing the heat losses to 9 percent instead of the ordinary losses of 12-13 percent.

The feedwater pump is a direct-acting steam type tandem, double-acting pump with a rated head of 70 kg/cm and a capacity of 15 tons per hour or 4.16 liters per second.

The permuit filter handles 8 tons of water an hour and supplements the thermal treatment of the feedwater in the superheaters and boiler-evaporator, and assures reduction of the hardness of the water from 20 degrees to 1-2 degrees. The permutit installation has been adopted as a temporary measure and is not organically connected with the locomotive design, since in servicing high-pressure locomotives in certain railway sections that equipment will be at the stations, and softened water will be delivered to the tender.

The working cycle of the locomotive installation proceeds as follows.

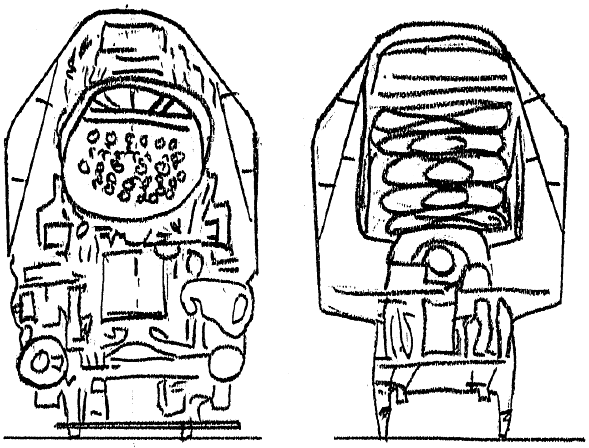

FIGURE 51

Transverse section through cylinder and low-pressure boiler (left) and through economizer (right)

Steam at a pressure of 60 atmospheres passes from the high-pressure boiler into the collector, thence to the superheater, and finally into the superheated steam chamber at a temperature of 450 degrees centigrade and a heat content of 789 calories; thence it enters the cylinders through the throttle of the steam supply pipe and expands (adiabatically) to 10-18 atmospheres (depending on the cut-off). From the high-pressure cylinder the steam passes through the oil-separator and enters the low-pressure superheater, where it is superheated to 325 degrees-350 degrees centigrade, and is collected in the superheated steam chamber; from that chamber it enters the low-pressure cylinder, expands to 1.2 atmospheres and is conducted through the exhaust nozzle into the outer air, creating a draft through the boiler.

The boiler is fed as follows. Water from the tender tank is pumped by the low-pressure pump into the low-pressure feedwater heater, in which it is heated by a part of the exhaust steam from the low-pressure cylinder (17 percent by weight) to a temperature of 90 degrees-100 degrees; thence it goes to the high-pressure feedwater heater, where it is heated by a part of the intermediate steam from the high-pressure cylinder (16 percent by weight); thence it passes into the low-pressure and is heated by the exhaust gases.

Part of the water delivered is evaporated in the low-pressure boiler and the steam obtained used for service requirements (pumps, whistle, syphon, brakes, etc.), while the remainder of the water is delivered by a pump into the collector and water economizer, where its temperature is brought up to 250 degrees-260 degrees centigrade, and from there it goes to the high-pressure boiler.

The steam-generating capacity of the boiler at normal power (2,000 HP) is 9,500 kg/hour, of which 1,500 kilogram goes for service requirements. A fuel consumption of about 1,200 kg/hour corresponds to this output of steam.

The rated heat liberation of the watertube firebox of the boiler amounts to about 50,000 kcal per square meter; it may be boosted for short periods of forcing to 75,000 kcal per square meter.

The locomotive is started up as a general rule by live steam from another locomotive. In exceptional cases steam may be gotten up by the following method. Fuel is thrown on the grate and ignited. When a steam pressure of 1-2 atmospheres has been obtained, the valve is opened and the steam allowed to pass into the first and second superheaters. Cooling these superheaters off, the steam then enters the low-pressure boiler. However, when this method of getting up steam is used, especially in forcing the boiler, there is always some danger of overheating, [Perezhog] the superheaters before they are cooled down by the steam from the low-pressure boiler.

In case of damage to the high-pressure superheater, it can be turned off, together with the high-pressure engine, and the locomotive run on the low-pressure steam engine by using reduced steam.

In case of damage to the low-pressure superheater, the low-pressure engine is turned off, and the exhaust steam from the high-pressure cylinder let out through the exhaust nozzle.

If both superheaters should go out of commission, the high-pressure steam is by-passed into the low-pressure boiler, whence it is conducted to the low-pressure engine.

The high-pressure boiler is attached to the frame by a special housing [karkasa] consisting of 6 portals of box-like section made of sheet iron electrically welded. The boiler is lined with fire-brick.

The high pressure cylinder is cast in a ~~single~~ unit with the valve chest. The clearance in front and in back is about 7 percent. The cylinder is not attached to the locomotive frame but to a special casting. The throttle is placed in the steam supply pipe over the high-pressure cylinder.

The low-pressure cylinder is similar in design to the high-pressure cylinder and is cast iron, with a separate valve chest.

The locomotive weighs 126 tons in operating condition and 118 tons empty. Its adhesive weight is 80 dons, and the weight imposed on the springs is 96,305 kilogram. The height of the boiler axis above railhead is 3,645 millimeter. The total wheelbase is 12,975 millimeter and the rigid wheelbase is 5,775 millimeter. The total length of the locomotive is 17,910 millimeter.

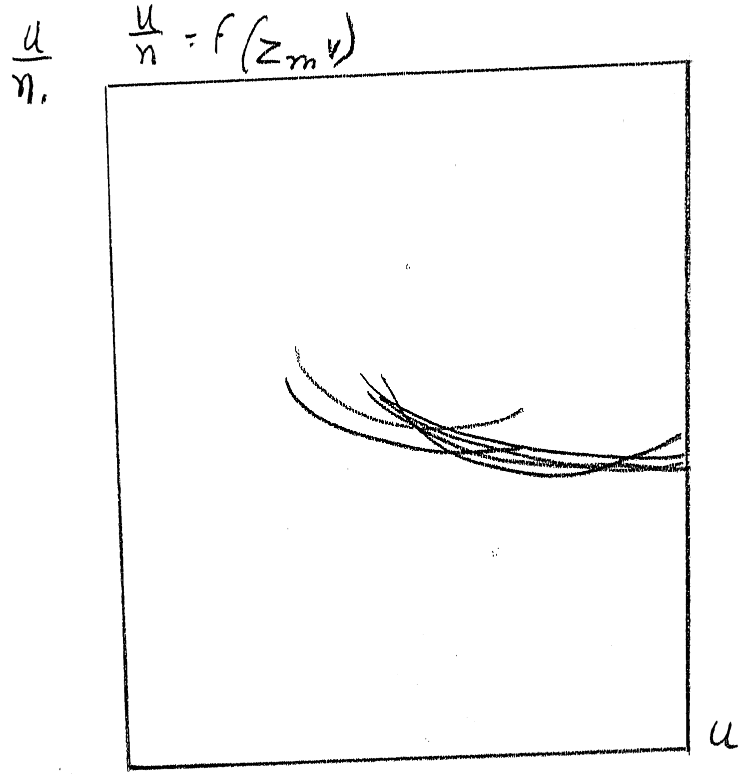

FIGURE 52

Curves of steam rates at indicated power for various speeds and rates of boiler forcing pressure cylinder and is cast iron, with a separate valve chest.

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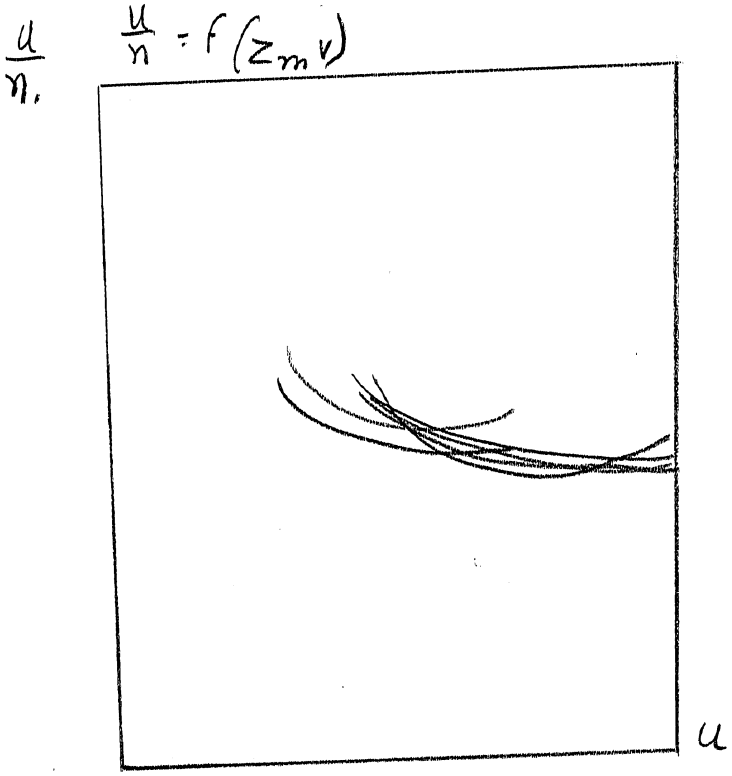


FIGURE 52

Curves of steam rates at indicated power for various speeds and rates of boiler forcing

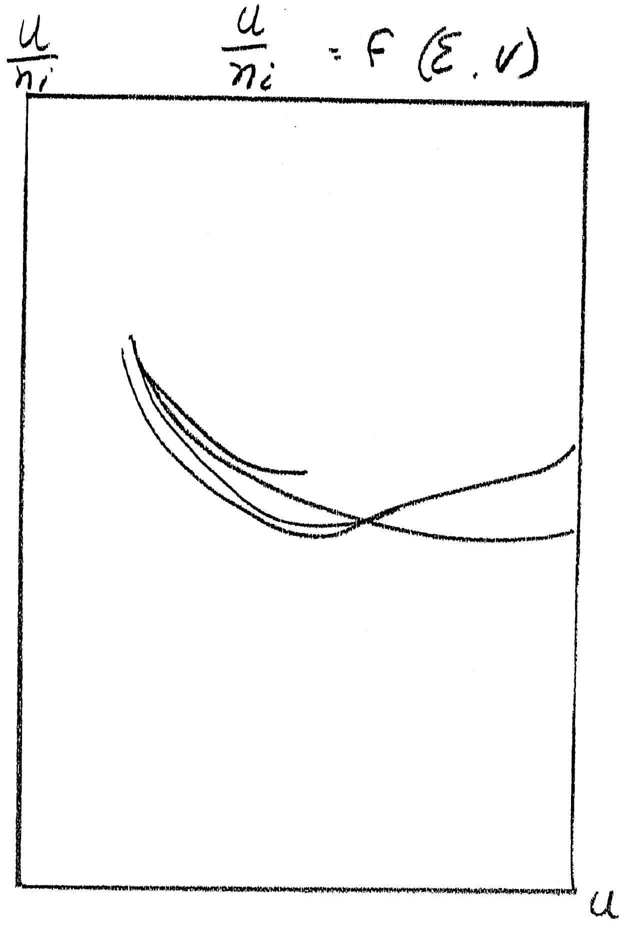


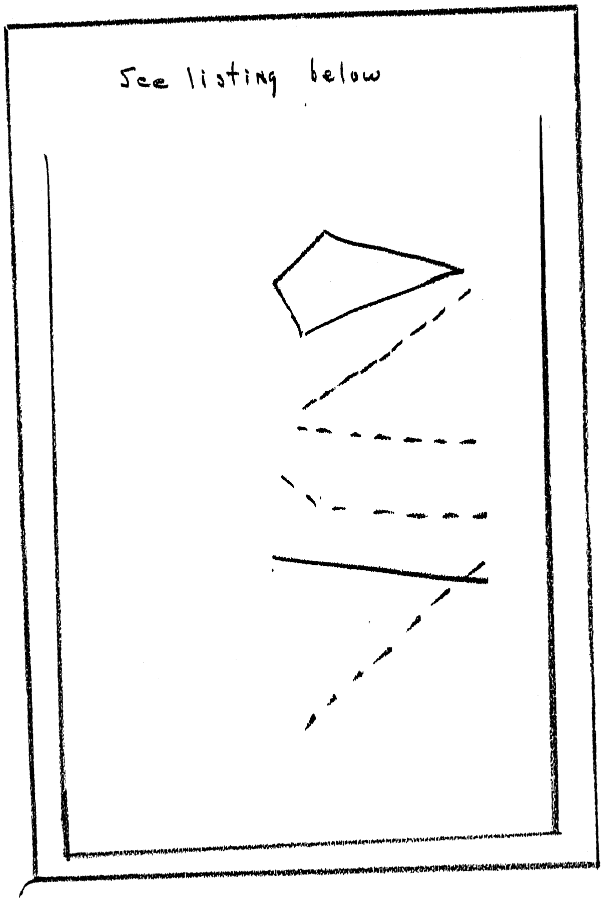
FIGURE 53

Curves of steam rate at indicated power for

various speeds and cut-offs

The tender empty, together with the permutit tank, weight 26.5 tons. In operating condition it weighs 60.6 tons, of which 20 tons consist of water and 7 tons of coal.

The tender has a base of 5,500 millimeter, and is 8,521 millimeter



See listing below

FIGURE 54

Tractive-thermal characteristics of high pressure boiler operating with intermediate bleeding of steam

Q fuel consumption times indicated HP-hours [?]

D fuel consumption per indicated HP-hour

D_1 actual steam consumption per indicated HP-hour

w Overall locomotive efficiency at rail

Power of high-pressure cylinders

Power of low-pressure cylinders

Power of feedwater-pump

long between the buffers. The volume of the permutit tank is 5.2 cubic meters. The neopermutit weighs 4.3 tons and the glauconite 1,250 kilogram.

The diameter of the drivers is 1,850 millimeters. The total weight of locomotive and tender in operating condition is 186.6 tons. The total length of locomotive and tender (between the buffers) is 26,420 millimeters.

The diagrams in Figure 52 and 53 give a very clear idea of the theoretical thermal economy of the high-pressure locomotive.

It will be seen from these diagrams that the unit steam consumption fluctuates according to the speed of forcing and cut-off, from 3.90 to 5.45 kg/HP-hour, which is about 65 percent that of the S^u locomotive. Roughly the same fuel saving is also obtained.

The diagram of Figure 54 characterizes the tractive-thermal properties of the high-pressure locomotive when operating as a bleeder. It will be seen that the overall efficiency of the locomotive at the drawbar is 17 percent at the full pressure of 60 atmospheres, and that at this pressure the equality of the power developed by each of the two cylinders is assured.

1-4-1 TYPE LOCOMOTIVE WITH UNAFLOW BOILER (USSR)

(The plans were worked out, and the locomotive constructed, by the Koloma plant in 1937).

The locomotive of which a general view is given in Figure 55 has, as an experiemental model, apower of only 600 HP.

Its principal power equipment consists of:

an unaflow boiler of an original system of Professor Ramzin;

a main steam engine of unaflow type;

a condenser;

a heat exchanger;

four water pumps and one fuel pump;

air blowers;

condenser fans and other apparatus.

The firebox is in the form of a cylindrical spiral, and the convection portion consists of plane spirals. The gas-operated draft-air preheater is installed on the gas exhaust and consists of 8/9 millimeter tubes. The boiler tubes are of molybdenum alloy steel.

The main steam engine is of horizontal unaflow gearbox type with 4 cylinders, double-acting, and is located on the locomotive frame. The high-pressure cylinder diameter is 140 millimeter and the piston stroke 350 millimeter. The diameter of the third and fourth cylinders is 280 millimeters, with the same piston stroke. At 920 r.p.m., the speed of the locomotive reaches 100 km/hour. There is a valve gear. The engine actuates two gears, rigidly engaged with a toothed rim placed on the gear shaft. The high-pressure cylinders and valve-chests are of cast carbon steel. The weight of the valve gear rests on needle bearings.

The auxiliary four-cylinder steam engine serves to drive the water and fuel pumps, the air blowers and condenser fans, and develops up to 100 HP at 1,200 r.p.m. The steam distribution is a valve-gear with constant cut-off.

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The auxiliary four-cylinder steam engine serves to drive the water and fuel pumps, the air blowers and condenser fans, and develops up to 100 HP at 1,200 r.p.m. The steam distribution is a valve-gear with constant cut-off.

The condenser consists of 10 sections with a total cooling surface of 820 square meters. The fan is of the TsAGI system, of 1,600 millimeter diameter and a capacity of up to 150,000 cubic meter of cooling air per hour.

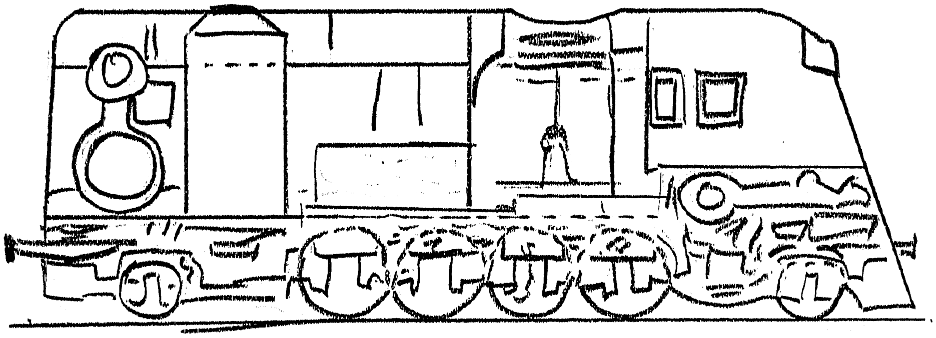

FIGURE 55

General view of high-pressure locomotive with Unaflow boiler: 1 Unaflow boiler; 2 heat exchanger; 3 main engine; 4 auxiliary group; 5 condenser; 6 water-tank

The heat-exchanger consists of a drum with condensation tubes of 23/29 millimeter diameter. The exhaust steam from the high-pressure engine passes through them at a pressure of about 18 atmospheres and a temperature of 206 degrees centigrade. The tubes are bathed in water at a temperature of about 194 degrees (at a pressure of about 14 atmospheres). The temperature difference of 206 degrees-194 degrees = 12 degrees is responsible for the heat exchange.

The main feedwater pump has four plungers, 25 millimeters in diameter, with a piston stroke of 30 millimeters. It does 1,200 r.p.m.

The air blower is rotational, with a revolving drum and Duralloy [DYURALEVIY] vanes, and also does 1,200 r.p.m.

The thermal scheme of the locomotive has been worked out in two variants. The first (Figure 56) provides a double water circuit and a secondary preheating [PODOGREV] of the low-pressure steam. The calculated effective efficiency of the locomotive

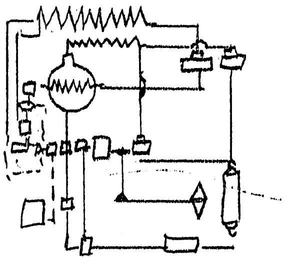

FIGURE 56

Thermal scheme of high pressure locomotive (first variant)

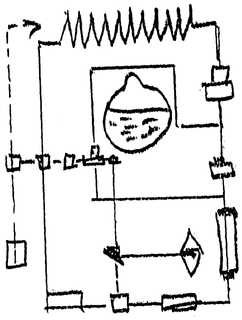

FIGURE 57

Thermal scheme of high pressure locomotive (second variant)

operating on this scheme is 15-16 percent. Tge scheme is simpler in the second variant (Figure 57) but the overall efficiency of the locomotive is considerably lower, around 12-13 percent.

The working cycle by the first scheme proceeds as follows:

From the boiler 1 steam under high pressure (up to 120 atm) at a temperature of 450 degrees enters the high-pressure cylinders 2, does its work in them, and then enters the tubes of the heat-exchanger 3 at a pressure of 18 atm. It gives up its latent heat to the low-pressure water, is condensed, and passes into the collecting tank 14, which has a filter, at 18 atm. pressure and

206 degrees temperature. Thence it is delivered by the pump 10' to the main water-pump 10, which pumps it back into the boiler 1.

The latent heat of the high-pressure steam, removed in the heat-exchanger 3, is transmitted to the low-pressure water, in consequence of which this water is evaporated and acquires, under this regime, a pressure of 14 atm. and a temperature of 194 degrees centigrade.

From the heat-exchanger 3, the steam passes into the low-pressure superheater 4, where it is superheated to 320-350 degrees. Part of it then enters the main low-pressure engine 5 and part of it the donkey engine 7. The spent steam from engines 5 and 7 passes into the sections of the condenser 6. From the condenser the steam, now transformed into water, flows into the collecting tank 13, which has filtrrs to free the condensate of cylinder oil. Thence the condensate is delivered by the POKDACHKA [secondary?] pump 8' through the filter 17 to the main low-pressure pump 8, which returns it to the heat-exchanger. And the whole cycle recommences.

Fuel is delivered from the tank 15 to the mechanical fuel atomizer jet 28 by the fuel pump 11.

The working cycle by the second variant (Figure 57) proceeds as follows. Steam from the boiler 1 enters the steam engine 2, and after doing its work enters the low-pressure cylinders 3, with a certain part of it being diverted through the receiver 13 for the heat-accumulator 5. The steam leaving the cylinders 3 goes to the condenser 4, where it is condensed and passes in the form of condensate into the tank 11, thence to the secondary pump 8' and then through the filter 16 to the main pump 8, which in turn pumps it back again to the boiler 1.

The basic purpose of the heat-accumulator 5 is to feed the donkey engine that drives the auxiliary equipment (pumps, blowers, etc.)

In this scheme there is no secondary preheating of the steam. The low-pressure steam engine thus operates almost entirely on saturated steam under a pressure of 14 atm., as a result of which the economy of locomotive operation under this cycle is considerably lower.

In providing these two schemes, it was intended finally to select the one that proved to be most rational during the trial operation.

The operation of the mechanisms and devices delivering water, liquid fuel and air is synchronized in such a way as to assure a reliable and quantitatively fixed ratio between them under any regime of locomotive operation. In this way the work of the whole installation is automatically regulated. For instance, if it is necessary to reduce the developed power to one half, the donkey-engine valve is closed, and its number of revolutions drops to about half; as a result the delivery of fuel and air is also reduced by about half. In addition, the boiler heating surfaces and their mutual dispositions assure a practically constant superheat regardless of the variations in the delivery of water and fuel (under the condition of their proportionality).

The principal proportions of the locomotive are as follows:

power developed at drawbar, 600-800 HP; adhesive weight, 60 tons; total weight, 80 tons; water supply, 5 tons; oil supply, 5 tons; cruising radius, for water, 1,000 kilometer, for fuel, 1,600 kilometer.

The designing, construction and test runs of this experimental locomotive furnished extremely valuable material for the further work of our engineers, technologists and inventors in the direction of creating a high-pressure locomotive.

2-4-1 100 ATMOSPHERE LOCOMOTIVE, (USSR)

(Plans drawn in 1939 by Voroshilovgrad Locomotive Building Plant.)

This locomotive, of which Figure 58 shows a general view, is intended for mixed passenger-freight service. Its main power equipment consists of:

an unaflow boiler of 100 atm. pressure with velocity firebox fired by lump coal;

[Figure 58 on the following page]

a main steam engine;

a donkey engine;

a condenser on the tender;

a rapid-acting feedwater pump;

a fan for delivering air to the firebox.

The unaflow boiler consists of pipe coils bathed by the combustion gases. The water is delivered from one side of the boiler into a pencil of parallel pipe-coils, under a pressure of 125-130 atm., after having been preheated in the feedwater heater and in the

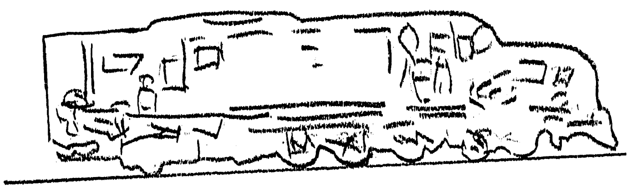

FIGURE 58

Scheme of arrangement of power equipment on high pressure locomotive: 1 Unaflow boiler with firebox; 2 main enclosed steam engine; 3 coal filters; 4 feedwater heater; 5 air reservoirs; 6 initial firing unit; 7 storage battery; 8 blower; 9 reducing valve; 10 feedwater pump; 11 auxiliary steam engine; 12 reducer; 13 steam distribution mechanism; 14 control instrument pannel

coils forming the firebox. In assing through the boiler coils, the water is converted into wet steam, which next enters a separator to remove the moisture. The separated steam is then directed into the pipe-coils of the superheater, where it is superheated to 485-500 degrees and enters the high-pressure cylinders, which are made in a single casting.

The torque of the crankshaft is transmitted through a connecting-rod mechanism. The crankshaft makes a maximum of 1,000-1,200 r.p.m.

The torque is transmitted to the driving mechanism by a reducer (a gear drive) and gear shaft, acting through a system of side rods. The gearbox type of engine is very compact, owing to its high speed.

The tender-condenser is on the whole analogous to the tender of the FD locomotive and has feedwater heating equipment.

The flash firebox operates on the following principle: favorable conditions for the combustion process are created under the action of the high velocity of the air relative to the fuel particles, while the carbon monoxide is completely burned over the fuel layer in the firebox, to which area the secondary air is directed; the velocity blast assures a high rate of heat liberation in the firebox, which reaches about 15 million kcal. per square meter per hour, or about five times as great as on the ordinary firegrate of the FD locomotive. Thus it is possible to burn fuel at the rate of 2,500 kg/square meter-hour as against 500 sg/square meter-hour in the FD locomotive, which means a fivefold increase in the intensity of combustion. A model of the flash firebox was tested in 1938, by the All-Union Institute of Heat Technology and gave results that were completely satisfactory.

The firebox is located in the back of the boiler. Coal is delivered from the tender by worm conveyors into an intermediate bunker on the locomotive. From this bunker it is thrust by slowly moving plungers into a special chamber, the retort. The retort is somewhat inclined to the horizontal. It should be full of coal when operating. A stream of compressed air from a special firebox blower is blown through the layer of fuel in the retort. The gases separated pass into the firebox space, where they are mixed with the secondary air and are completly burned. The gases then pass through the boiler coils, and are directed towards the smokestack after giving up their heat.

All of the equipment (Figure 58) is arranged as follows.

The boiler and firebox, together with the assembly of auxiliary equipment, consisting of a donkey engine, feedwater pump, blowers and generator, are located in the central part of the locomotive. The main steam engine is installed in the front of the locomotive, on the frame. This engine consists of a solid steel casting and serves at the same time as an interframe reinforcement of the front part of the locomotive.

The cab is located in this front part. A manual control stand with the corresponding controls is installed in the cab. The locomotive has a streamlined outer shell.

It can develop 3,500 HP.

LOCOMOTIVE WITH MARINE TYPE BOILER (GREAT BRITAIN)

(Built in 1939)

Locomotive of type 2-3-2, 4-cylinder compound. Figure 59 gives a general view.

The distinctive feature of the locomotive is the use of a water-tube boiler of the ordinary marine type, but with suitable modifications in design. The purpose was to test the possibility of enjoying those operating advantages that have been assured by such boilers over many decades in ship and stationary power installations.

In selecting the pressure the designer did not consider it expedient to go beyond 31.5 atm., in view of the fact that the relative advantages gained by high pressure are progressively reduced as the pressure increases beyond 50 atm.

FIGURE 59

Outside view of high pressure locomotive with water-tube boiler

[Photo]

In drawing the plans for this boiler there was a whole series of very important designing problems, stemming from the special conditions of locomotive service, that had to be solved. Firstly, the weight and clearance dimensions of the boiler had to be reduced to an extreme minimum, while at the same time preserving its proper steam-generating capacity. Secondly, so elastic a method of attaching the boiler to the locomotive frame had to be chosen as to assure the possibility of the thermal elongation and expansion of its separate elements, to absorb the vibration, shocks and jolts during motion of the locomotive, and yet, at same time, not to diminish the stability of the boiler. Thirdly, effective means of preventing boiler incrustation had to be provided, in view of using ordinary, untreated feedwater.

The boiler, of which Figure 60 gives a general view, consists of an upper (large diameter) steam barrel, a water-tube system, and four water-barrels of smaller diameter. As will be seen from the picture, the water-tube system and the water-barrels are, as it were, suspended from the steam barrel which constitutes the main boiler and which, at the same time, assures the structural stability and rigidity of the locomotive as a whole.

The steam barrel is attached to the locomotive frame by a special cast steel supporting block [? OPORNAYA PODUSHKA] in such a way as to assure the possibility of its unhindered thermal elongation, while at the same time restricting lateral displacements to a minimum.

FIGURE 60

Yarrow-Gresley system locomotive boiler

[Photo]

There are rectangular projections at the bottom of the four water-barrels. These projections slide freely in a longitudinal direction along the grooves of supporting castings attached to the locomotive frame. The tube system with the water-barrels are thus really in a state of suspension, thereby assuring the reliable absorption of the shocks and vibration that are inevitable while the locomotive is in motion.

This "suspension" method for the watertube system proved to be entirely justified.

During the period of trial operation not a single leak was observed in the tubes at the places of their connection to the large and small boiler barrels.

To reduce incrustation on the boiler walls to a minimum, the feedwater is heated to temperatures close to that of steam generation. This is achieved as follows. Feedwater is delivered from the tender, through two ordinary injectors, to a special feedwater chamber located at the front end of the steam barrel. This chamber is separated from the evaporative part of the boiler by an overflow passage at a height of about half its diameter. Before it enters the chamber, the feedwater first passes through a special injector pre-heater that raises its temperature to about 205-210 degrees. This method of thermal water treatment frees it from admixtures, and most of the incrustations and mud settle in the front part of the upper barrel.

The trial operation of this locomotive showed that, in spite of this, incrustation in this system had still not been entirely eliminated. The designer therefore worked out apparatus of special construction by which even badly burned-in incrustations could easily and quickly be removed without any harmful effects whatever on the tubes. Ordinarily this apparatus must be used after running 20,000 to 25,000 kilometers.

During the trial operation of the locomotive in the passenger service on the line from York to Edinburgh (the daily run from both ends amounting to 700 kilometers) it was established that after a run of 8,000 kilometers, without washing out the boiler was still completely clean and the whole tube system was in excellent shape, while the "Pacific" type locomotives serving this section usually needed to have their boilers washed out after running 1,500-2,500 kilometers. Careful inspection of the boiler showed that the incrustation and mud, which usually accumulates in standard boilers above the lowest firebox ring, settles here in the barrels under the grate on both sides of the firebox. This incrustation remains in the barrels in the form of mud, which is easily removed, (while in ordinary boilers most of it is transformed into boiler scale).

During the acceptance tests for this locomotive, the steam generating output of the boiler was held steady for four hours at the level of 9,100 kilogram of steam an hour at a pressure of 31.5 atm. With a boiler evaporative surface of 180 square meters, therefore, the forcing of steam generation amounts to 9,100 ; 180 = 50 kg/square meter-hour.

So intensive a steam generation is mainly due to the fact that a relatively large part of the boiler heating surface is under the direct influence of the radiated heat, while in the ordinary boilers radiant heat is received only by the surface of the firebox; and it is precisely for this reason that the rate of evaporation per square meter of heating surface in the tube part of the ordinary boiler is only about a fifth of that rate from the firebox walls.

The superheater elements are located in the front part of the central flue and are likewise under the direct action of the radiant heat. To prevent the flames from playing around the ends of these elements in the center of the main flue, a brick column is placed immediately beyond the reflecting arch. This reduces the superheat temperature somewhat, and it is ordinarily 370 degrees-375 degrees. The superheater elements are arranged between the boiler and the throttle and are therefore constantly under the full boiler pressure.

To prevent excessive superheat temperatures, when the throttle is closed the steam from the superheater is used to feed the auxiliary equipment (injectors, vacuum for the steam brakes, reversing mechanism, steam sand-ejector, steam heating, whistle, turbo-generator). In this case the superheated steam is passed through a ribbed coil which continues on into the feedwater chamber and thus increases the feedwater temperature; thence the steam is conducted (at a temperature already lower) to the reducing valve, where its pressure is brought down to 14 atm.

The principal dimensions of the boiler are as follows:

Steam barrel, length in millimeter	8520
Inside diameter in millimeter	915
Water barrels, front, length in millimeter	4100
Inside diameter in millimeter	483
Water barrels, back	
Length in millimeter	3370
Inside diameter in millimeter	457
Firebox, length in millimeter	4900
Total number of tubes	768
(Outside) diameter of tubes	51 and 63
Total boiler evaporative surface in sq.m.	180
Superheater:	
Number of elements	12
Superheater heating surface in square meter	13
Total heating surface of boiler in square meter	193

All the steam fittings of the boiler are the usual ones, except for the safety valves, the throttle and the water gauge glasses, which are specially adapted for this pressure.

The preheating of the air entering the firebox is accomplished by means of the heat of the gases that pass through the flues. The flues are arranged at the bottom, on both sides of the boiler, in such a way as to leave an air space between them and the heated boiler shell. This space serves for the passage of the outside air is usually heated to 120 degrees-125 degrees.

As will be seen from the picture (Figure 59) the smokestack is not carried to the outside, because the high position of the steam barrel completely exhausts the height clearance of the locomotives in a wind-tunnel, the designer contrived a special form of reflecting baffle-plate (which may be seen in Figure 59), thanks to which visibility is assured under all conditions of locomotive motion.

The diameter of the high-pressure cylinders is 254 millimeter that of the low-pressure cylinder is 508 millimeters, and the piston stroke in both pairs of cylinders is 660 millimeters.

There is a separate Gresley-Walschaert valve-gear for the high-pressure and low-pressure cylinders, which allows the cut-off in the high-pressure cylinders to be varied independently of that in the low-pressure cylinders. The adhesive weight of the locomotive is 63.5 tons and the starting tractive force is 15,000 kilogram.

In describing the Gresley locomotive, the British journals particularly stressed the following advantages of the Yarrow boiler by comparison with the ordinary locomotive boilers:

saving of fuel;

the more expensive parts of the all-forged boiler -- the steam and water barrels -- are not subjected to the direct action of the fire, and therefore their useful life should be considerably longer than that of ordinary boilers;

the absence of staybolts, the more reliable attachment of the tubes, the minimum temperature fluctuations in the system, and, consequently, the minimum temperature stresses at the tube-joints.

However, as has now become common knowledge, the merits of the Yarrow-Gresley boiler, both in design and operating chracteristics, have been greatly exaggerated. Evidence of this is the fact that after a long period of trial operation of this locomotive, its boiler was taken down and replaced by an ordinary one of standard type. The reason for this was leaking tubes and a fuel consumption higher than that expected.

DUAL-PRESSURE LOCOMOTIVE -- 120 AND 15 ATMOSPHERES (GERMANY)

(Built in 1936.)

This is a type 2-3-1, 3-cylinder locomotive, and Figure 61 shows a general view of it.

FIGURE 61

Outside view of Schwartzkopf Loffler high pressure boiler

[Photo]

The peculiarity of the construction of this locomotive is largely determined by its system of steam generation, designed and worked out in construction by Professor Loeffler. This system differs radically from all those previously employed in experimental locomotives, and has simply nothing in common with the standard locomotives' boilers.

The peculiarities of the system are, in the first place, the generation of steam in a boiler with no firebox, the so-called boiler-evaporator, and in the second place, the forced circulation of high-pressure steam through two parallel closed circuits.

The principal parts of the installation are:

a high-pressure boiler-evaporator (Figure 62 shows a general view);

a firebox chamber, formed by the so-called first system of superheater tubes of small diameter (which are connected to horizontal collectors on both sides of the firebox); the first superheat stage takes place in this system;

FIGURE 62

Boiler-evaporator (cover of manhole removed)

[Photo]

a second system of superheater tubes of the same diameter, which is installed in front of the first system and is consecutively connected with it; the second superheat stage takes place in this system;

an intermediate low-pressure superheater at 15.5 atm.;

a high-pressure feedwater-heater;

an air heater that preheats the draft air entering the firebox up to 150 degrees;

a boiler-heat-exchanger in which the water from the tender is preheated and low-pressure steam is also generated, both by using the heat of the spent high-pressure steam;

feedwater and steam-circulating pumps (one of the latter is shown in Figure 63);

other equipment and appratus (oil-separator, froth-separator, turbine generator, etc.).

Figure 64 is a simplified scheme of the arrangement of all these elements of the steam-generating system.

FIGURE 63

Steam circulating pump

[Photo]

The working cycle of the Loeffler steam-generating installation proceeds as follows (see the scheme).

The steam generated in the boiler-evaporator E at a pressure of 120 atm. is forced by the pump F into the tube-superheater system A, which is bathed by the combustion gases. The steam is heated here to about 500 degrees, and then proceeds further and branches out. Part of it (about 25 percent) enters the high-pressure cylinders, while the rest goes to the boiler-evaporator. After **doing** its work in the cylinders, the steam then passes under a pressure of about 18 atm. through the oil-separator and enters the tube system of the boiler-heat-exchanger, H, where it gives up its heat to the water in H, is condensed, flows into the collector and is delivered as condensate to the boiler-evaporator after having first passed through the high-pressure feedwater heater S.

The part of the steam that branches off (about 75 percent) enters the water of the boiler-evaporator (through a submerged pipe with apertures) and gives up its heat to evaporate it under a pressure of 120 atm. This steam is pumped back by the circulating pump F into the superheater system, and the cycle again recommences. The water losses from leaks in the high-pressure system are made up from the water in the boiler-heat-exchanger, pumped in by a by-pass pump.

The steam generated in the boiler-exchanger passes into the superheater B under the pressure of 15.5 atm., and is there superheated to 300 degrees by the combustion gases (that successively bathe the high-pressure superheater A, the superheater B, the high-pressure feedwater heater C and the air preheater D). Thence it goes to the low-pressure cylinder K, does its work, and is exhausted into the atmosphere through the exhaust nozzle, thus creating a draft in the combusion space.

The preparation of the locomotive for operation is sharply different from the usual and proceeds as follows.

Ordinary low-pressure live steam (from another locomotive under steam or from the steam main in the roundhouse) is fed into the boiler-evaporator and into the cylinders of the circulation pump system. This then commences to pump steam from the boiler evaporator through the closed circuit into the boiler-exchanger, where evaporation is initiated by the heat in the water. After the steam pressure in the boiler-exchanger has reached the normal level of 15.5 atm., the outside supply of steam to the pump is stopped, and the (circulation) pump continues to operate now under its own steam; and at the same time the fire is kindled in the firebox. After a certain definite period of time, when the steam pressure in the tube system has been brought up to normal (120 atm.) by the combustion gases, the outside supply of steam to the boiler-evaporator is stopped, and the system begins to operate under the normal cycle.

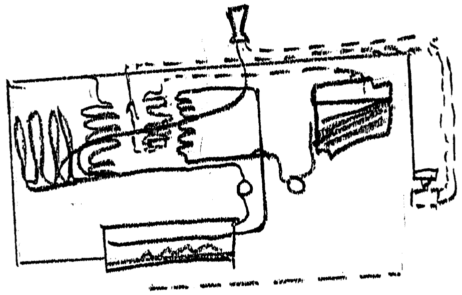

FIGURE 64

Skeleton diagram of Loeffler system boiler installation

A high-pressure super heater; B low pressure superheater; C high pressure feedwater heater; D air-preheater; E boiler-evaporator; F circulating pump; D feedwater pump; H boiler-heat-exchanger; I and L high pressure cyclinders; K low pressure cylinder

If ready steam is unavailable, the "firing" of the boiler may be effected by means of an auxiliary heating plant that preheats the water in the boiler-exchanger, then using the low-pressure steam so obtained to "charge" the boiler-evaporator. Fire is then kindled in the combustion chamber and the system goes over to work on the normal cycle.

For short periods of standing (e.g. in the turn-around roundhouse) the steam-pressure in the boiler-evaporator is usually entirely sufficient to "fire" the boiler with its own steam without needing outside steam supply.

The power consumed by the circulation pumps in the high-pressure circuit is about 2 percent of the total power developed by the locomotive.

The merits of this steam-generating system have been tested out over a period of many years of operating practice at the stationary power plants at Vienna and Witkowitz (Germany), and this fact was the motivation for using it as a locomotive installation.

In the opinion of the designer himself, the existence of two circuits (a high-pressure and a low-pressure) is not an obligatory feature of the Loeffler steam-generation system, and has been adopted to provide a certain amount of insurance against possible incrustation in the elements and parts of the high-pressure circuit. The designer considers that scaling in the barrel of the boiler-evaporator is unlikely with so high a velocity of water circulation through the high-pressure feedwater heater, and that even if scale should be deposited it would not have particularly injurious results, since the combustion gases have no contact whatever with the walls of the boiler-evaporator barrel. The possibility of considerably simplifying the thermal scheme of the steam-generation plant thus presents itself; the boiler-exchanger, the intermediate superheater, and other equipment and devices related to these parts, could be eliminated. In this case the steam exhausted from the high-pressure cylinders could be routed to the low-pressure cylinders after simply passing it through an oil-separator.

In design of the running parts, weight, clearance dimensions and power, this locomotive is entirely identical with the type 2-3-1 passenger locomotives of the German Railways.

Its design and operating proportions are as follows:

Type of locomotive	2-3-1, 3-cylinder: 2 high-pressure cylinders and 1 low-pressure; ~~which~~ the latter is located in the middle
Diameter of cylinders and piston stroke in mm	high-pressure 220 x 660 low-pressure 600 x 660
Valve gear	Walschaert-Schwartzkopf type
Wheel diameter in mm	
Drivers	1,999
Front supporting	840
Back supporting	1,250
Boiler installation	Loeffler system
Boiler heating surface in sq. meter	
Low pressure boiler-heat-exchanger (evaporative surface)	79.5
High-pressure superheater	87.2
Low-pressure superheater	31
High-pressure feedwater heater	68.8
Grate area in square meter	2.37

Locomotive weight, in operating condition, in tons	
On the driving axles	60
Total weight of locomotive	115
Wheel base	
Driving axles, in mm	4597
Total locomotive wheel-base in mm	13210
Rated tractive force in kilogram	17000

As will be noted from this description, the construction of this locomotive is considerably more complicated than that of the standard models. It was maintained that this complication produces no special increase in the cost of maintenance and repair of the boiler plant, firstly because all of the tubes in the tube system are straight, and secondly because the most expensive part of the whole plant -- the high-pressure boiler evaporator -- in general requires no repairs whatever.

The degree of safety of the Loeffler system boiler plant, in the designer's opinion, is not only no less than that of the standard boiler, but in certain particulars is even greater. Firstly, the tube systems of both circuits consist of tubes of small diameter, thereby reducing to a minimum the destructive consequences of any explosion, if one should occur, and secondly the walls of the non-firebox boiler-evaporator have no tube-joints and this fact guarantees a greater degree of safety.

The locomotive went through its plant tests and was then turned over for trial operation. It did not, however, go into series production. The reason for this was its complex design and its steam consumption, which was higher than that expected.

THE 0-B_0-B_0-0 CONDENSING LOCOMOTIVE WITH 60-ATMOSPHERE BOILER PRESSURE (UNITED STATES)

(Plans,)

In structural design this locomotive represents a fairly complicated mechanism. Figure 65 gives a side view, longitudinal section and plan. As may be seen from the illustration, the entire weight of the locomotive is placed on the two two-axle driving trucks.

The power equipment consists in the main of:

two multicylinder unaflow steam engines;

four compact light-weight boilers with smokeless oil-atomizing jets;

a condenser mounted above the body of the locomotive and running its entire length;

a gear-drive system.

The steam engines are of vertical type, 8-cylinder, direct-acting, and each is able to develop 1,000 HP. They are arranged in a single row. The cylinder diameter is 215.9 millimeter and the piston stroke is 254 millimeter. The steam admission valves are of two-seat balanced disc valve type, connected by a gear-drive to the main driving shaft of the locomotive. The gear-dirve has helicoidal gears and assures a maximum cut-off of 60 percent in both directions of locomotive travel.

The number and dimensions of the cylinders are so chosen that under ordinary operating conditions the cut-off will be from 10 to 15 percent; the most advantageous cut-off at any given speed is assured by the throttle, which automatically acts on the distribution

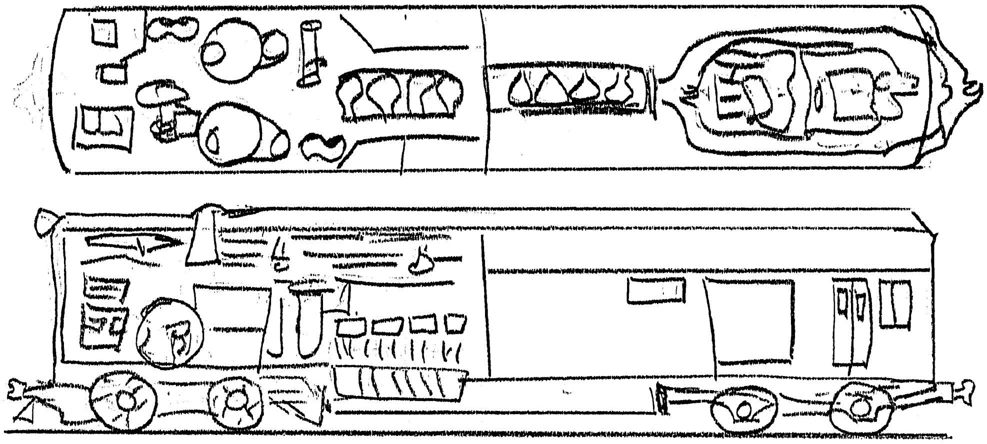

FIGURE 65

Side view, longitudinal section and plan of

$O\text{-}B_0\text{-}B_0\text{-}O$ condensing locomotive

1, boiler; 2, tubes; 3, feedwater pump; 4, drum; 5, heat exchanger; 6, blower-smoke suction apparatus; 7, box with geared transmission and blower-smoke suction apparatus; 8, water tank; 9, reservoir for heated water; 10, partition; 11, donkey engine; 12, steam-air pump; 13, hood; 14, 1000 HP steam engine; 15, Cardan shaft; 16, transverse equalizer; 17, box with geared transmission; 18, shaft for transmitting torque; 19, spring; 20, roller bearing; 21, box with gear drive for blower of condenser; 2, opening for condenser; 23, gear box for condenser blower; 24, poperechina.

shaft. The expected steam consumption (see diagram on page 66) is about 4.9 kilogram/HP-hour at the engine shaft, under normal operating conditions.

The boilers are continuous-flow, tube type, and can make two changes in pressure, the outer tube-spiral acting as a preheating section and the inner one acting as an evaporator section. The superheater is located between these two sections. The working pressure

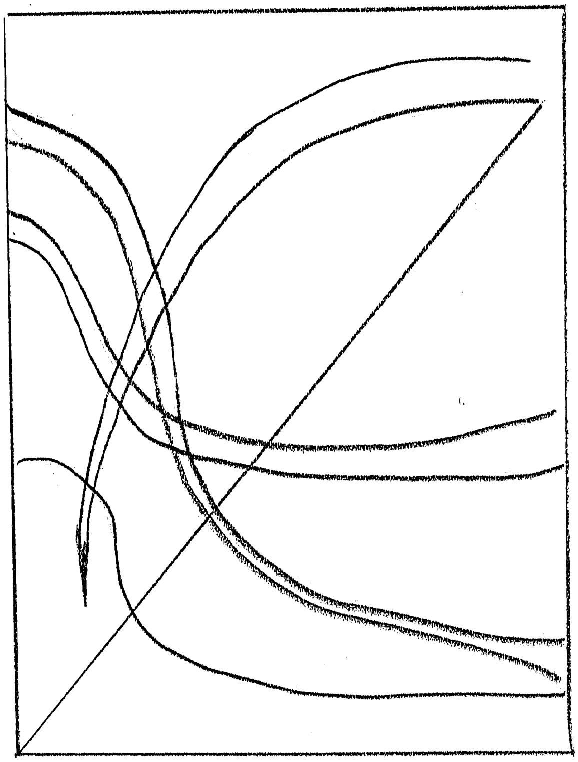

FIGURE 66

Curves of working characteristics of high pressure boiler shaft. The expected steam consumption (see diagram on page 66) is about 4.9 kilogram/HP-hour at the engine shaft, under normal operating conditions.

The boilers are continuous-flow, tube type, and can make two changes in pressure, the outer tube-spiral acting as a preheating section and the inner one acting as an evaporator section. The superheater is located between these two sections. The working pressure

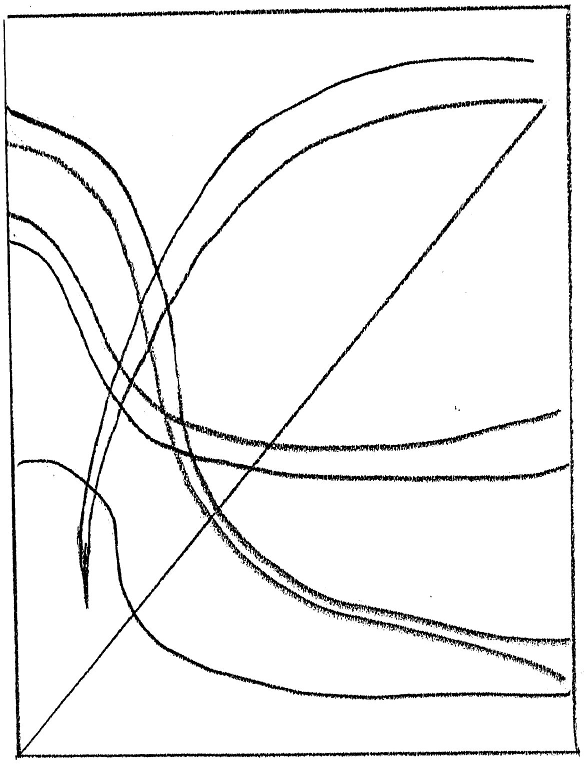

FIGURE 66

Curves of working characteristics of high pressure boiler in the boilers is 63 atm. The safety-valves are set to blow at 70 atm. The pressure in the engine, after the throttle, is 60 atm. The boiler diameter is 1,372 mm; and the boilers are arranged by twos at each end of the locomotive. Each pair of boilers has an independent feedwater pump, and each boiler has an automatic feedwater regulator.

The condenser (which is air-cooled) consists of welded aluminum sections that begin at the center line of the locomotive with admission apertures for the spent steam, and end in vertical discharge pipes connected to the water-chambers on the side of the locomotive body. The condensate flows from these chambers into the reservoir of the feedwater heater, in which a temperature of 93-99 degrees centigrade is automatically maintained; thence it is forced back into the boiler again after first passing through a special oil-separator.

Water and fuel oil are carried in separate chambers and tanks located on the sides of the engine.

Six fans, 2743 millimeter in diameter, are located under the condenser. Air is sucked in by the fans from the sides and ends of the locomotive through a by-pass pipe and is then forced upwards through the condenser. Each set of three fans is driven by a donkey Diesel engine through a shaft with a dual drive, giving three speeds. The capacity of each fan in 3540 cubic m/minute at 320 r/p/m. The same engine also drives a fan to produce an artificial draft through the boilers.

The Diesel burns the same fuel oil as the boilers.

The torque is transmitted from the shaft of each engine to the driving axles of the respective truck by means of a shaft, pinions and gear wheels. A high degree of uniformity of the torque is assured by the fact that the impulses follow each other every 45 degrees.

All the truck axles are driving axles. The load on each of them is 28.5 tons. The toothed wheels and gears of each axle are enclosed in a metal case that rests on the axle between the roller bearings.

The driving shaft from the engine passes over the driving axles of the locomotive. The cases of the pinion and gears are impermeable and are provided with a power lubricant pump to spread lubricant over the engaging surfaces. This design and this method of lubrication assures the noiseless operation of the drive and a high efficiency.

The gear ratio is chosen so that the speed of the locomotive will be 95 kilometer/hour at 650 r.p.m. and 145 kilometer/hour at 975 r.p.m.

The driving axles are completely balanced, which allows the locomotive to be used even on lines with relatively weak superstructure.

Total power developed at the shaft is 2000 HP. Total weight of the locomotive in operating condition is 114 tons, which is about 50 percent that of a standard locomotive of equal power. Fuel consumption according to the calculations, should be 50-70 percent that of the ordinary standard low-pressure locomotives.

The 3000 HP locomotive for which plans were simultaneously drawn will be completely analogous in design and operating characteristics. It differs only in having two three-axle trucks, 6 boilers and two 1,500 HP engines. The principal proportions of the locomotive in length, weight, etc., will be modified accordingly, but all parts and details of the two locomotives are to be completely interchangeable.

PART FOUR

HIGH AND LOW PRESSURE STEAM TURBINE LOCOMOTIVES

General Information

The use of the reciprocating steam engine as the prime mover for the locomotive seriously hampers the designers in their efforts to improve both running and tractive-thermal qualities of the locomotive.

The reason is that the reciprocating steam engine is:

firstly, a source of considerable inertial forces, which are responsible for the peculiar and extremely undesirable "recoiling motion" and "hunting" of a locomotion during its travel;

secondly, the transformation of the rectilinear motion of the engine piston into the rotary motion of the wheels requires the use of a connecting rod and crank mechanism, which in turn is the source of dynamic action of the railroad ways which is harmful, and, under certain conditions, even dangerous to the moving train, while the proper balancing of the reciprocating masses becomes less and less attainable as train speeds increase;

thirdly, the utilization of the power of a locomotive steam-engine is limited by the structural peculiarities of the connecting-rod transmission to about 700-800 HP per driving axle. In other words, no more than 3509-4000 HP can be obtained, for instance, from the ordinary locomotive with five driving axles on a single frame, and still less from one with only four driving axles;

fourthly, the piston engine is badly adapted (mostly by reason of its lubrication, packing, etc.) for work at the high pressures and temperatures of superheated steam. Yet the latter condition is the most important of all for the enhancement of the thermal efficiency of the steam locomotive.

This is why scientific-technical and inventive thought has long and intensively been working in the direction of creating a steam locomotive using other prime movers, which would be free from all these shortcomings. The steam turbine has proved to be such a prime mover.

As early as 1910, a low-power turbine-locomotive with gear drive was built in Italy for switching work. This experiment, however, proved unsuccessful. Its designers failed to take into account the peculiarities of the basic characteristics of the turbine, which require the use of an excessive amount of steam at low r.p.m., in other words for starting and acceleration. The locomotive was therefore dismantled.

In 1921, the Lungstrom type 2-3-1 steam-turbine locomotive was constructed in Sweden. It had steam condensation and a gear drive, developed 2,000 HP and had a rated speed of 130 kilometers per hour.

In 1924 the firm Krupp-Zelli (Germany) built a 2-3-1 type steam turbine locomotive, and two years later the Maffey also brought out a 2-3-1 steam-turbine locomotive.

During the same period, two steam-turbine locomotives were constructed in Great Britain by Ramsey and Company.

All these locomotives were of faulty design and did not come into production.

Around 1935 experimental construction of steam-turbine locomotives again came into the limelight. A type 2-4-2 condensing steam turbine locomotive weighing 133 tons appeared in Great Britain. It had an electric drive, used a working boiler pressure of 22 atm. and a superheat temperature of 450 degrees, and its rated speed was 175 kilometers per hour. This was followed by a steam-turbine locomotive of 2-4-2 type, also with a tender-condenser, and weight of 134 tons. It was equipped with a "Stenber-Mond" system boiler, with a working pressure of 40 atm. and superheat temperature of 525 degrees, developed 3,400 HP, and had a rated speed of 140 kilometers per hour.

A little later a steam-turbine locomotive was built, of type 2-4-2, with electric drive (but non-condensing), working boiler pressure 22 atm., superheat 450 degrees; service weight 145 tons, developing 2,800 HP and a record speed of 200 kilometers per hour.

Parallel to this, powerful steam-turbine, condensing, high-pressure locomotives were designed and built. Thus, for instance, plans for a steam-turbine locomotive with a pressure of 140 atm. and a power of 4,000 HP were completed in the USSR in 1936. In 1938 a steam-turbine locomotive with 105 atm. pressure electric drive, and 5,000 HP, was put into trial operation in the United States.

Although all these locomotives, both high and low pressure, possessed relatively high tractive-thermal qualities, not a single one of them went into series production. The reason for this was their complex design and the resulting high first cost and their higher operating costs as well.

Thus designer and inventors were confronted by the task of simplifying the steam-turbine locomotive so as to bring it within the range of the possible and make it able to compete with the steam locomotive in first cost and in operating cost. In practice this implied the need for going over to the mechanical drive.

But there were serious obstacles of purely constructional character on this road. The basic obstacle~~s~~ was the lack of such mechanical connections (clutches and reversing mechanisms) as could satisfy all the requirements of operation (reliability, flexibility and economy of operation) in transmitting such large amounts of power from the turbine shaft to the driving wheels.

During the last few years research and experimental work aimed at solving this difficult problem has been conducted at intensified tempos both in the USSR and abroad. The results of this work have been very considerable, and the construction of powerful locomotives with mechanical drive has now become entirely possible.

It must be emphasized in this connection that the use of the mechanical (geared) drive plays an especially important role in its application to the steam turbine locomotive. Besides the simplification of the locomotive that we have mentioned, it also allows solving a number of other and ~~very important~~ constructional problems. Let us briefly explain what is meant.

As is generally known, the power of a turbine in steam turbine locomotives is usually limited by the steam-generating capacity of the boiler. With a geared drive, the diameter of the drivers may be made of minimum proportions, and this means that it is possible to install a boiler of large dimensions (diameter) on the locomotive and correspondingly to increase the grate area, since this permits shortening the wheelbase (with the reduction in wheel diameter). Under such conditions the turbine can be supplied with steam without intensively forcing the boiler even at maximum loads. This in turn facilitates the solution of the problem of boiler draft, cuts to a minimum the losses from incomplete combustion (losses from escape of unburned fuel) and in the final result increases the thermal efficiency of the locomotive.

It follows from all this that a considerably greater power can be put into the geared steam-turbine locomotive than into the steam locomotive or motor locomotive, in a single unit, other things being equal.

Beginning in 1936, experimental geared steam-turbine locomotives of 2,000-6,900 HP per single unit were constructed in a number of countries (Sweden, Great Britain, France, United States), while plans have just been completed (in the United States for a such locomotive of even greater power (9,000 HP).

In the following pages three high-pressure steam-turbine locomotives and five low-pressure with geared or electric drives, are described, as the most interesting in their constructional formulation.

HIGH PRESSURE-STEAM TURBINE LOCOMOTIVE WITH UNAFLOW BOILER (USSR)

(The plans (first variant) were drawn in 1935 by LOKOMOTIVPROYEKT. There are two other variants: (1) a thermal scheme without the intermediate superheater, with introduction of regneration and reduction of pressure to 80 atm.; and (2) a thermal scheme with two closed circuits at different pressures).

This is a steam-turbine locomotive of passenger type 2-4-2. The wheel formula was chosen with the idea of assuring, firstly, the proper tractive force to haul heavy passenger trains (900 tons), and secondly of maintaining speeds up to 120 kilometers per hour.

The boiler is of unaflow type, with forced circulation, working pressure of 140 atm., superheat 450 degrees, and is placed (Figure 67) at the back of the locomotive. The heat accumulator and the group of pumps are placed behind the boiler.

The prime movers consist of two steam turbines, one high and one low pressure. The turbines are interlocked by a clutch with a reducing gear, and are located in the front of the locomotive. The torque is transmitted from the turbine shaft to the wheels by means of a reducing gear and a gear shaft.

An oil-cooler for cooling the lubricant in the reducing gear and the power aggregates is located in a special casing beneath the crown. The cooling is by air forced by fans.

The condenser consists of two barrels and is located between the turbine and the boiler.

The cab is in the front part of the locomotive, thus giving the engineman a good view of the track and signals.

The four-axle tender carries an oil supply of 10 cubic meters and a water supply of 5 cubic meters, which serves to replace the leakage from the heat accumulator. A reverse cooling system (OBRATNIY KHOLODIL'NIK) is also installed on the tender. It consists of 35 sections and a fan drive with four TsAGI fans. The reverse cooler cools the circulating water of the condenser, which is circulated by a pump-group installed on the locomotive.

The thermal scheme (first variant) is shown in Figure 68. The working cycle of the locomotive installation proceeds as follows.

The fuel (oil) is delivered by the pump 1 from the reservoir 2 to the atomizer jet 3. The pump 1 is interlocked through a reducer (to synchronize fuel and water delivery) with the water-pump 4, which delivers water into the boiler coil 5.

In its passage through the radiation coil, the water is heated and evaporated, while the steam in the last coils is already superheated to a certain extent. The steam then enters the convection superheater 6, and is delivered through the pressure-regulator 7, at a pressure of 140 atm. and a temperature of 450 degrees, to the working network, whence the main mass of it is directed to the high-pressure turbine 8, while some part of it is directed to the heat-accumulator 10, after first passing through the reducer, 9.

[See Figure 67 on next page]

In the high-pressure turbine the steam expands to 25 atm. and is then conducted through the steam pipe 11 to the intermediate superheater 12 and thence through the steam pipe 13 to the low-pressure turbine 14; in the latter it expands to 0.2 atm. and then enters the condenser 15, whence it goes in the form of condensate to the reservoir 16 and again to the pump 4.

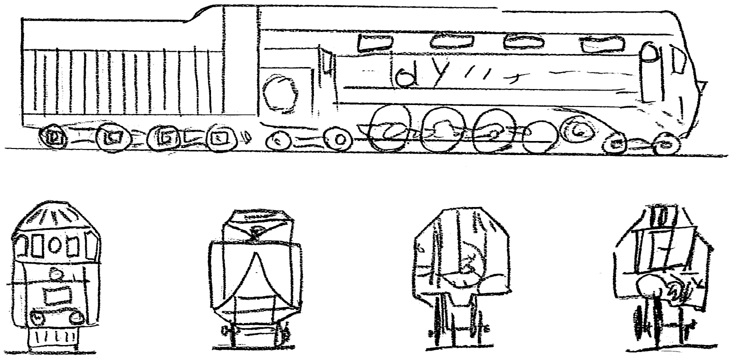

FIGURE 67

General view of a steam turbine with direct-flow boiler

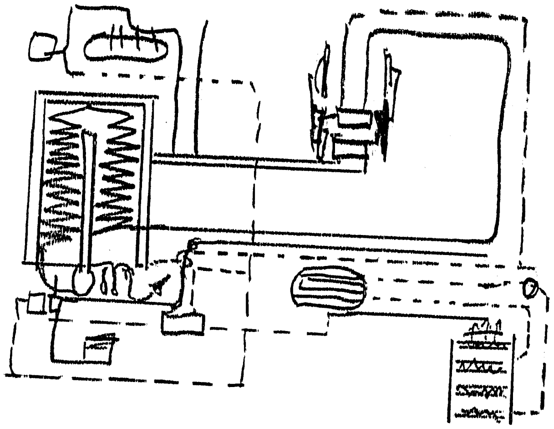

FIGURE 68

Thermal scheme of high pressure-steam turbine locomotive (first variant)

The accumulator 10 serves to equalize the load on the turbine, and also to prepare the condensate necessary to replace the natural leakage. From the accumulator, the steam is directed into the intermediate superheater 12 and then through the distributing column 17 into the auxiliary mechanisms (the circulation pump 18, the feedwater pump 4, the turbine exhauster 19, the turbine fans of the reverse cooler 20, the steam air-ejector 21, the special condensate pump 22, etc/) The steam exhausted from all these mechanisms likewise enters the condenser.

The condenser 15 is cooled by water pumped by the pump 18. The heated water enters the sections of the reverse condenser 23, where it circulates through ribbed tubes cooled by the fan 24.

The condensate pump 22 serves to pump a certain amount of sprayed and cooled condensate through the exhaust connecting branch, which is necessary for increasing the rate of steam generation during the period of operation at peak (starting from rest, and acceleration).

Pump 29 delivers the water to feed the accumulator 10 from the tender 28. The gas-operated rotation air-preheater assures the preheating of the air that enters the firebox.

The thermal efficiency of the turbine installation, determined by the J-S diagram, is 0.396.

The relative efficiency of both turbines is taken - 0.75; the boiler efficiency = 0.75; the efficiency of the reducer and the moving mechanism = 0.9; the service efficiency (considering consumption for service needs to be 15%) = 0.85.

Thus the overall efficiency of the steam-turbine locomotive at the drawbar is:

$$= 0.396 \times 0.75 \times 0.75 \times 0.9 \times 0.85 = 0.17 = 17\%.$$

According to preliminary calculations, this steam-turbine locomotive is able to develop up to 4000 HP at the drawbar.

Its consumption in terms of standard fuel amounts to 530 kg/HP-hour as compared to 1300 kg/HP-hour for the IS locomotive, or 40% thereof, while the water consumption of the former is only 3% that of the latter.

The unit weight of the locomotive (per HP) is 68% that of the IS locomotive. The dynamic coefficient is 1.1 against 1.8 for the IS locomotive.

The total weight of the locomotive is 150 tons, and together with the tender, 238 tons.

The high degree of balance, owing to the presence of the gear shaft, as well as the relatively light axle load (20-21 tons) make it possible to use the locomotive on lines with relatively weak superstructure.

HIGH PRESSURE CONDENSING STEAM-TURBOELECTRIC LOCOMOTIVE, 500 HP,
(UNITED STATES)
(Built in 1938)

This locomotive was put into trial operation for four years on one of the roads of the United States. In 1943 it was dismantled as unacceptable for series construction in view of the complexity of its construction.

The following excerpts from the report of the Railroad Committee of the American Society of Mechanical Engineers will give some idea of the tractive and operating characteristics of this locomotive.

"The steam-turbine locomotive ran about 160,000 kilometers and performed work on freight and passenger traffic equivalent to 212 million ton-kilometers.

It hauled 50 regular heavy long-distance passenger express trains, 43 trains, 4 test trains and 4 special trains. 49 passenger trains out of the 50 were hauled with a total saving of 28 hours and 17 minutes as against the scheduled running time, while one train was late, but not owing to locomotive trouble.

With boiler generating capacity of 20,400 kg of steam per hour, pressure 105.5 atmospheres, superheat temperature 482 degrees, and 1 atmosphere back pressure, each turbine developed 3,100 HP, or 6200 HP together. The unit fuel consumption at full load was 512 g/HP-hour. The boiler furnished 13 kg of steam per kg of fuel consumed. All the equipment on the locomotive, as well as the electric braking system, functioned in a manner giving complete satisfaction...

The trial operation showed that the construction of an air-cooled locomotive-type condenser would be entirely possible even with a higher vacuum, and that the turbine, as a prime mover in locomotives with high pressure and steam condensation, meets all operating requirements".

The concluding section of the report states that "the construction and trial operation of the high-pressure steam-turbine locomotive yielded rich experience and experimental material for designing a locomotive of this type, simpler in construction and at the same time more economical in operation."

It follows that this locomotive is of a certain interest, both theoretical and practical.

The locomotive consists of two completely identical sections, one of which is shown in Figure 69. Each develops 2,500 HP. The cab is at one end, and the sections may be used either separately or in their dual form. In the latter case the locomotive is controlled from a single cab by the multi-unit system.

The whole fairly complicated ensemble of equipment, devices and apparatus bears the clearly expressed traits of modern stationary power-plant technology, as is graphically portrayed by the scheme of Figure 70.

To effect maximum economy of space and weight, the designers and builders have extensively drawn on the experience in the installation of the most modern power plants on ocean-going ships.

Each section is of truck type, with two three-axle motor-trucks and two two-axle supporting trucks. The trucks are arranged so as to obtain sufficient free space for the "sunken" UTOPLLENOY installation of the boiler in the central part of the locomotive. The body construction rests on footstep bearings, thanks to which the locomotive frame itself takes up all shocks and tensile stresses.

To assure smooth running at high speeds, a special construction of limiting devices is provided between the motor trucks and the body, and likewise between the motor and supporting trucks.

The braking is combined: electrical and pneumatic. The driving and supporting wheel-pairs are equipped with clip brakes having two pairs of brake-shoes for each driving wheel.

The principal equipment of each section consists of:

a 2500 HP turbogenerator with 6 traction motors;

a steam boiler with working pressure of 105.5 atm. and superheat temperature of 490 degrees;

Photograph

FIGURE 69

One of the sections of the high pressure steam-turbine locomotive (in back of baggage-car)

a set of auxiliary equipment driven by the steam turbine;

an air-cooled condenser with turbo-fans.

The main D. C. generator is driven by a 10:1 reduction drive from the main turbine. It is cooled by a fan; in summer the heated air is let out through the roof, while in winter it is used to heat the machine room and cab.

A 220-volt three-phase alternator, driven from the main shaft of the turbine through an elastic disc clutch, is used to run the motors that drive the fans for cooling the traction motors, the air-conditioning equipment in the cars, etc.

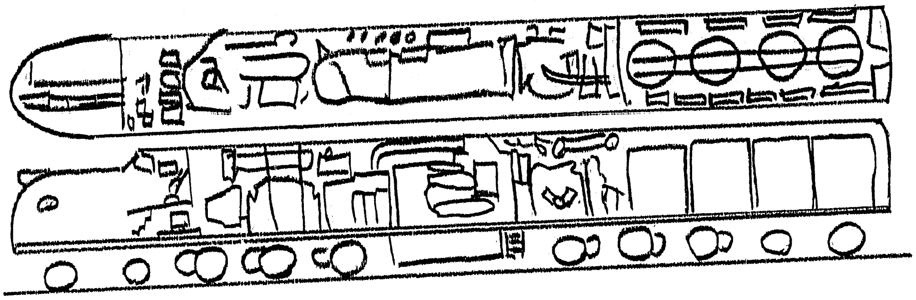

FIGURE 70

Scheme of arrangement for equipment of high pressure steam-turbine locomotive.

1-6, traction motors; 7-8, main generators; 9, alternators; 10, exciter; 11, charging unit; 12, braking rheostat; 13, contactors; 14, storage battery; 15, cooling blower for traction motors; 16, boiler; 18, main high pressure turbine; 19, low pressure turbine; 20, collector for condensate; 21, air-cooled condensers; 23, upper tank for condensate; 26, feedwater pump; 27, feedwater heater; 28, auxiliary turbo-unit; 29, turbo-blower for cooling condenser; 30, compressor; 31, steam generator for heating train; 33, fresh-water tank; 34, exhaust blower; 35, water-separator of braking rheostat; 36. control panel for boiler installation; 37, blowers for cooling traction motors; 38, fuel-oil tank.

To excite the main generator, when it is worked by the motor, and the traction motors, when they are worked by the generators (i. e., during the period of electric braking), there is a separate A.C. generator-excitor with its rotor mounted on the same shaft as the alternator.

The auxiliary equipment consists of:

a fan to deliver air to the combustion chamber and pumps to deliver water and fuel; they are driven by separate low-pressure auxiliary turbines worked by steam-drawn from the high-pressure turbine;

a rotary circulation pump delivering lubricant for the reducing drive, the bearings of the transmission shafts, turbines, etc., and operated by a 125-volt D. C. motor;

a separate turbo-fan for cooling the condenser.

The boiler installation consists of a boiler with forced water circulation, a fire-box and accessories, a superheater, air-preheater, and fuel jets, and structurally constitutes a single group, stabilized on the locomotive by special shock-absorbers that prevent shocks and vibration.

The water is replaced in the closed system by the addition of steam from a special low-pressure boiler termed a steam-generator, which consists of a coil through which either regulated steam from the boiler or bled steam from the main turbine is passed. The steam generator is provided to heat the train, and its feedwater is supplied by three piston pumps driven by electric motors.

There is also a small vertical tubular boiler producing 45 kg of steam per hour, fired by propane gas from the roundhouse. The steam from this boiler is used to heat the fuel-oil and also to spray it through the fuel jets when starting up the main boiler. If live steam is available at the roundhouse or station, there is no need for this boiler.

The condenser is mounted on the rear end of the body of each section and consists of vertical ribbed tubes. The spent steam enters the collector on top of the condenser, and settles by its own gravity into the mud drum under the locomotive body. A steam vacuum ejector is provided to remove the particles and air that enter the closed system.

Under normal circumstances the condensate is found in the tank under the locomotive body, and its predetermined level is automatically controlled by a float-actuated cut-out switch. Water from this tank is delivered by a centrifugal pump to another tank, located in the upper part of the locomotive body. Another pump delivers water from the upper tank to the suction side of the feedwater pump, which delivers it to the feedwater heater. It then passes through the economizer, enters the boiler tubes, and finally goes to the water-separating drum, whence the excess water is returned to the mud drum, while the steam continues on to the superheater and turbine and is then returned again to the condenser.

The main generator is used only to run the traction motors, which make it possible to regulate the speed of the locomotive by varying the voltage, thereby eliminating rheostat losses.

The control circuits are fed by a 125-volt motor-generator and a buffer battery.

The locomotive is controlled by three hand levers: "accelerate", "brake" (pneumatic and electric) and "reverse". The latter also serves as a selector for the various ways of connecting the motors: series, series-parallel, or parallel.

The operation of the whole power plant is completely automatic. The instrument-board is located on the main panel of the engine room. An acoustic signal (gong) is sounded when any of the protective devices instruments functions, and the corresponding signal lamp in the cab lights up. The rated speed of the locomotive is 200 km/hour.

STEAM LOCOMOTIVE WITH HIGH, VARIABLE STEAM PRESSURE

(UNITED STATES)

(Plans)

This locomotive differs substantially from the one described above both in design (which is considerably simpler) and its operating characteristics.

To secure an even higher thermal efficiency, the boiler pressure is increased to the limits now allowable in stationary installations, namely 140 atmospheres.

To reduce the weight and dimensions of the air-cooled condenser, the condensation is non-vacuum. The losses from heat-jumps at the lower limit of expansion, however, are compensated by its increase at the upper limits, inasmuch as steam pressure attains the limiting maximum of 140 atm. at periods of peak load.

There are two main prime movers, a high-pressure turbine and an unaflow rotary steam engine. The latter is fed by steam from a separate low-pressure boiler (10.5 atm.) and operates in conjunction with the turbine on a common shaft, and plays the part of a peculiar kind of booster. At low speeds it takes up a part of the turbine load on the condenser, which increases disproportionately at low turbine r.p.m., while at high speeds it reduces the slope of the power characteristic curve.

[See Figure 71 on next page]

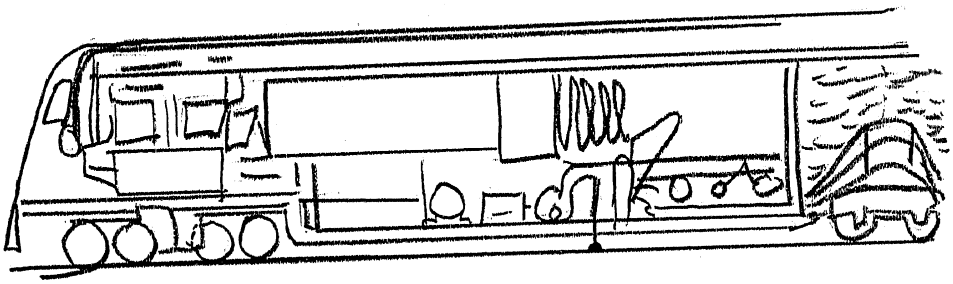

FIGURE 71

One of the sections of the steam-turbine locomotive with high variable pressure.

1, high-pressure boiler; 2, low-pressure boiler; 3, cooler; 4, condenser ; 6, steam engine; 7, turbine ; 8, blower; 9, blower ; 10, air-suction tube ; 11, turbine ; 12, gearcase ; 13, superheater; 14, feedwater pump; 15, combustion regulator; 16, motor for regulating combustion; 17, blower ; 18, burners ; 19, fuel tank .

The torque is transmitted from the common shaft to the axles through a vertical driving shaft, a toothed gearing, a hollow shaft and resilient cup-drive elements.

The low-pressure boiler makes it possible to reduce the dimensions and weight of the high-pressure boiler, and also assures a constant supply of water to the locomotive (in case of water and steam leakage).

The locomotive consists of two identical sections. One of them is shown on Figure 71.

A specific and exceedingly valuable peculiarity of this locomotive, which is exceedingly valuable under operating conditions, is the absence of the break in the power characteristic in the areas of medium and high speeds, which break is characteristic (and very undesirable) for ordinary locomotives and motor locomotives.

Why is this break undesirable and how is it eliminated here?

As everyone knows, the shape of the power curve and tractive force curve of a locomotive is determined by the normal, or, as they call it, the balanced regime of operation. This regime, for the given cylinder dimensions, diameter of the drivers, steam temperature and steam pressure, is assured by the regulation (cut-off) of the amount of steam entering the cylinder at each piston stroke.

Some modification of the shape of the curves, i. e. some reduction in their slope, thus adapting the locomotive better to the demands of operation, is of course possible, E. G., a larger size boiler may be installed, or the rate of combustion in the firebox may be increased, thus obtaining an additional amount of steam for use in the cylinders at higher levels of admission (cut-offs). But this method of improving the shape of the curves is by no means efficient; it is purchased dearly by increasing the steam rate, i.e., by reducing the already low efficiency of the locomotive, and likewise by increasing the dimensions and weight of the locomotive and tender.

However, a radical modification in the shape of the curves, i. e. a continuous rise in the power curve and a certain approach of the tractive force curve to the horizontal, is a necessary condition of the locomotive being easily adapted to varying regimes of operation and varying profile of the track, and this in turn will permit reducing to a minimum the diversity in type of the locomotive stock employed throughout the railroad system.

This situation is graphically illustrated by the diagram of Figure 72.

On this diagram we have plotted the curves of the power used at the locomotive drawbar to haul a 900-ton passenger express train over sections of track of varying profile, and have also plotted over them the curves of the characteristics of available power of three different locomotives: the conventional, reciprocating steam locomotive, the internal combustion locomotive and the planned steam-turbine locomotive.

It will be seen from the diagram that on a level track, the steam locomotive attains balancing speed at 95 km/hour, while the internal combustion locomotive reaches it at 90 km/hour; on a 5% grade the corresponding figures are 77 and 75 km/hour; on a 10% grade

58 and 60 km/hour. In other words, at these points the power of both locomotives is completely exhausted, and further increase in their speed is impossible.

The situation is different with the planned steam-turbine locomotive. Its power curve (see diagram) continues to increase uninterruptedly and thus makes it possible to accelerate the train speed throughout the entire range of speeds.

These tractive properties of the locomotive are attained by means of a special system of regulating the firing. This system functions so that the boiler pressure changes automatically and immediately with the changes in locomotive speed, with the maximum speed corresponding to maximum pressure. Under these conditions, the operating process proceeds as follows.

As the speed increases, the tractive force of the turbine declines in roughly the same proportion as with piston engines regulated by cut-off. But since increase in speed, and consequently also increasing need for power, correspond to increased boiler pressure, the temperature drop /PEREPAD/ in the turbine increases all the time. In other words, the power developed by it increases all the time (the curve goes up) thereby compensating in the appropriate

[See Figure 72 on next page]

proportion for the loss in tractive force (the curve of tractive force approaches the horizontal).

The weight of the two-section steam-turbine locomotive is distributed on two four-axle motor trucks and one supporting two-axle truck in the middle, which serves only as a guide on curves.

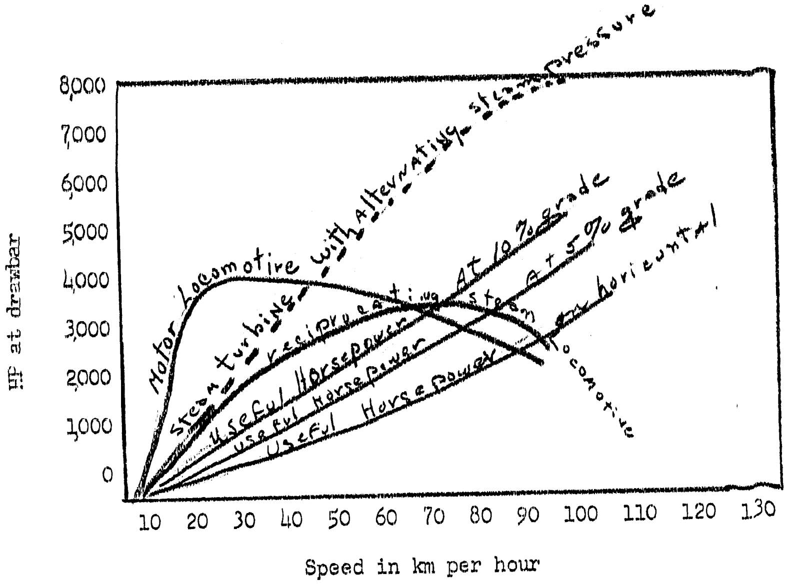

FIGURE 72

Curves of useful power at the drawbar of locomotive for hauling 900-ton passenger train over various track profiles and curves of available power of motor-locomotive, reciprocating steam locomotive and steam locomotive with variable pressure.

With a load of 20.5 tons on each axle, the adhesive weight of the locomotive is 165 tons. Taking into consideration the high degree of uniformity of the torque, coefficient of friction of 0.28 to 0.30 /28% to 30%/ may be taken as entirely assured of realization under ordinary operating conditions. The locomotive is thus able to exert a tractive force of the order of 46,000-50,000 kg at the drawbar without risk of slipping.

The unit weight of the locomotive is about 45-50 kg/HP at the drawbar, including the water supply.

LOW-PRESSURE GEARED STEAM-TURBINE LOCOMOTIVE (SWEDEN)

(Built in 1935)

In its design this locomotive is an improved variant of the two earlier Lungstrom steam-turbine locomotives built in 1921 and 1924. Figure 73 is an outside view of it.

In contrast to the first two, which operated on a closed cycle, this model is non-condensing. Its wheel formula is 1-4-0.

The principal equipment consists of a 2,000 HP turbine located in front of the smokebox, and an ordinary boiler with a working pressure of 13 atm.

The torque is transmitted from the turbine shaft by a system of gear-wheels to a gear shaft, and thence through side rods to the coupled wheels.

The locomotive is reversed by using a so-called idling or parasitic turbine wheel. When the locomotive is moving forward, this wheel turns without load. When it is necessary to travel

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The locomotive is reversed by using a so-called idling or parasitic turbine wheel. When the locomotive is moving forward, this wheel turns without load. When it is necessary to travel backwards, the parasitic wheel is placed in the engaged position with the transmission system and takes up the entire load of the locomotive.

Adhesive weight is 73 tons. During the trial tests, the locomotive developed a tractive force of 22,000 kg on a 10% grade, hauling a 1,730-ton train, thus giving an adhesion factor of 0.30; and showed no signs of slipping in doing this. This testifies to the high degree of uniformity in the torque applied to the driving wheels of the locomotive.

In its consumption of fuel and water the steam-turbine locomotive likewise proved more economical than a steam locomotive of equivalent power.

Photograph

FIGURE 73

Lungstrom low pressure steam-turbine locomotive with geared drive.

LOW-PRESSURE GEARED STEAM-TURBINE LOCOMOTIVE (GREAT BRITAIN)

(Built in 1937)

The design of this locomotive (of which Figure 74) gives a general view) has substantial differences from that of the Swedish model described above. It has two turbines, one forward, developing a power of up to 2500 HP, and the other - reverse - of lower power.

The forward turbine is located on the left side, at the site of the left cylinder on the ordinary locomotive, and is connected by a triple gear system (Figure 75) with the front driving axle. The reverse turbine is located on the right side and is connected to the same gear system by a cam clutch and an additional pair of gears. Resilient cup-drive elements and a hollow shaft assure elasticity of torque transmission from the latter gears to the driving axles.

The forward turbine is permanently engaged with the driving axles, while the reverse turbine is engaged only when backward motion is desired and does not run while the locomotive is moving forward.

Photograph

FIGURE 74

2500 HP geared steam-turbine locomotive

The forward turbine turns even while the locomotive is moving backwards, and without load, while a certain amount of steam is passed through it for cooling purposes under such circumstances.

Steam is delivered from the boiler to the turbines by means of a throttle, which thus performs the functions of a shut-off valve. Thence the steam passes to the steam admission chests on the turbines.

The steam-admission chest of the main turbine has six control valves, the work of which is regulated by a special lever from the cab, so that the desired turbine speed and developed power may be obtained at all times.

The reverse turbine has a steam-admission chest with three valves.

After passing through the valves, which open in a predetermined sequence, the steam is then conducted through a flexible steam pipe to a group of jets, and after doing its work in the turbines, passes through the exhaust nozzles (of which there are only two) into the atmosphere.

The working pressure in the boiler is 17.5 atm. with a superheat temperature of 400 degrees.

In the design of the main turbine, both in the number and type of the stages and in the shapes and locations of the vanes, economy of turbine operation with the widest possible limits of the speed range was a guiding thought.

[See Figure 75 on next page]

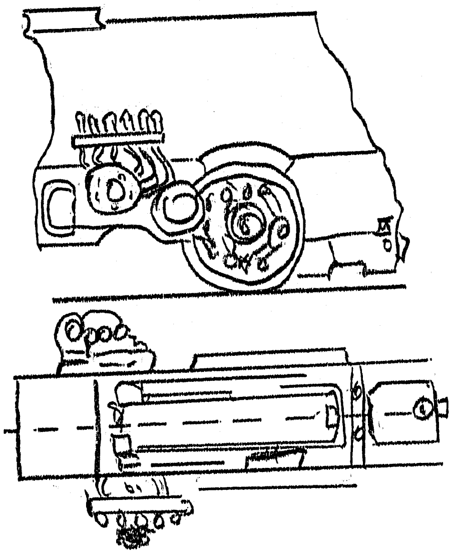

FIGURE 75

Scheme of arrangement of turbines and geared transmission

1, valves of forward turbine; 2, steam admission chamber; 3, reverse turbine; 4, reducing stage; 5, forward turbine.

The whole gear system is contained in a closed gearcase, lubricated mechanically under 1.75 atm. pressure by a pump driven by the same gear transmission. There is also a supplementary Worthington oil-pump to circulate the lubricant through the cooler, and likewise to lubricate the system on starting from rest and during acceleration.

The locomotive has a special magnetic filter to absorb (attract) the minute metallic particles, which are formed when the gears operate and thus to prevent their reaching the bearing surfaces (bearings, journals, etc.)

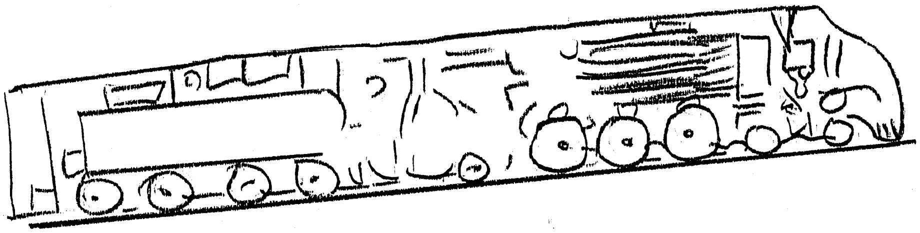

FIGURE 76

General view of steam-turbine locomotive with individual drive Schneider.

All the driving and supporting axles of the locomotive are mounted on roller bearings. The locomotive weights 110 tons in working condition, of which 69 tons is imposed on the driving axles. The tender weighs 52.5 tons and carries 15.2 cubic m of water and 9 tons of fuel. The total wheel base (locomotive and tender) is 19.15 m, and the length between buffers is 22.31 m.

The locomotive is designed to pull 600-ton passenger express trains at a speed of up to 160 km/hour.

During its trial operation it covered over 500,000 km with results that were entirely satisfactory both in reliability and smoothness of running qualities. Ease of control, smooth starting and quiet running at all speeds are characteristic features of this locomotive.

The turbine locomotive shows no substantial saving in unit consumption of fuel and water by comparison with steam locomotives of equivalent power. But this fact does not, in the designer's opinion, argue for the identity of the thermal properties of steam-turbine locomotive and steam locomotive, but is explained by the operating conditions, owing to which the power residing in the steam-turbine locomotive is very inefficiently and very incompletely utilized.

2-3-2 STEAM-TURBINE LOCOMOTIVE WITH INDIVIDUAL DRIVE (FRANCE)

(Built in 1939)

Figure 76 gives a general view of this locomotive.

The power equipment consists of three Schneider steam turbines, each developing 1,000 HP at 10,000 r.p.m. There are two working wheels on the same turbine shaft, one forward and one reverse motion. Thus according to whether the locomotive is moving forward or backward one of these wheels will run with no load. The corresponding shifting of the wheels from idling to working, and the reverse, is affected from the cab by shifting the reverse lever.

The turbines operate independently of each other. The torque from the turbine shaft is transmitted to the corresponding axle through a resilient reducing gear, thanks to which the shocks and vibration of running are completely absorbed by the resilient cup-drive elements and are not transmitted to the turbine shaft.

[See Figure 77 on next page]

The individual drive assures the fullest and most economical utilization of the power of the turbines, since (according to the weight of the train, the track profile, etc.) one, two, or all three

photograph

FIGURE 77

One of the Scheider steam-turbines.

1, driving arm of axle; 2, turbine; 3, reducer; 4, longitudinal axis of wheel-pair axle.

of the turbines may be operated at the same time. Oil is circulated under pressure by turbo-pumps, which assures abundant lubrication to the turbine bearings, gears, etc. under ordinary operating conditions, while when running without steam this circulation is handled by pumps driven from the locomotive axles.

The turbine, as will be seen from Figure 77, is very compact and is of simple design.

The boiler is standard type and works at a pressure of 25 atm., and is somewhat strengthned (to increase its safety) by the use of boilerplate and staybolts of special steel.

Since there are no unbalanced masses, and since the turbine itself operates at a uniform r.p.m., the torque remains constant throughout an entire revolution of the wheels, which fact substantially improves the running qualities of the locomotive.

Photograph

FIGURE 77

One of the Scheider steam-turbines.

1, driving arm of axle; 2, turbine; 3, reducer; 4, longitudinal axis of wheel-pair axle.

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This steam-turbine locomotive is able to develop 3000 HP.

LOW-PRESSURE GEARED STEAM-TURBINE LOCOMOTIVE, 6900 HP (UNITED STATES)

(Built in 1944)

This steam-turbine locomotive, which has the wheel-formula 3-4-3, is the most powerful locomotive of this type in the world and develops 6900 HP. Figure 78 is a general view of it.

Its principal equipment consists of:

a forward turbine with a double reducing gear and intermediate resilient cup-drive (between the final drive gears and the driving axle).

Photograph

FIGURE 78

6900 HP geared steam-turbine locomotive

a reverse turbine, having a geared drive that is clutched (when backward motion is required) to the driving pinion of the main transmission;

a pneumatically actuated throttle with apparatus to protect against "racing" and excessive reduction of the pressure in the oil pipes;

a system of oil pipes with auxiliary equipment (coolers, filters, two turbo-pumps, etc.);

distributing valves.

The forward and reverse turbines are located respectively on the right and left side and rest on the massive steel body of the transmission case. The latter in turn rests on the frame of the locomotive. Thus the turbines together with the transmission case constitute a single power-equipment assembly; as may be clearly seen on Figure 80.

The transmission case is attached to the locomotive frame at three points, two at one side and one at the opposite side; and thus the warps and other deformations in the frame are not transmitted to the transmission case.

The forward turbine is of the impulse type, with one Curtis stage followed by five full admission Rateau stages. The steam enters the turbine through four pipes, each 76 mm in diameter and connected to a group of jets, which cover about 20% of the total periphery of the Curtis-stage vanes. Each steam admission pipe is connected to a regulating valve and a steam collector located over the smokebox. The valves are opened by a cam roller in predetermined sequence, which assure precise regulation of the revolutions and thus also of the power developed by the turbine.

Photograph

FIGURE 79

Gear-transmission assembly (with cover removed) with turbines in place.

The forward turbine is permanently engaged with the driving pinion, but the reverse turbine is so engaged (through a hydraulic clutch) only when backward travel of the locomotive is required. The shift from forward travel to backward can be made only after the locomotive has come to a full stop. In the contrary case, a special blocking device termed the "zero speed" automatic control is actuated, and prevents the clutch from being engaged or disengaged, as the case may be.

The transmission is nested. The transmission consists of two high-speed double helical gears, two low-speed cylindrical pinions and two low-speed cylindrical gear wheels. The latter are mounted on the hollow shafts of the corresponding driving axles and are equipped with resilient cup-drive elements that assure the elastic transmission of the torque.

The elastic transmission between the final drive gear and the driving axle is identical in principle with that used on electric locomotives, but with substantial differences in design. While in electric locomotives the resilient elements are located on the same plane as the wheels, this position is impossible in the steam-turbine locomotive, with its coupling rods and internal frame (between the wheels), and for this reason the gear with its resilient elements is mounted on a short hollow axle in the central space between the wheels, in the plane of the longitudinal axis of the locomotive, and the torque from the resilient elements is transmitted through the spokes in the hub which is forged on the driving axle. To secure the reliable transmission of so great an amount of power, the elastic elements are arranged in two rows, 8 to a row, which distributes the load over the relatively large contact area between the cams and the hub spokes.

Photograph

FIGURE 80

Gearedbox mounted directly on wheel-pairs.

The entire drive is enclosed in a sealed case which prevents dust and dirt from entering the system, while the abundant pressure lubrication of the gears and shaft bearings sharply reduces the power loss through friction, which amounts under ordinary operating conditions to about 3%. Figure 80 shows the gear case, mounted immediately above the wheel pairs.

The boiler is of conventional type. Its barrel is of conical shape, with maximum and minimum diameter of the sections 3,550 and 2,360 mm respectively. The working pressure in the boiler is 21.7 atm. It is stoker-fired, has a feedwater heater and type E superheater.

The total heating surface is 450 sq. m, of which 30 sq. m are in the firebox, 17 sq. m in the enlarged combustion chamber, 8 sq. m in the circulators (there are only 6 of these), 47 sq. m in the firetubes and 348 sq. m in the flues. Grate area is 11 sq. m. The ratio of grate area to toal heating surface is 1:41. The superheater surface is 185 sq. m. The steam generating capacity of the boiler at 20 atm. pressure and superheat of 400 degrees is 43,100 kg/hour, which is entirely sufficient for the turbine to develop 6,500 HP at 115 km/hour.

The turbine shaft is turned by the pressure of a steam jet against the vanes, while the total expansion of the steam up to the moment it leaves the turbine is all only within the limits, of a single atmosphere, which assures a uniform (non-pulsating) boiler draft.

The adhesive weight of the locomotive is 118 tons, total weight 263 tons, tender weight 204 tons. Driver diameter is 1,727 mm.

Wheel base: driving axles, 5.9 m; rigid, 4.1 m; full locomotive, 16.15 m; locomotive and tender, 32.3 m. Water supply is 75 cubic m; fuel supply, 38.5 tons.

The starting tractive force is 32,000 kg forward and 29,500 kg backing. At 160 km/hour the turbine makes 9,000 r.p.m. Maximum locomotive speed is 165 km/hr forward and 35 km/hour backwards. In the latter case it develops 1,500 HP at 8,300 r.p.m. of the turbine.

The locomotive is very simple to drive. It consists merely in the manipulation of a single lever, placed on the right side of the cab. It has three main positions: neutral, forward and reverse. After moving the lever into forward or reverse, the engineman acts on a special pneumatic mechanism which actuates a cam roller regulate the degree of opening or closing the corresponding valves that admit steam to the turbine. If the locomotive exceeds the critical speed (175 km/hour forward or 40 km/hour reverse), or if the oil pressure in the lubricating system drops to 0.35 atm., an automatic control closes the admission valves and cuts off the entry of steam into the turbine.

The principal merits of the design and operating qualities of this turbine locomotive, which at the same time are advantages over the standard locomotives, and in some respect over the internal combustion locomotive as well, other things being equal, consist of the following:

the boiler power is about 20% higher;

smaller wheel-diameter and lower center of gravity;

uniform torque and absence of unbalanced masses;

greater tractive force throughout the range of medium and high speeds;

lower steam consumption throughout most of the speed range;

lower weight and smaller clearance dimensions than the locomotive with tender.

These advantages are very vividly portrayed by the diagrams (Figures 81-84) and the data of Table 5.

As shown by the curves of Figure 81, the internal combustion locomotive disposes of greater tractive resources at starting and at low speeds than the turbine locomotive; but from 55 km/hour on, up to maximum speed, the internal combustion locomotive lags behind the turbine locomotive in this respect, and at all speeds the turbine locomotive has an advantage over the steam locomotive on this point. This means in practice that the turbine locomotive can haul a heavier load, at the same speed, than the steam or motor locomotive, or it can haul the same load at higher speed.

[See Figure 81 on next page]

The curves of Figure 82 show that from a speed of 30 km/hour up to the maximum the turbine locomotive develops more power than the steam locomotive, and, from a speed of 55 km/hour, than the motor-locomotive. This is a very important factor, considering the current trends towards increasing train weights and speeds.

In the diagram of Figure 83 we have plotted the curves of

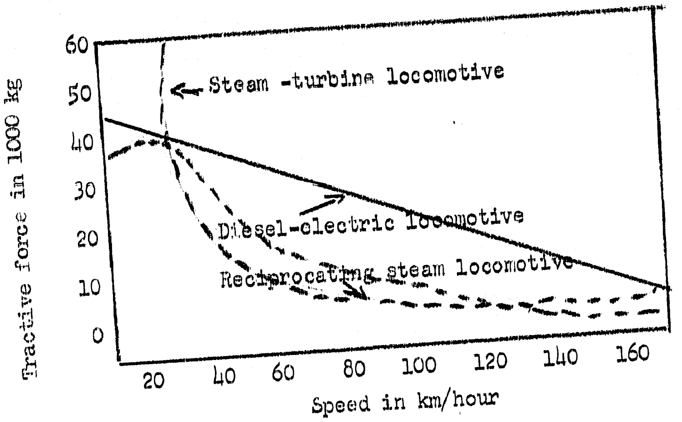


FIGURE 81

Tractive force at rail, plotted against speed (reciprocating steam locomotive, Diesel-electric locomotive, steam-turbine locomotive).

equilibrium speed for the turbine-locomotive, internal combustion locomotive and steam locomotive on different grades, hauling a 16-car passenger train weighing 1,100 tons, allowing for the power expended by the locomotives for air-conditioning in the trains. Table 5 gives the data characterizing the ability of these locomotives to accelerate, drawing a train of this weight along a level stretch of track.

[See Table 5 on next page]

As shown by the curves and tabular data, the turbine locomotive also possesses substantial advantages in this respect as well. If we take into consideration the fact that, in practice, the train speed is primarily determined by the locomotive's ability to maintain high speeds on up-grades, and also to accelerate quickly after station stops and runs at reduced speed, these advantages appear even more substantial.

TABLE 5

TIME IN MINUTES REQUIRED TO ACCELERATE A TRAIN WEIGHING 1,100 TONS FROM ZERO VELOCITY TO 115, 130, 145, AND 160 KM PER HOUR

SPEED IN KM/HOUR	TURBINE LOCOMOTIVE	CONVENTIONAL RECIPROCATING STEAM LOCOMOTIVE	INTERNAL COMBUSTION LOCOMOTIVE
115	5.12	5.81	5.63
130	6.80	8.18	8.50
145	9.46	13.26	14.26
160	16.00	*	*

* Maximum speed with an 1,100-ton train is about 150 km/hour.

In steam consumption the turbine locomotive is shown by the curves of Figure 84 to be less economical than the steam locomotive at speeds below 40 km/hour. At speeds from 40 km/hour up to the maximum, it is more economical.

This peculiarity is explained by the operating characteristics of the turbine, which requires considerably more steam at low r.p.m. than the piston engine. It must, however, be borne in mind that this locomotive is designed for high-speed movement and this shortcoming is thus not too important. Besides this, it is also possible to get this locomotive to operate more economically even at low speeds, by changing the gear ratio and installing turbines with shape and

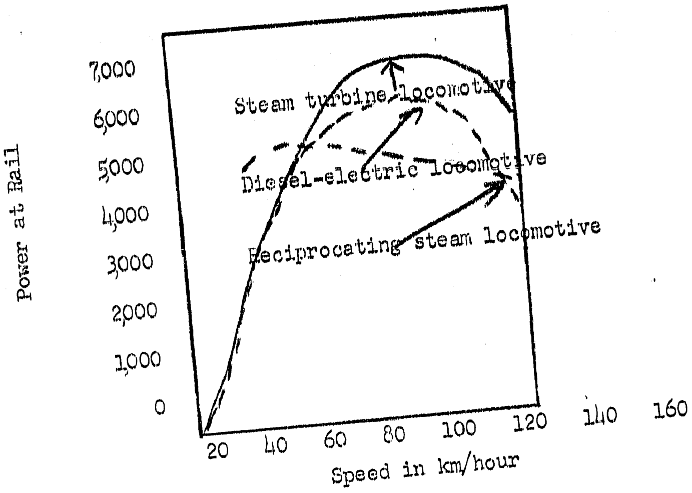


FIGURE 82

Power at rail, plotted against speed (reciprocating steam locomotive, Diesel-electric locomotive, steam-turbine locomotive).

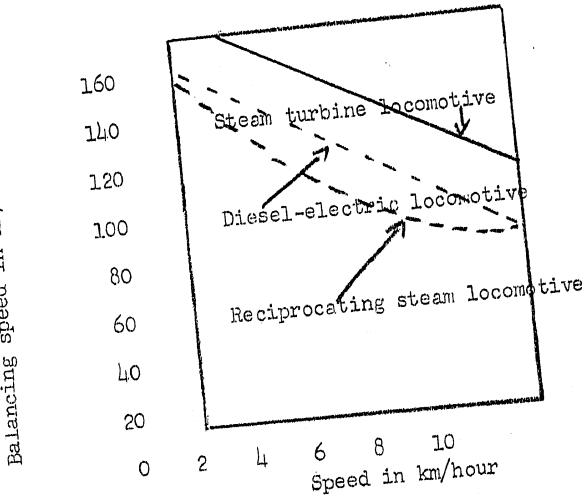


FIGURE 83

Balancing speeds on various grades (reciprocating steam locomotive, Diesel-electric locomotive, steam-turbine locomotive).

arrangement of the vanes suitably modified, which is a precondition in designing a turbine locomotive for freight service.

The thermal efficiency of the steam turbine locomotive may be further enhanced by suitable modifications of the working parameters of the steam. The diagram of Figure 85 illustrates very strikingly the economy resulting from such a modification; at certain values for pressure, back pressure and temperature, the steam consumption and the corresponding fuel consumption is reduced by 10, 15, 20, 25 and 30%.

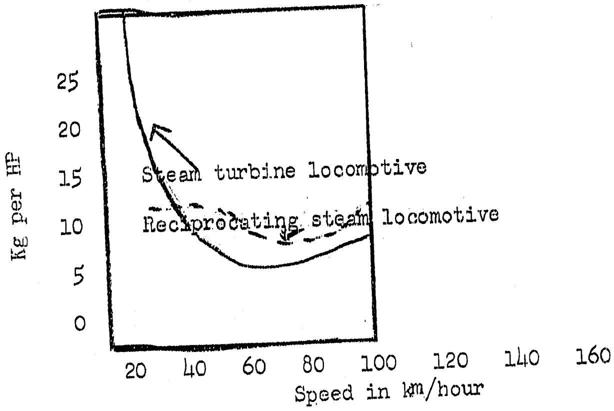


FIGURE 84

Steam rate in KP/HP at rail (reciprocating steam locomotive, turbine locomotive).

The riding qualities of the turbine locomotive are equivalent to those of the internal combustion locomotive. In contrast to the steam locomotive, with its pulsating torque, the turbine locomotive, like the internal combustion locomotive, delivers a torque of practically perfect uniformity throughout an entire revolution of the wheels, if its driving parts are properly balanced.

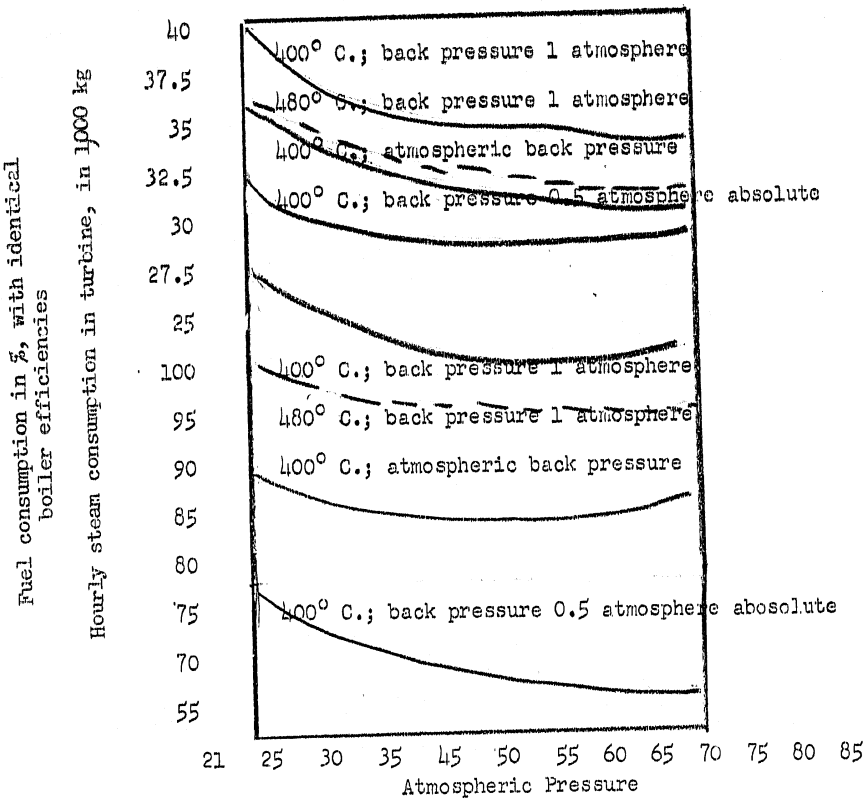


FIGURE 85

Curves of relationship between steam and fuel consumption and the pressure, back pressure, and superheat temperature for 6,900 HP geared steam-turbine locomotive.

This is a very important advantage from the operating point of view, for the reduction of the harmful action on the roadbed makes lines of relatively weak roadbed "passable" for the locomotive without adversely affecting the safety of movement, while the coefficient of friction that can be counted on is also increased, etc.

The weight, clearance and operating proportions of the geared steam-turbine locomotive are given for comparison together with those of the three-section internal combustion locomotive in Table 6, below.

It will be seen from this table that the turbine-locomotive, having considerably greater tractive power (15% more at the shaft and 26% more at rail, is at the same time 21% lighter in unit weight, and shorter than the internal combustion locomotive by almost half.

TABLE 6

Indices	Geared Turbine Locomotive	Internal Combustion Locomotive with Electric Drive
Adhesive Weight in tons	118	314
Power developed at shaft, in HP	6,900	6,000
Maximum power at rail, in HP	6,550	5,200
Starting tractive force in kg	32,000	78,500
Total length in m	37.4	68
Total weight in tons	467	471
Unit weight in kg per HP (at rail)	71	91
Unit power, in HP (at rail) per ton	14.00	10.66

With all of these merits, this locomotive nevertheless also has a number of shortcomings, of which the most essential was revealed by the trial operation to be the lack of flexibility in the functioning of the gear drive.

LOW-PRESSURE NON-CONDENSING STEAM-TURBOELECTRIC LOCOMOTIVE (UNITED STATES)

(Built in 1947)

The shortcomings of the high-pressure condensing steam-turboelectric locomotive and the low-pressure geared steam-turbine locomotives, which we have already noted in the course of their descriptions, forced another solution to be sought in the shape of increasing the power of the steam-turbine locomotive. The experimental steam-turboelectric locomotive described below is one of the variants of this solution. Figure 86 is a general view of it.

The locomotive has a conventional boiler to supply the prime mover, an impulse turbine, with steam. The steam generating capacity of the boiler at 21.7 atm. pressure and 400 degrees C. superheat temperature is 38,500 kg/hour. At a pressure of 1.05 atm. on the exhaust side, and 6,000 r.p.m., the turbine is able to develop 6,000 HP at the shaft.

The turbine is connected to two main D. C. generators by a helicoidal reducing gear drive with a gear ratio of 1:6. The maximum general-speed is thus 1,000 r.p.m. Figure 87 gives a general view of the steam-turbogenerator installation.

The main generators are 8-pole, multiple-wound, having commutating (DOBAVOCHNIY) poles and supplied with two excitation windings on the main poles. One of these windings serves for self-excitation and is connected to the commutator by a two-stage rheostat, of which the first stage would be entirely sufficient to prevent the voltage from rising above the allowable limits; while the second stage allows the maximum voltage to be obtained from the terminals of the windings. Switching over from one stage to the other is automatically accomplished by the operation of a voltage relay connected to the terminals of the generaltor armature.

The current strength through the independent-excitation windings is regulated by the "Speed" lever of the main controller, which has 11 stages and thus makes this regulation exceptionally smooth.

Photograph

FIGURE 86

6000-HP steam-turboelectric locomotive

Two armatures are mounted on the shaft of each generator. Their commutators emerge on each side of the generator. A pulley is mounted at the extreme end of the shaft of each generator, and serves to drive an auxiliary 9-kw. 750-volt generator (by a Vee-belt drive). Both auxiliary generators are mounted, as shown by the illustration of Figure 87, on the bodies of the corresponding main generators.

Forced ventilation of the generators is provided by vertical propeller-type turbo-fans with a capacity of 700 cubic m per minute. The air delivered by this fan enters the space between the stators of the generators, whence it flows in both directions through the commutators, cooling them and removing coal-dust. An additional air passage is also provided, through which cold air from the outside is conducted to the commutators. Each generator develops 2000 KW.

Eight electric traction motors, each developing 620 HP at 508 volts and 720 r.p.m., are arranged in four groups of two, connected in parallel. Each group is fed from the corresponding armature of the main generator. The torque is transmitted from the

Photograph

FIGURE 87

Steam-turbo generator installation with outside turbine casing removed, together with transmission.

motors to the corresponding axles through a reducing gear with a gear ratio of 24:55.

Two propeller-type turbo-fans installed on the front part of the coal bunker furnish forced-air cooling for the motors. All the fans have centrifugal air-filters to clean the cooling air properly. To prevent the entry of smoke and soot into the cooling air, as far as this is possible, this air is taken from in front of the smokestack.

The principal difference between the control of the power installation on the turboelectric locomotive and that of the Diesel-electric is in that acceleration effected partly by varying the strength of the current exciting the generators and partly by relating the speed of the turbine. To assure an acceptable rate of water (steam) consumption, the turbine is so adjusted as to make about 60% of its rated r.p.m. with the controller in the "idling" position.

The main controller has two levers, one for speed and the other for reversing (changing the direction) locomotive travel. In starting from rest and accelerating the locomotive, the engineman performs the following manipulations: moves the "speed" lever from the "off" to "idling" position. This admits steam to the turbine, and it begins to run at a speed of about 3500 r.p.m. The engineman then pushes the controller lever further and reaches the following, or "first" position. The generators then become excited and deliver a certain small voltage to the terminals of the motors. As the lever is successively moved through all of the 10 positions, the strength of the excitation current, and consequently also the power developed by the generators, gradually increases, while the speed of the turbine reaches 75% of the full rated r/p.m. Further movement of the controller handle brings the speed of the turbine up to the limiting maximum.

The strength of the current in the motor circuits, and likewise the speed of the turbine, is constantly shown on the corresponding instruments on the instrument panel in the cab. At night the panel is lit by ultraviolet light ("black light"), which assures good visibility and at the same time eliminates glare, which is very objectionable under these conditions.

The same panels also has signal lamps to show the tripping of the overload relay and instruments to indicate grounding, the operation of the blowers, the temperature and pressure of the oil in the oil lines.

The circuit of each group of traction motors has an electropneumatic cut-out. The locomotive is reversed by a cylindrical reverser, actuated by a reversing cam roller from the main controller.

The excitation of the motors is automatically shunted (by electropneumatic cut-out switches) on actuation of the voltage relay, which is connected across the terminals of the generator armature.

A so-called "sliding" relay is connected (PODKLYUCHAT) between the armature and inductor of each motor. So long as the counter-E.M.F. and consequently also the speed of the group motors in question remains constant, no current flows through the relay; but when the ring begins to slip, the counter-E.M.F. in the armature of each motor increases, thus causing a current to flow through the relay winding, and the contacts in the buzzer circuit close, the buzzer begins to sound, and the engineman knows that slipping has commenced.

A special overload relay protects the motors from overload. This is connected in the circuit of each motor group and is set for the maximum acceleration of the increase in tractive force. When this rate of increase begins to exceed the allowable value, the relay is actuated, cutting off the current from the damaged magnetic valve, which by its contacts has closed the circuit of the turbine regulator. The load on the motors can then be restored only if the controller handle has first been placed in the "off" position.

If necessary, each motor may be switched off at any time, and the locomotive can then continue its operation with correspondingly

[See Figure 88 on next page]

reduced speed or diminished train weight.

The independent excitation windings are fed by auxiliary generators, which also supply current to the electropneumatic braking system and the motors that drive the pumps for the mechanical lubrication system. The work of these pumps is in accordance with the position of the handle of the main controller; when this is placed in the "off" position, the motors stop running and the delivery of oil is interrupted.

As will be seen from this description, the driving of this locomotive reduces down, essentially, to the manipulation of two

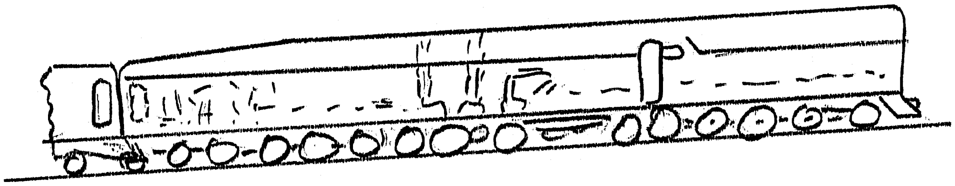


FIGURE 88

1, automatic coupler; 2, main frame (front section); 3, front truck; 4, turbo-blowers to cool traction motors; 5, stoker engine; 6, coal plungers; 7, coal bunker; 8, worm of stoker; 9, flexible expansion brackets; 10, footstep bearings (2)(of main frames); 11, electric traction motors (8); 12, stoker feed pipe; 13, boiler; 14, regulator; 15, expansion brackets of boiler; 16, lower frame of cab; 17, intermediate truck; 18, steam pipe; 19, mechanical lubricator; 20, main frame (back section); 21, collector of superheater; 22, smokestack; 23, exhaust nozzle; 24, feedwater heater; 25, stationary boiler bracket; 26, main turbine; 27, reducing gear; 28, generators (2); 29, exciters (2); 30, back truck; 31, instrument room; 32, spring buffer; 33, hot-water pump; 34, steam valves; 35, safety valves; 36, sandboxes (2); 37, turbine of smoke eliminator; 38, smoke eliminator; 39, ashpan; 40, siphons (3); 41, tender.

controller handles. For a locomotive of such great power and having relatively complex equipment and devices, these operating controls must be considered fairly simple.

The use of six-pole traction motors, with six auxiliary poles (instead of the usual four-pole motors), and also the use of roller bearings for the rotors, made it possible to bring the weight of the motor, together with the geared drive (and including the weight of the gearcase) down to 3350 kg.

In designing this locomotive a number of serious difficulties arose, mainly in arranging and locating the equipment, distributing the weight among the axles, and especially in getting the locomotive to take curves properly, since the total wheel base of the locomotive reached almost 28 m.

The schematic diagram of Figure 88 gives some idea of the structural designing of this locomotive as a whole.

As will be seen from the illustration, the wheel formula is most unusual: $2\text{-}(3_0 + 1)\text{-}0 + 2(3_0 + 1) - 2_0$. The arrangement of the power equipment and devices on the locomotive is also an unusual one. The boiler, for instance, is installed in the middle, and faces the smokestack behind and the firebox in front; there is a

Photograph

FIGURE 89

Back articulated section of running parts (the spring plungers with flat plates above them, which take the weight of the locomotive, may be seen on the front plan).

coal bunker where the boiler is usually located; the power assembly and the other engine equipment is located in the most forward part of the locomotive body.

The running parts of the underframe are constructed in the form of two autonomous articulated sections, one of which Figure 89 shows.

Each section of the running parts carries supporting pistons or plungers with flat discs on the top. The plungers rest on two spiral springs (some of them on three). There are three such plungers in the front section (two in front and one in back), and four in the back section (two at each end).

Two center-pins in the main frame and seven spring expansion brackets (of special construction) take up the entire load of the locomotive weight. The expansion bracket has a flat plate of round shape, which serves as supporting surface for the frame; while the position of each expansion bracket corresponds precisely to that of the above-mentioned plungers on the articulated sections.

This construction of the locomotive underframe assures the uniform distribution of the weight of the locomotive and at the same time enables each section of the running part to turn about the corresponding center-pin. In turn, each of the trucks is similarly able to turn about its own center-pin of lesser dimensions.

The stability of the underframe when travelling at high speeds, and also the reduction, to the lowest possible limit, of lateral displacements and the inertial stresses on taking curves that result from such displacements, is assured by centering devices specially

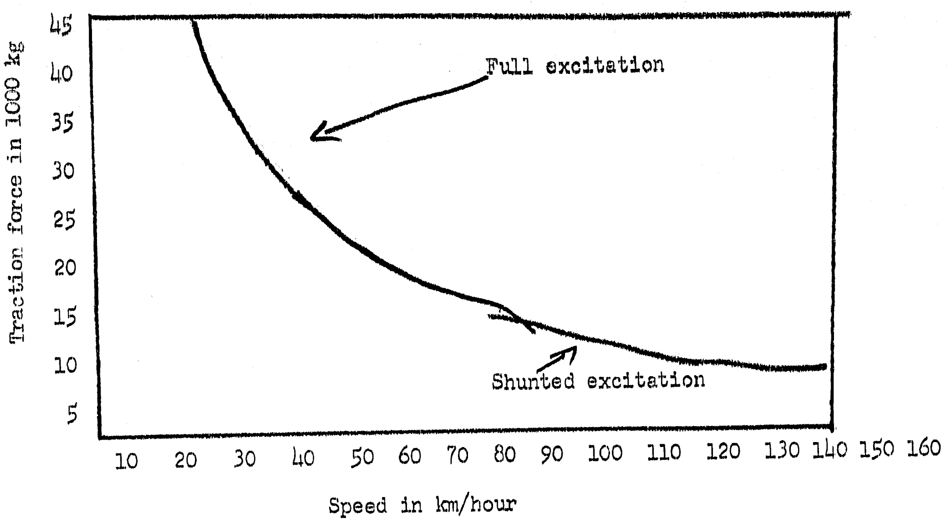


FIGURE 90

Tractive force of turboelectric locomotive with full and shunted excitation of motors.

designed for this type of locomotive.

Since this underframe design was employed first in American locomotive-building practice, a model of it was first constructed on a scale of 1/4 and this was then subjected to careful experimental study and the work checked under all conditions possible in operation.

The tractive qualities of the turboelectric locomotive (under full and shunted excitation of the traction motors) are shown by the diagram of Figure 90.

The following diagram (Figure 91) characterizes the tractive qualities (power and tractive force) of the turboelectric locomotive and, for comparison, of the geared steam-turbine locomotive. The superiority of the former within the limits from zero to 65 km/hour will readily be noted from this diagram. If we take into account the fact that the geared turbine locomotive selected for comparison has a power of 6,900 HP, i.e., almost 13% more than the turboelectric locomotive, the superiority of the latter holds true even for the high-speed range.

The basic structural and operating characteristics of the turboelectric locomotive are as follows:

Working boiler pressure	21.7 atm.
Temperature of superheated steam	400° C.
Evaporative heating surface	397 sq. m
Superheating surface	160 sq. m
Grate area	10.4 sq. m
Weight of turbogenerator	37,650 kg
Weight of electrical equipment	68,850 kg
Total weight of locomotive in operating condition	373,300 kg
Adhesive weight	230,420 kg
Load on driving axle	28.8 tons
Weight of tender in operating condition	168,650 kg
Total wheel base of locomotive	27,610 mm
Total wheel base of locomotive and tender	42,765 mm
Wheel diameter	1,016 mm
Starting tractive force	44,500 kg
Sustained tractive force at 65 km/hour	21,770 kg
Maximum speed	160 km/hour

Nothing can yet be said of the results of the year's trial operation of this locomotive, since this data is still unpublished. But it would be difficult to assume

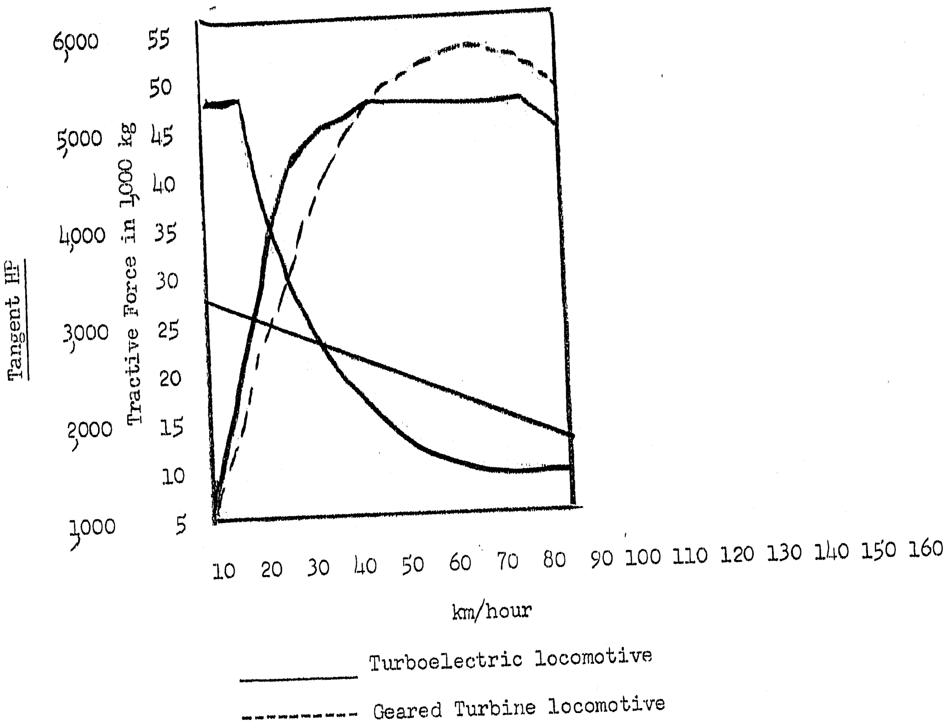


FIGURE 91

Curves of power characteristics and tractive force characteristics of turboelectric locomotive and geared turbine locomotive.

that this locomotive proved able to satisfy all the requirements of present-day operation. The considerations in favor of this view are as follows.

Even from the above exceedingly brief and to a considerable extent oversimplified description it is still impossible to have overlooked the fact that the design of this locomotive, both with respect to its power equipment and the arrangement of the running parts of the underframe, is characterized by a considerable degree of complexity. The practice of many years of experimental locomotive construction in both the USSR and abroad has demonstrated that complexity in the design of any new locomotive becomes, as a rule, an insuperable obstacle to its introduction and successful integration into railroad operating practice.

Its relatively high unit-weight also speaks unfavorably for this locomotive, for it is 90 kg per HP, as against 62 kg per HP for the geared turbine locomotive, and 76 kg per HP for the Diesel electric.

PART FIVE

GAS-GENERATOR AND GAS-HOLDER LOCOMOTIVES

General Information

Of all forms of fuel used, liquid (petroleum) and gaseous (natural or artificial gas) give the highest thermal effect when they are burned to produce mechanical or thermal energy.

But petroleum is a most expensive fuel. Its subsurface stocks are everywhere limited. While it is true that modern technology is able to produce what is termed synthetic fuel out of various forms of solid and gaseous fuel (coal, bituminous shale, natural gas, etc.) its cost is considerably higher than that of petroleum and its derivatives.

The special attention given in all countries, more especially the USSR, to the utilization of gaseous fuel in industry and transport is thus entirely natural. Besides natural gas, gaseous fuel, just like the liquid form, can also be obtained artificially by what is called gasification of various forms of solid fuel (coal, wood, boghead, peat, etc.)

The utilization of gaseous fuel for train traction, however, encounters serious difficulties. Firstly the transportation of gas, in view of the bulkiness of the containers, is inconvenient and unprofitable. Secondly present methods of generating gas are technically imperfect and give a low return on the investment. Locomotives converted to gaseous fuel are thus bulky and of complicated design, which is a very substantial disadvantage under the specific conditions of railroad service.

Three methods of solving the problem are possible:

1. The gaseous fuel is produced on the locomotive itself by gas generators, and is then burned in the firebox of the boiler of a steam locomotive or in the cylinders of the internal-combustion engine, of the internal combustion locomotive; in this case we have a steam (or internal combustion) locomotive with individual gas production, or, in a shorter term, a gas-generator steam (or internal combustion) locomotive.

2. The gas is produced in stationary gas-generating installations (of subsurface or surface type), is processed into proper condition, stored under high pressure (up to 200 atm.) in special steel cylinders, delivered to the place of consumption (or piped there in pipe-lines and compressed before being filled into cylinders) and is ready for use when taken on the locomotive.

3. On railroad lines that touch natural-gas producing areas or main pipe-lines (such as, e.g., the Saratov-Moscow or Dashau-Kiev line, etc.) the locomotives may be supplied with gas direct from the pipe-line under the pressure of 80 kg/sq.cm.

The second and third methods thus make centralized supply feasible, and in this case the locomotives are called gas-holder motor (or steam) locomotives.

When used for internal combustion locomotive traction (the case of the steam locomotive will be separately discussed) the gas-generator and gas-holder types each have their own merits and faults. Let us briefly enumerate them.

The merits of the gas-generator internal combustion locomotive:

the locomotive is independent of stationary installations and may therefore be used on any main line or railroad, as needed.

The faults of the gas-generator internal combustion locomotive are:

any change in the kind of fuel or grade of coal makes it necessary to adapt the gas-generator accordingly;

the relative complexity of the equipment on the tender;

it takes a long time to get the gas-generator into working condition and requires firewood for firing purposes;

wet gas scrubbers cannot be used (under the clearance conditions), which leads to rapid engine wear, owing to the use of imperfectly purified gas;

the frequent changes in the load regime of the locomotive under the ordinary conditions of operation result in impairment of the gasification process, instability of the operating conditions of the gas generator, and reduction of its efficiency;

unproductive consumption of fuel for firing up and maintaining the fire during stops at stations, in the roundhouse, etc.;

considerable consumption of water for the gasification process, which is a serious handicap, especially when the locomotive is used in waterless regions;

presence of various accessory devices and mechanisms on the locomotive (for instance, for loading the fuel, removing the cinders, blower installation for starting up the fire, compressor, etc.), while the frequent clogging of the gas-cleaner causes considerable idle time for the locomotive while that cleaner is being repaired;

the necessity for increasing the locomotive crew, for besides the engineman and his assistant at least one man must be carried to service the gas generator and the auxiliary equipment.

The merits of the gas-holder internal combustion locomotive:

simplicity of design and ease of servicing the locomotive as a whole;

high coefficient of availability, since the gas in the cylinders is ready for use and the locomotive can therefore be quickly put into service;

the quality of the gas is always the same, thereby assuring economy of engine operation and constant power developed by it;

with compressed high-calory gas it is possible to work on the Diesel cycle (separate delivery of the fuel and air) as well as on the Otto cycle (combined delivery of gas and air);

speed in supplying the locomotive with gas at the home and turn-around roundhouses;

the need for servicing the locomotive at both home and turn-around roundhouses is done away with;

the good condition of the gas completely eliminates the entry of mechanical and chemical impurities into the engine cylinders;

the locomotive needs no water for the process of generating the gas;

the absence of the gas generator and its accessory equipment reduces the locomotive's time lost in repairs;

high economy of operation; according to the calculations of Engineer Khlebnikov (see *Transportnoye mashinostroyeniye*, [Transportation-machine Construction] 1936, No. 1, and *Sotsialisticheskiy Transport*, [Socialist Transport] 1939, No. 1), the efficiency of a gas-cylinder locomotive, at rail, is 14.7% for the above-ground method of gasification, allowing for losses during generation and processing (compressing) of the gas at central stations, and is 21% using the subsurface method of gasification, while the efficiency of a gas-generator internal combustion locomotive is only 8.3% using gas generated from low-grade coal, and 12% using high-grade coal for the gas.

The faults of the gas-holder internal combustion locomotive:

The locomotive is tied down to a railway section having "gasified" traction.

Comparison of all these factors leads to the conclusion that the technical-economic advantages are on the side of the gas-cylinder internal combustion locomotives. This does not, however, dispose of the necessity for using gas-generator internal combustion locomotives as well, for under certain conditions they may even prove more advantageous than the gas-cylinder type.

It is clearly doubtful that the "gasification" of traction, especially for manufactured gas, would yield a proper return on the investment required. Without going into the details of this great and complex question, we shall present only a few figures and the consideration on which this statement is based.

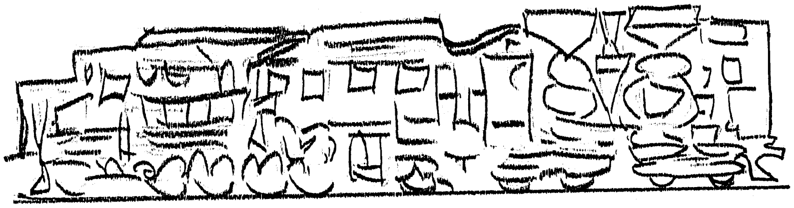


FIGURE 92

Gas-generator internal combustion locomotive for anthracites.

a, mechanical transmission; b, clutch connecting motor shaft with transmission; c, blower; d, cooler; n, motor of internal combustion locomotive; m, gas-generator; p, boiler; k, dry purifier for gas; l, charging mechanism; q, cinder-removal mechanism.

The efficiency of the best types of transport gas-generators is 70-80% at full load. At lower loads this value falls off sharply. Since the average load on the steam engine is around 65-70% under ordinary locomotive operating conditions, the efficiency of the gas-generator will be about 67.5%. Allowing for the more economical combustion process in the boiler firebox when firing its gas, the efficiency of the generator may be considered equal to that of an oil-fired boiler, and the overall locomotive efficiency accordingly assumed to be equal to that of the oil-fired locomotive, namely 7-8%. It follows that, taking into account the efficiency of the generator, the efficiency of the gas-generator locomotive will amount at best to only 0.675 x 0.075 = 0.05 = 5%, or in other

[redacted]

words, it will be lower than that of the ordinary coal-fired locomotive.

To this it must be added that the locomotive gas-generator is considerably more complicated in its design than the standard conventional locomotive, and accordingly its first cost as well as its operating cost will be considerably higher.

The possibility of practical utilization of gas-holder locomotives is even less real. According to the calculations of the above-mentioned author, the volume of the gasholders on the tender required for a trip of 365 km would be 189.5 cubic meters, (at a pressure of 200 atmospheres). Assuming the weight of the carbon steel gasholders to be 1.1 tons per cubic meter of compressed gas, the total weight of the gasholders would be 189.5 x 1.1 = 208 tons, while a volume of only 49.5 cubic meters would be required for the motor-locomotive gas, and a corresponding weight of 54.5 tons for the gasholder.

Four tenders would thus have to be coupled on to the locomotive to carry the cylinders, and this obviously cannot be considered rational under any circumstances.

It follows from all this that the use of gaseous fuel is technologically expedient and economically profitable only for motor-locomotive traction. During the last decade and a half this question has been the subject of technical-scientific and experimental investigation by the appropriate institutions and enterprises of our railway transportation system and transportation industry, and plans have been drawn for a number of gas-generator and gasholder motor locomotives. A short description

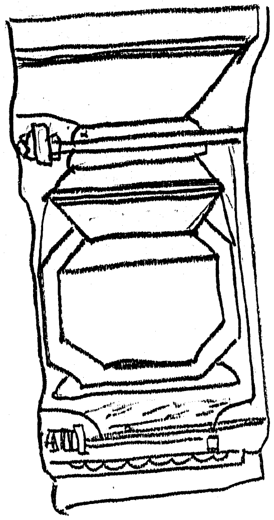


FIGURE 93

Reverse process gas generator for high-power internal combustion locomotive.

a, reserve bunker; b, mechanical charger; c, cam clutch; d, bunker before shaft; e, shaft of gas generator; f, cinder box; g, mechanical device for grinding the cinders; h, worm conveyor for removing the cinders.

of several of these will be found below.

GAS-GENERATOR INTERNAL COMBUSTION LOCOMOTIVE FOR ANTHRACITES (USSR)

(Plans drawn by NIIZhT in 1935)

This internal combustion locomotive has the wheel-formula 1-4-1 and is sketched in Figure 92. The gas-generator installation on the tender consists of two units, working under what is termed the reverse process (obratniy protses).

Figure 93 gives a skeleton diagram of the reverse process gas-generator.

The fuel is charged out of the supply bunker a by means of the mechanical charger b, actuated by a shaft common to all the generators, which is connected to the electric motor by the cam clutch c.

The fuel charged enters the pre-shaft bunker d, whence it is fed by gravity into the shaft e as combustion proceeds. It is pre-heated here and is then gasified when it enters the zone of high temperature.

The cinders formed are discharged into the cinder-box f, which is filled with water, and are ground by a mechanical device g, driven by an electric motor, and are then removed by the worm-conveyor h, which is likewise driven by an electric motor.

Air and water are supplied through tuyeres, and the gas drawn out through the bottom of the generator. In view of the contamination of the gas from the generator by various mechanical admixtures and chemical compounds, a dry purifier is provided.

The torque from the engine is transmitted to the locomotive axles by the drive system a, which is connected to the engine by the clutch b. On the other side, the engine is connected by a shaft with the horizontally arranged fan c, which serves the cooler d.

The rated locomotive efficiency at rail is 8.27% at 65% load.

GASHOLDER INTERNAL COMBUSTION LOCOMOTIVE (USSR)

(Designed in 1935 by Engineer G. K. Khlebnikov)

This gasholder freight motor-locomotive is of type 2-5-1, and is sketched on Figure 94. The gasholders are placed on a four-axle tender. The engine is the series production model used on ordinary internal combustion locomotives, four-cycle, with cylinder diameter 450 mm and piston stroke 420 mm.

The compressor b (Figure 94) is connected to the engine shaft and serves to charge the gasholders for starting the engine and the gas for auxiliary pressure feed on starting the locomotive from rest and for use on grades. The former hold 0.42 cubic meters at 60 atm. pressure and are arranged on both sides of the engine. They are not shown on the drawing. The latter hold 1.42 cubic meters under the same pressure.

The end of the engine shaft is connected by an intermediate shaft with the gear-box d of the fan e and with the fan itself, which is installed in the shaft of the cooler f.

The other end of the engine shaft is connected by the hydraulic (or electromagnetic) clutch g and the pair of conical gears h with the transverse shaft i, which in turn is connected by the pair of cylindrical gears j, with the gear shaft k.

Gas at high pressure from the gas-cylinders enters the turbine through the collector m, passing through the valve n or the reducing valve o, whence by way of the pipe p it enters the mixing chamber and then the engine cylinders a.

The locomotive may be started from rest by one of two methods:

(1) the motor is started by compressed air and idles; the clutch g is then engaged, and the locomotive starts; to obtain a high torque, the fuel mixture is enriched during this period, and supplementary air is supplied through a special valve from the tanks c and from the compressor, by the method of overhead pressure feed;

(2) the clutch g is permanently engaged with the entire system; air and gas enter through the starting and gas valves respectively; the mixture is ignited by a spark-plug after the valves have closed; the engine operates under this system during the entire period while the locomotive is starting and getting under way, and is then switched over to operate by the normal method.

[See Figure 94 on next page]

The rated locomotive efficiency at rail is 22.7% at 65% load, and 26.2% at full load. Allowing for the loss in gas generation and compression (at the central stations), the locomotive efficiency is 13.6 and 15.7% respectively.

GAS-GENERATOR INTERNAL COMBUSTION LOCOMOTIVE FOR MIXED FUEL (USSR)

(The plans were developed by the TsNII. The designers are A. A. Poydo and P. V. Yakobson, candidates for the degree of Doctor of Technical Sciences).

The internal combustion engines with which gas-generator internal combustion locomotives are equipped to work on the Otto cycle and consequently have a relatively low indicated pressure. The unit consumption of heat is therefore high while the unit power of the

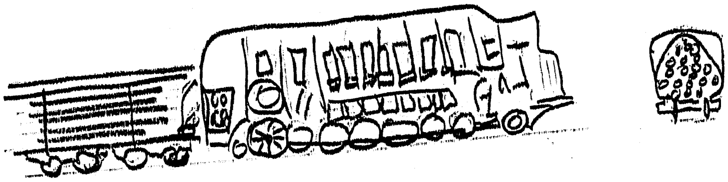


FIGURE 94

Gasholder internal combustion locomotive

a, motor of locomotive; b, air compressor for braking, starting and pressure feed; c, cylinder for pressure feed; d, gearbox for blower; e, blower; f, cooler; g, main clutch; h, conical gears; i, transverse shaft; j, cylindrical gears, k, gear shaft; l, gasholders; m, collector; n, valve; O, reducer; p, low-pressure gas duct.

locomotive is relatively low. In practice this makes it necessary to increase the weight and dimensions of the engine and the gas generator, and requires the introduction of ignition devices and their accessory equipment, etc./, which is very objectionable under the conditions of railroad service.

All of these shortcomings are completely done away with by the transition to mixed feed. Calculations show that the efficiency of such a gas-generator internal combustion locomotive will be 28% higher than that of the conventional model operated by a low-compression internal-combustion engine, for it will be 17.5% against 13.5; the unit consumption of heat is 2,100 Cal. per effective HP-hour against 2,750 Cal.; the diameter of the gas-generator shaft will be 1.40 m instead of 1.86 meters; and the whole gas-generating installation will weigh 8,400 kg instead of 10,800 kg. Besides all this, such a system allows the use of the series produced internal combustion locomotive engine, with very slight modifications, in the gas-generator internal combustion locomotive, with engine power and engine efficiency remaining the same for operation on mixed fuel as for operation on oil. Figure 95 gives a general view of the gas-generator locomotive with its tender.

FIGURE 95

General view of gas-generator internal combustion locomotive for mixed fuel.

The principle of Diesel operation on mixed fuel, with individual fuel preparation (on the tender) is as follows.

An impoverished air-gas mixture prepared in special mixers is sucked in through the admission valve of the engine (which exists in the present engine form). This mixture has an ignition temperature higher than its temperature at the end of compression. At the instant compression ends, a small amount of fuel oil (10-15% of the ordinary quantity), having a lower ignition temperature, is introduced through the existing fuel delivery. The fuel oil is ignited and in turn ignites the gas-air mixture introduced into the cylinders. The process is then repeated.

The Diesel is started up, as usual, on fuel oil, with the air valves open and the gas valve shut; at the same time the gas generator should be prepared for operation, and before the engine is changed over to mixed fuel the gas is allowed to escape into the air through what is termed a flare [SVECHA].

Before the Diesel is put on mixed feed, the following operations are performed successively:

the quality of the gas is tested by igniting it at the test-cock; if suitable for use the gas should burn;

the flare on the gas-generator is closed;

the gas delivery valve is opened;

the air valve is throttled to a predetermined position.

When the engine is running on mixed feed the fuel is regulated by a special lever, and not by the reverse. In all other details the servicing of the engine is identical with that when running on oil.

When idling, the engine runs on oil with a small admixture of gas (40-50%). As the load increases, the delivery of gas is increased, but that of oil remains unchanged.

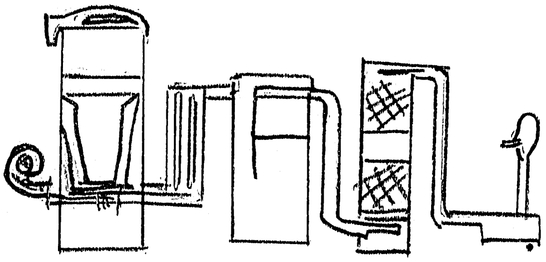


FIGURE 96

Scheme of PSNII type DT-5 gas-generator installation.

1, generator; 2, cooler; 3, coarse cleaner; 4, fine cleaner; 5, water repeller; 6, mixer; 7, kindling fan.

As engine speed varies, the delivery of oil should vary from the maximum, set by the limiter mechanism, to zero.

The motor may be changed over from oil to mixed feed at any time and with any load, and mixed feed to oil.

In the latter case the following operations must be performed:

the liquid-fuel-delivery-limiter is removed;

the air valve is opened;

the delivery valve of the gas-air mixture is closed;

the air valve is throttled to a predetermined position.

The trucks and frame of the four-axle tender of the series E steam locomotive serve as the basic underframe of the gas-generator tender, which is without a car body and has an awning to shelter it from the elements.

The gas-generating installation, of which a schematic diagram is given in Figure 96, is of type BG-5 TsNII, using the so-called inverted [OBRATNIY] process, and employs brown coal.

The gasification process proceeds in general as follows. At the suction stroke of the piston, outside air is sucked through a valve into the gas-generator 1 (Figure 96). After passing through the preheating stage, the air is conducted to the combustion zone in which the generator gas is formed. Thence the gas descends, passes through the firegrate into the ashpit, and then ascends and is cooled by the stream of air entering the generator. The gas then enters the so-called sub-bunker cavity, whence it goes to the cooler 2. Here it gives up its heat and passes in succession, first through the rough scrubber 3, next through the fine scrubber 4. Thence it passes through the water OTBOYNIK 5 and reaches the engine on the motor-locomotive through the mixing chamber 6.

The fan 7, driven by an electric motor, serves to deliver air on starting up ROZZHIGA the engine.

The outside diameter of the gas-generator is 1,900 mm. Its capacity is 1,550 cubic m per hour. Coal consumption at full load is 520 kg/hour. Oil consumption is 31 kg/hour. Efficiency of the generator is 73%. The tender carries 9 tons of coal, 1,120 liters of water, 4,650 liters of fuel oil and 1,000 liters of lubricating oil.

The engine is 4-cycle, 6 cylinder, with no compressor, cylinder diameter 450 mm and piston stroke 420 mm. The stage of compression is 12.4. The mean indicated pressure is 7.94 kg/cm^2. The effective power is 1,050 HP. Locomotive efficiency is 18% when running on mixed fuel. The cruising radius is 540 km.

GASHOLDER INTERNAL COMBUSTION LOCOMOTIVE FOR MIXUED FUEL (USSR)

(Plans drawn by TsNII. Designers, A. A. Poydo and P. V. Yakobson, candidates for the degree of Doctor of Technical Sciences).

The principle of Diesel operation with centralized gas supply (natural gas) is in the main analogous to that we have just described.

The inconsiderable modification in the engine consists in converting the suction pipes into mixers through which the gas and air enter the cylinders. This is effected by welding on air inlet connecting branches with valves. A general view of the series EL-5 gas-cylinder motor locomotive is shown in Figure 97.

It will be seen from the picture that the tender rests on a four-axle 60-ton flat car. The wooden floor of this car has been removed and crossbeams of channel-bar profile have been attached to the frame. The gasholders are placed on the cross-beams and are shackled together by yokes and ties.

The service weight of the tender is 74 tons.

According to the plan the gasholders (57 of them in all) are to be fabricated of the pipe used in the Saratov-Moscow pipe-line. They are 11 m/ long, 320 mm in diameter, weigh 870 kg, have a volume of 77 cubic m, allowable pressure of 110-110 kg/cm^2 and a working pressure of 50-80 kg/cm^2.

The tender will be charged directly from the main pipe-line at a pressure of 80 kg/cm^2. Bringing the pressure in the gasholders up to the allowable limit would allow a considerable reduction in their number and weight (or could increase the length of the run between chargings), but this would require large capital investment for the construction of charging stations.

The working cycle of the locomotive installation proceeds as follows. The work of the engine produces a vacuum in the reducer on the tender. This automatically opens the valve of the reducer, and the gas from the gasholders begins to enter the collector of the engine. Subsequently, gas together with air, enters the inlet or suction valve by the inlet connecting branch.

Photograph

FIGURE 97

General view of gasholder internal combustion locomotive for mixed fuel.

The quality of the fuel mixture is regulated by the setting of the air slide-valves: as these are closed, the vacuum in the collector increases, thus causing an increased delivery of gas to the engine cylinder, while, on the other hand, as the air slide-valves are opened, the delivery of gas is diminished, and when they are opened completely, it is entirely [text has "closed" which appears to be a printer's error], interrupted and the engine passes over to operation on liquid fuel.

The tender is charged with gas in the following manner. The internal combustion locomotive arrives at the gas main and connects its inlet connecting branch to it. The gas begins to enter the collector and then the gasholders. After the pressure in the gasholders has reached its limit, the valves are closed and the gas enters the reducer, and from the reducer it flows through the valves and pipes into the engine.

The radius of action for the internal combustion locomotive is 330 km at a pressure of 50 kg/cm^2 in the gasholders, and 660 km at 100 kg/cm^2. Thus, when the locomotive works a normal round-trip, it is possible for it to go and return without refuelling except at its home roundhouse.

PART SIX

ORIGINAL TYPES AND DESIGNS OF INTERNAL COMBUSTION LOCOMOTIVES

General Information

The modern internal combustion locomotive represents a machine more perfected than the steam locomotive from the technical-economic and operating points of view. But it, too, is not free from faults, of which the most essential is the existence of a special supplementary assembly, the so-called transmission.

For what is this drive needed on the internal combustion locomotive, and why is it undesirable?

The prime mover of the internal combustion locomotive, the Diesel engine, is the most economical of all heat-engines, but lacks the working characteristics necessary under the conditions of locomotive service. Thus, for instance, it cannot be started under a load, and this means that the Diesel internal combustion locomotive is not by itself able, without supplementary equipment, to start moving a train from rest and accelerate it to the required speed. Almost throughout its entire range of speed (in revolutions) the Diesel engine develops a torque that is constant (in magnitude), which likewise fails to meet the practical needs of railroad operation. For these reasons an intermediate link must be interposed between engine shaft and drivers. This link is the transmission, or drive.

In itself the drive, whether electrical, hydraulic or mechanical, represents a peculiar kind of transformer of the revolutions and the torque, and its efficiency, like that of all transformers, is always less than unity. For instance, the efficiency of an electrical drive is about 0.83, that of a hydraulic drive, 0.85, that of a mechanical drive, 0.90. In other words, of all the power developed by an engine there is irretrievably lost, in the first case, 17 percent, in the second case, 15 percent, and in the third case 10 percent.

In addition to this, any drive considerably complicates the design of the internal combustion locomotive and increases its weight, first cost and operating cost. For instance, the electric drive involves a weight increase of some 25 percent, and an increase of 33 percent in first cost. The corresponding figures for the hydraulic drive are 10 percent and 20 percent respectively, while for the mechanical drive they are 12 percent and 15 percent.

The efforts to eliminate this intermediate link entirely and to effect a direct drive are therefore entirely natural. This would mean transmitting the torque directly from engine to wheels, as is done with the steam locomotive.

In the USSR the Railroad Transportation Research Institute has carried out a great experimental project for the study of the Diesel-engine cycle, with the purpose of using it for the internal combustion locomotive with direct drive, or, as the present parlance runs, the direct-drive internal combustion locomotive. Plans have already been drawn for original types and designs of such locomotives.

A number of plans for direct-drive internal combustion locomotives have also been drawn abroad, and the locomotives built accordingly (the Sulzer internal combustion locomotive, the Ansaldo internal combustion locomotive, the Humboldt-Deitz internal combustion locomotive, etc.); but not one of them went into series production.

Thus, the direct-acting internal combustion locomotive has still not emerged from the stage of planning and experimental study of individual experimental specimens.

But the very idea of the "direct drive" does need elaboration and refinement, since it is frequently identified with various systems of mechanical drive; and incidentally we shall enumerate the conditions that such a drive must meet.

There are two methods of connecting the engine with the wheels that may be considered direct drives:

1. The cylinders are arranged at the sides of the locomotive frame, and their pistons are connected with the driving wheels by means of a connecting-rod-crank mechanism, similar to what is used, for example, on the steam locomotive.

2. The cylinders are arranged horizontally or vertically on the locomotive frame, and their pistons are connected with the axles by means of connecting rods, acting through a gear shaft (in the case of horizontal cylinder arrangement, through a single pair of cylindrical gears, and in the case of vertical cylinder arrangement, through one pair of conical gears and one pair of cylindrical gears), with the gear ratio of the system being either unity or some other constant quantity.

Thus, with any method of "direct" connection, the torque of the engine will always have a constant ratio to the torque of the driving wheels, while with a mechanical drive it may have different ratios, according to the number of stages, at different regimes of locomotive operation.

The requirements that must be met by an ideal direct drive reduce in substance down to the following:

(1) minimal losses not exceeding 3 - 4 percent, in the coupling elements between engine and drivers;

(2) absence of any need for supplementary power equipment to bring the Diesel into operating condition under full load, i.e., on starting from rest and getting under way, or in running up slight grades at low speed;

(3) economy of Diesel operation at medium and high speeds of the internal combustion locomotive; while, when the Diesel runs on the normal cycle (i.e., without pressure charge or artificial ignition of the mixture), the economy of operation of this locomotive should not be less than the economy of a Diesel operating with other drive systems.

These conditions should constitute the starting point for the evaluation of the merits of any variant of the direct-drive internal combustion locomotive.

A very important task that likewise confronts internal combustion locomotive engineers, builders and inventors is increasing the unit power of this type of locomotive, or in other words reducing its unit weight. Let us briefly explain the necessity and practical implications of this.

The tractive force of a locomotive, whether motor or steam, is limited, at speeds beginning at 35 - 40 kilometers and higher, no longer by the adhesive weight, but by the power it is able to develop with the given proportions of the boiler and of the steam engine(in steam locomotives) or of the Diesel-engine (in internal combustion locomotives). Under the contemporary conditions, however, with the steady increase in the weight and speed of trains, the inadequate power of the locomotive throughout the range of medium and high speeds is a substantial shortcoming. In order to emerge from this situation, it is necessary to give the locomotive as high a power as is possible, or in other words, to install on it boilers of greater capacity, more powerful prime and secondary movers, etc.

But such a method of increasing power implies in practice further increase in the weight and clearances of the locomotive, which would be most objectionable under the specific conditions of railroad service.

It must also be borne in mind that even without this increase the total weight of the existing standard types of locomotives is far greater, as a general rule, than the weight usefully employed for the adhesion of wheels to track under the given weight norms of the train being hauled. For example, only 103 tons of the total weight of the FD locomotive (135 tons) is applied to the driving axles. This means that 32 tons, or 25 percent of the weight of the locomotive, constitutes a peculiar form of ballast, which produces, month after month and year after year, a certain amount of unnecessary "ton-kilometers". Such "ballast" amounts to about 37 percent in the

Su locomotive, to about 40 percent in the IS locomotive, and so on.

Nor are internal combustion locomotives with free axles free from this ballast. Further than that, even internal combustion locomotives with weight wholly distributed on the driving axles are far from fully utilizing that weight under the actual operating conditions. The following example will illustrate this point. The internal combustion locomotive 0-3_0 + 3_0-0, planned for series production in the USSR, with weight of 120 tons and power of 1,000 HP, fails even under the most unfavorable conditions (at starting, on various grades from 0.4 to 1.2 percent with trains weighing 3,000 to 1,500 tons) to utilize from 3,000 to 10,000 kilograms of the tractive force that would be possible with its adhesive weight. This conclusion may be drawn from the diagram No 3 (see "Prospects for the Development of Internal Combustion Locomotive Traction in the USSR," ~~in~~ Tekhnika Zheleznikh Dorog [Railroad Technology], 1944, No 3) presented by Professor Shishkin, and implies that this type of internal combustion locomotive in fact has an excess weight of 12 to 30 tons, or 11 percent to 26 percent, if we assume the coefficient of friction to be 25 percent (which is entirely realistic for an internal combustion locomotive).

This is why the thinking of designers and inventors seeks other, more effective methods of increasing locomotive power.

One of these methods is to increase the unit power of the internal combustion locomotive, i.e., the power corresponding to unit weight, of the locomotive. Under this condition the weight of the internal combustion locomotive remains unchanged, or even declines (to the limits allowed by the conditions of adhesion), while its relative tractive resources are considerably increased throughout the entire speed range. The plan for an internal combustion locomotive with a subdivided power plant which is described in this Part (together with direct-drive internal combustion locomotives) is one of the variants of the solution of the problem of increasing unit power.

INTERNAL COMBUSTION LOCOMOTIVE WITH COMPRESSED-AIR DRIVE (GERMANY)

(Built in 1929)

There is a rather close similarity in principle between this internal combustion locomotive and the reciprocating steam locomotive: the Diesel engine performs the function of the steam engine; the piston compressor and the air-preheater replace the locomotive boiler; air is the working body instead of steam. The whole locomotive underframe, and all mechanisms and details are interchangeable with ordinary locomotives.

The principle of construction and operation of this internal combustion locomotive is as follows. An ordinary Diesel engine actuates the piston compressor. The air compressed by it, at 7 atmospheres pressure, is preheated to 330 - 360 degrees, by using the heat of the engine exhaust gases, in a special preheater, and then enters ordinary cylinders (like those of a locomotive). By expanding in these cylinders, the air performs work, i.e., it turns the locomotive drivers through a connecting-rod transmission.

The idea of using air as a working medium dates back for some time. This question began to be discussed in Great Britain and Germany after the first world war. It was feared at first that the use of compressed air at high temperatures in the cylinders of a steam engine would inevitably lead to ignition of the lubricant and explosion. With precisely these considerations in mind, an experimental, low-power internal combustion locomotive (100 HP) was built in Germany, using as the working medium in the cylinders the very inert exhaust gas from a Diesel engine, after first compressing it.

Trial operation of this locomotive showed this idea to be practicable, but the efficiency of the locomotive proved far less than that expected -- about 17 percent at the coupling. After this another unit using air as the working medium was given a long test on the testing stand. It developed that the above-mentioned fears were completely unfounded and that all that was necessary was to be sure that the amount of lubricant in the cylinders did not exceed the established norm, and thus to exclude the possibility of any oil surplus accumulating in the cylinders.

On the basis of these experiments, the designing of a powerful 1200 HP passenger internal combustion locomotive with compressed-air drive was commenced in 1925. In 1929 the locomotive was assembled, tested in the plant, and placed in trial operation on the Stuttgart division of the German Railways.

On 22 November this internal combustion locomotive made the run from Oberturkheim to Augsburg with a passenger express train weighing 233 tons. During this run it hauled the train over one clear stretch 20 kilometers long with a 2.5 percent grade without a pusher engine. During all of 1930 this locomotive was experimentally tested with a dynamometer car and a braking locomotive. The results were published in the German journals at that time (See Glazer's Annalen, 1931, volume 109, No 11).

The power equipment of the locomotive consists of:

a 6-cylinder Diesel engine;

a single-stage piston compressor;

an air-preheater;

a cooler;

auxiliary equipment (fans, air blower for the boiler of the train heating system, fuel and lubricant pumps, generator, etc).

The Diesel engine is a four-cycle MAN with maximum speed of 450 rpm developing a sustained useful power of 1,000 HP and short-time useful power of 1,200 HP. Cylinder diameter is 450 millimeters; piston stroke 420 millimeter. The unit as a whole (engine and compressor) is shown in Figure 98.

The piston compressor, with cylinder diameter 640 x 350 millimeters, is mounted on a common base plate with the motor. The base plate is bolted onto the locomotive frame. The compressor piston is driven by the engine through two cranks, opposed at 180 degrees, of a crankshaft. Figure 99 gives a general view of the compressor.

The compressor is one of the most important elements of the locomotive power plant. It is the economy of its operation that in fact determines the operating economy (efficiency) of the locomotive as a whole. It was therefore necessary to reduce the power consumed by it to the lowest possible level, which could be achieved only by a very intensive cooling of the cylinder.

Figure 98. Diesel motor and compressor mounted on common base plates [photo]

Figure 99. Compressor [photo]

Three variant cooling systems were planned: water-jacket, oil-cooling of the piston, and, finally, cooling by direct water injection into the cylinder.

In view of the presence of a sufficient amount of heat in the exhaust gases to preheat the compressed air, it was decided that the maximum temperature in the delivery valve should not exceed 200 degrees. Under these conditions (assuming polytropic compression), 70,000 to 75,000 Cal per hour had to be withdrawn from each square meter of cooled cylinder surface. Experience showed that with the first two methods of cooling the temperature of the compressed air exceeds the rated value at a power as low as 400 HP. It was therefore decided to use the third method of cooling.

The quantity of water injected is a negligible amount -- about 2 - 3 percent of the weight of the air being compressed; the water thus is instantaneously converted to steam, and its consumption at full power amounts to 0.5 m^3 per hour.

The fears that the injection of water into the cylinders would result in rusting the metal and in intensive deposition of impurities and incrustations on the cylinder walls proved unjustified.

The possibility of working the compressor without cooling (for instance, in cases where water is lacking, etc.) was also studied. Experiment showed the possibility of running the installation, though at very much reduced efficiency, for about half an hour to 45 minutes without cooling the cylinder.

A single-stage compressor with maximum possible compression of the air to 7 atm (by manometer reading) is used for the purpose of making the design of the power assembly as simple as possible. The initial pressure at which the working air enters the locomotive cylinders thus ranges from 6.5 atm at 400 rpm to 7 atm at 540 rpm, which was responsible for the relatively large dimensions of the cylinders and the correspondingly lower efficiency of this ~~[illegible]~~ internal combustion locomotive by comparison with the conventional models.

The output of the compressor at 400 rpm, 7 atm pressure and 208 degrees air temperature (corresponding to about 5.5 kg of injected water) is 183 kg of mixture (air and water) [per hour].

The air preheater is arranged parallel to the Diesel-compressor and consists of a system of tubes, through which the exhaust gases pass and give up their heat to the compressed air that bathes the outer surface of the tubes.

A usual throttle valve of the Schmidt-Wagner system is placed between air-preheater and cylinder. On the side of the engineroom gangway the water-tank, air-cylinders and storage battery are placed so as to equalize the load. In addition, water and fuel tanks are also arranged on the sides of both ends of the locomotive frame, with coolers for lubricating oil and water on the sides in front.

Figure 100 gives a general view of this internal combustion locomotive.

The locomotive is controlled by levers regulating the amount of fuel entering the engine and the amount of water injected by the compressor into the cylinder.

The principal proportions of the locomotive are as follows:

Adhesive weight	64.6	tons
Weight of locomotive in running order	124.6	tons
Diameter of drivers	1,600	mm
Fuel supply	2,000	kg
Tangential tractive force	12,000	kg
Maximum speed	80	km/hour

Figure 100. General view of internal combustion locomotive with compressed-air drive [photo]

The diagram of Figure 101 gives a very clear idea of the operating characteristics of the internal combustion locomotive (fuel consumption, tractive force, power and efficiency) and, for purposes of comparison, those of a locomotive of conventional standard type.

Since the tractive qualities of locomotives of different type and form can be compared only if their tractive-thermal parameters are equal throughout the entire speed range (which is in practice unattainable), the factor selected as the starting point for comparison was the equality of indicated power (1,000 HP) developed by both locomotives at the same most economical speed (50 km/hour). Under the regime of reciprocating steam locomotive operation assumed

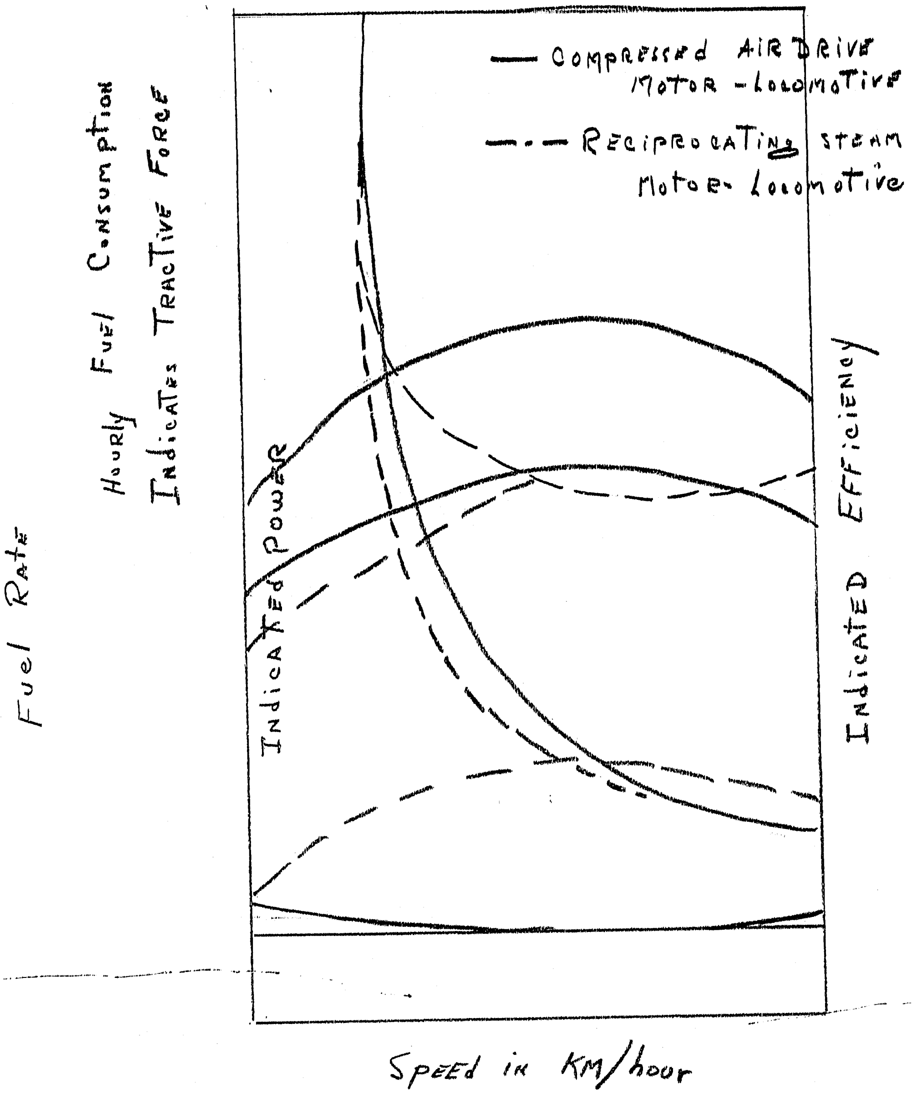


Figure 101. Fuel consumption, power, tractive force and efficiency of internal combustion locomotive and standard locomotive

the rate of combustion is 450 kg of coal with a heat value of 7,000 Cal per kg, per hour per square meter of grate surface; boiler efficiency, 70 percent; temperature of feedwater delivered to boiler, 90 degrees Centigrade; superheat temperature, 350 degrees; and pressure in boiler, 12 atm. (by manometer reading). For the internal combustion locomotive it is assumed that maximum efficiency of the drive is 85 percent, fuel consumption related to useful load is 0.185 kg per HP-hour; and the curve $F_i = f(v)$ is plotted from data of the trial operation.

As will be seen from the diagrams, at a speed of 50 km/hour and indicated power of 1,000 HP, the tractive force F_i is 5,400 kg for both locomotives; the fuel consumption B for the internal combustion locomotive is 217.5 kg/hour = 2,175,000 Cal/hour; the unit fuel-consumption B' for the internal combustion locomotive is 0.2175 kg per HP-hour and 0.946 kg per HP-hour for the steam locomotive; the thermal efficiency η_{thi}, with respect to the indicated power, is 29 percent for the internal combustion locomotive and 9.5 percent for the steam locomotive.

It will also be seen from the diagram that the economy of operation falls off more sharply at lower and higher speeds, for the internal combustion locomotive than for the steam locomotive. Thus, for instance, at speeds of 10 and 80 km/hour, the thermal efficiency of the internal combustion locomotive, with respect to the indicated power, amounts respectively 22.4 percent and 25.7 percent, while the unit fuel consumption is 0.282 and 0.244 kg per HP-hour respectively.

Under ordinary operating conditions the efficiency of the internal combustion locomotive at rail, even under the most favorable operating regime, does not exceed 20 - 21 percent.

Another substantial shortcoming of this locomotive is the considerable vibration, especially at high speeds, which results from the presence of the unbalanced masses of the driving mechanism of the compressor.

In appraising the merits and shortcomings of this locomotive, the conditions for which it was designed and constructed must be kept in mind. The technology of that period was not as highly developed in the designing of power installations (engines, compressors, etc) as that of the present day. It must be assumed that the design and construction of a similar type of locomotive under contemporary conditions could yield more favorable results than those obtained in this case.

DIRECT-DRIVE INTERNAL COMBUSTION LOCOMOTIVE, TYPE 2-2-2 (GERMANY)

(Built in 1933)

Figure 102 gives the scheme of this internal combustion locomotive with the corresponding designations of the equipment and apparatus.

The main engine is 3-cylinder, two-cycle, double-acting. As may be seen from the illustration, the arrangement of the cylinders is analogous to that on the engine of a steam locomotive. The extreme cylinders act on the second driving axle, while the middle cylinder -- an inclined one -- acts on the first crankshaft.

The maximum power developed by the locomotive at 330 rpm of the engine, corresponding to a speed of 110 km/hour, is 1,200 HP. The stresses in the connecting-rods, crossheads, axles and journals do not exceed the corresponding stresses in steam locomotives.

Rutz air-blowers, suspended beneath the rear truck and driven by the axles, blow air through the working cylinders. The alternate delivery of air to the front and back cylinder chambers is adjusted by a distributing mechanism. The distribution shaft is driven by the second driving axle with the help of two conical drives and a Cardan shaft.

The 150-HP three-stage compressor for pressure-feed is driven by an auxiliary 3-cylinder, 4-cycle 225-HP engine, which also drives the fan, water pump and DC generator.

The cooler for the main engine is on the side of the locomotive, in front, and the cooler from the auxiliary engine on the side in the back. Cylinders holding 2 cubic meters are also provided for compressed air.

The operation of the power plant of this locomotive, from the moment it starts from rest, proceeds as follows:

compressed air is admitted into the front working spaces of the cylinders;

at a certain moment the pressure of this air in the cylinders becomes sufficient to overcome the total resistance of the locomotive and train, and the train begins to move;

from the instant that the train starts to move, the low-pressure fuel pumps are actuated and begin to deliver fuel through the corresponding valves in the cylinder-heads; thus the cylinders are slowly filled with finely-divided fuel, which is ignited by contact with a spiral heated by the passage of an electric current

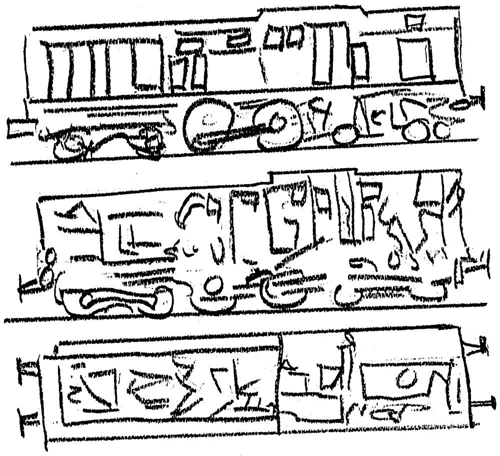


Figure 102. Scheme of Humboldt-Dietz direct-drive internal combustion locomotive

A -- auxiliary Diesel engine; B -- compressor; C -- generator;
D -- pressure-feed blower; E -- auxiliary pressure-feed blower;
F -- main pressure-feed blower; G -- Cardan shaft; H -- distribution
shaft; J -- fuel pump; K -- compressed air lubricating system;
L -- operator position; M -- distributor panel; N -- distributor box;
O -- valve for varying direction of pressure-feed air; P -- sander;
Q -- fuel tank; R -- front and back coolers; S -- compressed air
cylinders; T -- electric blowers; U -- coolant water pumps;
V -- exhaust

(igniter); such a start, commencing with a few ignitions of the mixture of fuel and compressed air, proceeds in a manner analogous to the start of a reciprocating steam locomotive with "motion in full gear" and assures sufficient tractive force for any position of the crank;

after the locomotive has started to move, the engineman readjusts the distributing mechanism, thus limiting the admission of compressed air and thereby obviating the possibility of sliding; simultaneously the engineman moves the throttle, and in this way reduces the throttling of the compressed air.

The duration of the intake, which at first is regulated by the "starting fuel" lever (since the regulating fuel pumps are still not in a position to assure the proper pressure to cause the valves to function under the normal Diesel cycle), amounts to as much as 100 degrees of crank angle and thus corresponds to the time of the admission used in reciprocating steam engines. Such a regime of engine operation is called additional or external feed.

As train speed increases and tractive force accordingly declines, the additional feed is also gradually reduced, and from a certain moment on, the valves begin to function, thus assuring the injection of the combustion mixture. The arrival of this moment is marked by a slight coloration of the exhaust gases.

The regime of supplementary feed thus lasts from zero speed up to 70 km/hour, and further acceleration of the locomotive speed then takes place on the normal Diesel cycle.

The diagram of Figure 103 very clearly illustrates, graphically, the course of the operating process in starting the train, getting under way, acceleration and travel on grades, and, finally, in travel on level tracks.

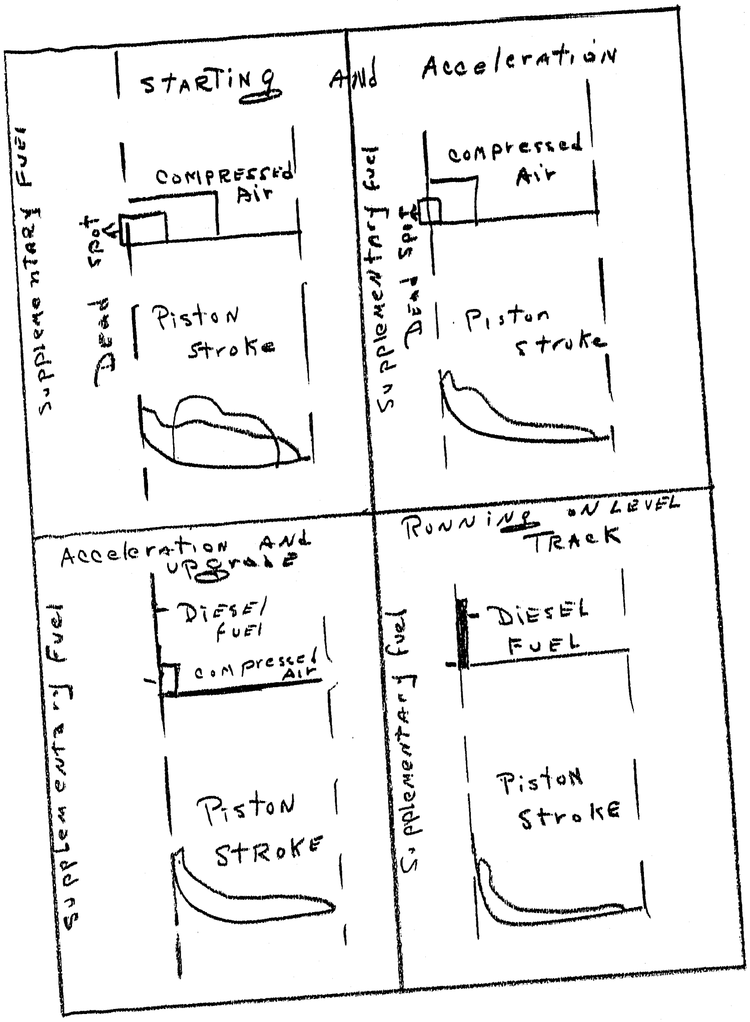


Figure 103. Process of cylinder admission and corresponding working diagram (at starting from rest, acceleration, running upgrade and running on level track)

The manipulations involved in driving this internal combustion locomotive are very simple. In general they resemble driving a reciprocating steam locomotive. The air throttle valve of the former corresponds to the throttle of the latter, while the longitudinal displacement of the cam that regulates the duration (in time) of air admission to the cylinders of the former corresponds to the shifting of the position of the valve gear of the latter. The only additional controls are the two fuel levers for the main feed and supplementary feed.

All the operating controls and apparatus are concentrated in the cab. As a matter of fact, driving the locomotive reduces down to merely making the proper shifts of the fuel levers for supplementary and main feed.

This internal combustion locomotive is designed for hauling fast, light trains. Its total weight is 80 tons, of which 36 tons are imposed on the driving axles. With a wheel formula of 2-2-2, its riding qualities are entirely identical for forward and backward motion, while the engineman is assured of good visiblity in both directions, as the general view (Figure 104) shows. The length of the locomotive between buffers is 14,550 millimeters. Driver diameter is 1,750 millimeters. Total wheel base is 10,750 millimeters, rigid wheel base 2,500 millimeters. Fuel supply is 2 tons. Maximum speed is 110 km/hour.

Figure 104. Direct drive internal combustion locomotive hauling a 265-ton passenger train [photo]

Figures 105 and 106 give diagrams characterizing the mean indicated pressure in the cylinders and the locomotive power, operating with pressure feed and normally, while Figure 107 gives the curves of tractive force for the internal combustion locomotive, and, for purposes of comparison, for a steam locomotive of series P-S with a total weight of 131 tons, of which 51 tons is imposed on the driving axles.

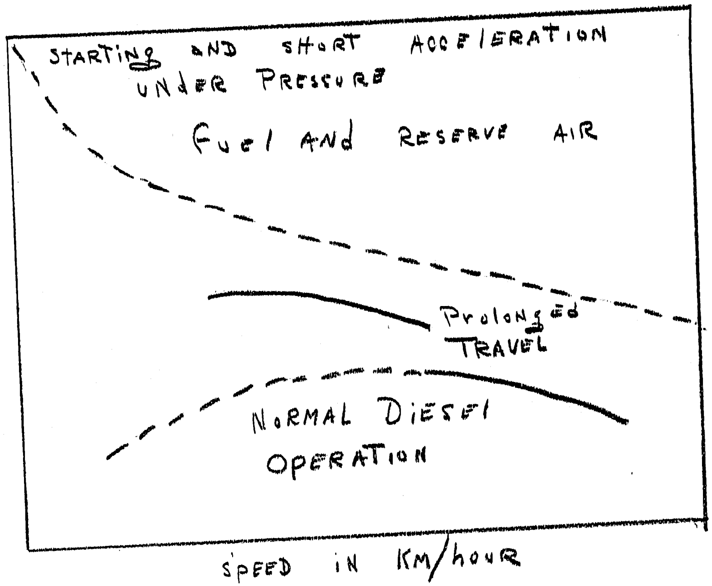


Figure 105. Mean indicator pressure in cylinders

It will be seen upon examination of these diagrams that the direct acting internal combustion locomotive is more efficient than the steam locomotive in mean indicated pressure, in power and in tractive characteristics, notwithstanding the considerable advantage of the latter in weight and the corresponding power of its power equipment.

During the first three years of trial operation, this internal combustion locomotive covered over 40,000 kilometers, 16,000 kilometers of this distance with regular trains, producing a total of 3.3 million ton-kilometers.

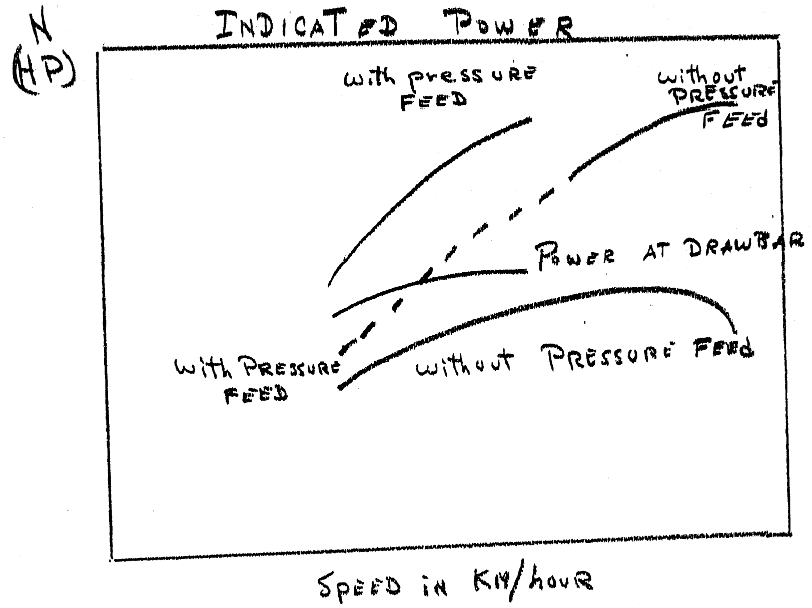


Figure 106. Curves of indicated power with and without forced feed

To test the reliability of its operation, mainly during starting, the locomotive was used to haul passenger trains weighing 265 tons on a section 250 kilometers long, with stops on the average every 5 kilometers. If we omit from consideration various trouble that cropped up during the initial period (for instance with the Rutz air blower, overheated bearings, etc.), which was promptly remedied, this internal combustion locomotive in general assured higher operating indices than the above-mentioned P-S steam locomotive that usually served these trains. Thus, for example, the consumption of heat per unit of work was 28 percent that of the steam locomotive. The fuel supply carried by the internal combustion locomotive by weight (allowing for its unit heat value) was only 20 percent of that carried by the steam locomotive. The total weight of supplies (fuel, water, lubricants, etc) on the internal combustion locomotive was only 3 percent that of the steam locomotive.

The cruising radius of the internal combustion locomotive without refueling or taking on water, was 1200 kilometers.

INTERNAL COMBUSTION LOCOMOTIVE WITH SUBDIVIDED POWER INSTALLATION (PLANS) (UNITED STATES)

The substantial distinction between this locomotive and the conventional types consists, firstly, in the installation on it of a number of high-speed engines with unit weight of 4-5 kg/HP, instead of one or two low-speed engine of great power, and secondly in the use wherever possible of aluminum as structural material in place of iron and steel.

The following Table 7 gives the calculated data characterizing the weight of the individual elements of this locomotive, and for comparison the corresponding figures for a conventional model of internal combustion locomotive of equivalent power.

[See following page for Table 7]

Besides the reduction in unit weight of the locomotive, which according to the data of the table amounts to 16 percent, the subdivision of the power plant results in a considerable number of other advantages, which are very substantial, in the designer's opinion:

the smaller cylinder diameter gives higher engine speed than in the large engines for the same speed of piston travel;

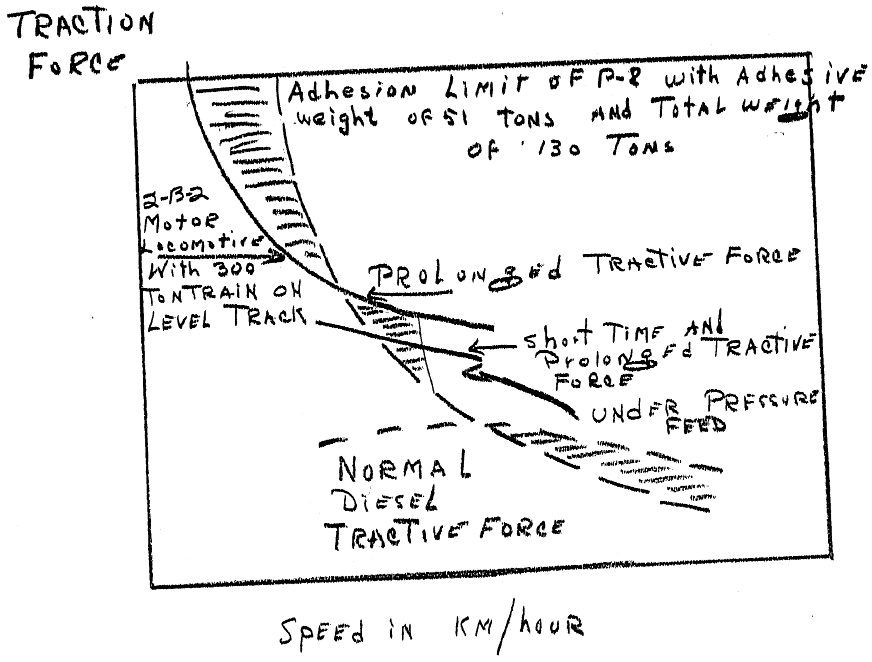


Figure 187. Tractive force at drawbar of motor-locomotive direct drive and (for comparison) series P-S steam locomotive.

TABLE 7

Internal Combustion Locomotives

Comparative Data	Conventional Design	With Subdivided Power Plant	Saving in Weight in tons
Power in HP	6000	5250	-
Number of engine cylinders	36	120 - 128	-
Total engine weight in tons	91	24	67
Unit engine weight in kg per HP	15.00	4.60	-
Total weight of electrical drive in tons	85.50	75.50	10
Unit weight of electrical drive in kg per HP	14.25	14.38	-
Total weight of mechanical equipment in tons	272	245	27
Unit weight of mechanical equipment in kg per HP	45.30	46.65	-
Other economy in weight, in tons	-	-	-
Total weight in tons	469.5	344.5	125
Weight per HP in kg	78.25	65.60	-
Unit power at rail with efficiency of drive = 0.83, in HP per ton	10.6	12.7	

a considerable saving in area is attained, since the linear dimensions of the engine are reduced in the same proportion as cylinder diameter; for example, four Diesel engines each of 250 HP take up only half the space required for one 1000-HP engine and weighs only half as much;

the thermal load on the surfaces surrounding the combustion space is reduced in small engines by almost half, which makes it easier to solve the problem of carrying off the excess heat;

the rigidity of attachment and the stability of small motors is approximately doubled, thanks to which vibration and various types of deformation is considerably diminished;

the economy of locomotive operation is increased by the existence of several motors, since individual units can be turned on and off according to the weight of the train, the profile of the run, etc; and similarly the reliability of locomotive operation is increased, since even if half the engines should fail (which is most unlikely) the train could still be hauled though at reduced speed to the nearest roundhouse;

the low weight and small dimensions of the parts and details of the power equipment facilitates their replacement at roundhouses or under way; and it is even possible to make medium repairs during train travel.

The characteristic curves of tractive force for the internal combustion locomotive with subdivided power plant are almost identical with those of the conventional internal combustion locomotive (diagram of Figure 108), in spite of their substantial difference in absolute weight.

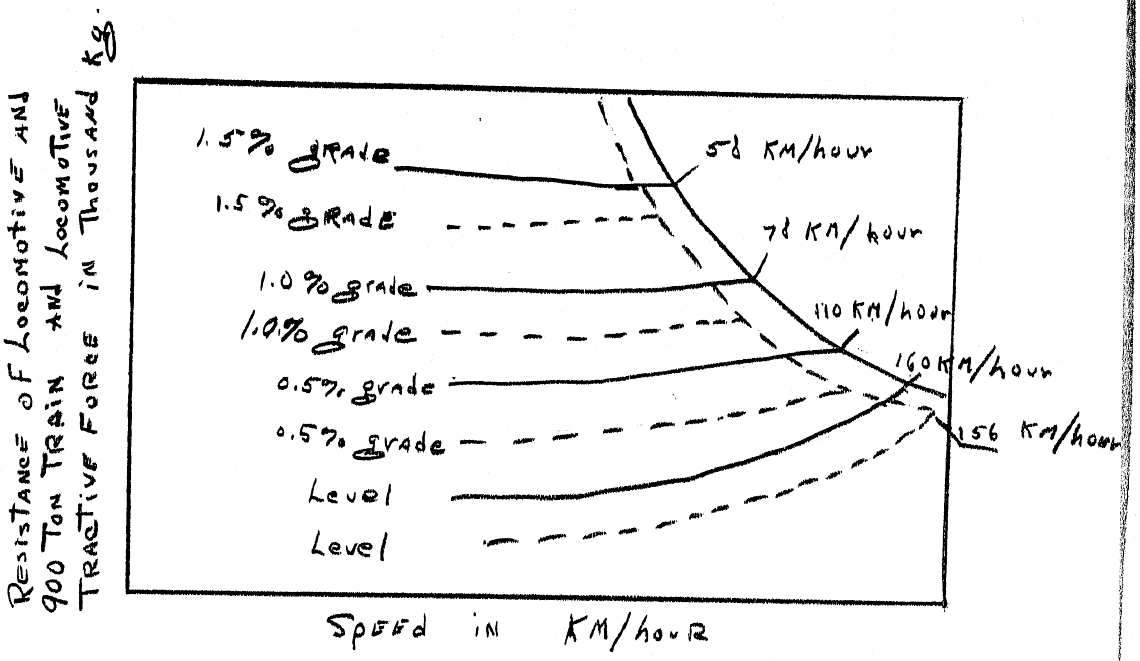


Figure 108. Curves of balancing speeds of motor locomotive with subdivided power plant, and a conventional internal combustion locomotive, with 900-ton train

It will be seen from the diagram that the balancing speeds of the internal combustion locomotives under comparison, hauling a 900-ton train over a level track, are 156 and 160 km/hour respectively; on an 0.5 percent grade, 107 and 110 km/hour respectively; on a one percent grade, 75 and 78 km/hour; on a 1.5 percent grade, 56 and 58 km/hour.

This internal combustion locomotive also possesses substantial advantages in fuel economy as well. Based on a load factor under ordinary operating conditions of 60 percent for the internal combustion locomotive hauling trains, and 6000 hours of operation a year, the designers estimate the annual fuel saving at 550 tons and the annual lubricating-oil saving at 3.4 tons.

The estimated cost of this internal combustion locomotive is 544,250 dollars against 600,000 dollars for a conventional internal combustion locomotive.

PART SEVEN

GAS-TURBINE LOCOMOTIVES

GENERAL INFORMATION

The utilization of the very latest engine, the gas turbine, as a traction engine, opens up wide prospects in locomotive building.

The use of the term "latest" with respect to this engine is a little arbitrary. The invention and the idea of the practical use of the gas turbine dates back as far as the end of the 18th century.

However, all efforts to construct this engine so as to make it suitable for practical use remained futile until a few years ago. The efficiency of the gas turbines that were constructed during this long period was zero in a number of cases and sometimes was even negative, which means in other words that the turbine consumed more energy than it yielded at its shaft. Only during the contemporary stage of the logical development, mainly in the field of matellurgy and aviation, has this problem been at last successfully solved. The first 3700 HP gas turbine was built and installed in a power station of one of the Swiss steel mills in 1933. The very favorable results of the operation of this installation stimulated the further expansion of its sphere of application, including that of train traction.

One of the substantial advantages of the gas turbine over all other engines known today is its extreme simplicity of design. A rotor with vanes, a combustion chamber, and an air compressor -- these are all its essential elements. There are no regulating valves, as in the steam turbine; the single valve in the combustion chamber is used only in case of the need to stop the turbine in an emergency. Turbine speed is regulated by varying the amount of fuel delivered to the combustion chamber.

The principle on which the turbine acts is that the products of combustion, containing from 300 to 600 percent of excess air, expand within the turbine, causing the rotor to rotate, and are then discharged into the outside air. The power delivered to the shaft is equal to the difference between the total power developed by the turbine and the power used by the compressor. The compressor is a axial type, of a design which has been very recently developed on the basis of the experimental investigation of the separate elements of aviation equipment. In fact, the creation of this high-efficiency compressor was one of the main conditions for the rapid progress and constructional improvement of the gas turbine.

The efficiency of the turbine varies directly with the temperature of the working gas, or, in other words, with the capacity of the compressor; let us explain what is meant.

As the capacity of the compressor is increased (and the power consumed by it is consequently also increased) more air enters to cool off the gas, as a result of which the temperature of the gas is reduced and consequently the efficiency of the turbine is also reduced, and vice versa. Thus, for instance, with a gas temperature of 540 degrees the turbine efficiency is about 18 percent, but at a gas temperature of 650 degrees it increases to 22 percent. Further increase in the temperature (and thus also of the efficiency) is, in practice, inadvisable, since it lea~~ves~~ds to rapid wear on the turbine vanes. In aviation, where long service of the vanes is a secondary consideration to weight and fuel saving, temperatures of the working gas in turbine installations are allowable as high as 1100 degrees.

There are various devices that can be used to increase the efficiency of a turbine installation, for instance, regenerators, the doubling of the compressors to cool the air sucked in by the compressor, etc.

As a traction engine, the gas turbine has a large number of advantages over the piston engine, both steam and internal combustion. These advantages are: neither feed water nor water cooling is required. There is no smoke and soot in the exhaust gases (since combustion of the gas in the chamger is complete); the consumption of the lubricants is entirely insignificant (since the turbine is a mechanism that rotates as a single unit); a low-grade liquid fuel, fuel oil, can be used; the turbine can easily be converted to run on producer gas, natural gas or manufactured gas, and in the future also to burn solid fuel in the form of dust (this problem is now being experimentally developed in Switzerland and in the United States).

The first gas-turbine locomotive, built in Switzerland in 1941, successfully passed a 4-year period of trial operations and at the present time is in regular service on one of the French railroads.

It must be said that since this locomotive was built it has attracted an extraordinary amount of attention. In various countries, including the USSR, many plans for such locomotives have been drawn. The experimental gas-turbine assemblies have already been constructed, together with the auxiliary equipment and apparatus for its employment on locomotives, and a large amount of work is being done in the field of laboratory and test-stand experimental investigation.

Most of the plans provide an electric drive and only in isolated instances is the hydraulic drive used.

This preference for the electric drive is mainly because its technique has been entirely mastered in long years of operating practice in all countries of the world, and it is very reliable in operation. It must be assumed that in the future the position of the electric drive will be still more consolidated. We have here in mind the possibility of the use of AC for electric transmission. The point is that the turbine operates at a speed that is 6 to 20 times as high as that of a Diesel, which assures a high starting torque, and that the turbine does not stall on overload, and its power throughout a very considerable part of the speed range remains constant. The existence of such characteristics creates favorable conditions for the use of AC drives. This means in practice that it will be possible to reduce the weight and cost of the entire assembly of equipment for electric transmission, as well as to improve the quality of that transmission itself.

2200 HP GAS-TURBOELECTRIC LOCOMOTIVE (SWITZERLAND)

(Built in 1941)

Figure 109 gives a general view of the locomotive while Figure 110 gives the scheme of arrangement for the power equipment and apparatus. So as to make it possible more easily to explain the principle under which this equipment acts, let us follow the very simple manipulations of the engineman from the moment when he prepares this locomotive to leave the station with a train.

First of all he starts the auxiliary Diesel generator (which is not shown on the diagram), and which is intended to bring the turbo-generator up to the speed at which the compressor is able to deliver sufficient air to the combustion chamber. For this about 4 minutes is required; he then ignites the mixture by using an electric lighter, and as a result the speed of the main turbine assembly begins to increase rapidly. After this he switches the Diesel generator over to feed the traction motors and in this way he leaves the station with the train at a speed of about 10 kilometers per hour without using the main turbine assembly. When the turbo-generator, 4 minutes later, reaches it normal r.p.m., the engineman switches off the auxiliary Diesel generator and switches the traction motors into the main generator circuit. From this moment on, the main turbine assembly is able to take the load, while the current for all the auxiliary equipment and the apparatus and control apparatus is automatically switched over to a small storage battery, which also serves to start the auxiliary Diesel generator.

It requires 4 minutes to "fire" the locomotive in the round house, and 8 minutes to bring the locomotive from the "cold" condition up to the condition of complete readiness for work.

Figure 109. 2200 HP electric-drive gas-turbine locomotive (the Red Cross on the locomotive is to prevent air attacks)

[Photo]

As will be seen from Figure 110, the rotor of turbine B and compressor C are on a single shaft, while the generator F is connected with the shaft through a reducing gear.

Parts of the compressed air from the compressor are delivered under a pressure of 2 atmospheres to the combustion chamber A through the annular jet 1 (after first passing through the stage of pre-heating by the exhaust gases in the air-preheater D) and part of the air is delivered at the same pressure through the passage 2

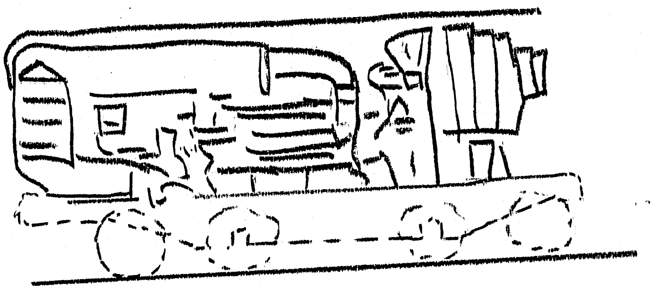


Figure 110. Scheme of arrangement of equipment and mechanisms on gas-turbine locomotive.

into the chamber 4, where it is mixed with the working gases and cools them to the required temperature before they enter the turbine.

The proper relation between the power developed by the turbine and that delivered by the generator, under varying conditions of locomotive operation, is obtained by the use of an auxiliary rheostat.

Figure 111. Operator's cab on gas-turbine locomotive.

[Photo]

This rheostat is automatically switched over to the proper position as a result of the action of the speed regulator on it. All of the organs of the regulating system are actuated by oil relays, which are fed under pressure by the general oil pump; this pump also serves to lubricate all of the bearings during the starting period.

There is a cab on each side of the locomotive with the corresponding apparatus and control instruments. Only one of these cabs is shown in Figure 111. The driving of the locomotive reduces down to the successive movement of the controller from one position to another. In this way the engineman regulates the delivery of fuel to the combustion chamber and consequently changes the number of revolutions (power) of the turbine. All the remaining operations are performed by an automatically controlled control, which switches the auxiliary rheostat into the proper position and thus assures the proper regime for the operation for the electric transmission.

All defects and abnormalities in the operation of the power installation of the locomotive (overheating of the bearings, exceeding the allowable temperature of the working gas or the allowable speed of the turbine, fall in the pressure in the oil system, extinction of the flame in the combustion chamber, etc) are signalled by signal lamps. If the engineman fails to take the proper measures or if the perform any erroneous operation, the corresponding automatic control is actuated, and the delivery of fuel to the chamber is cut off after a certain length of time, thus forcing the locomotive stop. The existence of these automatic controls, and the simplicity of their operation, makes it possible for a single engineman to handle this locomotive without an assistant, in view of which a "dead man's lever" is provided.

The power assembly with all of the auxiliary equipment and apparatus, is mounted on a firm auxiliary frame, which makes it possible to install it, as is shown in Figure 112, as a single unit in the locomotive body.

Figure 112. Power assembly with all auxiliary equipment before installation on locomotive frame.

[Photo]

The locomotive is designed to haul trains on lines where electric traction would not return an adequate profit on the investment, and this consideration was responsible for its small weight, clearances, and power. The wheel formula is 1-4-1. The sustained useful power of the turbine at the clutch of the generator is 2,200 HP. The tractive force at rail is 13,150 kilograms from zero speed up to 25 kilometers per hour; the 1-hour sustained power at 50 kilometers per hour is 7,700 kilograms; at 70 kilometers per hour the sustained power is 4,900 kilograms. The rated speed is 115 kilometers per hour. The locomotive weight is 91 tons in operating condition, the maximum axle load is 16 tons, the efficiency is 18 percent at 80 percent load, and the efficiency at rail under operating conditions is 15 percent. The weight per unit of power (at rail) is 50 kilograms per HP. The consumption of standard fuel during the plant tests was 423 grams per HP per hour at 1/2 load, 362 grams per HP per hour at 1/4 load and 399 grams per HP per hour at full load. The thermal efficiency at the generator clutch is 15.27; 17.74 and 16.07 percent respectively.

The turbine develops 8,000 HP, of which almost 2/3 (about 600 HP) is used by the compressor. In view of this ratio, the increase or decrease in the power absorbed by the compressor, which depends on the fluctuation of temperature and barometric pressure

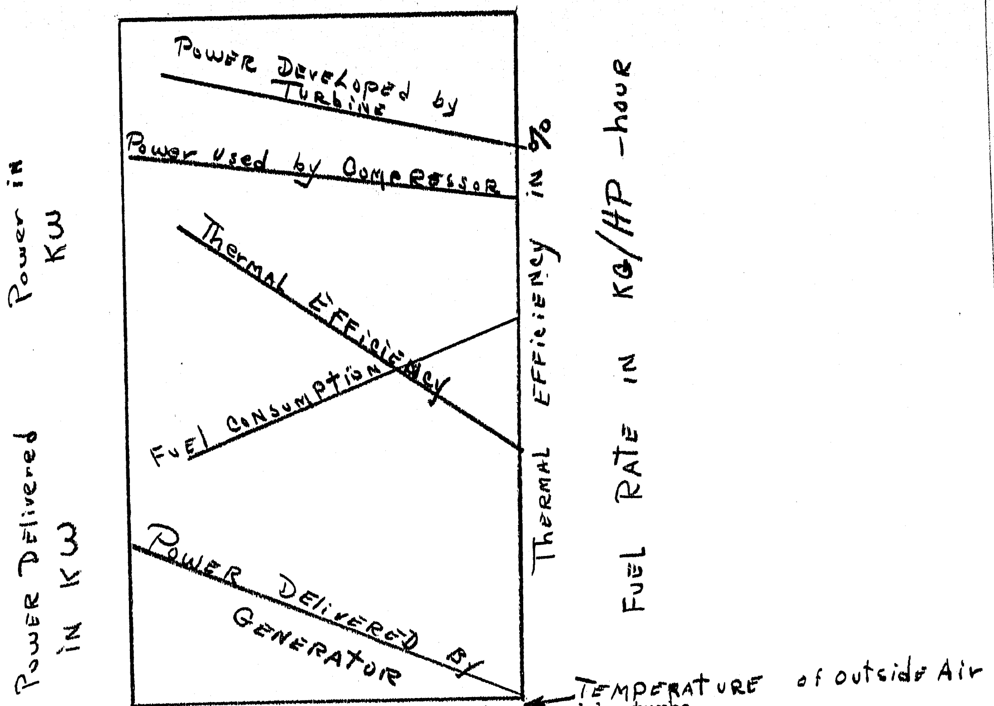


Figure 113. Curves of power developed by turbo-generator, efficiency and fuel rate, plotted against temperature of outside air.

very sharply influence the fundamental characteristics of the locomotive, and consequently also the economy of its operation.

If for instance the power developed by the locomotive at a temperature of +15 degrees is taken as 100 percent, it will only be 65.5 percent at a temperature of + 50 degrees, while this difference for the internal combustion locomotive amounts to only 5 percent. On the other hand, when the temperature declines, the power of the locomotive increases in roughly the same ratio. The diagram shown on Figure 113 clearly illustrates this situation.

The influence of barometric pressure is expressed by the following relation. If the power of the locomotive at sea level is taken as 100 percent, it will only be 60 percent at an altitude of

5,700 meters. But the losses in power in this case are more than compensated by the increase in power resulting by the fall in temperature which usually accompanies an increase in altitude.

After all that has been said it is not hard to understand that if the part of the power used by the compressor is reduced, i.e., with a less intense cooling of the working gas (and consequently with a higher temperature of that gas), the fluctuations of temperature and barometric pressure would only affect the stability of the basic characteristics of the locomotive to an insignificant extent, and its efficiency would be considerably increased. Calculations show that with a temperature of 815 degrees for the working gas (against the temperature of 600 degrees that is now usual), the efficiency of the locomotive would be increased to 29 to 30 percent, i.e., it would then be comparable with the Diesel-electric locomotive. Such a solution of the problem, however, is still impossible because of the unsuitability of the metal from which the vanes are constructed to withstand such high temperature stresses. It must, however, be assumed that in the near future the proper alloy for this purpose will be prepared, and the economy of the locomotive operations thus be almost doubled.

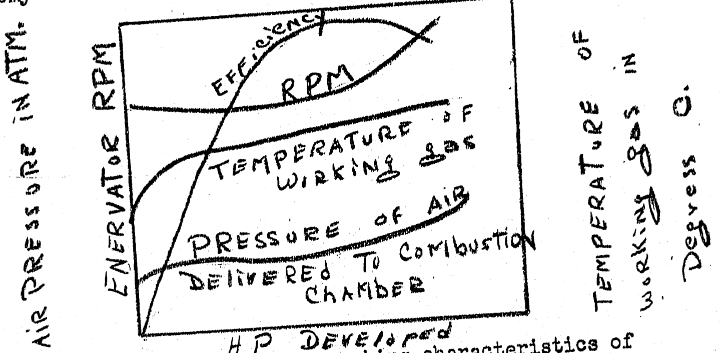


Figure 114. Curves of working characteristics of gas-turbine locomotive.

On Figure 114 the curves of the working characteristics of the locomotive, obtained during its acceptance tests, are shown, while Figure 115 gives the curves of fuel consumption and of the thermal efficiency of the locomotive.

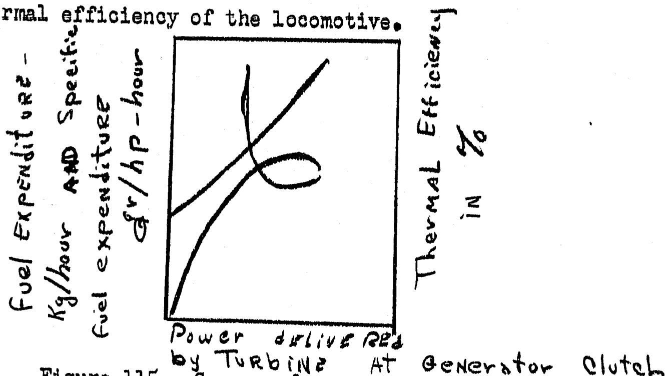


Figure 115. Curves of consumption of standard fuel (fuel oil) and efficiency of gas-turbine locomotive.

The results of 3 test runs of the gas-turbine locomotive with trains of various weights under ordinary operating conditions, are given in Table 8.

[See Table 8 on following page]

It must be observed, in this connection, that when the gas-turbine locomotive is used in passenger service, it becomes possible to heat the entire train during the cold season, by means of the "temperature increase" of power (which as is shown by the diagram of Figure 113, reaches 25 percent) without using a single kilogram of fuel for this purpose. A single-phase generator is installed on the same train as the main generator. It develops 200 kilowatts and feeds the electric heating system of the train.

In a special report to the annual conference of the American Society of Chemical Engineers in 1943, a parallel was drawn between the technical and operating policies of the steam locomotive

TABLE 8

Indices	Runs I	Runs II	Runs III
Length of run in kilometers	160	103	66
Total weight of train in tons	387	282	282
Difference in altitude between initial and final points of the run	+276	+451	-81
Average grade in percent	0.171	0.427	0.121
Running time in minutes, including stops	147.5	101.5	52
Number of stops	9	7	1
Net running time in minutes, excluding stops	130.5	83.5	50
Technical speed* in kilometers per hour	73.6	69.6	79.5
Capacity of generator at terminals in kilowatt hours	1579.6	892.5	466
Energy absorbed at generator clutch, in kilowatt hours	1735.5	985	520
Fuel consumption in kilograms	1272	800	432
Fuel consumption in kilograms per HP per hour	0.544	0.675	0.725

*[The "technical speed" is the average speed of a train during actual travel (excluding stops) over a run between 2 locomotive-change points.]

the internal combustion locomotive and the gas turbine locomotive, with the report based on the data of the operating practice of the American railroads with respect to the first 2 of these and on the data of the test operation in Switzerland, and in part on calculations, with respect to the third. We mention no considerations given in this report, and here reproduce only Table 9 with the resultant data.

TABLE 9

Indices for Comparison	Steam Locomotive	Motor Locomotive	Gas-Turbine Locomotive
Cost of locomotive of HP in dollars	35	87	65
Drawbar efficiency in percent	6-8	26-28	15-16
Annual run in kilometers	288,000	400,000	Over 400,000
Time required to take on water and fuel	Maximum	Minimum	Short
Allowable speed	Lowest	Highest	Highest
Wear on ways	Greatest	Less	Least
Electric braking-	No	At full power	At full power
Approximate service life in years	30	15-20	30
Cost of current repair	Low	Higher	Lowest
Cost of fuel in percent	100	50-75	50-75
Cost of lubricant in percent of fuel cost	10	10-30	Less than 5
Starting tractive force	Minimum	Great	Great

4800 HP GAS-TURBOELECTRIC LOCOMOTIVE (UNITED STATES)

(Plans)

The principal equipment of the locomotive consists of two gas-turbines, developing a total useful power of 4800 HP (2400 HP each), an auxiliary Diesel generator of 150 HP, for starting the main gas-turbine units, and two steam boilers for heating the train, with a steam generating capacity of 1000 kilograms per hour each.

Fuel oil is used as fuel, and the necessary preheating is done by utilizing the exhaust gases from the turbine.

At the bottom, in the central part of the locomotive, between the trucks, there are 3 tanks: one for fuel oil, holding 15,000 liters, another for lubricating oil, holding 5,700 liters, and a third for water, holding 10 cubic meters. The fuel supply is sufficient for a 10 hour trip without refilling. 2 tanks for Diesel fuel, each holding 1,150 liters, are located in the back of the locomotive body.

The full weight of the locomotive is 205 tons and is entirely distributed on 2-axle trucks. 6 electric traction motors, 1 for each truck axle, with a nose [nosovoy] suspension, are fed by the main generator. The motors may be switched over to take current instead from the auxiliary Diesel generator, so that the locomotive can move inside the station limits at speed up to 25 kilometers per hour without using the main turbine; such speeds are necessary for instance in leaving or entering the roundhouse with a train.

The braking is electrodynamic -- the traction motors in this case function as generators, while the main generator functions as a motor, actuating the main turbine and compressor, and the energy of braking is used in compressing air which is then allowed to escape into the atmosphere.

The total length of the locomotive is 27 meters, the wheel base of the truck is 4.8 meters, and the axle load 34 tons. The weight of the locomotive, in relation to the power developed at rail, is 51.5 kilograms per HP.

The tractive-thermal properties of this still little known and little studied locomotive type are of considerable interest, and for this reason they will here be discussed, even though very briefly, from the point of view of the operating requirements.

Let us take an example in which demands under the given operating conditions a high thermal efficiency for the locomotive is the primary requirement. In this case the temperature of the gas entering the turbine must be maintained at a level of 650 degrees at all levels of load (Figure 116, curve ADE), while the speed of the turbine must vary from the maximum of 5000 r.p.m. at full load to the minimum of 1500 r.p.m. when idling (Figure 117, curve ADE). Under the conditions the locomotive efficiency at the drawbar will be characterized by the curve ADE in Figure 118.

Such a regime, however, does not assure the possibility of rapidly increasing the speed of the locomotive when this is required by traffic conditions.

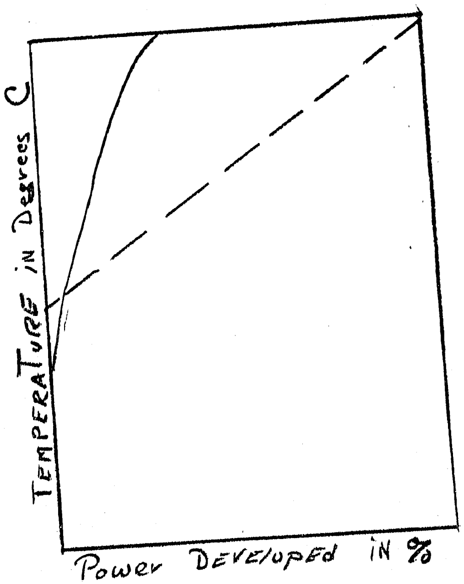


Figure 116. Temperature of gas entering turbine.

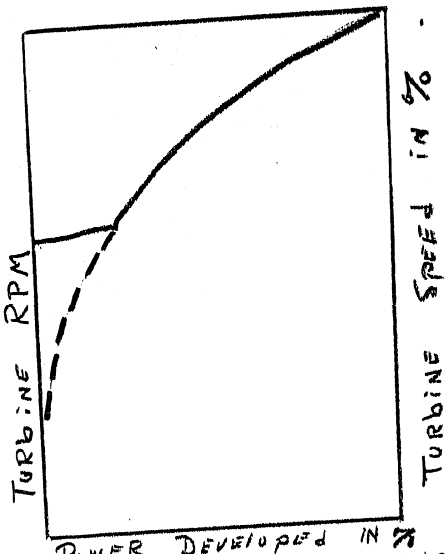


Figure 117. Rotative speed (r.p.m.) of 2400 HP gas-turbine.

For a certain amount of time must be consumed in overcoming the inertia of the rotating masses of the unit, before it begins to develop additional power for acceleration of the train.

Where the primary need of operation is for rapid acceleration, the speed of the turbine must be held at all times within the limits of its maximum, 5000 r.p.m. (curves CE on Figure 117), while the variation of the power developed by the turbine must be effected by varying (regulating) the temperature of the working gas that enters the turbine (curve CE of Figure 116). As will be seen from the diagram, the temperature of this gas varies from a maximum of 650 degrees at full load to 415 degrees when idling. Under this regime of operation, the thermal efficiency of the locomotive, however, is considerably reduced at less than full loads (curve CE of Figure 118).

The regime of operation under which the efficiency curve has the form of VDE on Figure 118 is the most acceptable, in other words, the regime under which there is a certain degree of compromise between a high acceleration and a low efficiency. In this case the variation in temperature is characterized by the curve BDE of Figure 116, while the variation in turbine speed is characterized by the curve BDE of Figure 117. With this, the minimum speed of the turbine is limited to 60 percent of the maximum. Under this regime a very high degree of acceleration is assured, and at the same time the highest efficiency is obtained within the limits of most of the load range.

The diagram of Figure 118 also shows that the locomotive efficiency at maximum loads is the same for any of the above described operating regimes, and amounts to about 20 percent.

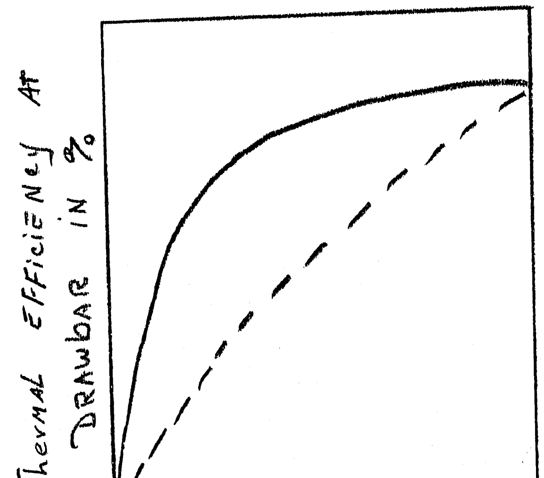


Figure 118. Drawbar efficiency of gas-turbine locomotive with one turbine operating.

The operation of the locomotive may be regulated by 3 different methods. To illustrate the essence and the results given by each of these methods, let us assume that the locomotive is operating at point D of Figures 116 and 117, and that an acceleration of the locomotive from this point is required, with an admission temperature for the gas of 700 degrees throughout the entire period of acceleration (this temperature will not be destructive to the turbine vanes since the duration of this period is very short).

In regulating the locomotive by the first method, the engineman places the throttle at a higher speed, which produce~~d~~s a rapid increase in the admission temperature to 700 degrees, and consequently also leads to an increase in the power developed at the shaft. By means of the appropriate adjustments of the generator exitation, an increase in the power delivered to the traction motors is obtained, which is proportional to a rise in the curve of turbine speed DE (Figure 117). But since the latter is based on the constant admission temperature of 650 degrees (curve DE of Figure 116), it follows that the additional energy obtained as a result of increasing the admission temperature to 700 degrees, will go to increasing the number of revolutions per minute made by the rotating masses, and it takes about 45 seconds to bring the speed of the turbine from 60 percent (point D of Figure 117, at 32 percent load) to 100 percent (point E at 100 percent load).

The second method of regulation is distinguished from the first in that the load on the turbine, from the moment the temperature is increased to 700 degrees, must remain constant throughout the entire period of acceleration (the segment DE of the curve in Figure 117), i.e., it must correspond to point E until the speed of the turbine unit has reached its maximum. In this way the increase in power that results from the increase in admission temperature is utilized entirely to increase the speed of the turbine to its maximum value.

Regulation by this method makes it possible to bring the speed of the unit up to the maximum inside of 18 seconds.

The third method assures an even more rapid acceleration, requiring about 8 seconds. In this case, the external load is entirely removed at the same time the admission temperature is increased to 700 degrees, and the entire power, together with the additional power (from the increase in the admission temperature) goes to increasing the number of revolutions to the maximum after which the turbine takes over the rated load.

In all these cases of regulation, the amount of fuel inducted into the combustion chamber is such that the admission temperature of the gas into the turbines shall not exceed the limiting maximum of 700 degrees. This is achieved by means of a special thermostat.

The basic characteristics of the gas-turbine locomotive are very clearly illustrated by the diagram of Figure 119. The curves A and B characterize the tractive force and the power that can be developed by the locomotive. Curve C characterizes the resistance to motion of the locomotive weighing 200 tons with a 15-car train weighing 900 tons on a level. The intersection of curve A and C gives the maximum speed which the locomotive is able to develop on the level, which in this case amounts to 153 kilometers per hour.

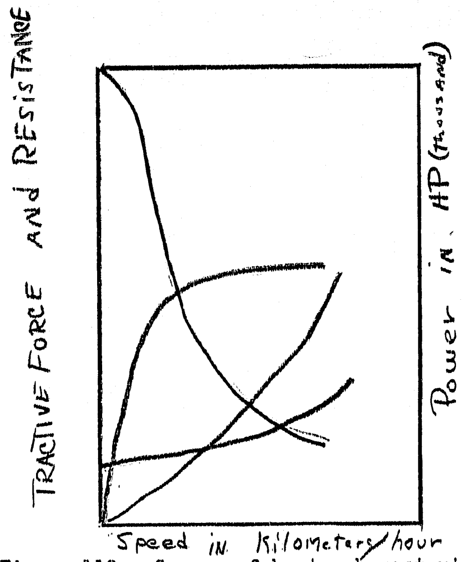


Figure 119. Curves of basic characteristics of 4800 HP gas-turbine locomotive.

The required power at rail to haul this train at various speed is characterized by curve D. The curves F, G, H, I, J, and K characterized the train resistance on various grades, from 0.5 percent to 3.0 percent. The intersection of curve A with each of these curves gives the balancing speed for the corresponding grade for a train weighing 1100 tons. The locomotive can operate under the following variant regimes: (a) one unit does not operate at all, while the other operates under full load, thus assuring the corresponding balancing speeds on the stretch: if it is necessary to increase speed, the second unit is started: (b) one unit idles while the other runs with the load; when the load of the latter reaches the limit of its power, the second unit is engaged and takes up its share of the load and the train is accelerated accordingly; (c) both units operate all the time with the same loads; (d) both units operate, but the apportionment of the load between them is constantly changing.

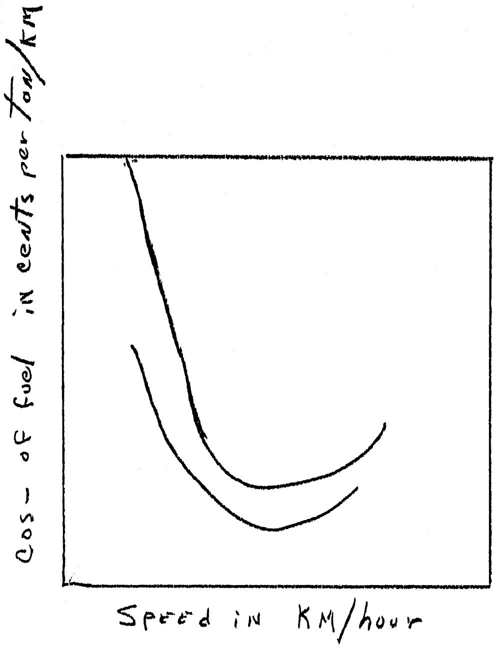


Figure 121. Fuel cost per ton-kilometer for 4800 HP gas-turbine locomotive weighing 205 tons, hauling 900-ton train; one 2400 HP unit is operating for curve A and B; both units, each of 2400 HPm, are operating for curves Cm D and E,

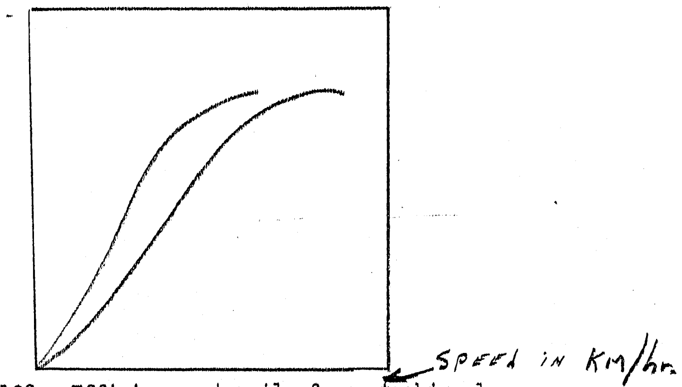


Figure 120. Efficiency at rail of gas-turbine locomotive.

The varying values of the efficiency at the wheels of the locomotive for all of the above variants are characterized by the diagram of Figure 120. Here the curve ABDE is the locomotive efficiency in running on variants a, while the segment a b of the curve characterizes the efficiencies.

When running on a single unit, when the second unit is started up, the efficiency falls sharply by the value BD owing to the fact that a certain amount of fuel is expended on idling during the transitional period of starting; but as soon as this unit takes its share of the load, the efficiency rises rapidly (curve D e) and reaches its maximum at the point E when both units operate at full power. The curve CDE characterizes the efficiency of the locomotive when working on variants b, c, d.

It is clear from this diagram that the operation of the locomotive on the variant a is more economical than with the other variants in the speed range from 0 up to 115 kilometers per hour. This is explained by the fact that in the first place the consumption of fuel for an inoperative turbine is completely excluded, and in the second place the operating turbine works throughout the entire speed range with a more complete load.

The diagram of Figure 121 gives the cost of fuel in cents per ton-kilometer for a locomotive weighing 205 tons at various speeds, with a train weighing 900 tons.

The curve ABDE relates to the operation of the locomotive on variant a while the curve CDE is for variants b, c and d. The cost of 1 liter of fuel oil has been arbitrarily taken as 1 cent.

It will be seen from the diagrams that the optimum speed of the train for any variant is around 65 kilometers per hour. At this speed the cost of the fuel consumed by the locomotive amounts to 0.0052 cent per ton per kilometer. In other words, for every liter of fuel consumed, the locomotive produces 190 ton-kilometers, while at speeds near 150 kilometers per hour, these figures are respectively 0.010 cent and 100 ton-kilometers.

Under present traffic conditions, especially of passenger traffic, the locomotive must run most of the time at the higher speeds. For this reason, the gas-turbine units have been designed and constructed so that the thermal efficiency of the locomotive reaches its maximum at full load at the upper limits of the speed range. Based on the use as fuel of fuel oils of the low heat value of 9,870 kilocalories per kilogram, and the arbitrary efficiency of 15.8 percent, the unit fuel consumption for this locomotive is 632.3: 9870 x 0.158 or about 400 grams HP per hour at rail.

The thermal efficiency of the locomotive can be further increased to approximately 20 percent by the full utilization of the heat of the exhaust gases from the turbine (for air preheating, etc).

8,000 HP GAS-TURBOELECTRIC LOCOMOTIVE (United States)

This gas-turbine locomotive, of which Figure 122 is a general view, consists of 2 sections, each of 4,000 HP. Each section has its own controls, and therefore can be utilized individually. When being run in its dual condition, the locomotive is driven by the multi-unit system.

The principal power equipment of each section consists of 2 gas-turbine units, 1 of which is shown in Figure 123, and each of which develops a useful power of 2,000 HP.

The main and auxiliary generator are both driven by a reducing transmission.

The principal proportions of a power unit are: length, 7.88 meters; width, 1.05 meters; height, 1.8 meters; total weight, 17,670 kilograms. Two such aggregates are installed side by side, as shown by Figure 122, thus making it possible to place all of the equipment in the engine-room of the locomotive, which is not longer than a unit.

Figure 122. 8,000 HP gas-turbine locomotive with electric drive.

[Photo]

Figure 123. One of the 2,000 HP gas-turbine units.

[Photo]

The total weight of the locomotive (both sections) is 410 tons. It is entirely distributed on 8 2-axle motor trucks with a load of 25.6 tons on each axle.

The locomotive is designed to haul heavy freight trains. Its rated starting tractive force is 102,000 kilograms with a coefficient of friction of 0.25, which is considered entirely realistic, considering the high degree of uniformity in the torque of the driving-wheel pairs. The tractive force is 72,500 kilograms at a speed of 25 kilometers per hour, and 54,300 kilograms at 40 kilometers per hour. The rated speed is 115 kilometers per hour. With an efficiency for the electric drive amounting to about 83 percent, the weight of the locomotive, with respect to power at rail, will be 62 kilograms per HP.

GAS-TURBINE LOCOMOTIVE WITH HYDRAULIC DRIVE (United States) (Plans)

The advantage of the electric drive is that it assures the possibility of maximum use of the power of the prime mover of the locomotive under the most varied regimes of its operation (speed, load, etc).

On the other hand, the electric drive has a considerable number of disadvantages which have already been discussed in Part Six. In addition, the electric drive does not make it possible to bring the power of any locomotive in a single unit up to the value that can be reached, for instance, by electric locomotives, other things being equal.

The internal combustion locomotive is a very clear example. As everyone knows, wheels of diameter from 915 to 1,016 millimeters are employed in these locomotives. The further increase in this diameter is limited by the clearance conditions since the locomotive body, with its fairly bulky electric power equipment, is already unable to fit to the height clearance. But with this wheel diameter, there is just room to install motors, by suspension on each driving axle, if they are no larger than 500 HP.

It follows that a locomotive of let us say 6,000 HP must have 12 driving axles (not counting the free axles). In other words, such a locomotive can be manufactured, and usually is manufactured in three or even four separate sections.

The multi-section locomotive, which is a flexible machine that is easily adapted to varying operating conditions, is not free however from substantial defects, namely: unwieldiness (a poor-section motor locomotive for instance already represents a whole train about 80 meters long) and the complexity of its design as a whole, which results in high first cost and increased cost of maintenance and repair.

It is therefore entirely natural that designers and builders should strive to equip a single internal combustion locomotive or gas-turbine locomotive with a power which, if it is not equivalent to the power of a modern electric locomotive, still at least approaches that value. In practice this implies the necessity of changing over from an electrical to a mechanical drive, which when applied to a powerful locomotive is connected with serious difficulties of construction.

The plan for a 6,000 HP gas-turbine locomotive described below is one of the variants of the solution of this problem.

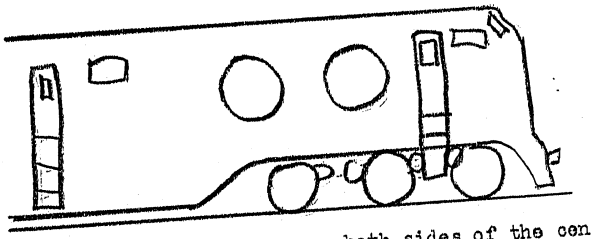
The principal equipment of this gas-turbine locomotive (Figure 124 gives a sketch of half) consists of 2 gas-turbine units, developing a total useful power of 6,000 HP (3,000 HP each), a starting Diesel generator, for steam boilers for heating the train, with a steam generating capacity of 720 kilograms per hour, and other equipment and apparatus.

The turbines are located in the central part of the locomotive body, so that their shafts are parallel to the longitudinal axis of the locomotive.

The torque is transmitted from the shaft of each turbine to all three axles of the corresponding truck through a reducing gear and a forward and reverse hydraulic clutch.

The forward clutch is driven by the turbine through the main reducing gear, while the reverse clutch is driven by the turbine through an intermediate or reversing gear, which is engaged with the main reducing gear when the locomotive is required to travel backwards.

Figure 124. Scheme of arrangement of power plant and apparatus of gas-turbine locomotive with hydraulic transmission (half of it is shown on figure) 1 hypoid wheel with pinion; 2 hydraulic torque converter and clutch; 3 gear transmission; 4 driving shaft and coupling; 5 chambers for liquid fuel and water; 6 universal joint; 7 half of body; 8 3,000 HP gas-turbine; 9 boiler forheating train; 10 gas-turbine; 11 blower for cooling and radiators; 12 combustion chamber; 13 axial type compressor; 14 starting Diesel motor; 15 generator; 16 oil burner



The cab and all equipment are on both sides of the center line.

Between the center-pins of the trucks 14.78 m

Wheel base 4.57 m

Between the centers of the trucks 17 m
Wheel base 21.64 m
Length of locomotive body 24.38 m
Length between buffers 25.75 m

The gear wheel on the motor shaft of the hydraulic clutch is engaged with a single gear wheel, which is placed on the driving axle. The latter is arranged parallel to the longitudinal axis of the locomotive, immediately above the driving axle and is connected with those axles by means of a hypoid pinion.

Reversing (passing from forward to backward motion and vice versa) is effected with the help of a sturdy reversing mechanism of special construction, which assures the engaging of the corresponding hydraulic clutches for forward or backward motion, as the case may be.

For absorbing shocks and vibration during travel of the locomotive, resilient (spring) elements are provided, which constitute intermediate links between the turbine shaft and the reduction drive, and also between the hypoid [hypocycloid?] pinions and the gears of the driving wheels.

There is a combination braking system -- dynamic and pneumatic. Dynamic braking is effected by the simultaneous forcing of liquid into the forward and reverse hydraulic clutches. The synchronization of the dynamic and pneumatic braking is assured automatically by a special device.

The pneumatic braking system is intended to supply only a relatively small percentageof the braking effort required by the train and is mest efficient at medium and low speeds, while the dynamic braking is utilized at high and medium speeds.

The universal joint is one of the important elements of the mechanical drive. Its function is to make it possible to displace the driving shaft along the vertical (to absorb the shocks from the uneveness of the roadbed) and in this way to maintain its continuous elastic donnection with the hydraulic clutch and the driving axle. The disconnection must also be elastic when the locomotive rounds a curve, for the relative position of the driving shaft and the driving axles changes as a result of the shifting of the trucks in a certain dependence on the radius of the curves. The universal joint is able to assure such an elasticity to the driving shaft up to the maximum degree of its displacement (15 degress) with respect to the longitudinal axis of the locomotive, in other words, throughout the entire range of action of the devices that limit the turning of the trucks when rounding curves of minimum radius.

However, the existing type of Cardan joints, as has been shown by experiment, are unable to transmit properly so great a power throughout the entire speed range. A special design of universal joint had to be worked out for this purpose.

This joint, the so-called universal joint, is a strengthened variant of the design of the well known Bendix joint shown on Figure 125.

The experience with the use of this type of joint for transmission in trolley motor cars of streamlined type testifies to its high merits in operation. Thus, for instance, Bendix universal joints are usually inspected and lubricated after running 130,000 to 160,000 kilometers. Its peculiarity consists in the fact that the transmission of the force takes place through the four steel balls, and not through the spokes, as is usually the case with ordinary Cardan joints. This assures the uniformity of the transmission of the force during a full revolution of the wheels at any position and any speed of the driving and driven shafts.

The universal joint is enclosed in a casing made of a special composition, which entirely eliminates the possibility of the entrance of dust and dirt or the leakage of the lubricants.

Figure 125. Universal Bendix joint. Upper part assembled; lower part disassembled.

[Photo]

The weight of the locomotive is 195 and is entirely distributed over the 2 3-axle driving trucks. The maximum starting tractive force is 41,000 kilograms with an entirely assured coefficient of friction, for the locomotive, of 0.22. The rated speed is 190 kilometers per hour, the weight in terms of power at rail (assuming a transmission efficiency of 0.9), is 36 kilograms per HP and the corresponding power at rail, in relation to the weight, is 27.7 HP tons.

PULVERIZED-COAL-FIRED GAS-TURBINE LOCOMOTIVE (United States) (Plans)

Even in the present stage of its development, the design and operating characteristics of the gas-turbine locomotive make it a serious competitor of the steam locomotive, and in certain respects of the internal combustion locomotive as well. On roads where this machine has been extensively introduced into operating practice, there is, however, one serious obstacle -- the kind of fuel its uses. Thence comes the natural effort of designers and inventors to convert this locomotive to solid fuel, namely, pulverized coal.

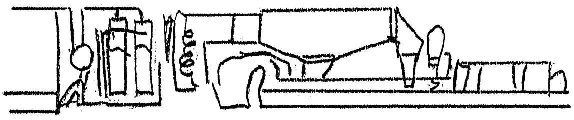
This problem, which seems simple at first sight, proved in fact to be exceedingly complex and difficult, and until very recently all attempts to solve it in practice have ended in complete failure.

The complexity and difficulty of this problem consisted, in the first place, in working out a design for the equipment and mechanisms to pulverize the coal and feed it, which would be acceptable (in its clearance dimensions, weight and method of operation) for installation on locomotives, and in the second place in improving the process of combustion of the pulverized coal in the combustion chamber, so as to make combustion absolutely complete and exceedingly rapid, and, in the third place, in achieving conditions under which gas entering the turbines would be free from abrasive material, consisting of minute particles of ash, since these result in rapid wear and consequent destruction of the turbine vanes, which, as a matter of fact, has been, up to now, the main obstacle to the conversion of gas-turbines to pulverized coal.

At the present time this problem, so far as may be judged by the published material, has been on the whole already solved. An experimental gas-turbogenerator locomotive installation with all the pulverizing and feeding equipment and mechanisms (Figure 126 gives a diagram of its arrangement) was assembled, and in December 1945, it was placed in operation in the laboratory of Johns Hopkins University (in the United States); ~~and~~ the year-long laboratory tests have confirmed the correctness of the designers' assumptions and calculations, and the locomotive assembly as a whole has proved to satisfy all the demands of operation.

Omitting the description of the gas-turbogenerator, since it is in no way substantially different from the conventional models, we shall here give only a few data of the construction and principle of the main elements of the coal and fuel feed and of the pulverized fuel preparation.

Figure 126. Scheme of arrangement of power equipment and mechanisms on pulverized-coal fired gas-turbine locomotive. 1, turbine; 2, compressor; 3, regenerator; 4, air supply; 5, generator; 6, reducing drive; 7, compressor to deliver air to atomizer; 8, to waste heat boiler; 9, combustion chamber; 10, coal atomizer; 11, exhaust pipe; 12, coal bunker; 13, Airotek filter; 14, air for turbine; 15, air for atomizer under pressure of 9.8 atmospheres; 16, coal grinding to 6 meshes; 17, coal conveyor.



The coal conveyor. The worm conveyor to feed the coal is of a special type; it is constructed so that the coal is taken from along the entire length of the coal bunker on the tender, thus eliminating the formation of dead (immobilized) zones, which in turn results in the uniform lowering of the level of the coal pile in the bunker. The rate of coal delivery is regulated by varying the speed of the motor that drives the conveyor.

The coal delivered by the conveyor is dried during its passage along the conveyor by the introduction of hot exhaust gas into the chute along which the coal passes. Special cleaning plates are provided to remove from the turns of the conveyor lumps of iron that accidentally get into the coal.

The grinding crusher. Before it enters the "coal atomizer", the coal passes from the conveyors into a special crushing mill, by means of which the size of the separate lumps of coal is reduced to a value smaller than the meshes of a sieve, usually 4 per linear centimeter. As a matter of fact, the crushing mill transforms the coal into a powdery mass with grains the size of those of ground coffee grains. After this, the coal is again dried and is delivered to the so-called delivery reservoir. Thence it is delivered by the help of a special pulverized coal conveyor to the "coal atomizer", which is schematically shown in Figure 127.

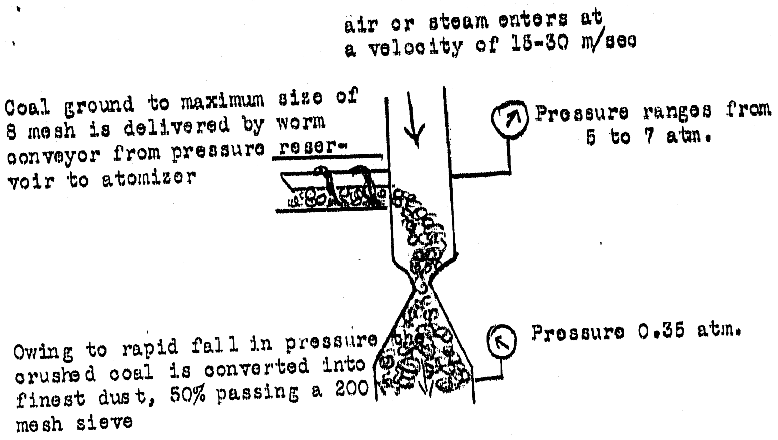
The "coal atomizer." The coal powder that enters the atomizing reservoir (Figure 127) is subjected to the action of compressed air (5 to 7 atmospheres) which is delivered from above with a velocity of 15 to 30 meters per second. In this way the "charge" (filling up) of the pores of the coal particles with air is accomplished. The charged coal mixture proceeds further through the constricted orifice of the atomizer. When the coal-air mixture issues from the orifice, the pressure to which it is subjected falls sharply, which results in the release of air from the pores of the coal particles. As a result millions of peculiar explosions, following each other uninterruptedly, are produced, and transform the coal powder into the finest coal dust. The amount of air required for this operation is 1 kilogram for each kilogram of coal powder.

The atomized coal is reduced to a fineness at which 50 percent of the dust will pass a sieve with 80 meshes per linear centimeter. By adding a special device to the atomizer, known as the "cyclonizer" the fineness of the "grind" may be increased to the stage at which 80 percent of the dust passes a sieve with 130 meshes per linear centimeter.

The power used in preparing the coal dust amounts to about 2 percent of the power developed by the turbine.

The combustion chamber. The combustion chamber, schematically represented on Figure 128, is constructed so that the stream of coal dust entering it maintains a whirling rotary motion for the entire time until combustion is completed, and is simultaneously penetrated by the air entering the chamber through tangential admission orifices, and which then leaves the chamber through a central exhaust outlet.

Owing to their centrifugal force, the particles of coal dust tend to fly towards the sides (towards the walls of the chamber tub) at the same time as the air jet opposes this force. In consequence, the burning particles of coal dust are carried together with the air through the central admission aperture.



The high velocity of the coal-air mixture as it issues from the burner is converted into heat, owing to constriction of the steam, and this heat dries out the coal-dust to a moisture content under 1 %.

Figure 127. Scheme and principle of operation of coal atomizer.

Laboratory studies of the combustion process in the chamber of this system showed that the liberation of heat in the space of the chamber reaches 4.5 million kilocalories and higher per cubic meter, while the application of pressure in the chamber considerably shortens the duration of the combustion. The rate of combustion of coal dust of the finest possible grind is almost equal to that of oil in the turbines which are used today as jet motors on airplanes.

The gas filter. No matter how perfect the combustion of the coal dust may be the gas entering the turbine is still not free from the most minute flying particles of ash, which as has already been noted above, act in a very harmful manner on the metal of the turbine vanes. [Electro-microscopic] study of the coal dust established that the flying dust particles are spherical in shape and that their diameter is approximately 10 microns. (The micron is equal to a thousandth of a millimeter.)

It also established that the particles of ash of diameter smaller than 5 microns exert a very insignificant effect upon the metal of the vanes, and they can in practice be considered harmless. It was therefore necessary to filter the gas before it enters the turbine, using such filters as would retain all particles of ash larger than 5 microns in diameter.

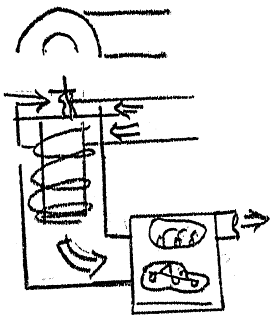


Figure 128. Combustion chamber: 1, pulverized coal; 2, igniter; 3, burner; 4 air for combustion; 5, for cooling; 6, spiral flame; 7, interior of body made of rustless steel; 9, purified air for turbine; 10, external body of carbon steel; 11, mixing zone; 12, Airotek filter; 13, air under 4.2 atmospheres pressure heated to 670 to 760 degrees, with suspended particles of flying ash; 14, ejector for flying ash.

Figure 129. Airotek filter. 1, purified air; 2, unpurified air or gas; 3, unpurified air or gas; 4, the air is conducted out on top; 5, the particles of flying ash settle to the bottom.

An Airotek type separator was used as a filter. This filter was designed and built by the American Firm Airotek during the war for cleaning the air in airplane engines operating in the African theater of operations. Figure 129 gives a schematic view of the Airotek separator.

Laboratory tests of the operation of this filter established that it actually does retain all of the particles suspended in the air of diameter over 10 microns and about 80 percent of those of diameter under 5 microns. The principle on which the Airotek separator works is that the air (gas) passing through the tube of the separator, is caused to move vertically with an immense velocity, thanks to which the ash particles are hurled by the action of the centrifugal forces against the walls of the tube, from which they descend and are then removed through the discharge opening. Experiments have shown that by the help of this separator about 95 percent of the ash particles are removed from the gas, while the remaining 5 percent, being the most minute in size, are practically harmless for the metal.

Calculations show that a separating installation (filter battery) for a 5,000 HP gas-turbine will remove from 150 to 350 kilograms of ash particles per hour from the gas. At the present time the laboratory is making an experimental study of the possibility of using this ash for sanding the rails instead of the sand which is usually used. If the results turn out to be positive, it will be possible to simplify still more the process of preparing the locomotive for a run at the round houses, and this will also free the locomotive from an excess dead weight of about 2 tons of sand.

A turbine is also being designed to operate on either pulverized coal or fuel oil. This will make it possible to use the same locomotive on lines firing oil and those firing coal.

The development of a system of control for the gas-turbine locomotive, that would automatically assure the proper coordination and synchronization in the operation of the individual elements of the power plant, is one of the most difficult problems and has still not been completely solved; and a number of sections of the above-mentioned, committee is now working on it. The calculations made by the committee on locomotive improvement show that the gas-turbine locomotive, firing pulverized coal, has an operating cost of 5 cents per kilometer, over a running distance of 415,000 kilometers which is apparently entirely attainable for this locomotive, as compared with 14 cents per kilometer for the conventional type of passenger Diesel-electric locomotive of equivalent power, for the same annual run.

PART EIGHT

SINGLE-PHASE NORMAL-FREQUENCY ELECTRIC LOCOMOTIVES

General Information

The use of electric energy to draw trains has been one of the most outstanding achievements of transport technology in the entire history of the railroad.

It is hard to imagine how the manifold problems of transportation could be solved at the present time if we did not have such effective means of traction as the electric locomotive and the electric motor-car. In any case it would be impossible without them to solve these problems in complete conformity with present-day economic, technical-operating, sanitary and hygienic and other demands, and with the interests of traffic safety, especially in the suburban areas of capital cities, metropolitan, industrial and large economic and administrative agglomerations, as well as on sections with extensive mining operations, trans-shipments, or tunnels.

In spite of the fact that the electrification of the railroads in some countries of Western Europe and America commenced as early as the first years of the present century, the Tsarist government undertook no real action in this direction down to 1917, i.e., up to the very end of its rule, and, as is commonly known, did not construct a single kilometer of electrified line. The country likewise lacked the scientific and technical base, as well as the organizational and productive base, which could have been used, after the revolution, as a starting point for the conversion of even a few railroad sections and lines to electric traction.

The period of foreign military intervention and of the 3-year civil war that followed the October Revolution, which was then succeeded by the supremely difficult years of liquidating the destructive consequences of the imperialist and civil war, postponed by almost a full decade the practical realization of the railroad electrification that had been decided in advance, as early as 1920, by Lenin's GOELRO plan. Only in 1929 was the first electrified section, from Moscow to Mytishchin, 18 kilometers long, placed in regular operation. Thus, on account of special and historically complicated conditions, our country commenced the electrification of its railroads almost 3 whole decades late.

But the tempo with which the Soviet state began to realize its electrification program was such that already today there are many foreign countries that are far behind us in the length of their electrified railroad lines. Here are a few figures to characterize the dynamics of growth of the electrified railroads in the USSR.

In 1932 we had 62 kilometers of electrified lines; in 1933, 351 kilometers; in 1934, 378 kilometers; in 1935, 1,033 kilometers; in 1936, 1,220 kilometers; in 1937, 1,632 kilometers; in 1938, 1,690 kilometers; in 1940, 1,900 kilometers.

The Second World War slowed down further progress in this direction, but did not completely halt it. Thus we had 2,045 kilometers by 1945, i.e., the growth during this period amounted to 145 kilometers.

But the electrification of our roads is proceeding, and will continue to proceed, at an incomparably faster pace during the present postwar period. As is commonly known, the Law on the Five-Year Plan of Reconstruction and Expansion of the National Economy provides for the electrification of 5325 kilometers of railroad lines.

Thus the USSR will have 7863 kilometers of electrified railroad lines in 1950, and will be first in the world in length of such lines.

What is represented by the electric locomotive as a railroad engine and what is the reason for its high efficiency?

The fundamental difference between the electric locomotive and all other existing locomotives is that the energy that moves it is received from outside, from great regional thermal or hydroelectric power stations. It is thus free from the heavy, bulky power equipment, that requires care and servicing, and must be carried by all other locomotives.

The equipment of the electric locomotive consists primarily of electric traction motors, auxiliary motors, electric and pneumatic apparatus, and the mechanical part (underframe and body). Its power is determined by the number and power of the electric motors installed in it, and an important consequence results from this fact: the maximum power permitted by the adhesion conditions, without exceeding the clearance dimensions and the allowable axle-load, may easily be installed in an electric locomotive, which is in practice unattainable for all other types of locomotives. Furthermore, when electric locomotives are used, sectional traction [distribution of electrics through the train] may easily be arranged (for hauling heavy trains on lines with severe profiles) and operated from a single cab under what is called the "multi-unit system".

It must be borne in mind that the tractive qualities of an electric locomotive cannot be directly compared with those of other locomotives, even of equivalent power, without allowing for the specific peculiarities of the operating characteristics of each, as otherwise erroneous results will inevitably be obtained.

The reciprocating steam locomotive, for instance, is able to develop its full power only at one definite point of the speed range. At speeds above and below this point it is no longer able fully to utilize its tractive resources. Moreover, it can only consume as much steam as it can produce with a given capacity (steam-generating capacity) of the boilers. Consequently, no matter at what speed the steam locomotive is travelling, its power from the boilers always remains unchanged, while its power at rail is always changing with the efficiency at which it is operating during each given interval of time.

While it is true that the power of the steam locomotive may be increased if necessary (by roughly 25 to 30 percent over the rated power), by going over to the regime of intensified steam generation (forcing the boiler) and selection of the appropriate stage of admission (cut-off) of the engine cylinders, still such a regime is not stable, reliable or permanent, primarily because there are many factors that play a role in this case: fuel quality, condition of boiler and engine, the qualifications of enginemen, assistant, stoker, their skill and their understanding of how to handle the locomotive, etc. Precisely for this reason it may happen that the locomotive "runs out of steam" on the track, especially where the grades are steep.

The motor-locomotive is even less adapted to handle overloads, whether it has a mechanical drive or an electrical one. The limitations of its load are strictly defined by its rated engine power.

In this respect the electric locomotive is substantially distinguished, and to its advantage, from the steam locomotive, and to some extent from the motor-locomotive as well. Firstly, it has an automatic characteristic; in other words, the speed of an electric locomotive is automatically varied according to the pull exerted during each given period. Secondly, the power that it can develop is limited only by the allowable limits of overheating fot the traction motors, but not at all by the available power of the source generating the energy, which in practice is not limited. Thirdly, the motors, which possess a considerable thermal capacity, are able to stand an overload of 50 to 70 percent and even 100 percent (depending on duration), without any reduction in the efficiency of the electric locomotive, similar to that which occurs with the steam locomotive, where forcing the boiler and working on high cut-offs is accompanied by a sharp fall in the thermal efficiency.

Usually in evaluating the tractive qualities of an electric locomotive, account is taken of the power that it can develop, in continuous operation and in 1-hour operation, without overheating the motors beyond the limit (145 degrees).

All these features of the electric locomotive, more especially its adaptability to operation with overloads, are of exceedingly great practical importance. Let us explain this again by way of comparing this locomotive with others.

In determining the power of a steam of internal combustion locomotive being designed, under given conditions of operation, (weight norms of the trains, speed on the runs, track profile, etc) one starts out, in the last analysis, from the most difficult, or as it is called the ruling grade. In other words sufficient power is provided to overcome the steepest grade, at the given speed. But since such grades constitute (in total length) only a negligible quantity in comparison to the total length of the line or route, it follows that the locomotive must be given a certain amount of "reserve" power that is very little utilized. In practice this implies reducing its thermal efficiency, or in other words reducing an efficiency that is already low (e.g., with the steam locomotive).

The situation is entirely different with the electric locomotive. There is no more need for such a "reserve" power here, since this locomotive is adaptable, by virtue of its overload capacity, to work on lines and routes with the most diverse track profiles. And besides this, the gear ratio can also be changed so as to develop maximum possible power at the expense of train speed (if the latter cannot be increased due to the limitations placed on tractive force by the adhesive weight of the train).

Moreover, the simplicity of the design of the electric locomotive, and the high reliability of operation of all the equipment installed on it, result in a high availability factor, amounting to 97-98 percent. This means that of every 100 hours of its operation, only 2 to 3 hours are required for light and medium repairs, inspection, equipment, etc, while this factor is about 70 to 75 percent for the steam locomotive

It is thus clear that the electric locomotive is capable of performing a far greater amount of work than a steam locomotive of the same power, as has been confirmed by experiment and operating practice. Thus, on the individual sections of our railroad system, one electric locomotive replaces 2.5 and even 3 steam locomotives.

But in spite of all its merits and advantages, the electric can still not displace the steam locomotive, the internal combustion locomotive, and the otherlocomotives of the future (steam turbine locomotives, gas-turbine locomotives, etc) -- and apparently never will.

The point is that electric traction is economically justified only on lines, main lines and sections with great density of passenger and freight traffic, and especially where the route profile is difficult. On all other lines the steam and internal combustion locomotives can furnish more economical traction. This is explained by the following reasons.

Electrified railway lines usually take 3-phase current from the high-tension public transmission lines. This energy is transformed (stepped down from high voltage to working voltage) at traction substations located along the electrified lines, and is then converted to DC or single-phase AC (according to the current system in use), and in this form is conducted through the contact system to the electric locomotives.

Such "processing" and "transportation" of energy result in considerably losing energy, and requires the installation of expensive transformer-converter substations, contact wires, etc, with subsequent high expense for their maintenance, repair and servicing.

It is obvious that the limits of the technical-economic advantageousness of electric traction of trains can be extended only by maximum simplification and cost-reduction of the whole complex of stationary installations and equipment, and if possible even elimination of individual elements in it.

The simplest way of solving this problem, for instance, would be given by the electrification of the railroads on the basis of general standard 3-phase current. In this case the traction substations would be nothing but peculiar transformer kiosks set up along the lines. Such a system was adopted in Italy, for example, from the very beginning of electric traction (in 1902). But it was not generally adopted, and apparently has no such prospects for the future. The point is that this system has a number of disadvantages, of which the most substantial are the following: the 3-phase contact system is expensive to build and operate, requiring two contact wires; current collection is unsatisfactory, even at the relatively low voltages in the contact wire that are possible under this system (about 10 kilovolts); and, finally, the injurious influence of traction currents on telegraph and telephone lines and on STsB [presumably automatic block signal system].

The system of electrification with single-phase current of reduced frequency appears more rational than the 3-phase system. If the electrified lines are supplied by special power stations, this system likewise does not require conversion of the energy. Besides this it is possible to increase the voltage in the contact wire even more (to 15 to 22 kilovolts) which in turn allows spacing the traction substations further apart (70 kilometers or more), and at the same time, to reduce the cross-section of the contact wire, as little as to 100 square millimeters for a single-track line. All this as a whole results in considerably reducing the cost of the stationary installations. This system has been adopted in many countries of Europe and America.

This system, however, also has its disadvantages, of which the most substantial is the interference with the unity of the energy system in a country. If it is supplied by the power stations used by the public, with the consequent need for converting the 3-phase current to single-phase at lower frequency, the rate of return on investment in this system drops sharply, so that in most cases it cannot compete with the 3 kilovolt DC system that is widely accepted both in the USSR and abroad.

The system of DC electrification has indisputable merits with respect to economy of energy-conversion and from the tractive-operational viewpoint. But this system, as well, has its faults. The most substantial of them is the need for heavy capital investment in the construction of a large number of traction substations (every 20 kilometers on lines with high density of freight traffic, and even more closely spaced than that) and a heavy contact system (with the cross-section of a feeder line reaching 400 square millimeters and over). The only way of eliminating these faults in the DC system would be to increase, as much as possible, the voltage used at present. Up to now, however, even such a relatively low voltage as 6 kilovolts has still not emerged from the stage of experimentation. The difficulties are primarily in the manufacture of traction motors, auxiliary motors and arc-arresters for this voltage.

Finally, there still is another very effective method of solving this problem. This is by changing over to single-phase current of industrial (normal) frequency. The studies made at one time by a team on transport electrification of the Academy of Sciences USSR established the following approximate relations between the amounts required for capital investment in a single-phase (industrial frequency) system and a DC 3,000 volt and 6,000 volt systems.

If the capital investment for a DC 3000 volt system is taken as 100 percent, then for a 6000 volt DC system it will be 85 percent, and for single-phase current at industrial frequency it will be 75 percent. Use of non-ferrous metals in installation of the 2 latter systems will be 60 percent and 50 percent, respectively, of that for the first.

The following 2 variants of solving the problem of the single-phase industrial-frequency system, both in the USSR and abroad, have been noted:

(a) single-phase electric locomotives with commutator motors;

(b) electric locomotives with rotary converters: single-phase to DC, and single-phase to 3-phase.

The first of theseis undoubtedly of most interest. It allows the electric locomotive to have the simplest design, since no converter unit is required. Besides this, its traction characteristic, like that of the DC electric locomotive, is of the series form, which best meets operating requirements.

But this variant, at least for the present, is also the most difficult for practical realization. The point is that AC commutator motorshave substantial faults, namely: difficult conditions of commutation, due to the so-called transformer voltage (The voltage induced in the sections of the armature windings, supported, at the moment of commutation, by the brushes and interfering with proper commutation, especially at the instant of starting) which is of considerable magnitude, and the low power factor (cos φ) on starting. For this reason the power of each motor must be reduced, in other words, the number of the motors must be increased, and consequently the design of the electric locomotive complicated and its weight increased.

In the USSR, work to develop a single-phase commutator-motor meeting the requirements of train service has been going on since before the war. Thus, at one time, Professor O.B. Benedikt of the MIIT proposed a commutator-motor of special construction, free of the faults inherent in conventional motors of this type. Engineer L.M. Shildiner of the MEI in turn proposed using the conventional commutator-motor, but feeding it during the starting period and until reaching a speed equal to 0.2 of the 1-hour rating with DC from a special auxiliary unit; thus the motor would operate at zero frequency of the input current during the period most difficult with respect to commutation, when the power factor is most unfavorable.

Abroad (in Germany) an improved single-phase commutator-motor, having special built-up brushes and auxiliary commutation windings, has been proposed. The author of the proposal claims that the windings make it possible to increase the transformer sparking voltage and thus to increase the power of the motor. But nothing about the practical utilization of this motor has been published, and apparently it too has not yet emerged from the experimental stage.

A single four-axle experimental single-phase 50-cycle electric locomotive with commutator-motors was built in Germany in 1936, but for reasons which will be taken up later, it did not go into series production.

Using the second variant a single-phase-triphase electric locomotive on the so-called Kando system was built in 1928 in Hungary. The results of the trial operation proved so favorable that it was decided to electrify a 190 kilometer section on this system, and in 1932 this section went into regular operation.

In the USSR, in 1938, the "Dynamo" plant imeni S.M. Kirov completed the construction of an experimental single-phase-DC electron locomotive with mercury-arc rectifier and grid control. During about the same period, two such locomotives were also produced in Germany, together with one single-phase-triphase model on the so-called Punga-Somon system.

It must, however, be borner in mind that the converter electric locomotive is by no means a novelty in locomotive construction. One was built (in Germany) as early as 1904 as an experiment. It was a single-phase-DC model of 650 HP, and equipped with a motor-generator converter, but it was a very imperfect, uneconomical and low-efficiency converter engine. In 1911 a more powerful (1,600 HP) electric locomotive on the same principle, of more improved design, was built (in France). This was of type 2-B_0 + B_0 -2, with voltage of 12 kilovolts, and frequency of 25 cycles.

Over ten motor-generator single-phase-DC electric locomotives were built in different countries during the years that followed. They ranged from 11 to22 kilovolts, and were 16 2/3 and 25-cycle. There were also a few mercury-arc-rectifier models (one in the United States, which did not give positive results, and the others, which ran, in Europe).

Beginning in 1915 and in the following period, over 50 single-phase-triphase electric locomotives were built (in the United States), with synchronous and asynchronous phase-converters. They ranged from 1,500 to 5,100 HP, weighed 130 to 236 tons, exerted a tractive force of 20,000 to 40,000 kilograms, and operated on a voltage, at the contact wire, of 15 to 22 kilovolts.

The construction of such motor-locomotives and their introduction into service did not, however, solve the problem of increasing the economic yield of electric train traction. Here, as previously, the reduced frequency in the contact systems interfered with the unity of the whole energy system of the country, while costly conversion of the energy was required where the electrified lines were powered by publicly used power stations. Then, too, it involved a considerable complication in the design of the electric locomotive, in comparison to the single-phase, commutator-system, if it was to carry conversion equipment. As a matter of fact, the transition to motor-generator locomotives of these types and designs was dictated only by the effort to adapt the locomotive as well as possible to the specific operating conditions for the given electrified section, or, to put it more simply, to evade the difficulties caused by commutator-motors by replacing them with the more rational DC or triphase motors.

The first practical step toward this transition to the more rational single-phase system at normal or industrial frequencies was taken by us, in the USSR, and in a few other countries (Hungary, Germany) by the construction of the experimental locomotives we have already mentioned.

Three such locomotives are described below: the mercury-arc-rectifier electric locomotive, built in the USSR, and the commutator-motor locomotive and the phase-converter locomotive built in Germany.

50-CYCLE-SINGLE-PHASE DC ELECTRIC LOCOMOTIVE (USSR)

The trucks and the type DPE-340 traction motors of the series SM electric locomotive were used without modification in constructing this experimental locomotive, of which Figure 130 gives a general view. As will be seen from this photograph, the body is of special design, to permit installation of the rather bulky and complicated equipment.

Figure 130. General view of 50/cycle single-phase DC mercury-arc rectifier locomotive.

[Photo]

The principal equipment consists of:

two trolleys with bracket insulators;

oil switch;

transformer unit, main and auxiliary, enclosed in a common tank;

12-anode rectifier of usual PB-20 type used at traction substations;

smoothing choke;

six DC traction motors.

The auxiliary equipment consists of:

split-phase converter;

motor compressor;

two motor-driven fans for cooling the motors;

radiator installation with motor-driven fans to cool the water in the mercury-arc rectifier circulating and cooling system;

other apparatus and driving controls.

Figure 131 is a skeleton diagram of the locomotive installation.

The mercury-arc rectifier 6 (see diagram) has 12 anodes, arranged in three groups: two phase-groups of 5 anodes each and one null-phase group of two anodes to help increase the power factor (cos φ) during the starting period. The load is uniformly distributed among the anodes, operating in parallel, by the three anode reactors 5. In view of the strong pulsation in the rectified voltage due to the input of single-phase current into the mercury-arc rectifier (which pulsation creates unfavorable conditions for the communication of the traction motors), the special so-called smoothing choke 13 is provided. The excitation windings of the motor arc shunted, for the same purpose, by the ohmic resistance 8.

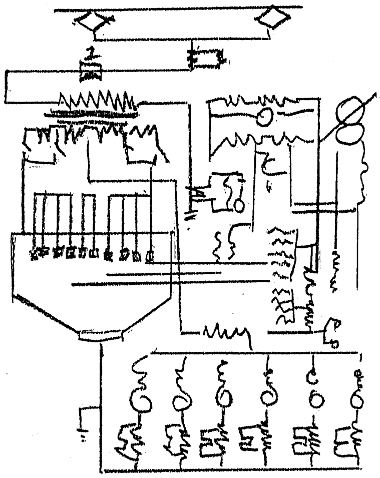


FIGURE 131

Skeleton diagram of circuits of power equipment of mercury-arc rectifier electric locomotive.

The starting of the locomotive proceeds in two stages. In the first stage, of travel, the output leads from the secondary winding of the transformer deliver only 750 V, or half of the usual voltage, to the mercury-arc rectifier. In the second stage, the full voltage is supplied by the outer leads of this winding. The switch 4 switches over the transformer leads. But only coarse regulation of the voltage, and consequently also of the locomotive speed, is effected by this switching. The smooth variation of the voltage (and locomotive speed) is handled, within the limits of each stage, by what is termed grid regulation, which consists essentially of the following.

Each anode of the rectifier has a grid which is electrically connected to the special, so-called grid-generator 15. Thus the grid is continuously kept under a negative voltage (potential). The value of this potential is entirely adequate to prevent passage of the rectified current from anode to cathode, or, as they say, to "block" the anode.

The alternating voltage delivered from the phase-regulator 21 is in turn superimposed on the negative grid potential. This voltage passes through the so-called peak transformer (a strongly saturated transformer) and is there converted into periodic pulses of positive potential against the grid. Thus at certain instants the positive potential neutralizes the negative grid-potential and "unblocks" the anode, or in other words creates the proper conditions for igniting the rectifier anodes. These instants, or, as they are called, the ignition phases, depend on the position of the phase regulator.

By using the controller handle to change the position of the phase regulator, the operator can lengthen or shorten the time during which any particular group of anodes is lit, from the instant of ignition to the end of the half-cycle, and can therefore smoothly increase or decrease the voltage applied to the motors, from zero up to the maximum. It will be readily understood that grid regulation does away with the need for a starting rheostat, and thus eliminates the starting losses that are inevitable when one is used.

The sharp jars on transition from one stage to another (for instance from I to II, when the rectifier passes over from the intermediate leads to the outer leads, are also entirely eliminated by grid regulation. In this case the voltage at the motor terminals remains unchanged at 750 V, since an alternating voltage, displaced to the middle of the half-period, will be applied to the grid; i.e.) the regulation angle of 90° will be established. By gradually turning the handle of the phase-regulator controller around to 180°, the operator thereby prolongs the burning-time of the anodes, or in other words increases to the maximum of 1500 V the voltage applied to the motors.

The grid likewise has the function of protecting the power circuit from short circuits and overloads. Its protective action in short circuits operates as follows.

Under the action of a heavy current, the power-coil of the rapid-acting relay 14, which is connected in the general circuit of the traction motors, begins to demagnetize the current created by the holding coil as a result of which the relay is actuated and the contact 23 in the phase-regulator circuit is opened. In consequence the delivery of positive peaks to the grids of the phase anodes is interrupted, thus also causing the blocking potential of the grid to interrupt the burning of the arcs in the mercury-arc rectifier.

Overloads of the traction motors actuate the overload relays 9 which are in series with each motor, thus opening the circuit of the holding coil of the rapid-acting relay 14, which finally leads, as in the case of short circuits, to the blocking of the anodes of the mercury-arc rectifier.

Three rapid-acting grid-relays, the primary 17, the intermediate 19 and the secondary 20, protect the mercury-arc rectifier from backflashing. (OBRATNOYE ZAZHIGANIYE, formation of a cathode spot on one of the anodes, causing the anodes to short circuit and current to pass from the cathode to the damaged anode). The primary relay is connected with the transformer current of the primary winding of the main transformer through the neon lamp 18, the ignition threshold of which provides a reliable accuracy for the grid protection. Its protective action proceeds as follows.

When a flashback occurs, the primary relay 17 is actuated and its contacts shunted through the intermediate and secondary relays across a part of the resistance of the potentiometer 16 of the grid generator 15. In consequence the voltage distribution becomes such that the value of the negative (blocking) potential on the grids cancels out the positive peaks delivered by the phase-regulator, and the mercury-arc rectifier is blocked. After the secondary relay has been actuated, its contacts short circuit the primary windings of the peak-transformers, thus interrupting the delivery of the positive peaks to the grids of the phase anodes, thus still more intensifying the de-ionizing action of the grids. Simultaneously with the primary and secondary relay, the intermediate relay is also actuated and through its contacts closes the circuit of the solenoid contact-breaker of the oil-switch. As a result, the latter is also switched off after a certain time has passed.

If the primary winding of the main or auxiliary transformer should ground, the oil switch is thrown by the maximum-relay 24. The latter is fed by the transformer current that, at first, is in the high-voltage circuit of the electric locomotive.

The auxiliary transformer is used to feed the motors that drive the auxiliary equipment (compressors, blowers, pumps, etc.). In view of the difficulty of manufacturing single-phase motors of normal frequency, triphase asynchronous motors fed by split-phase converters, drive this equipment.

The split-phase converter is a synchronous machine with two stator windings, separated by a phase angle of 90°. One of these is called the motor winding and is connected on 220 V to the auxiliary transformer, producing a pulsating current of which the inverse (opposite) component is quenched by the damping coil of the revolving rotor. The other, or generator, winding, is connected at one end to the intermediate lead of the motor winding, while the rotative field, i. e. the synchronous component of the pulsating current, induces in that generator winding an E.M.E. that leads the voltage in the motor winding by 90°. Appropriate choice of the coils in the generator winding and in the two parts of the motor winding, produces the result that the end leads of the motor winding form a symmetric system with the second lead of the generator winding only under normally connected load (blowers and pumps).

The starting torque for the split-hase converter is obtained by connecting it with the motor winding through a choke coil, and with the generator winding through an ohmicresistance. At the same time, to accelerate starting, the split-phase converter is turned by the control generator, which is mounted on the same shaft, with the generator operated as a motor by a storage battery. All this combined method of starting the split-phase converter, as well as its transition, and that of the control generator, to the normal regime of operation, is effected by completely automatic means after the proper button is pressed.

The auxiliary transformer likewise feeds the primary windings of the transformer for excitation, and supplies current for igniting the mercury-arc rectifiers and the mercury pumps.

All the instruments that indicate current, voltage and power in the high-voltage circuit and the tractor motors, the condition of the vacuum in the mercury-arc rectifier, etc., are mounted on panels in the cab.

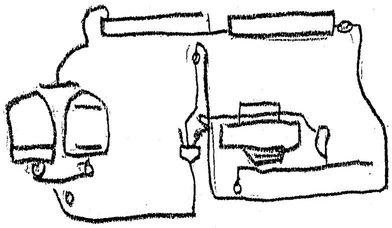


FIGURE 132

Simplified diagrams of air-water cooling system for mercury-arc rectifier electric locomotive.

The mercury-arc rectifier is cooled by the help of a closed air-cooling circulation system, of which a simplified diagram is shown by Figure 132. This system acts in the following way:

The water heated in the jacket of the mercury-arc rectifier 6 is delivered by the centrifugal pumps 1 and 2 to the radiator system 3, through which air is blown by a fan. The water then returns to the rectifier. The thermo-regulating valve 4, which automatically intensifies or diminishes the delivery of water, keeps the temperature of the body of the rectifier constant. To give the system overload capacity, its thermal capacity may be artificially increased by incorporating the reserve water-tanks 5. The mercury pump of the rectifier is cooled by a special system using a small compressor cooling plant of 700 kcal/hour capacity.

The total power of the auxiliary machines is 100 KVA. the breakdown capacity of the oil switch is 100,000 KVA.

The principal proportions of the locomotive are as follows:

Wheel formula	0-3+3-0
Total and adhesive weight	132 tons
Axle load	22 tons
Wheel diameter	1,220 mm
One-hour power	1,884 KW
Other-hour tractive effort	19,200 kg
Maximum speed	85 kg/hour

Plant tests showed satisfactory operation of all main and auxiliary equipment. Subsequent tests on the test track of the MPS, however, disclosed a number of faults, especially in the cooling

Photograph

FIGURE 133

General view of single-phase 50-cycle electric locomotive with commutator motor.

of the mercury-arc rectifier, back-flashing, etc. Work to eliminate these defects is still under way at present.

50-CYCLE SINGLE-PHASE B_0 - B_0 ELECTRIC LOCOMOTIVE WITH COMMUTATOR MOTORS (GERMANY)

(Built in 1936)

This electric locomotive was designed for use on the Hollenthal Railway, which has an exceptionally difficult profile~~s~~ (curves of radius down to 240 m and grades as steep as 5.5%), and its design has much in common with that of the German single-phase electric locomotives running on reduced frequency (16 2/8 cycles). Figure 133 is a general view of it.

Each axle of both two-axle trucks is driven by two commutator-motors, arranged, as will be seen from Figure 134, on both sides of a pair of drivers.

At 1540 r/p.m. (corresponding to 70% of maximum locomotive speed), current strength 1450 A, voltage 214 V and power factor 0.95, the motor develops a one-hour power of 246 KW and a continuous power (at the same r/p.m.) of 227 KW.

Photograph

FIGURE 134

Wheel axle with two motors

Figure 135 is a graph of the power developed by all motors of the locomotive, as a function of locomotive speed.

As has already been pointed out at the appropriate place, the fundamental difficulty in using 50-cycle single-phase commutator-motors for locomotive traction is the existence of a high transformer voltage. Their frequency is three times that of reduced-frequency (16.66 cycles) motors.

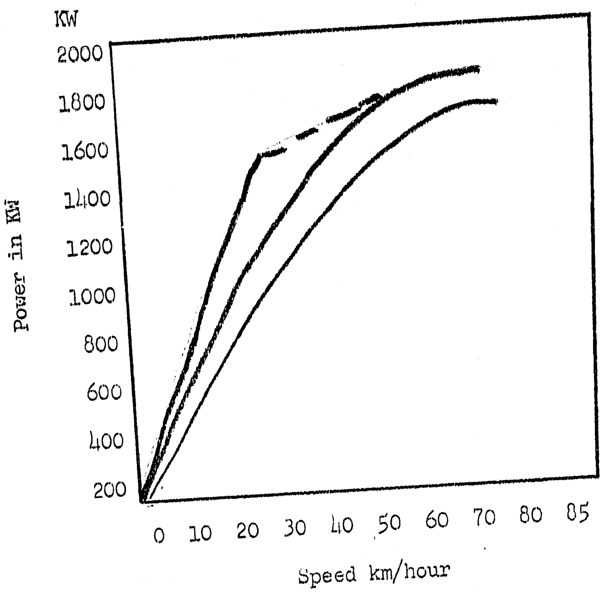


FIGURE 135

Power diagram for 50-cycle single-phase electric locomotive.

1. power at starting and getting under way; 2. one-hour power; 3. continuous power; 4. load limit: a. 225 V (maximum voltage under load, at 20 KV in contact feeder; b. 240 V (900% of maximum idling voltage).

To assure the same sparking conditions (on the commutator segments) at starting, the magnetic flux of the main poles of a 50-cycle motor must be reduced to about a third of its usual value. This requires increasing the number of poles and substantially reducing the voltage at the motor terminals. In turn this reduction of the voltage results in increasing current strength, but this requires lengthening the commutator. As a result both weight and dimensions of the motor are considerably increased.

All these considerations, taken together, made it necessary to distribute the planned power over eight 14-pole motors, with successive inclusion of two motors in each group.

The following Table 10 gives a few comparative figures for two motors: 14-pole 50 cycle motor, and the 8-pole 16.66 cycle series produced motor employed on the German Railways.

TABLE 10

Indices	14-pole 50-cyle motor	8-pole 16.66-cycle motor
Continuous power rating in KW	227	425
R.p.m. (corresponding to 70% of maximum speed)	1540	1280
Power per pole, in KW	16.2	53.1
Weight with gear drive and protective casing in kg	2800	4430

It is clear from this data that the aggregate weight of the eight motors for the 50-cycle single-phase electric locomotive is more than 20% higher than that of the four motors of almost equivalent total power for the 16.66-cycle model.

The torque is transmitted from the shaft of each motor to the corresponding driving axle by means of a small gear-wheel attached to the motor shaft, and a large gear-wheel stamped into the elongated hub of the driving wheel. The large wheel has 88 teeth and is engaged with two smaller wheels, each with 15 teeth. Thus the transmission ratio is 5.87. The protective casing for the gear-wheels is welded of sheet steel.

In case of accident or damage to one of the two motors, there is a device for rapidly and easily disengaging the motor from the large gear-wheel.

Two blowers cool the motors -- one for each four. Each motor is also provided with its own blower on the side of the commutator.

Single-phase 50-cycle current at 20 KV is conducted from the contact wire through two trolley-pantographs and the main switch to the main transformer. A metering voltage transformer, installed in the roof of the locomotive body, has a step-down factor of 20,000/200 V. Voltmeters in both the cabs are connected to the transformer secondary.

An expansion switch of series model, which is successfully employed on the German E 44 electric locomotives, is used as the main switch.

The main transformer is oil-cooled. Figure 137 gives a general view of it. Its purpose is to step down the voltage from the outside feeder to a value suitable for feeding the traction motors and auxiliary equipment. The high and low tension transformer windings are switched on successively (auto-transformer scheme) and the middle low-tension winding is grounded. A metering current-transformer is connected across the high and low-tension windings to measure

[See Figure 136 on next page]

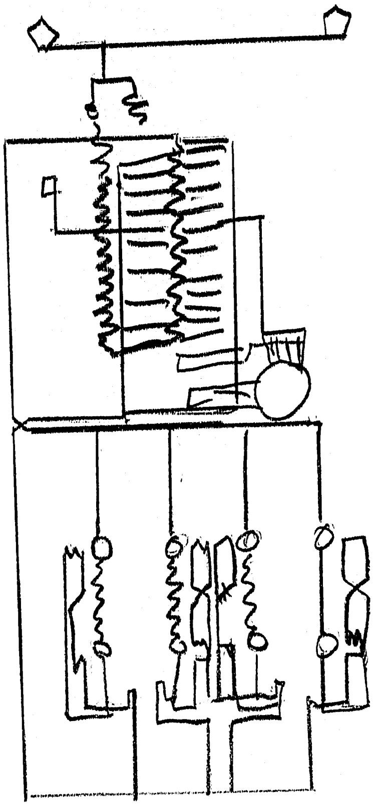


FIGURE 136

Power diagram for 50-cycle single-phase electric locomotive

Simplified electrical circuit diagram of equipment and apparatus on 50-cycle single-phase electric locomotive. a: pantographs; b: circuit-breaker; c: main switch; d: metering voltage transformer; e: main transformer; f: current transformer for metering current of higher harmonics; g: cam switching mechanism; h: auxiliary transformer; i: excitation switch with switching rheostat; k: voltage divider; l: precision regulator; m_1,m_2: traction motors; n: commutating resistances; r: current transformers of motor groups; s: circuit-breaker relay; t: current transformer in ground connection; u: reverser; v: manual circuit-breaker; w: contactor of brake switcher.

the current of the higher harmonics.

The transformer has taps at 90, 126, 162, 198, 234, 270, 306, 342, 378, 414, 450, 486, 522, and 552 V, for feeding the traction motors; at 216 V (with respect to ground) for the auxiliary motors, equipment and control apparatus; 800 and 1000 V for the train heating system, which takes as much as 200 KW in the winter, or about 12% of the total transformer output of 1720 KVA.

The transformer and oil together, without the oil-pumping unit, weigh 4300 kg; with the pumping unit and the auxiliary transformer, the weight is 4900 kg. The oil-cooler, including the oil weighs 510 kg.

These figures show that the 50-cycle transformer is considerably lighter than the 1450 KVA series manufactured 16.66-cycle transformer with which the German E 44 electric locomotives are equipped. The latter transformers, including the oil-pumping unit and the auxiliary transformer, weighs 7370 kg. For the same power, (i.e. 1720 KVA), it would weigh about 8400 kg. It follows that 3500 kg of weight are saved on the transformer.

Photograph

FIGURE 137

Transformer

Thus the increase in the weight of the single-phase electric locomotive of normal frequency on account of the motor is almost entirely compensated by the lightening of its transformer installation.

The voltage conducted to the traction motors, and thereby also the tractive force and the speed of the locomotive, are regulated by the help of a mechanically acting system of precision regulation, which is, in the main, identical with that used on German single-phase reduced-frequency electric locomotives, and includes:

a cam switching mechanism;
an auxiliary transformer;
a precision regulator with voltage divider;
a current-breaker relay and four current-breakers;
a reverser;
a braking switch

The cam switching mechanism consists of 14 stage-cam switches, one exciter switch for the volgate voltage divider, two switches for control current, and three switches for the cooling-system blowers.

All of these switches are actuated by cam-discs attached to the vertical shaft located in the middle of the cam mechanism.

The stationary contacts of the stage-switches are connected to the taps of the main transformer (see circuit diagram of Figure 136), while the movable contacts are connected to the corresponding bus bars.

The bus bars are connected at the ends u v with the current-dividing windings of the auxiliary transformer. The current is conducted from the central tap O of this winding to the four groups of traction motors, connected in parallel.

The auxiliary transformer is air-cooled and mounted on the cover of the main transformer; its flat iron core has a second winding, known as the excitation winding.

The precision regulator consists of a voltage divider with 55 taps (branches) and a stationary collector with a vertical axis, located above the voltage divider.

Photograph

Controller

FIGURE 138

The collector consists of two broad plates, taking up about 86° of a circumference, and two groups of narrow plates (each of 55 plates), placed between the broad plates.

The wide plates are connected to the ends yz of the voltage divider and the narrow plates to the taps of the voltage divider. In turn the voltage divider is connected at its ends yz to the 450 V and 270V (with respect to earth) taps of the main transformer.

A V-shaped yoke is located on bearings in the middle of the collector. Two spindles on opposite sides are attached to the yoke. Each has six holders for the carbon brushes. Both groups of brushes are connected through contact rings with the ends of the winding v'u' of the auxiliary transformer.

The controller, of which a general view is given by Figure 138, has a large vertical hand wheel, by the help which the cam switching mechanism and the yoke with the brushes are actuated through the distribution shaft, a driving chain, and a gear transmission. Besides this, each controller also has a guide shaft, a braking shaft, a cut-out button and a stage-indicator.

The circuit-breaker relay serves to switch the traction motors on and off (in case of need), and is actuated by a special pneumatic relay.

The reverser allows the direction of the current in the excitation windings of the tractor motors to be changed, thereby changing the direction of locomotive travel. Turning the handle of the reverser switches over four contacts in the excitation circuits of the traction motors. A cylinder of compressed air with two electrically controlled valves is provided for actuating the reverser.

The braking switch serves to switch the traction motors over from the working (traction) regime to that of braking and is likewise actuated pneumatically.

The precise regulation of the voltage delivered to the motors is affected automatically while the operator is turning the hand-wheel of the controller by 180°, i. e. while he is shifting from one position to another. During this period, firstly, the stage-switch in the motor circuit of the lower tap of the main transformer is opened, and it then makes contact with the following tap with higher voltage. Secondly, the yoke of the precision regulator makes a full turn and its carbon brushes successively make contact with the collector plates, thus gradually leading out the resistance of the voltage divider. As a result, the voltage at the terminals of the excitation windings of the auxiliary transformer is gradually increased, causing a smooth voltage rise of 36 V at the terminals of the traction motors (during each turn of the controller wheel).

Contact is each time made and broken at the corresponding stage switches at the instant when the carbon brushes slide over the broad plates of the collector. At the final (14th) speed stage, the voltage at the terminals of the motor groups is 540 V (at 20 KV in the contact conductor, and idling).

When the controller wheel is turned in the opposite direction, the stage-switches break and make contact in the reverse sequence.

This mechanism and the method of regulation with it assure a gradual growth or decline in the tractive force and locomotive speed, with no jars or shocks whatever.

The traction motors may be cut out rapidly (when necessary) by the circuit-breaker relays in the circuits of the corresponding motor-groups. The relays are actuated by pressing a special cut-out button on the controller.

The traction motors are protected from overload by maximum-current relays connected with the metering transformers of the respective groups of traction motors. When a relay is actuated, the corresponding circuit-breaker relay is excited and the group of motors involved is shut off.

The precision regulator is protected against overloads by a maximum-current relay in the circuit of the voltage-divider. Actuation of the relay excites the windings of a remote circuit-breaker, and the main circuit-breaker is opened in consequence.

The main circuit-breaker is also opened when short-circuits to earth take place. In this case a maximum-current relay connected to the secondary of the metering current-transformer is actuated. This transformer is on the circuit of the low-tension earth winding of the main transformer.

Besides pneumatic brakes, the locomotive also has a mechanism e for electrical braking, quenching the braking energy in the rheostats. The latter are made from constantan [nickel-copper alloy] poles located in a tank on the roof of the locomotive body.

The electric braking effort is calculated on the basis only of the locomotive weight, which amounts to 84850 kg, and accordingly this effort is limited to 4300 kg at the driver rim.

A special braking system, is employed to reduce the weight of the braking mechanisms and equipment. It consists essentially in the use of a small 25 W, 52 ampere-hours storage battery, 3-hour discharge, to excite the first group of motors (m_1 and m_2) on transition of the locomotive to the braking regime. In turn the motors m_1 and m_2, operating as generators, and developing the corresponding values for braking effort, at the same time also supply the required power to excite the remaining three groups of motors.

The strength of the current thus generated by the motors, and, accordingly, the regulation of the braking effort, is in stages. It is effected by varying (reducing or increasing) the resistance of the rheostats in the excitation circuit of the first pair of motors, and also in that of the other three groups of motors.

The transition to electric braking is effected very simply. The operator leaves the reverser in the position "Forward", and places the hand controller wheel in the zero position, then moves the lever of the braking shaft into the position "First Stage". As a result the proper switching of the switching circuit is automatically effected by the help of pneumatic valves, relays and switches.

On the first stage of braking about two-thirds of the resistance still remains in the storage-battery circuit and a considerable part of the battery voltage is lost in the rheostat. Consequently the strength of the excitation current in the windings of the first pair of traction motors will be relatively small. It will be readily understood that under these conditions the exitation of the remaining motors will also be relatively weak, and consequently the total braking current, or in other words the braking effort, will be insignificant.

When the braking lever is then turned to the second and third stages, and so on, the resistance in the excitation circuit of the first pair of motors will gradually fall, and the excitation of all motors gradually rise. As a result the braking current (braking effort) will increase.

The allowable maximum strength of the braking current is inindicated by the pointers of the ammeters in both the cabs reaching the "red line".

To prevent excessive braking when both pneumatic and electrical systems are operating at once, two circuit-breakers are provided, one for each braking cylinder.

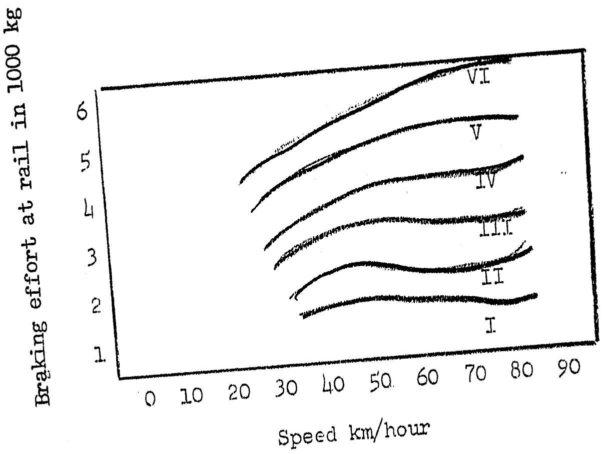


FIGURE 139

Diagram of braking effort

When the pressure in the cylinder exceeds 2 atm., the corresponding circuit-breaker is actuated, interrupting the current in the storage-battery excitation circuit. The system is then automatically switched over from the braking to the traction regime of motor operation. After this occurs, renewed braking is only possible when the braking lever has been placed in the "zero position".

Figure 139 gives the curves of braking effort for electric braking on all six stages as a function of locomotive speed. It will be seen from the diagram that the braking effort is approximately uniform throughout the entire speed range.

The entire assembly of auxiliary equipment and apparatus on this electric locomotive consists of:

Two centrifugal fans for cooling the traction motors; they have a capacity of 5.7 cubic m/second of air under a pressure of 165 mm of water. Each fan is driven by a single-phase series motor with a continuous power rating of 20 KW, 145 V, 50 cycles, 2,000 r/p.m. One of these motors is also used to drive a fan (with a capacity of 2 cubic m/second of air at a pressure of 55 mm of water) for cooling the main transformer.

Two fans with capacity of 4 cubic m/second of air at a pressure of 40 mm of water; both of which are driven by a single 13 KW, 200 V, 2000 r.p.m. D. C. motor. The operation of the fans, their circuit scheme, as well as their switching order is determined by whether the locomotive is on traction or braking, and by whether it is summer or winter.

An oil-pumping unit to circulate the oil in the transformer. It consists of a centrifugal pump and a single-phase condenser motor with continuous power rating of 2.4 KW at 220 volts, 50 cycles, 2,000 r/p.m. Pump capacity is 500 liters per minute. Its motor is automatically turned on as soon as load is applied to the main transformer. The transformer oil is cooled by an air cooling system rated to carry off 47,000 kcal. of heat per hour.

A two-stage compressor delivering 100 cubic m/hour of compressed air at 8 atm. pressure, running at 329 r/p/m/, with 760 mm pressure and 0° temperature of the outside air. The pump is driven through a geared transmission by a 12 KW repulsion motor operating at 220 volts, 50 cycles, and 1500 r/p.m., which is turned on and off automatically according to the pressure in the main air reservoir.

A cuprous-oxide rectifier to rectify single-phase current to 24-volt D. C. for feeding the lighting system, control apparatus and the storage-battery charger.

Each cab has two 1.6 KW electric stoves.

The electric heating system of the train is supplied by the 800-volt and 1000-volt taps of the transformer through interlocked electromagnetic relays. The electric heating system is protected from short-circuits by special maximum-current relays which when actuated excite a remote circuit-breaker of the main switch and disconnect it.

Figure 140 shows the arrangement on the locomotive of the entire assembly of power equipment, apparatus and mechanisms.

As far as can be judged from the information published at the time in the German technical press, all the claims of the designer, both with respect to operating indices and to reliability in the work of all equipment and apparatus, were on the whole justified by the one-year trial operation of the locomotive, thus confirming its suitability for the operating conditions involved.

Nevertheless the management of the German State Railways avoided making a final decision on the series production of this locomotive, considering such a decision to be possible only after protracted operation and also after detailed dynamometer-car study of the operating characteristics (of this and of other experimental electric locomotives of normal frequency) with the dynamometer car especially built for this purpose in 1937.

Although in the interests of maximum simplicity we have omitted all of the details and fine points from the above description, it is still not difficult to note the very considerable complexity in the design of this locomotive, which is a substantial disadvantage for such a machine as a locomotive. If we approach the task of appraising this locomotive from this point of view, the conclusion may

[See Figure 140 on next page]

be drawn that the problem of creating a single-phase, normal-frequency electric locomotive that satisfies all contemporary operating requirements is still far from complete solution.

SINGLE-PHASE-TRIPHASE 50-CYCLE ELECTRIC LOCOMOTIVE (GERMANY)

The original design and the peculiarity of the tractive-operating qualities of this single-phase-triphase electric locomotive are primarily due to the Punga-Schon traction motors installed on it. It is therefore necessary to acquaint oneself first with the principle of the construction and operation of these motors so that the following description of this locomotive, which must necessarily be very brief, may be more easily understood. The Punga-Schon motor is a normal induction non-commutator single-phase compensated machine, with very much expanded space between the iron. In this space, beside the ordinary rotor, there is also a supplementary, so called intermediate rotor. This is mounted freely on the common

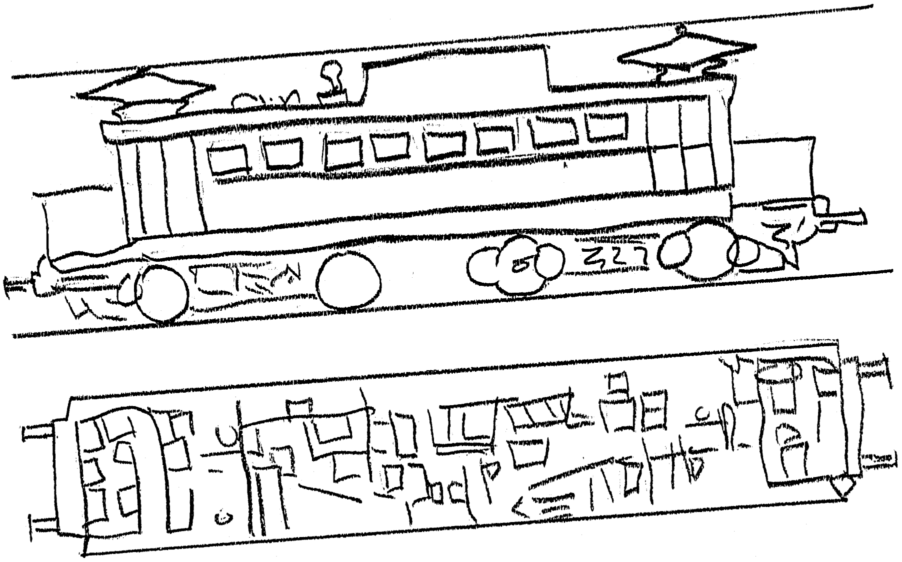


FIGURE 140

Arrangement of equipment and mechanism on electric locomotive

a. traction motors; b. pantographs; c. high-voltage voltage-metering transformer; d. main switch; e. transformer; f. cam switching mechanism; g. precision regulator; h. controller; j. compressor; m. commutating resistance; n. regulating braking valve; o. engineman's braking cock; p. carcass of back distribution board; q. carcass of middle distribution board; r. blower to cool motor; s. blower to cool transformer; t. oil cooler; u. braking switch; v. carcass of front distribution board; w. air reservoir; x. instrument bracket; y. storage battery.

shaft and is able to rotate independently of the main rotor, and its windings receive their excitation through contact feed rings from the D. C. source. The stator of the motor has a single-phase winding, which receives its input of single-phase current at 825 volts from the output leads of the secondary windings of the transformer; and it also has a starting winding. The main rotor, which is rigidly mounted on the shaft, has a triphase winding which is connected through contact rings with a starting rheostat. The principle of operation of the motor is as follows.

The single-phase voltage conducted to the terminals of the stator creates a pulsating alternating field which is immobile in space, and may be regarded as the resultant of 2 magnetic fields rotating with the same speed, but in opposite directions. If the intermediate rotor turns, if at a certain position of the reverser (that is, at the given direction of locomotive travel), the rotation of the intermediate rotor is synchronous with the rotation of these magnetic fields, then the number of its revolutions per minute will be double with respect to the magnetic field that is rotating in the opposite direction, or, as it is called, the inverse magnetic field. If at this time the winding of the intermediate rotor is shortened, then currents twice the frequency (in comparison with that of the network) will be induced in it by the inverse field. These currents in turn will create a magnetic field of opposite direction to the inverse field, and will consequently be completely annihilated in practice. As a result, in spite of the single-phase input into the stator, the magnetic field will act on the main (working) rotor as a purely rotational field, and will consequently induce a tri-phase voltage in its tri-phase winding, just as though the stator were receiving a tri-phase input.

Thus the Punga - Schon motor is at the same time also a peculiar kind of phase-converter.

In addition to this, if the winding of the intermediate rotor, rotating synchronously with the working field, is excited by D. C., then this rotor will begin to perform the function of the inductor of a synchronous motor: at the proper strength of the excitation current, it will sustain a linear current in phase with the voltage, i.e., cos will be equal to unity; in case of under-excitation, this current will lag behind the voltage, but if over-excited, it will lead the voltage.

This property of the motor is of exceedingly great practical importance.

In the first place, the fundamental fault of the commutator motor is thus eliminated - the low power factor at starting, and the resulting voltage drop at its terminals.

In the second place, the proper regulation of the strength of the excitation current can not only keep the power factor (cos φ) at unity, but may even achieve conditions under which this value may become negative, or in other words the voltage at the terminals of the motor will actually increase with increasing load. As a result, in contrast to electric locomotives operated by DC or triphase current, an electric locomotive with the Punga-Schon motor is not sensitive to fluctuations of voltage in the conductor.

In the third place the regulations of the strength of the excitation currents of the intermediate rotor makes it possible to compensate the inductive voltage drop in the motor, and thus to obtain the maximum torque under all load conditions, while this torque is limited, in the normal tri-phase motor, each time that the voltage drops at its terminals.

It is of course true that under very great-over loads the torque of a Punga-Schon motor is also limited, as the result of the ohmic drop in voltage and the resultant weakening in the magnetic field. But this is of no practical importance since the motor can never be subjected to so great an overload, if only because it would exceed the limits of adhesion between the locomotive wheels and the rails, and the wheels would begin to slip. It is thus clear that all danger from over-load to the mechanical and electrical part of the motor is thereby eliminated.

The single-phase Punga-Schon motor, as an induction motor, has a shunt characteristic, and, according to the number of its poles, has one single most economical running speed. Moreover at rotative speeds slower than synchronous, the machine functions as a motor, while at speeds higher than synchronous it works as a generator, while in the latter case the current delivered to the network, owing to the automatic regulation of the strength of the excitation current, will be purely active, i.e., cos φ is equal to unity. The transition of the machine from the motor to the generator regime and vice versa is thus entirely automatic, without any participation of the operator, and without the use of any supplementary devices or apparatus. When for instance, the train begins to travel on a downgrade, or the operator changes over from a higher speed to a lower speed, for instance on arrival at a station, the engines automatically begin to operate as generators and perform regenerative braking, and when the train begins to move on a level track again, at equilibrium speed, or with acceleration, the machine again passes over to the motor regime.

Finally, the motors of this system may be operated either in parallel or in cascade with other such motors or with ordinary tri-phase motors. In the locomotive in question, each of the four axles is driven by one pair of motors, consisting of one single phase and one tri-phase (Figure 141).

The practical meaning of such a combination of motors is that it makes it possible to utilize the undoubled operating merits of the tri-phase motor while at the same time preserving the single phase system of railroad electrification, and, together with this eliminates the most vulnerable place in the power plant plant of the single phase electric locomotive, namely the commutator.

The use of the Punga-Shon motor likewise solves, rather simply and reliably, the problem of short circuits, the prevention of which is practically impossible under ordinary operating conditions. By means of the appropriate choice of the values for the magnetic resistance in the main circuit and the leak of the circuit of the intermediate rotor, the short-circuit current may be limited to 2 to 2.5 times the value of the maximum hourly current. It is likewise possible ~~to~~ connect a choke coil to limit the short-circuit current from the contact conductor to 3 to 5 times the normal value.

Let us now consider the principle of operation and construction of this electric locomotive.

A 2000 V single-phase current from the contact system enters the primary winding of the transformer on the locomotive through the trolley (see the simplified circuit diagram of one of the motor groups in Figure 142). The current from the secondary winding at 825 V is conducted through the k,v,u, cam switching mechanism) to the stator windings of the non-commutator traction motors. The k, v,u, assures the proper switching of the 4 motor groups from one stage of speed to another. The smooth regulation of the voltage

[See Figure 142 on next page]

at the motor terminals during starting from rest and getting under way, and also during transmission from one stage of speed to another, is effected by the aid of liquid rheostats (one rheostat for each motor).

The reason why the speed of locomotive travel must be regulated by stages is as follows: The rotative speed of the traction motors, either below or above the synchronous speed, can only be regulated by varying the resistance in the rotor circuit. Since under ordinary operating conditions the speed of the locomotive is often changed from minimum to maximum, this method of regulation will be very uneconomical, and the efficiency in using the rated power of the motor would be badly impaired. It is therefore possible to solve the problem of increasing the economy of locomotive operation to the maximum possible degree by subdividing the maximum speed into a number of economic stages. In the present case, 3 such stages are provided.

On the first stage of locomotive speed, each pair of motors is connected in series, that is, the rotor of a single phase motor is connected with the stator of a tri-phase motor, and both of them yield mechanical power.

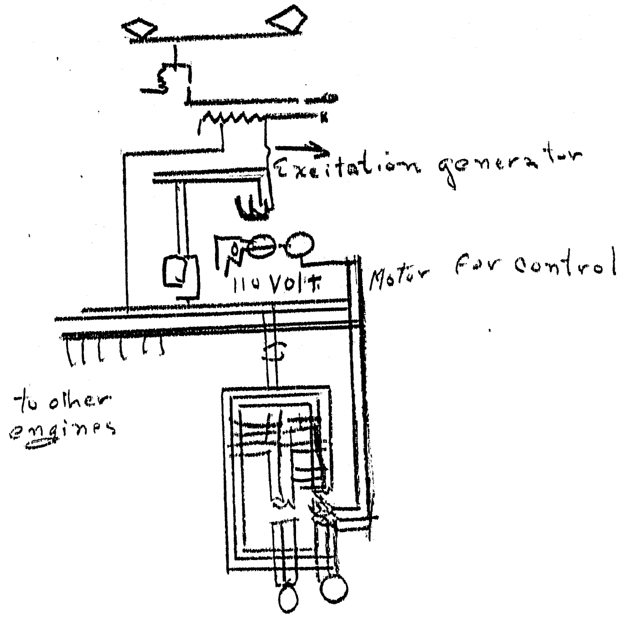


FIGURE 142

Circuit diagram of one of the motors of 50-cycle single-phase-triphase electric locomotive.

a. pantograph; b. circuit-breaker; c. high-voltage metering transformer; d. main switch; e. transformer; f. current-metering transformer on high voltage side; g. control switch; h. converter-exciter; i. current-metering transformer for motor circuit; k. circuit-breaker for motor circuit; l. starting and protective resistance; m. single-phase motor; n. cam switching mechanism; p. triphase motor; r. triphase liquid rheostat; s. single-phase liquid rheostat; A to E cam switch of switching apparatus; 1. main relay; 2,3 starting and idling relays; 4 triphase relay; 5 exciter relay; 6. rotary-converter relay.

In the second stage, ~~the~~ only the single-phase motors develop torque while the tri-phase motors idle.

On the third stage, the mechanical power is furnished only by the three-phase motors, which are connected in parallel with the stators of the single-phase motors, and these latter operate as split-phase converters, delivering the third phase to the tri-phase motors.

The attainment of three economical speeds when a single-phase compensated motor is paired with a normal tri-phase motor is accomplished without difficulty. It is enough to select motors with different numbers of holes, in the instant case the former has 6 holes and the latter has 4.

In cases where the operating conditions require a still larger number of stages, this can also be easily accomplished by using tri-phase motors with switched poles which makes it possible to connect them in series and as split-phase converters. The synchronous speed of the electric locomotive for the third stage, with a 50% wear on the tires, was selected as 83.3 km/hour. At this stage, only the tri-phase motors operate, as has already been said above. The synchronous rotative speed of these motors corresponding to the number of holes is 1500/r.p.m. Thence the transmission ratio from the motor shafts to the driving axles worked out at 4.07:1.

On the second stage of speed, only the single-phase motors operate. These have 6 holes each. If the same transmission ratio is used as with the tri-phase motors, the synchronous speed for this stage would be 55.5 km/hour. For purely operating reasons, this speed was held insufficient, and it was decided to increase it to 60 km/hour, which was easily done by selecting another transmission ratio, namely 3.8:1, is accordance with which the synchornous speed worked out at 59.4 km/hour.

The synchronous speed of the first stage was determined by the number of poles of the single-phase and tri-phase motors and the transmission ratio selected. In the instant case it corresponds to34.7 km/hour.

The locomotive speeds established under operating conditions with the tractive or braking efforts developed by the locomotive (for a given value of the load, i.e. of the train weight) determine the degree of deviation of the rotative speed of the motor (r,p,m,) from the synchronous speed of the stage in question. In this locomotive, the resistance in the rotor circuit of the motor is so calculated that the actual speed under a 1-hour constant load deviates about 4% from the synchronous speed.

Figure 143 presents a diagram which graphically illustrates the operating qualities of this locomotive. The curves of the power returned to the network as a result of the operation of the motors under the generator regime, are characteristic in this diagram. These curves (which run below the axes of abscissae) show that, at locomotive speeds above the first stage, the electric locomotive is equally good for hauling a train and for braking it. In other words, the electric locomotive is able to decelerate or to brake

[See Figure 143 on next page]

on a downgrade, by purely electrical braking, a train of the same weight that it can start from rest, accelerate, and bring up to the proper speed. This locomotive hauled a train weighing 200 tons over

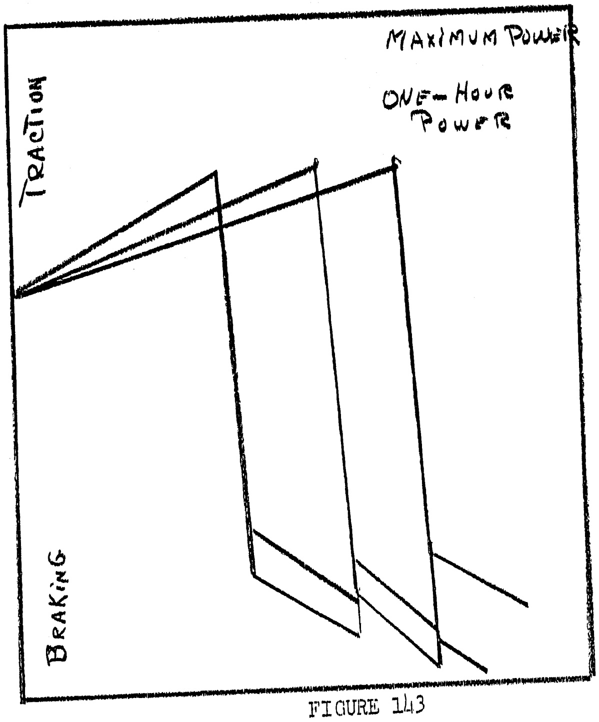


FIGURE 143

Power characteristic curves for single-phase and tri-phase 50-cycle electric locomotive.

the Hollental Railroad and developed a braking effort, measured at the wheel-rim, of over 14,000 kg on a 5.5% downgrade, 7 km long, at speeds not exceeding 35 km/hour. The power returned to the conductor system during this process of braking amounted to 1,100 KW.

TABLE 11

Stage	Power developed			
	1-hour		continuous	
	KW	at speed in km/hr	KW	at speed in km/hr
1	1840	33.2	1760	33.2
2	2120	57	1960	57.3
3	2020	80	1920	80.2

TABLE 12

Stage	At speeds from -- to -- km/hour	Tractive force in kg		
		starting	1-hour	continuous
1	0-34	25000	19500	18600
2	34-57	19000	13100	12100
3	57-80	14000	8900	8500

It is clear from the tables that the locomotive disposes of a reserve tractive force, until maximum speed of the third stage is attained, which reserve is available to accelerate the speed of the train.

The longitudinal section and plan presented in Figure 144 gives a general idea of this electric locomotive, its principal proportions, equipment and arrangement.

Without going into any details, we shall here give only ~~a~~ very brief data on the most essential elements of this equipment.

The transformer is of core type, with vertically arranged cores. The high-tension winding has two taps, a ground tap and a 20-KV tap. The secondary winding has three taps: 220 V for feeding the auxiliary motors, 825 V for the traction motors and train heating system, and 1,000 V for the second stage of the heating. The transformer is oil-cooled; the oil is circulated by a pump driven by a repulsion motor of 220 V. The continuous power rating of the transformer, with the load of the traction motors, is 1,900 KVA, which corresponds to a current strength on the high tension side of 97.5 A. In winter, 200 KW is left over for heating purposes.

The liquid rheostat is one of the important elements of the locomotive equipment. To simplify the scheme of the circuits, each of the 8 traction motors is provided with its individual rheostat. One of them is shown in Figure 145. It differs from the liquid rheostats used on the Italian tri-phase electric locomotives and also from those of the American and Hungarian split-converter phase electric locomotives, by the fact that, besides the three stationary electrodes, it has also three rotating electrodes.

The rheostats are subdivided into two groups, each placed in a separate chamber. One group serves the four single-phase motors while the other serves the 4 tri-phase motors. Thus each group has 12 stationary and 12 moveable electrodes. The electrodes are of helical form, and the stationary ones are bathed by a 1% water solution of potasium bichromate.

The design of the rheostat and the shape of the electrodes assures a rapid and at the same time smooth process of variation in the circuit resistance, a uniform density of the current on all electrode surfaces as well as its continuity, and, finally, requires a relatively small amount of water -- about 650 liters. The current is conducted through the electrodes by means of flat copper strips, which are able to withstand up to 300,000 startings, as has been shown by experiment.

The DC motors for driving the rheostat are fed by a small generator and are equipped with 2 excitation windings, which are alternately connected in the circuit. When the corresponding side of the hand wheel of the controller is turned around, excitation occurs first in one and then in the other, and as a result the movable electrodes are either "screwed in" or "screwed out", with corresponding increase or reduction of the resistance.

The generator is automatically switched over to feeding the motor drive of one group of rheostats or the other.

[See Figure 144 on next page]

A considerable amount of power is transformed in the liquid rheostats into heat during starting the train from rest and getting under way, and also on shifting from one stage to another, and as a result the current density on the electrode surfaces goes as high as 2 KW per sq. cm. To avoid any possibility of the water boiling and forming steam, the liquid is circulated in the chambers with the aid of suction and force pumps, and is also cooled by Betz type blowers. The air for cooling the water and the transformer

[See Figure 145 following next page]

oil passes through slots in the side of the locomotive, and when it has served its purpose, is exhausted to the outside air through the roof.

FIGURE 144

Longitudinal section and plan of 50-cycle single-phase and tri-phase electric locomotive.

1. pantograph; 2. circuit-breaker; 3. expansion switch; 4. transformer; 5. front carcass of distribution mechanism; 6. back carcass of distribution mechanism; 7. cam switching mechanism; 8. single-phase motor; 9. tri-phase motor; 10. front liquid rheostat; 11. back liquid rheostat; 12. converter-exciter; 13. motor-blower; 14. Betz blower; 15. oil cooler; 16. oil pump; 17. water cooler; 18. water reservoir; 19. suction pump; 20. pressure pump; 21. switching valve; 22. compressor with motor drive; 23. main air reservoir; 24. auxiliary air reservoir; 25. device for equalizing load on axles; 26. storage battery.

Photograph

FIGURE 145

Liquid rheostat, drive and terminal switch

The k.v.u. (cam switching mechanism) handles all the switching in the power circuits of the connected motor groups when changing over from one stage to another, and accordingly has three contact positions. A 110-V shunt motor is used to drive it. The transition from stage to stage takes 0.8 second. Figure 146 gives a general view of the k.v.u. The motor that drives it is controlled by the master-controller of the main controller, and by the k.v.u. controller. The one-hour current in the tri-phase circuits of the k.v.u. and on the bus bars is only 360 A, which allowed its weight, counting the drive and connecting circuit to be reduced to 605 kg.

The converter-exciter performs an important function in the locomotive installation. It feeds the intermediate rotor and the control circuits with D. C. Its driving motor also serves as an Arno-rotary-converter (split-phase converter) for feeding the auxiliary equipment with tri-phase current, and also for starting the intermediate rotor of each motor and keeping it running, when the hand-wheel of the controller is at the zero position.

[See figure 144
2 pages preceding]

FIGURE 144

(Blown-up copy of small Figure 144, between pages 237 and 238)

The excitation of the intermediate rotor requires, for one-hour power, about 1.9% of the total power developed, or 38 KW. The control generator develops a maximum of 5 KW. The total required power of the motor of the rotatry converter thus amounts to about 50 KW. In its capacity as a split phase-converter, the motors that drive the blowers, pumps (air and water) and the converter-regulator of the tractive force; at starting the intermediate rotor, the split-phase-converter when the auxiliary motors are turned off) delivers the third phase to the four single-phase traction motors.

To improve the qualities of the motor as a split-phase converter, the tri-phase winding of its stator, and also the winding of the rotor, are made with very insignificant ohmic resistance and leakage. The motor accordingly possesses a very inconsiderable starting torque. For this reason it must first be brought up to the predetermined rotative speed before the load can be connected up with it. For this purpose the control generator is used as a starting motor, and is provided with a special starting winding. During the starting period, this generator is operated as an A. C. series motor from the 235 V tap of the transformer secondary, connecting up the starting resistance. The entire starting process and the switchings accompanying it are effected automatically by the corresponding relays.

The controllers are in many ways similar to those employed on 16.66-cycle single-phase electric locomotives. An additional element is the starting lever by which the converter-exciter and the intermediate rotor are started. The starting lever and the handwheel of the controller are so interlocked as to make erroneous switching impossible.

The handle of the reverser is permanetly attached, while the starting lever is detachable, but only when the reverser is in the "middle" position, which again is possible only if the stage-switch is at "zero". After removal of the starting lever, no manipulation of the reverser or the hand wheel are possible.

The locomotive is prepared for duty in the following manner.

After the expansion switch is turned on, the operator places the starting lever in position 1 (to start the converter-exciter) and brings the reverser into position B (forward travel).

When the rotative speed of the converter-exciter has reached its maximum, the control generator gives the required voltage (which is shown by the voltmeter), and simultaneously the pumps and the converter regulator of the tractive force are actuated.

The operator then moves the starting lever into position 2 (starting the intermediate rotor). This actuates the relay corresponding to the control-panel and cab in question and connects the windings of the stators of each of the four single-phase motors in parallel to winding of the stator of the convertor-exciter. The operator convinces himself of the existence of the proper starting current by consulting the four ammeters on the control panel. After 17 seconds have passed, the speed of the intermediate rotor reaches its normal value. The operator makes sure of this by the ammeter pointer, which starts to recede and drops almost to zero.

The operator then moves the starting lever into position 3 (synchronizing), and thereby turns on the excitation relay. After its release, the starting lever is returned by its spring to the normal working position 2, and the locomotive is thus placed in a state of readiness for departure.

The operator then turns the hand-wheel of the controller through 180°. This switches the four single-phase motors over from being fed by the stator of the motor of the converter-exciter to being fed from the 825 V-tap of the transformer secondary. Simultaneously the four tri-phase relays switch on the traction motors in series, as prepared by the k.v.u.; besides this, the starting relay is also excited, and as a result the motor that drives the tri-phase liquid rheostats is switched over to the yoke of the generator-regulator of tractive force. The function of the operator after this is primarily limited to handling the liquid rheostats, for all other operations are performed automatically.

The operating qualities of this locomotive from the point of view of economy of operation are graphically shown by Table 13.

The data presented were obtained from hauling test trains on different sections of the Hollental Railway, which is characterized by a very difficult track profile (grades up to 5.5%). They show that losses in regulation (rheostat losses) exceed (and at that only very slightly) the power gains from regenerative braking only for the trains weighing 1,000 tons, while for the other two cases the amount of regenerated power exceeds the rheostat losses. It is of course obvious that the ratio between these power losses and gains would be different for different train weights and operating regimes. The conclusion may be drawn from the tables that this locomotive is not inferior, in economy of operation, to one regulated without a rheostat.

TABLE 13

Stage	Regime of Operation	Tractive or braking force chosen, in Tons	1000-ton train Rheostat losses in KWH	1000-ton train Regenerative braking in KWH	500-ton train Rheostat losses in KWH	500-ton train Regenerative braking in KWH	200-ton train Rheostat losses in KWH	200-ton train Regenerative braking in KWH
1	Acceleration	20	17.2	-	8.6	-	4.1	-
	Deceleration	18	-	14.1	-	8.2	-	4.4
2	Acceleration	17	10.8	-	5.1	-	2.3	-
	Deceleration	14	-	21.7	-	13.3	-	7.1
3	Acceleration	13	16.1	-	6.3	-	2.6	-
Total work	Acceleration	-	44.1	-	20.1	-	9.0	-
	Deceleration	-	-	35.8	-	21.5	-	11.5
Difference in work between acceleration and deceleration	-	-	8.3	-	-	1.5	-	2.5

In comparison to the single-phase-tri-phase Hungarian locomotive which has been mentioned by us in its proper place, supra, the Punga-Schon electric locomotive is a more simple machine, for it lacks the special and fairly complicated phase-conversion installation, and the traction motors are non-commutating.

Moreover, it also has the advantage over the single-phase locomotive with commutator motors of normal or reduced frequency, in that: commutation difficulties are absent; there is a radical solution of the problem of improving the power factor; the motors are automatically switched over to operate as generators, or vice versa, and this in turn reduces the wear on the tires, reduces the net consumption of energy (since power is regenerated by braking), reduces to a minimum the dynamic action on the roadbed); the danger of short circuits is eliminated and thereby the reliability of locomotive operation is increased; the shunt characteristic of the motors makes it possible to ascend grades at higher speeds;

The Punga-Schon system electric locomotive also has its faults, however. The most substantial of these are:

the complicated design of the motor, mainly on account of the presence of the intermediate rotor; it takes a relatively long time to reverse the single-phase motors. This is caused by the fact that the direction of rotation of the working rotor depends on that of the intermediate rotor, and therefore this must first be brought from its maximum of 1000 r.p.m. down to zero and then brought up again to the maximum [in the opposite sense], which takes about 50 seconds, and so when the operator changes over to the control position in the other cab it takes 1.5 to 2 minutes. The time for reversing, (when the cab is not changed) can be shortened by switching over the feed from the stator to the rotor, which takes about 5-10 seconds;

the locomotive must have a transformer installation, since the voltage from the contact conductor is too high for direct feed to the motors of this system;

given the essential features of the tri-phase motor, a single-phase input will result in incomplete utilization of its rated power. In practice this makes it necessary to increase the dimensions and weight of the motor, or in other words to reduce the unit power of the locomotive. But it must also be borne in mind that in high-power electric locomotives this increase in weight (relative to the total weight of the locomotive) is very inconsequential, and the total weight may still be even less than that of single-phase reduced-frequency electric locomotives of the same power.

CONCLUSION

Everthing with which the reader has here become familiarized can and must be considered to be only the first steps of modern locomotive-building technology towards the creation of more perfected types and designs of locomotives. There can be no doubt that during the impending postwar period the progress in experimental locomotive building will be even more rapid, and the accomplishments in this field even more significant.

Even today this statement finds its concrete expression in the appearance, both in the USSR and abroad, of more and more new plans for locomotives, in the reconstruction and varied improvement of the old standard locomotives, in the intensification of the experimental development of more improved locomotive equipment and apparatus, etc.

This may be illustrated by a few examples.

In the USSR a considerable number of plans for high-efficiency locomotives, both standard and of radically new types and designs, have already been completed.

Abroad, plans have already been drawn for type 2-3-3-2 and 2-4-4-2 electric locomotives. The clearance dimensions of the former do not exceed those of the existing high-power electric locomotives, but they will be able to develop about 50% more power: continuous power rating of 7,500 HP, short-time power rating of 10,000 HP. The latter will be able to develop continuous power of 10,000 HP and short-time power of 17,000 HP.

Each of these locomotives will have enough tractive force to haul 15 to 20-car passenger expresses at speeds of 160-200 km/hour, or 100-125-car freight trains at speeds of up to 115 km/hour over any track profiles. They are planned in two variants, A. C. and D. C.

Plans for what is called a universal steam-turbine locomotive are now in the development stage. It will have six axles and a boiler generating enough steam for turbines developing 8,000 to 9,000 HP. The geared drive of this locomotive is so constructed as to vary the transmission ratio, in an entirely automatic manner, with change in the direction of travel. Thus for forward travel the locomotive will be for passenger service and will be able to develop a speed of 190 km/hour, while for backward motion it becomes a freight locomotive and can handle a heavy train at speeds up to 110 km/hour.

The structural design and the control system are worked out in such a way as to assure all the requisite conditions (visibility, convenience of servicing, driving, etc.) when running either forward or backward.

The design of a special mechanism, termed the drive shift, has very recently been worked out. This mechanism continuously varies (shifts) the gear ratio in the transmission system of high-power locomotives as the speed changes. It is proposed, as an experiment, to equip one of the projected high-power locomotives with this mechanism. Preliminary calculations show that this locomotive will be able to develop over 7,500 HP and a tractive force up to 63,000 kg, throughout almost all of the speed range (30-160 km/hour), while the steam rate will remain practically unchanged.

It is obvious that we cannot rest on the achievements already made registered in locomotive-building. We can only assure the correspondence of our means of train traction to the level of a progressive transportation technology during each given period of time by moving steadily and unswervingly forward. The railroads of the USSR can, should and, under any and all circumstances, will dispose of the most efficient and most perfected locomotives in the world.

One of the most important prequisites for this is the strengthening and expansion, by every possible means, of the scientific-technical and the productive-material bases of experimental locomotive construction.

Publication of the appropriate technical literature will also prove of substantial help - literature in which all achievements of transportation technology in experimental-locomotive construction, both in the USSR and abroad, would be regularly and promptly reflected. And not only reflected, but subjected as well to discussion and criticism. That this would encourage the participation of many thousands of our most active engineers, technicians, inventors, and traction specialists in creative work is a propositon that hardly needs proof.

The present work is a first attempt to reflect, in more or less systematized form, all that has already been achieved in the field of locomotive construction. For the reasons explained in the introduction, the author did not consider it either possible or expedient to go deeply into the details, which are frequently very complicated; and he has here given a description of the experimental locomotives. Readers who familiarize themselves attentively with the contents of this book will therefore obtain only a general idea of the designs and operating characteristics of these experimental locomotives. It stands to reason that those readers who desire to obtain more exhaustive data cannot be completely satisfied by the information herein presented; and we can only recommend that they turn to the original sources.

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