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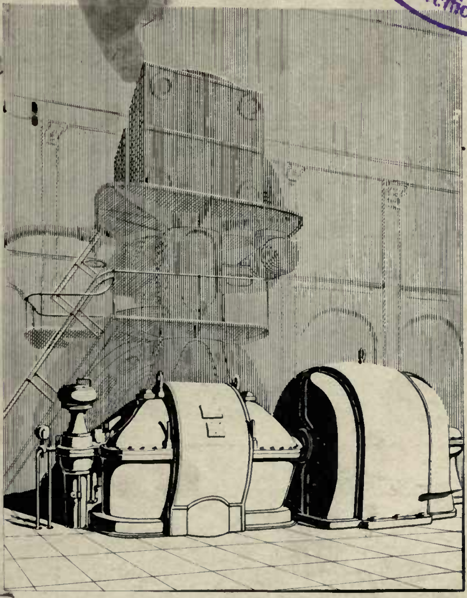
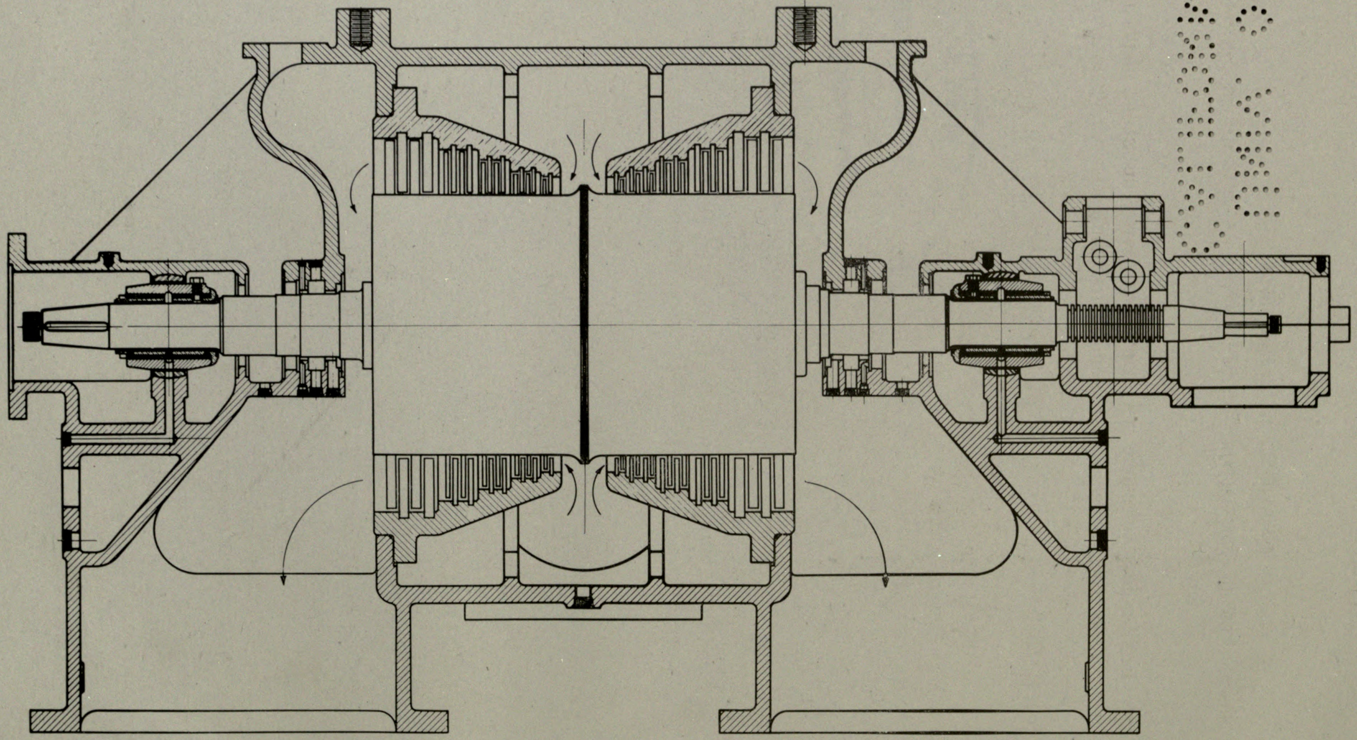
The Westinghouse Machine Company

The Application of



Low Pressure Turbines

PITTSBURG, PA.



Typical cross-section of low pressure turbine, showing the increase in area of passage from the middle where the steam enters, to the two ends where it is discharged to the condenser. The general simplicity and symmetry of construction is evident.

THE APPLICATION OF LOW PRESSURE TURBINES

BY

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Inasmuch as a low pressure turbine works with substantially half the heat drop of a high pressure condensing turbine, its construction is more simple and there are fewer turbine elements. As the volumes of steam which pass through the turbine are comparatively greater, large blade passages are permitted, all of which conduces to the simplicity and ruggedness of the turbine and facility of design. In low pressure turbine applications, therefore, the skill of the engineer is frequently called upon, more in connection with the method of applying the turbine than in its actual design. It is the object of this pamphlet to set forth some of the considerations of which account must be taken in making such applications.

The following may be cited as questions which arise when such an installation is contemplated. Is there enough steam for the low pressure turbine, and has its quantity been properly estimated? Although for preliminary purposes a sufficiently accurate guess of the available quantity of steam may be made, the use of indicator cards from the high pressure machines is advisable. The analysis of these cards may be made in a most satisfactory manner by the method described before the A. S. M. E. at Cleveland in May, 1912, by Mr. Paul Clayton. Steam meters furnish an alternative method of arriving at the desired figures, although the preferable procedure is a complete test of the boiler plant itself. It is advisable to make a deduction of 10% from the apparently available amount of steam to allow for the moisture in the exhaust from the engines.

A second typical question is that of the governing of the turbine. Should this be accomplished by the direct application of a centrifugal device to the turbine, or should arrangements be made to tie together electrically the generators driven by the turbine and by the reciprocator furnishing the exhaust steam. If a governor is used, acting directly on the turbine, should it control the inlet to the turbine alone, or should it be connected to a valve in the low pressure line permitting a portion of this steam to pass directly to the condenser and thus lowering the back pressure on the reciprocating engines whenever possible, due to low load on the turbine? Should the turbine be complicated and its overall efficiency somewhat reduced by the addition of a high pressure element so that it will operate with passable efficiency on steam direct from the boilers?

Finally, should the low pressure turbine be installed at all? Does the condition of the reciprocating engines warrant their perpetuation, or would the best results be obtained by the installation of complete expansion turbines? This condition exists in many plants where low pressure installations are suggested.

CLASSIFICATION.

Low pressure turbine installations may be more or less readily classified, and the various types are here enumerated for convenience. A more detailed discussion of each appears in the succeeding pages.

Case A: A low pressure turbine taking steam from the exhaust of a reciprocating engine, the generators of each being connected to the same bus bars and no governing device used.

Case B: A turbine or a number of turbines and engines connected similarly to Case A.

Case C: A low pressure turbine operating in conjunction with one or more engines as in Cases A or B, except that the turbine and engine-driven generators are of different electrical characteristics. A direct current street railway generating plant, with alternating current distribution to distant substations, is a good example of this case, the turbine and engine-driven generators being tied together by rotary converters or motor generators sets. Another expedient by which the use of a governor could be eliminated is the connection of the turbine-driven alternator to bus bars upon which floats a synchronous motor belted or direct connected to the reciprocating machine.

Case D: A low pressure turbine operating on the steam exhausted by a number of engines, pumps, or other apparatus, without any relation between the electrical output from the turbine and the amount of steam available. In such a case a governor controlling the admission valve of the turbine is obviously necessary, as is a relief valve, permitting any excess of low pressure steam to pass to the atmosphere.

Case E: A low pressure turbine operating on the exhaust from engines which are carrying an independent load, as in Case D. The turbine governor, however, controls a valve which connects the reciprocating engines with the condenser, imposing on them only enough back pressure to enable the turbine to carry its load. The engines thus have the benefit of some vacuum whenever the load on the turbine is light enough to require less than atmospheric inlet pressure.

Case F: A low pressure turbine operating in conjunction with an engine driving a mill or a system of shafting, the output of the turbine being used for motors, lights, etc., and any excess of current generated over the electrical demand may be returned to the shafting by using a synochronous motor, coupled or belted to the line shaft, and thus acting as a balance to proportion the load between the two machines so that the best economy may be obtained.

Case G: A low pressure turbine receiving steam from an intermittently operating engine such as a hoisting engine or a rolling mill drive. If the interval in the steam supply are not too great, a regenerator may be employed, absorbing the excess supply of steam at one time to give it up again to the turbine when the latter demands an amount exceeding that passing from the engine.

Case H: Practically all turbines equipped with generators have a valve which will admit sufficient live steam to carry the normal load should the low pressure supply fail. Such an arrangement does not, however, give high efficiency on high pressure steam since its expansive energy is wasted in throttling and only a small amount is recovered from the resultant superheat. Case H, therefore, provides what is termed a mixed pressure turbine which, in addition to the low pressure section, is equipped with elements enabling it to expand steam from boiler pressure to that of the condenser. Such a turbine is, of course, so constructed that all the available low pressure steam enters it at the proper point. A mixed pressure turbine is, therefore, used where it gives better overall efficiency, although it has a poorer economy on low pressure steam alone due to the dead load of the idle high pressure element. The relative proportion of the high and low pressure elements will be determined by the amounts of steam of each class to be handled and the continuity with which they are supplied. Such a turbine must, of course, be equipped with a governor.

GENERAL.

The primary general consideration in any low pressure installation is to insure that on the one hand the turbine will receive sufficient steam to enable it to meet all demands for load; and on the other hand, to insure that all the available exhaust steam is utilized either in the turbine or in some manner even more efficient about the plant. The installation should, therefore, be so arranged as to absolutely preclude the possibility of exhaust steam escaping to the atmosphere.

In this connection it is pertinent to state that while the low pressure turbine is an exceedingly efficient machine mechanically and affords an economical means of using a by-product often wasted, its absolute thermal efficiency is only approximately 10%. Exhaust steam condensed in a feed water heater, on the other hand, shows a return of approximately 80%, so that such a heater should have first consideration in any low pressure installation. In general, the amount of exhaust steam required for heating the feed water is about one-sixth of the total amount. In several cases previously cited, the pressure in the receiver from which the turbine draws its steam, is subject to variation. It rises with the load, and below full-load, is apt to be slightly less than atmospheric. If the feed water heater were connected with this receiver' the temperature would be low when the receiver pressure was low.

In such a case, a good arrangement would be to take exhaust from all the plant auxiliaries and collect it into a single main leading to the heater. Then any steam not condensed in the heater would pass from it through a constant pressure valve such as shown in Fig. 1, and thence into the receiver from which the low pressure turbine draws its steam. Thus the feed water heater pressure would be maintained at that of the atmosphere and the water passing to the boiler feed pumps would be at 212°, an ideal condition and one readily obtained provided the amount of exhaust steam from the auxiliaries is always sufficient to produce the desired heating effect. Obviously, the heater must be protected by a relief valve in order that the pressure may not reach an unduly high value. This valve should be preferably a back pressure valve of first-class make, absolutely tight and capable of being loaded to about 10 lbs. above the maximum receiver pressure. The auxiliaries, of course, must be capable of operating against the pressure corresponding to the highest receiver pressure.

It is advisable in all low pressure turbine work that particular care be taken to remove from the steam before it enters the turbine, all moisture and foreign matter. Wet steam will do no harm of itself, but has a bad effect on the economy of the turbine since its presence acts as a brake. The amount of oil present in the exhaust from the reciprocating engines, has been found in several instances choking the steam passages through the blades. Pure, clean oil itself would pass through a turbine without accumulating, but in cases where the boilers sometimes foam, discharging sulphates, carbonates or other solid matter with the steam, this mixes with the oil to form a gummy deposit on the blades which is exceedingly difficult to remove.

Any of the turbines mentioned above, whether equipped with a governor regulating the admission of steam or not, will naturally have a speed-limiting governor or automatic throttle which will prevent the machine from running away should other means of control

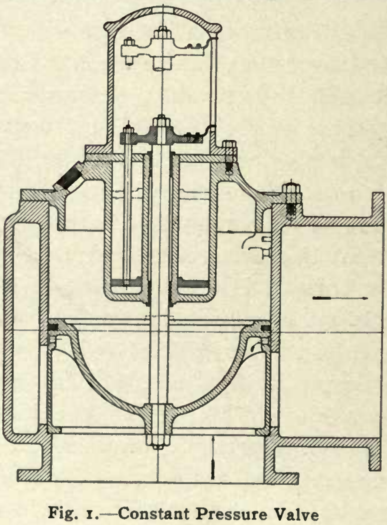


Fig. 1.—Constant Pressure Valve

fail. In speaking of turbines operating without a governor, the reference is, therefore, to a device for regulating the machine within close limits of speed, and while, for reasons which will be shown hereafter, the most economical performance of the turbine will generally not be obtained when it is under such control, it may be desirable to equip the turbine with such a governor so that it could be operated as an independent unit in the case of a failure of the reciprocating apparatus. When operating normally, however, the governor may be adjusted by means of a speed-changing screw so that the governor valve will remain wide open at all times, and thus all the exhaust steam will be used by the turbine and none wasted to the atmosphere. In this event, the governor would, of course, control the turbine should the speed rise materially above the normal. A governor might also be provided, controlling the admission of live steam alone, thus saving the expense of a low pressure valve and permitting proper operation of the turbine with live steam when there was no low pressure steam available, a condition which might arise due to accident to the machine from which the exhaust was passing to the turbine.

It will be understood that in any of the foregoing cases, the application may be made with direct as well as alternating current generators, the only difference being that with direct current generators the speed will rise slightly as the proportion of load taken by the low pressure turbine rises, or as the quantity of exhaust steam increases, this rise in speed being in accordance with the voltage characteristics of the generator. For the same reason, it is possible to vary the speed of the turbine slightly by manual adjustment of the field rheostat.

Obviously when the turbine generator is an alternator and operates in multiple with others driven by reciprocating engines, the starting of the unit is extremely simple. The process of synchronizing need not be resorted to, as it is customary, before starting the reciprocator and turbine, to establish the field charge. Therefore, when the reciprocator is started, the low pressure turbines will come up to speed with it in synchronism.

Another consideration that should be borne in mind is that low pressure turbines may be installed in conjunction with engines previously operated condensing, as well as those performing noncondensing service. The gain will, of course, be somewhat less, but roughly speaking, the use of 30% more steam than was required by the reciprocators operating condensing, will produce 75% more power when these are converted to noncondensing operation and their exhaust passed through a low pressure turbine of proper proportions. Condensing engines so converted, do not necessarily suffer reduction of capacity because of the back pressure to which they are subjected. On the contrary, the capacity of such an engine may be increased if it is a high expansion ratio engine; i e., providing the

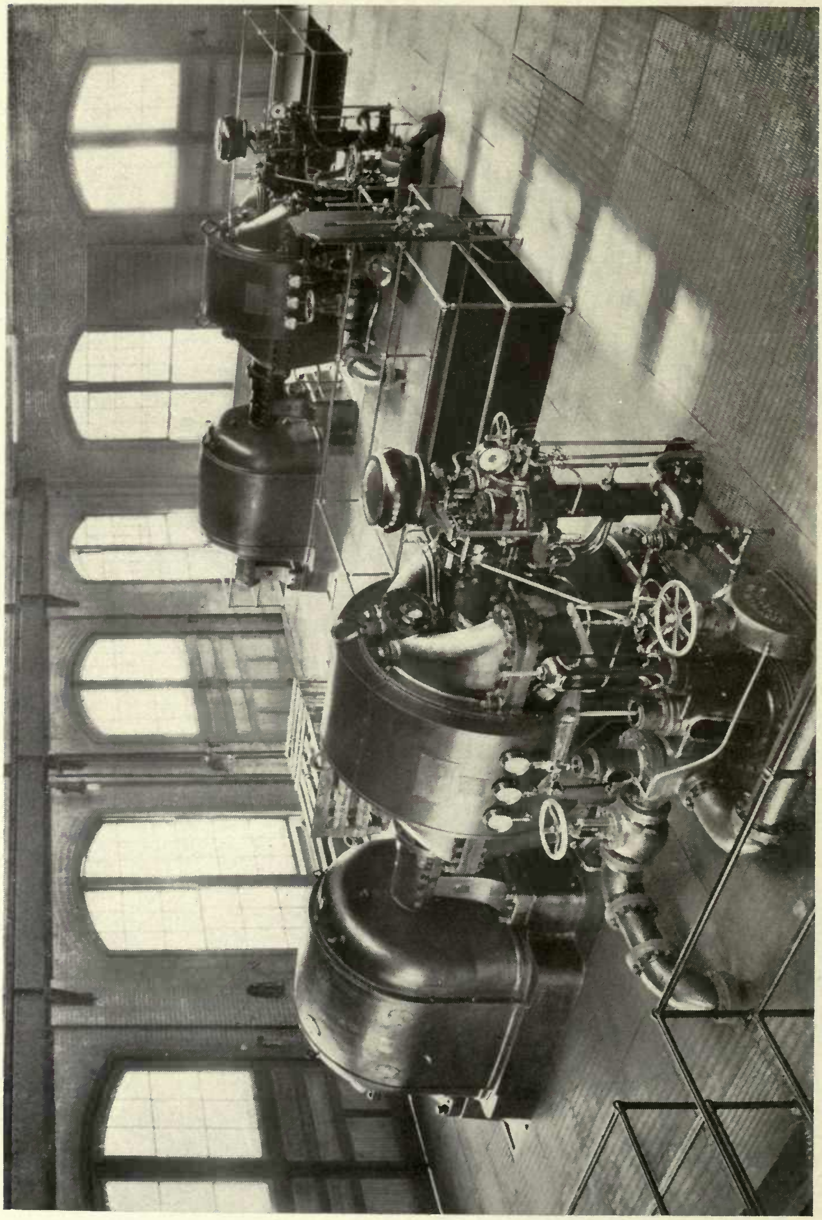


Fig. 2.—Case A or B installation in a metropolitan central station. Two 1500 kw. Low Pressure Turbines operating in parallel with engine-driven alternators. The low pressure piping is so arranged that almost any combination of units may be obtained. The engine sets were formerly operated condensing.

generator will stand being increased in ratio and providing that the high pressure cylinder of the engine has enough volume to pass the required amount of steam without taking steam for the entire length of its stroke. In many cases it is well worth while to make provision for this increased capacity by such modifications of the generator as increased air circulation, etc. The reason for this increase in capacity is that in laying out the altered indicator card of the engine for a higher back pressure, the cut-off in the high pressure cylinder will have to be moved along to a point late enough so that expansion in the low pressure cylinder will not result in looping, or, in other words, to a final pressure at the opening of the low pressure cylinder exhaust valve, lower than that of the line to the turbine. Under these conditions it will be found that the top portion of the card will be increased in area or fattened, adding more area to the total than is taken from the lower portion by raising the back pressure to that of the atmosphere or thereabouts.

There will sometimes be found compound engines operating condensing in which release in the low pressure cylinder takes place at a relatively high pressure, possibly close to atmospheric. If a low pressure turbine were applied in this case with a view of obtaining increased over-all efficiency, the engine capacity, instead of being increased, will be decreased since the possibility of adding area to the upper part of the card does not exist.

Having shown the classes into which low pressure turbine installations naturally divide, and the general considerations which affect all such installations, the remaining pages will be devoted to a more detailed discussion of the application of such machines in the various classes indicated. It will be well to recall at this point that the primary function of a low pressure turbine installation is to produce the maximum obtainable amount of power per unit of steam generated in the boilers, and that, therefore, every care should be taken that all steam so generated, will be used in the most efficient manner possible.

Case A: This is the simplest form of low pressure turbine installation, and is shown diagramatically in Fig. 3. From the diagram it will be seen that the turbine and reciprocating engine are tied together electrically and that no governor is indicated on the turbine, although as suggested before, one may be provided so arranged that it is normally out of action but will control the turbine when desired. If, for instance, the reciprocator should be disabled, the turbine could still operate if so equipped. If the turbine drives an alternating current generator, it will take its share of the load in proportion to the steam available. As it tends to forge ahead of the reciprocating engine generator, it will take more of the load, thus removing load from the reciprocator and reducing the supply of exhaust steam. The self-regulation is, therefore, perfect, the governor on the reciprocating engine controlling the amount of steam to the complete system. In case the turbine and reciprocator drive direct current generators, as the turbine tends to take more load, the speed increases slightly, and with that, the voltage, and the system is again self-regulated.

There is a great inherent advantage in this application of a low pressure turbine which is directly due to the variable pressure existing in the receiver or pipe line between the engine and turbine. The absolute inlet pressure of a turbine varies directly with the amount of steam passing through it. Reciprocating engines designed for either condensing or noncondensing operation generally have such a valve setting as will normally provide a considerable pressure at the point of release of the low pressure cylinder so that when the load on the engine is light, the indicator card will not loop. Such an engine, therefore, when carrying full load does not completely expand the steam within the cylinder, and this is a serious source of loss in engines designed for operation on variable load. In this case when the low pressure turbine is applied, there is no necessity for this provision of pressure at the point of release. The valve setting may be made such that with normal load, expansion within the cylinder will carry the steam to approximately atmospheric pressure, or perhaps a half pound above this, in order to pass the steam readily through the ports. The low pressure turbine blading proportions will then be made such that the inlet pressure will

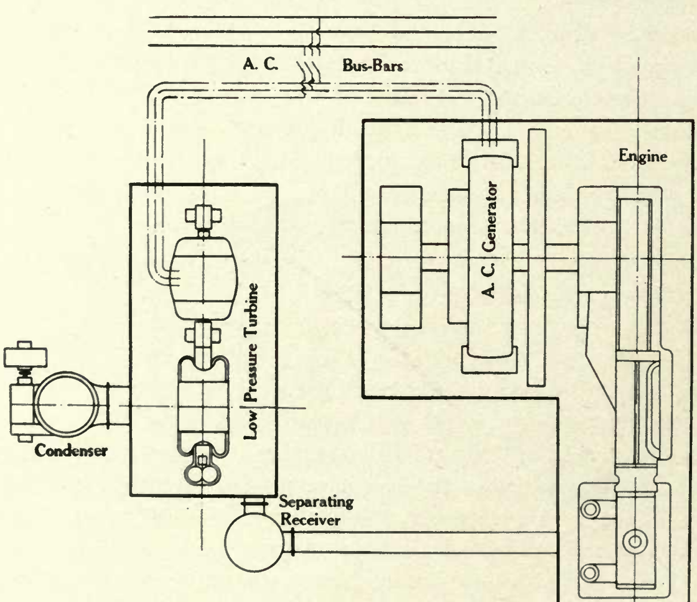


Fig. 3.—Case A

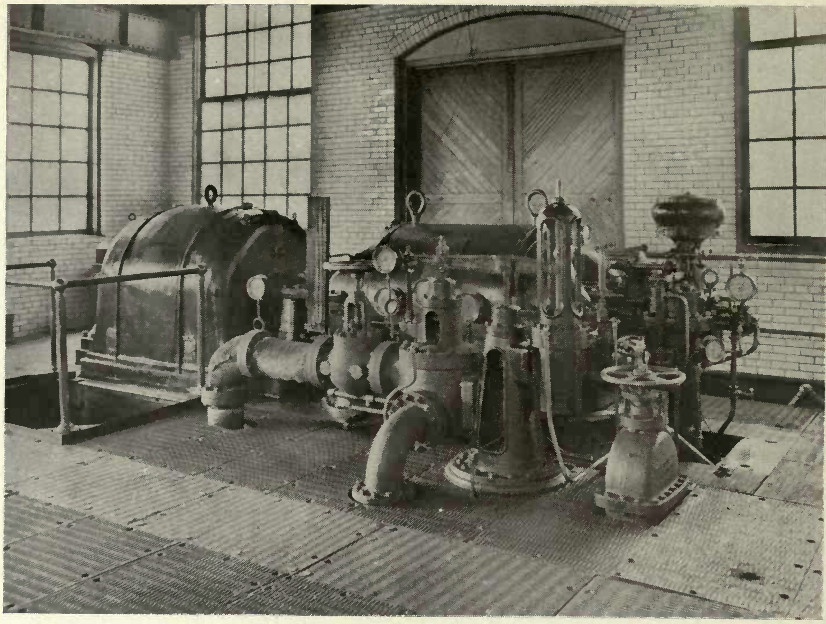
be equal to atmosphere when passing the quantity of saturated steam exhausted by the engine when operating at normal load. If, now, the quantity of steam taken by the reciprocating engine is reduced say to one-half, the absolute inlet pressure of the turbine will similarly be one-half. The high pressure cylinder of the recipocator will have its cutoff reduced approximately one-half and the extension of steam within the low pressure cylinder will continue to a point corresponding approximately to the turbine inlet pressure. There will be no looping of the card and the expansion of the steam through the cycle will be effected in an ideal manner. It is hardly necessary to point out that a reciprocating engine designed to expand the steam to atmospheric pressure at full load would expand it to a point below this pressure at light loads, and if the back pressure were maintained constant, would soon slam the valves to pieces.

It should be noted that the proportion of load carried by the engine and the turbine respectively, varies with the quantity of steam. The greater the total load, the greater the proportion taken by the turbine, due of course, to the variable receiver pressure. The higher this becomes, the greater is the heat range through which the turbine works. This particular feature is of such an extensive nature that a complete discussion of it is impossible in the space here available.

In turbine applications of this kind, as several of those that follow, a synchronous or induction type generators may be employed. These have the advantage of requiring no field adjustment.

Case B: This, as stated previously, is similar to Case A, except that the larger the number of units involved, the greater is the number of combinations possible. A plant of this type is shown in Fig. 2. The desirable arrangement in installing a number of low pressure turbines is to equip each with its own condenser. This conduces to flexibility of the plant over that obtainable where one large condenser is installed to serve all the turbines as it materially reduces the probability of a shut-down due to condenser failure. In plants of any considerable size, the desirable method of applying low pressure turbines is to install one for each engine, the plant becoming a multiple of Case A and each engine-turbine unit being comparable to a simple engine which has been compounded by the addition of a low pressure cylinder, the only difference being that the two portions are tied electrically instead of mechanically.

The regulation of the system is exactly the same as that of Case A, except that the capacity of the low pressure turbine may be too small to handle the amount of steam exhausted from the number of engines that are in operation. Part of the exhaust steam would, therefore, escape to the atmosphere and be wasted. A low pressure turbine is generally designed so that the maximum load on the generator will be reached



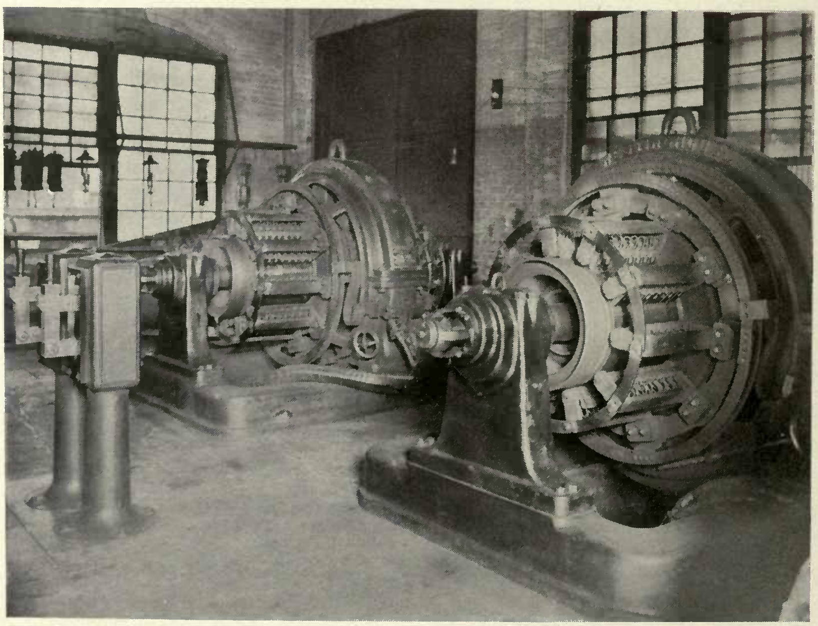


Fig. 4 & 5—Case C plant of an Ohio steel company in which there are two 600 kw. Low Pressure Turbines tied through rotary converters to direct current engine-driven alternators. Since some exhaust steam is available from other sources, governors are fitted to permit operation when the engine units are shut down.

when the inlet pressure on the turbine is about 20 or 21 pounds per sq. in. absolute, and it is, therefore, customary to set the relief valve on the low pressure pipe line to open at about this pressure.

The same consideration affects the variable back pressure on the engines in this case as in Case A.

In installations of these two classes care should be exercised that no air may leak into the system when the receiver pressure is below that of the atmosphere, since such air will seriously affect the performance of the condenser, the vacuum will be reduced, and the full possibility of gain from the use of the turbines will not be realized. Obviously, the greater the number of engines and the longer or larger the exhaust pipe system, the greater attention must be paid to this point. It is frequently necessary to provide special double packing rings on the rods of all the engines, such packing being so arranged that steam at a pressure slightly greater than the atmosphere is admitted between the two rings and any leak into steam spaces will, therefore, be of steam rather than of air.

In some case A and B plants there are found additional reciprocating engines and other steam using machines carrying loads having no possible relation to the electrical load. Air compressors and pumps would be examples. The steam from such sources is, however, generally insufficient to drive the turbine except during some abnormal condition of infrequent occurrence, such as a small electrical load occurring at the same time with a high pump and compressor load. Where this factor is involved, it would be advisable to equip the turbine with a governor, setting the speed adjusting screw so that the turbine would regulate at about 6% above normal speed. Operation under normal conditions, therefore, would take place as if no governor were applied, but as soon as the over-supply of steam occurred, the governor would exercise perfect control over the turbine. In making this provision, it would, of course, be necessary to keep the live steam valve to the turbine closed, except when it was desired to operate on steam direct from the boilers.

In the operation of such a plant, provision should be made for turning over each additional engine which is put on to load for a few revolutions, exhausting to the atmosphere, in order to completely expel from it the air which has collected in the cylinders and receiver while it was at rest. Otherwise this air discharged into the exhaust system and passing to the condenser is very apt to cause a loss of vacuum, and consequently to interfere with the operation of the entire station.

Case C: In the two classes of installation just discussed the generators of the low pressure turbines and reciprocating engines were all of the same electrical characteristics. In Case C, the generators driven by the reciprocating apparatus may be either direct or alternating current and the generators driven by the low pressure turbine different from all or some of them. An electric railway power house is often of this type, the direct current machines supplying the local feeders and the alternating current derived from existing engines or to be derived from the turbine distributing to distant substations. If the low pressure turbine in this plant were equipped with a governor arranged to meet only the demands for alternating current, steam would be wasted when the A. C. load became light and the installation would be unsatisfactory for that reason. There is a further objection that to meet the demands of certain alternating current loads occurring at times when the direct current load was light, it might be necessary to install some high pressure alternating current apparatus or to furnish the low pressure turbine with live steam which would again be uneconomical operation. A convenient

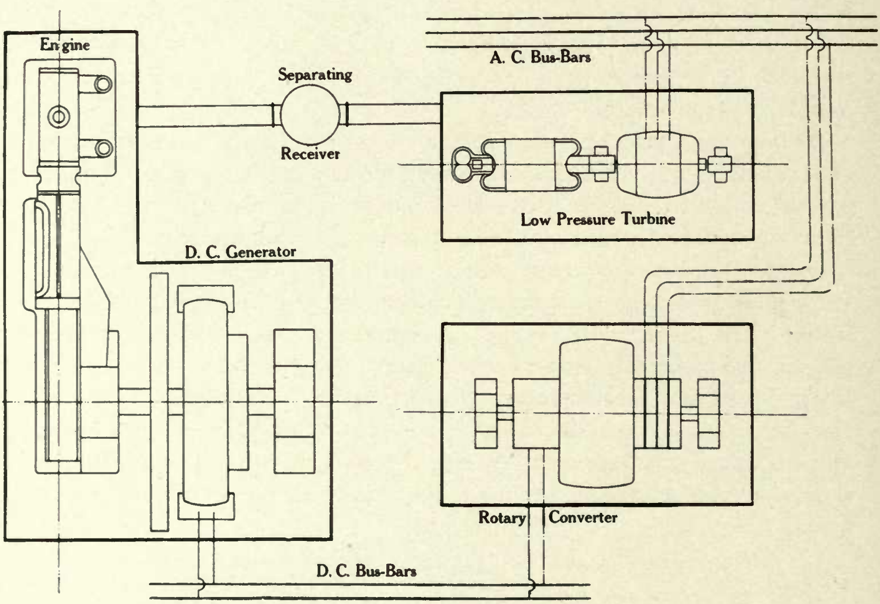


Fig. 6.—Case C

and satisfactory solution is afforded by tying the alternating and direct current systems together by means of a rotary converter or motor generator set, as shown diagrammatically in Fig. 6. This will insure the use of all the steam in the most economical manner possible. Any lack of balance between the electrical loads will be taken care of by the rotary, the load on the turbine and engines being divided for best economy irrespective of the division in the total output of the station. Such a plant might possibly be undesirable where lighting service is involved due to the voltage variation of the rotary in swinging over from full load alternating direct current operation to full load direct alternating current operation, amounting probably to 10%. In the majority of cases, however the direct current engine load will predominate over the alternating current demand, and the rotary or M. G. set will be uni-directional, in which event lighting could be satisfactorily served. Even in the previously mentioned case the use of separate excitation in conjunction with a Tirrel regulator for the M. G. set will remedy the difficulty of voltage variation.

Another method of solving the same general problem is to connect with the reciprocating engines, directly or by belt, a synchronous A. C. generator in multiple with that driven by the low pressure turbine. This synchronous motor must have sufficient capacity for the maximum unbalancing of the direct and alternating current loads.

By making use of this expedient the reciprocator automatically takes sufficient steam for the needs of the whole system with maximum economy and quite ideal regulation, at the same time satisfying the primary requirement that under no condition of operation shall steam escape to atmosphere.

Case D: Many plants contain a large number of engines, pumps or other steam-using prime movers which do not drive electrical apparatus. The exhaust from these may be collected and brought to a common point at which it is used in a low pressure turbine which must obviously be controlled by a governor. In such installations when the demand of the turbine for steam is greater than the amount supplied by the various sources, the pressure in the piping system will fall until it becomes less than that of the atmosphere, and under this condition the inleakage of air is practically unavoidable. It is, therefore, essential to place a constant pressure valve in the low pressure steam line adjacent to the turbine, thus insuring the maintenance of a pressure in this line slightly greater than that of the atmosphere, at such times as the available amount of

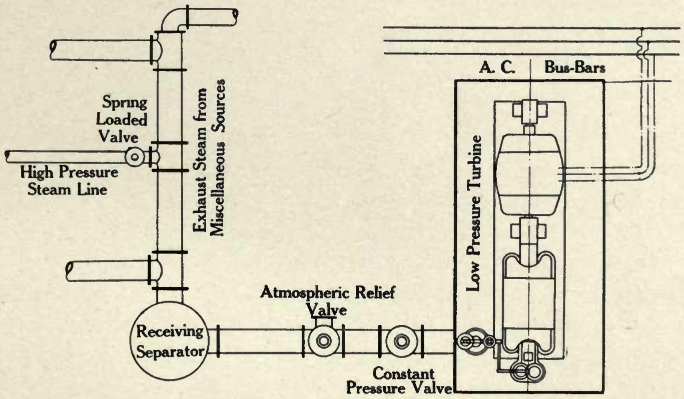


Fig. 7.—Case D

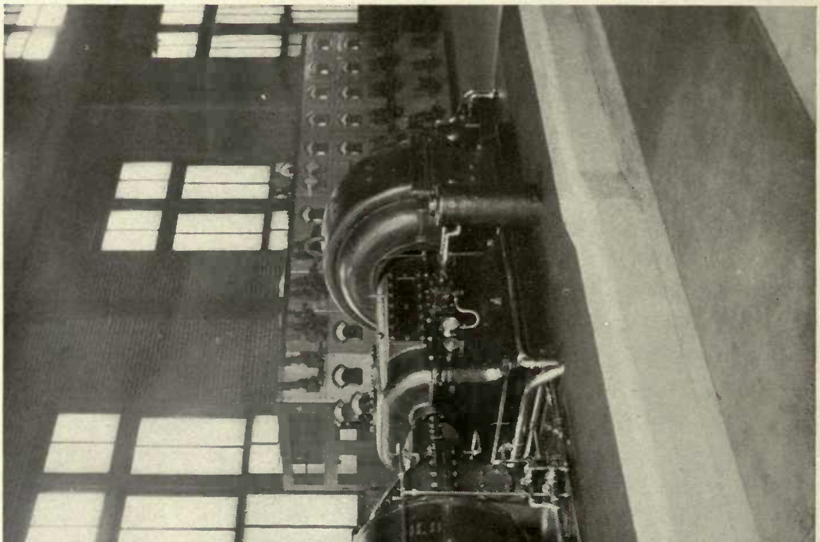


Fig. 8—An interesting Case D installation in the shops of a steam railroad where the low pressure turbine drives direct current generators through reduction gearing.

exhaust steam is not sufficient to so maintian it if the turbine were drawing from this line. A considerable saving can generally be effected by this expedient since it makes unnecessary a large investment for a heavy pipe line to prevent such inleakage. A constant pressure valve is shown Fig. 1. A relief valve should also, of course, be fitted to the line so that any steam not used by the turbine will escape to the atmosphere. As the service in this case may be such that the supply of exhaust steam is not always sufficient to carry the load imposed on the turbine, an auxiliary valve under the control of the turbine governor should be provided to admit live steam to the turbine when necessary.

At first glance the use of live steam in the turbine designed for low pressure work would appear to be poor engineering, but in general this is not the case. The fact that the supply of low pressure steam is insufficient generally indicates that some of the reciprocating apparatus has been relieved of its load, and since the boiler plant is producing steam at a rate sufficient to carry the former load on the reciprocators, the safety valves will soon blow unless it is used in some way or other. Its admission to the turbine will, of course, prevent this condition from arising, unless the turbine load also is considerably reduced. It is, therefore, quite frequent practice to pipe the safety valves on the boilers into the low pressure system between the engines and the turbine. Conditions such as these suggested immediately above are most frequently found in rolling mills or hoisting sheds where the reciprocators are in intermittent service. If, however, there is a larger proportion of the time when it is desired to operate such a turbine on high pressure steam, the correct solution is that of Case H. Fig. 7 shows a plant of this type diagrammatically.

Case E: There are a good many plants where the engine and turbine loads are independent or cannot be yoked together. Thus the load on the turbines may be very much lighter than that on the reciprocating engine, and if the installation were made as in Case D, the excess of steam from the reciprocating engines would escape to the atmosphere and be wasted. Case E, therefore, makes provision for operating a reciprocating engine partially condensing under such conditions. The turbine governor controls a valve which, instead of admitting steam to the turbine, allows the exhaust from the reciprocator to pass to the condenser. If there is no load at all on the turbine, this valve would stay wide open and the engine would operate with substantially full vaccum. As the turbine load increases, the governor tends to close this valve, making a sufficient difference between the inlet and exhaust pressures of the turbine so that the desired load may be carried. Finally the governor valve may be entirely closed, thus forcing all the steam from the reciprocator to pass through the turbine.

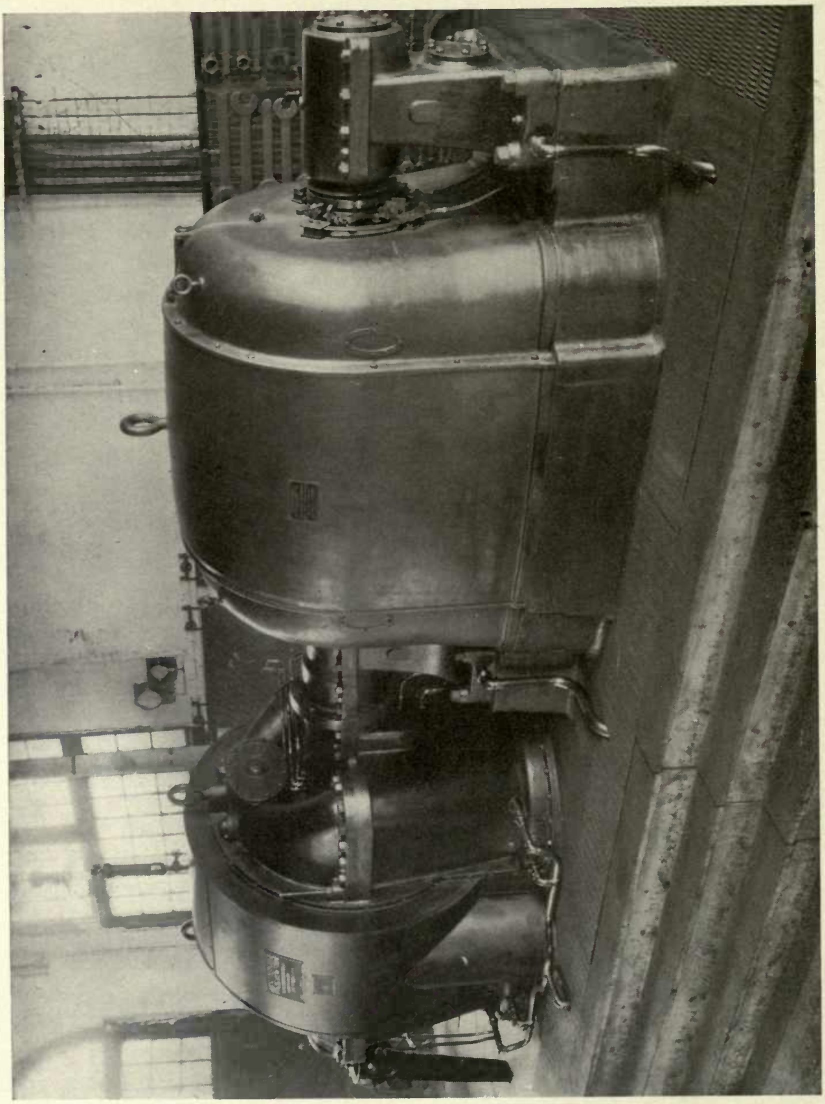


Fig. 9 —Case E installation of a Pennsylvania steel company in which the exhaust steam is collected by steam lines having a total length of 2475 feet. The owners estimate the net annual saving at 20% of the orignal investment.

Obviously the advantage of this arrangement is that whenever the load on the turbine falls below normal, the reciprocating engine will obtain the benefit of some vacuum. The turbine inlet is, of course, provided with a butterfly valve connected to the governor so that the turbine will be prevented from running away if the load be entirely removed, or if for some external cause the reciprocators disgorge an inordinate amount of steam which could not get through the bypass without a material rise of pressure in the exhaust steam line. In some cases the installation described might be better arranged by treating it as Case C, using a synchronous generator tie.

Case F: This is a modification of Case C installation and has found a wide application among the cotton mills of New England. It is again a case where the low pressure turbine and reciprocating engine loads are entirely different, but a tie may be established between them and in this way all the exhaust steam used. As in Case A the turbine normally operates independently of a governor, although generally one

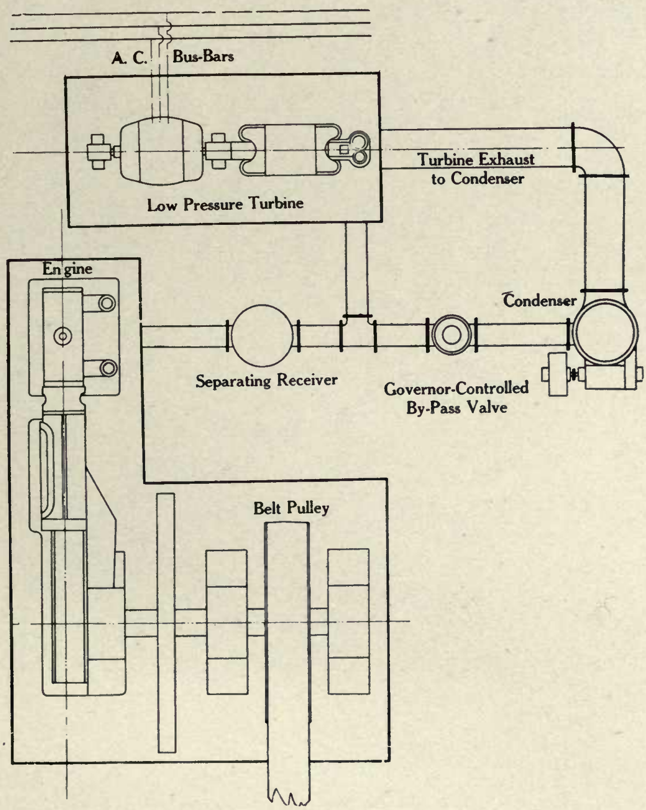


Fig 10.—Case E

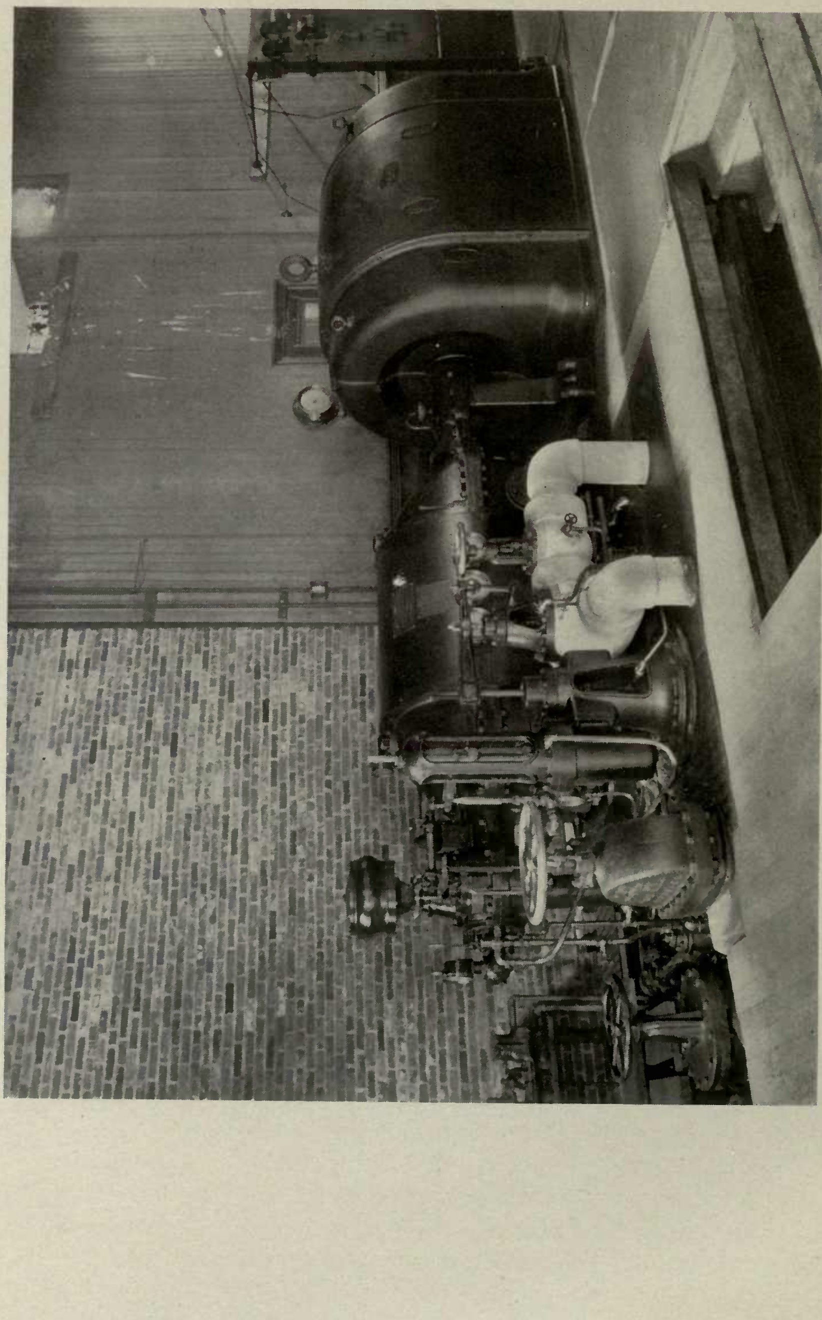


Fig. 11—Case F installation of a New England manufacturing company. The governor, which may be seen in the illustration, is ordinarily inoperative, being employed as noted on page 21

would be fitted to provide for operation should the reciprocating engine go out of service. An ideal case of such an installation is found where the reciprocating engine is driving a mill through line shafting and it is desired to enlarge the mill using motor drive, for individual machines, or to increase the power plant capacity for any purpose. The low pressure turbine is installed and electrically connected to a synchronous generator belted, or otherwise connected, to the mill shafting. This synchronous generator will either take energy from, or give energy to the mill shafting

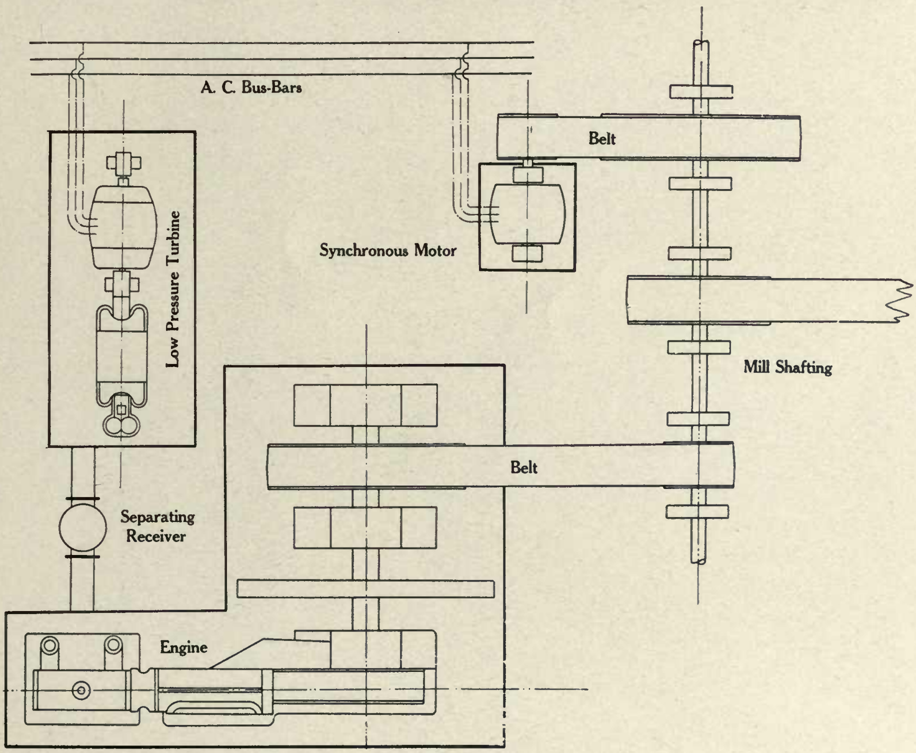


Fig. 12—Case F

in accordance with the varying demands of the power and electrical systems. Should the mill load increase, the governor on the reciprocating engine will admit more steam which will pass through to the turbine. The excess load produced by the turbine is delivered to the mill shafting through the synchronous generator. An increase of the motor load driven by the low pressure turbine, means that it will tend to slow down and energy will be taken from the mill shafting by the synchronous generator whereupon the reciprocating engine governor will admit more steam to the engine. If all the energy from the low pressure turbine is to be employed in driving the mill and the purchaser does not desire to operate

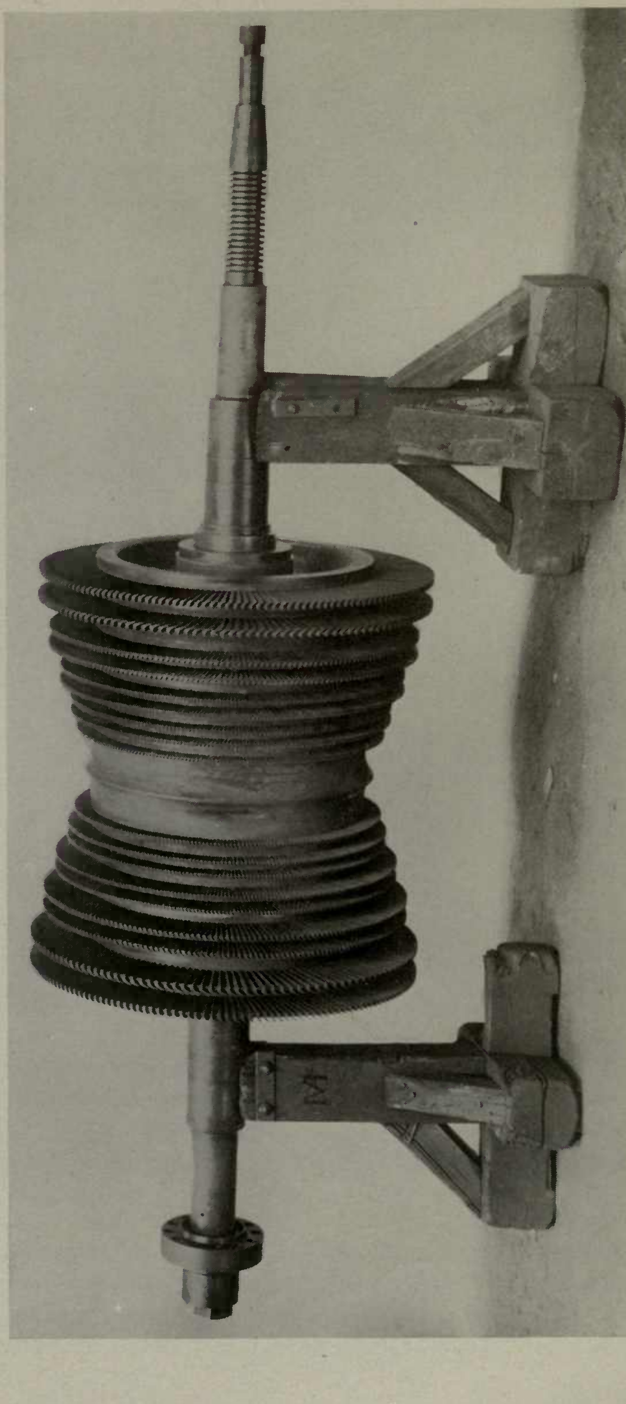


Fig. 15—Spindle of Low Pressure Turbine, showing the blading

motors or lighting circuits, the turbine may be connected to the mill shaft directly through gears and all the advantages of the Case A installation may be realized, the connection being mechanical instead of electrical.

Case G: Where the supply of the exhaust steam is obtained from rolling mill or hoisting engines and is therefore, very variable, there may often arise a condition where there is a complete cessation of the flow of exhaust steam. To continue the operation of the turbine, it will, therefore, be necessary to supply live steam or else employ a heat storage

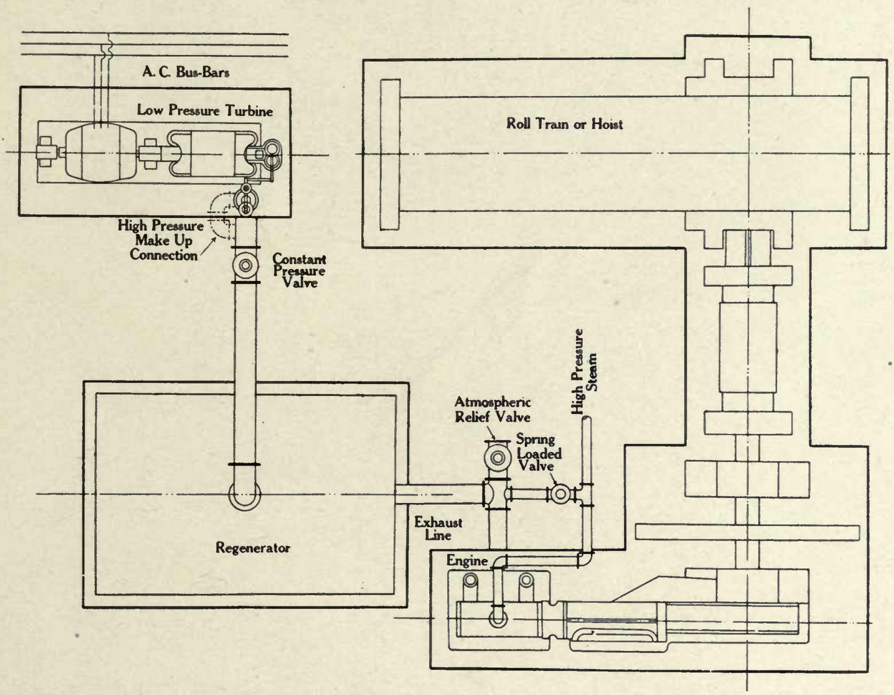


Fig. 14—Case G

means, such as a regenerator, of sufficient capacity to bridge over the period when no exhaust is being furnished by the engines. This case will be recognized as an elaboration of Case D, differing only in that means are provided for storing heat when an excessive exhaust steam supply is available and giving up this stored heat when there is an insufficient supply. The regenerator consists generally of a large vessel partially filled with water through which the exhaust steam passes on going from the reciprocating engine, the water being thus maintained at the temperature of the steam. It is usual to design a regenerator to operate between the limits of atmospheric pressure and 5 or 10 lbs. gauge, the lower limit being selected in order to avoid the possibility of

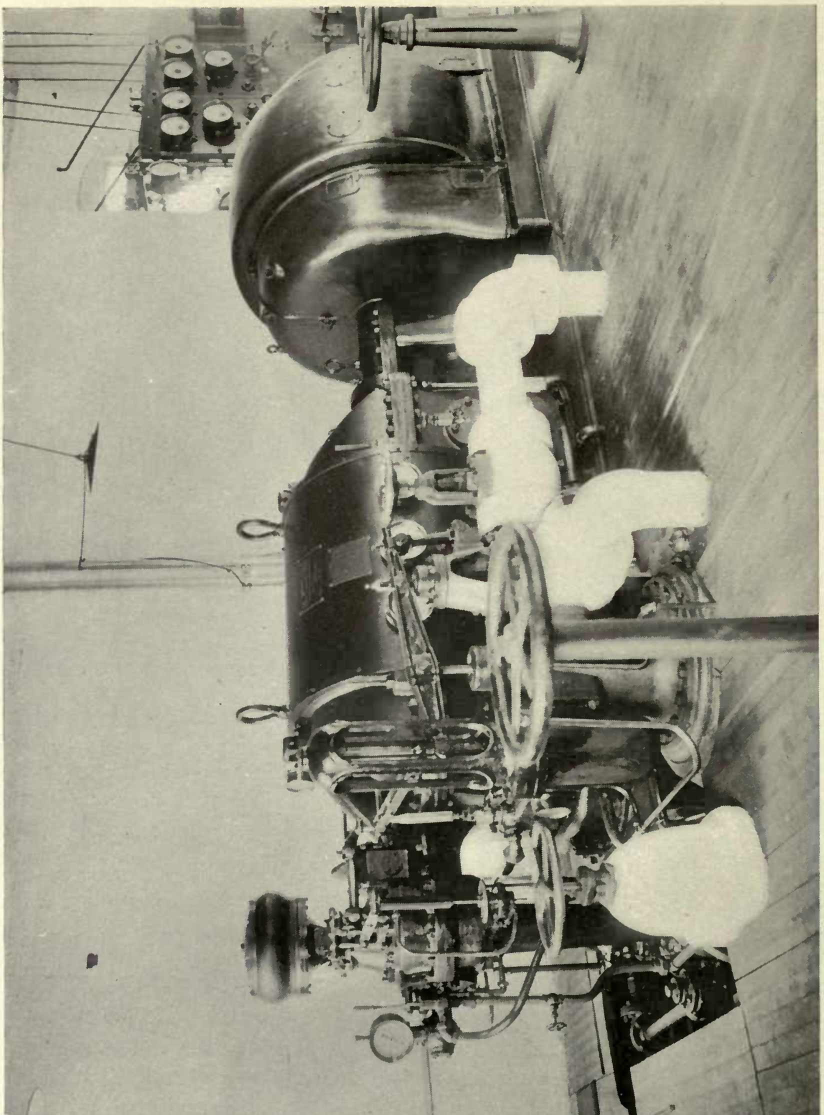


Fig. 15.—A Case D installation in a Massachusetts paper mill. The turbine operates on exhaust steam not required for heating purposes. Installation complete, including motors and a transmission line, is being paid for by the turbine savings approximately at the rate of 25% per annum, although it is in operation only half of the time.

inleakage of air. To indicate the action of a regenerator, the following actual case may be cited:

Assuming that the pressure limits for its operation are 14.7 lbs. and 25 lbs. absolute; i. e., atmospheric pressure and 10 lbs. gauge, the corresponding temperatures will be 212° and 240° Fahrenheit, the difference between which is 28°. Assume that the water in the regenerator is at 212° and the steam at a corresponding pressure, and that the steam delivered by the reciprocating engine is exactly equal to the demand of the low pressure turbine. So long as this condition exists, the steam flows through the water in the regenerator and no heat is taken up or given out. Now assume the load on the reciprocator, and consequently the amount of steam it discharges, to increase while the demand of the turbine for steam remains constant. Then the pressure within the regenerator, and accordingly the temperature of the steam, will begin to rise, resulting in an increase in the temperature of the water if provision is made for intimately mixing the steam with it. As the pressure increases, the steam comes in at a temperature higher than the water and is so in part condensed, which assists in maintaining the temperature of the water corresponding to that of the steam. This process may continue until the pressure within the regenerator reaches 25 lbs. at which point the relief valve has been set. Under these conditions, each pound of water within the regenerator will have absorbed 28.3 heat units. Now suppose the flow of exhaust steam from the reciprocating engine to absolutely cease, in which event the pressure within the regenerator begins to fall because the turbine continues to draw steam from it. When this pressure has reached 14.7 lbs., the water in the regenerator will have evaporated until its temperature corresponds to that of steam at this pressure; i. e., 212°, and each pound of water in the regenerator will have given out 28.3 heat units, exactly equivalent to the amount absorbed while the pressure was rising. The mean latent heat of evaporation through this range being 961 units, each pound of water so reduced in temperature will liberate .0294 lbs. of steam. Obviously, in installing a regenerator, the important point to determine is the length of time the regenerator will be expected to carry full load on the turbine without any supply of steam from the engines. From the above figures it will be seen that if this is long, the quantity of water within the regenerator must be very great. Then again, the pressure limits assumed in the above example were quite wide. In a good many installations it would not be possible to impose 10 lbs. back pressure on the reciprocating engines. Reference to this matter is made because generally the disposition of a prospective installer of a regenerator is to make the time element much greater than is necessary. Some early installations of regenerators provide for six to seven minutes of operation without a supply of exhaust

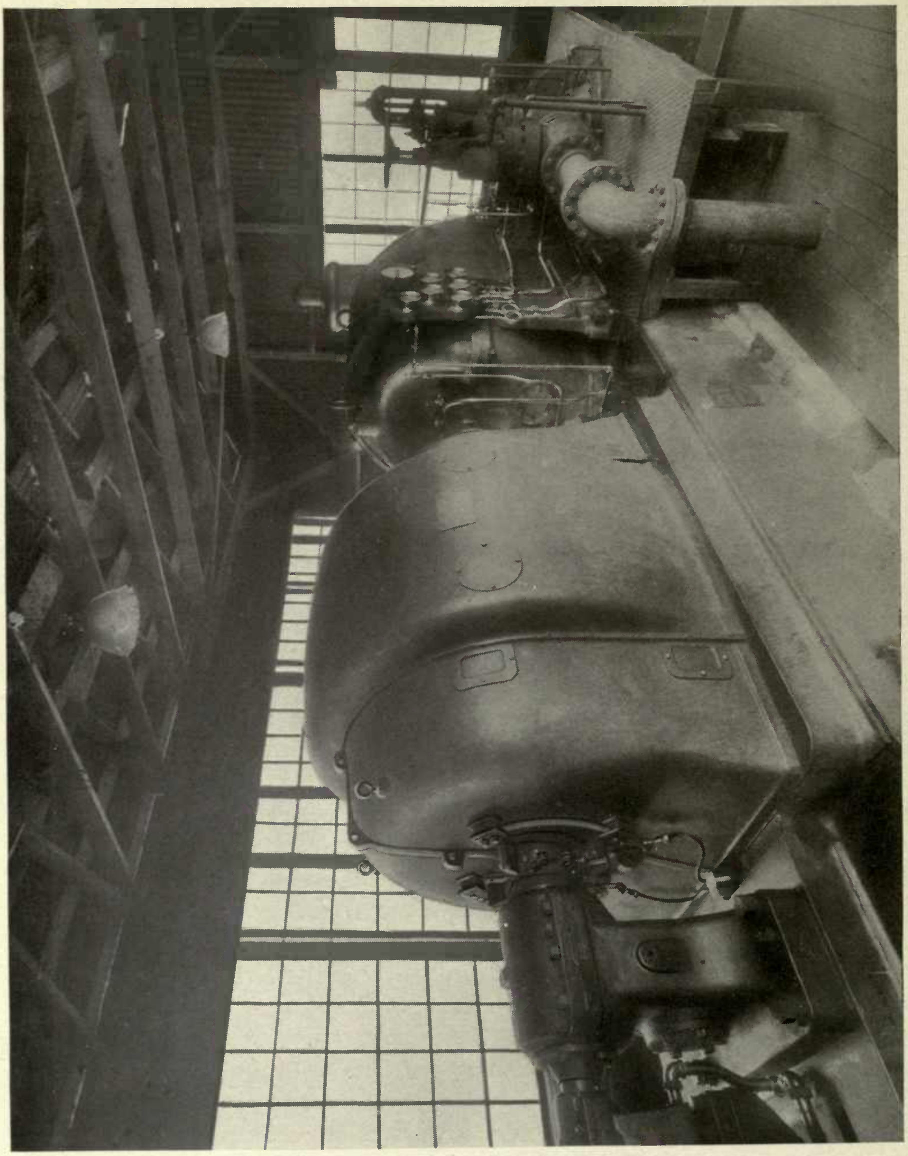


Fig. 16.—Mixed Pressure Turbine, installed in the plant of a sheet and tinplate company.

steam, whereas six or seven seconds would have been better. For instance, in steel mill practice, if the exhaust from a blooming mill engine is to be considered, the time element should bear reference to the period between the passes of an ingot, and to the maximum time from the last pass of one ingot to the first pass of a new ingot, and the regenerator should not be designed to cover such delays as would arise due to the clogging of the mills or because a new ingot might not be ready to be bloomed.

As was indicated in Case D, there is another source of exhaust steam available when such an unforseen interruption arises. The boiler plant is being continually fired, and if the demand for steam is interrupted in this unusual way, the safety valve will blow. The steam escaping in this way should be led direct to the regenerator so that the turbine will continue to carry its load without drawing live steam. The best method of providing for this is a cross-connection between the steam and exhaust lines of the engine in which is placed a spring-loaded valve set to blow at a few pounds lower than the safety valves.

There will always be periods of more or less duration when the regenerator cannot furnish enough steam for the turbine and the only alternative is to supply live steam. This has been frequently accomplished by admitting steam to the regenerator through a reducing valve so set that when the pressure within the regenerator reaches the lower limit, steam will be admitted. Such valves are, however, generally unsatisfactory and troublesome, and it is better practice to employ for this purpose the secondary or live steam valve under control of the turbine governor. This valve may be arranged to admit steam either to the inlet side or outlet side of the regenerator. If admitted to the inlet side, no water hammers will be produced, a condition which might arise with admission on the outlet side if the regenerators were arranged for wide pressure limits. The disadvantage of admission on the inlet side, however, is that the pressure in the regenerator cannot be raised without condensing steam therein, thus necessitating supplying a large amount of live steam to tide over temporary heavy loads on the turbine. In such an arrangement it is conceivable that when the exhaust steam again flows into the regenerator, the latter being already partially charged, it will be unable to absorb all of the supply and some of it will pass through the relief valve to the atmosphere, thus violating the primary consideration for which the regenerator was installed. If live steam is to be admitted, therefore, and the regenerator is arranged to work within wide limits, arrangement should be made to admit it between the turbine and regenerator. It may prove desirable to install a check valve between the point in the pipe where the live steam is admitted and the regenerator so that if the regenerator were at the lower pressure limit and no steam was

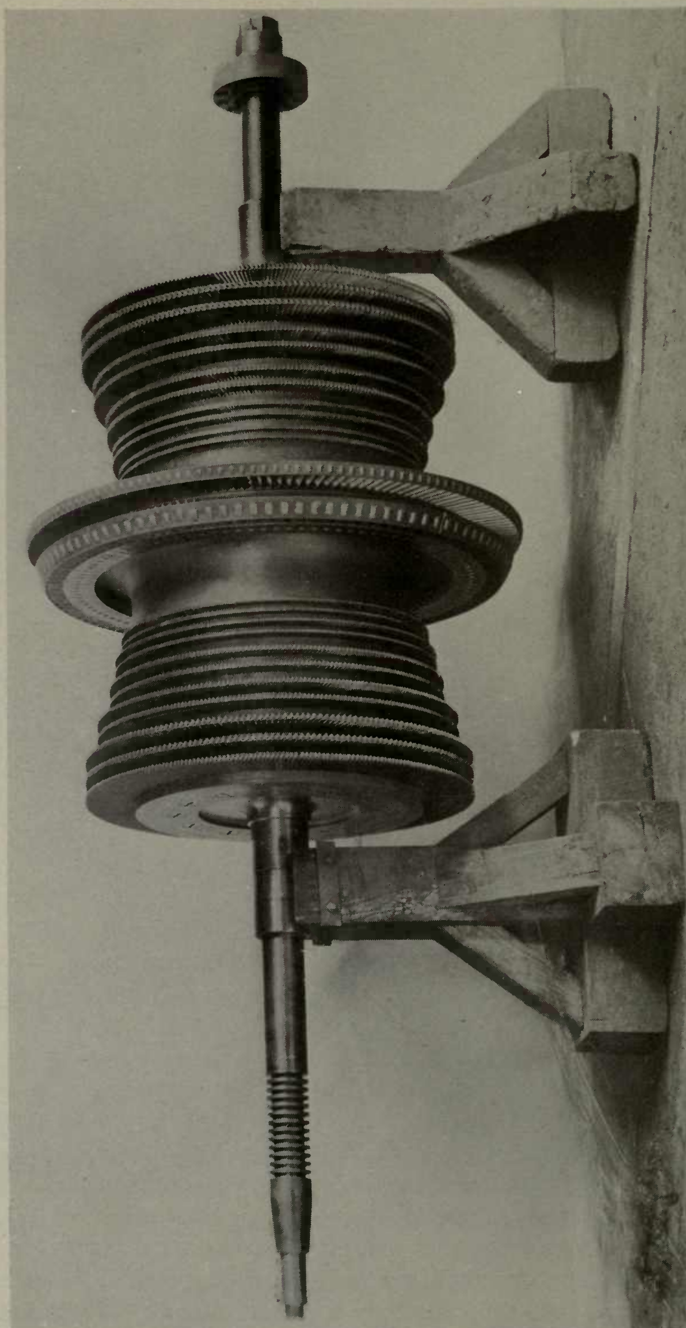


Fig. 17—Spindle of Mixed Pressure Turbine, showing the impulse element for efficiently absorbing the expansive energy of the high pressure steam before it passes to the low pressure blading

being admitted to it and the load on the turbine was such that more steam was required, the pressure in the regenerator would not be raised without the temperature of the water rising correspondingly. Obviously, if the pressure in the regenerator were raised by admitting steam in the reverse direction; that is, without passage through the water from the secondary valve on the turbine, then when steam comes from the reciprocating engines in the usual direction, it would be at a temperature higher than that of the water within the regenerator and might cause hammering, the violence of which would correspond to the temperature difference.

Case H: Occasionally the conditions in a plant are such that it is desirable to utilize a quantity of exhaust steam which is intermittently available, but there are also long periods of time unrelated to this supply

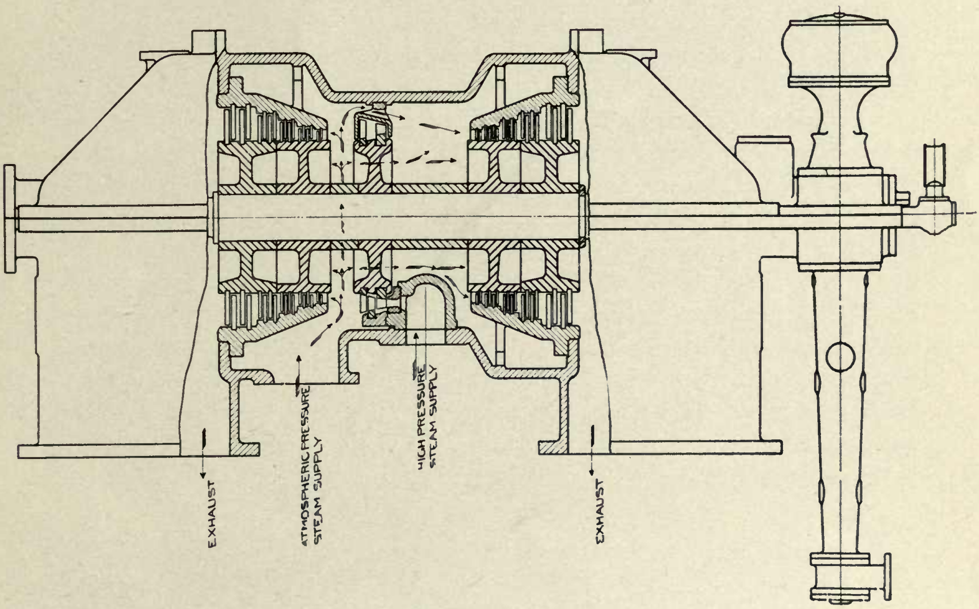
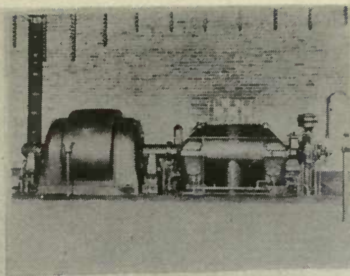
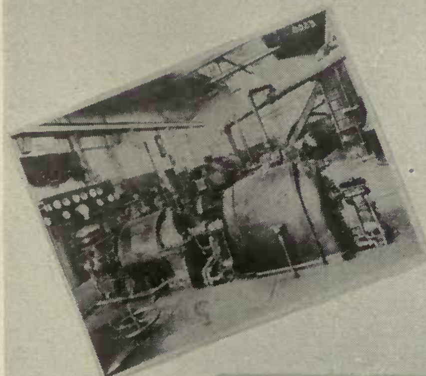


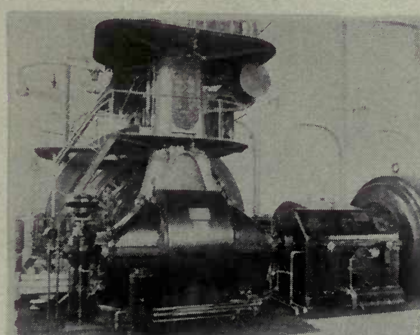
Fig. 18.—Case H.

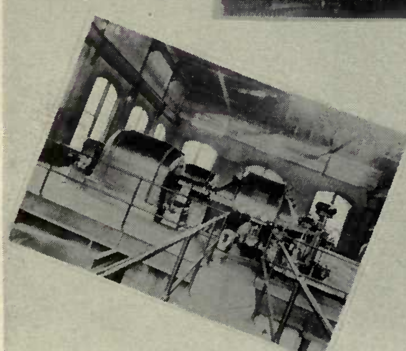
over which the output of the turbine is desired and when it would, therefore, be preferable to arrange to operate on live steam. Or again there may be constantly available an amount of exhaust steam insufficient to carry the average load on the turbine. The simple low pressure turbine does not have a high efficiency when operating with live steam, and in this case, therefore, a special type of machine is employed. This is commonly called the mixed pressure turbine; but as used here, this expression refers specifically to a turbine having a separate high and low pressure element in one cylinder. All such turbines of course, are fitted with governors and special valves arranged to supply high pressure steam to appropriate nozzles when the supply of exhaust steam is insufficient or fails entirely. The steam is then expanded in the high pressure nozzles and its expansive energy absorbed down to the pressure at the inlet to the low pressure elements. Such a turbine is obviously the same as any other low pressure turbine fitted with a governor and live steam valve, except that the live steam passes through the high pressure element before entering the low pressure section.

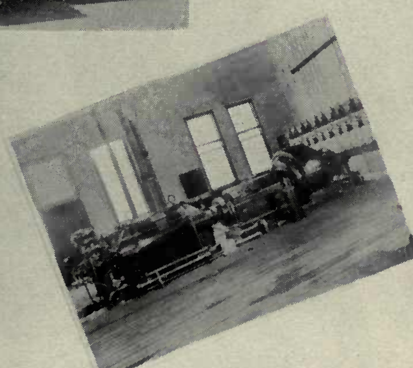
A large number of applications of such a mixed pressure turbine may very conveniently be made where the exhaust steam available comes from pumps or other apparatus of that kind, but it is generally not suited for work in large sizes, the most economical solution of the problem being afforded by the use of a small low pressure turbine and another complete expansion machine to give the necessary capacity. Again a solution of the problem may be found in Case C or F. It should be remembered that the high pressure element revolving without doing work when the turbine is running on exhaust steam, is a source of loss amounting to at least 2%; and further than this, it adds a complication to what has been previously pointed out as an inherently simple machine. In cases where they are desirable, the construction consists of an impulse element in which the energy of expansion to approximately atmospheric pressure is absorbed, the remainder of the energy being taken out through reaction low pressure elements. A sectional view of such a machine is shown in Fig. 14. The control valves are so arranged that no high pressure steam is admitted until the low pressure valve is fully open, or in other words, until the turbine is unable to carry its load with the available supply of exhaust steam. There may occasionally arise a case where a mixed pressure turbine could be used, as in Case G, in which event the check valve indicated as desirable should not be omitted.











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