STEAM TURBINE ENGINES

STRUCTION, CARE AND OPERATION
WITH QUESTIONS AND ANSWERS

SWINGLE

STEAM TURBINE ENGINES

Their Construction, Care and Operation

The principles governing the Action of the Steam in the
various types of Steam Turbines are clearly set
forth in plain language, not too technical
for the man with an ordinary
education to understand.

*Full Instructions Regarding Correct
Methods of Operating Steam Turbines,
Adjusting Clearances, etc., etc. :*

BY

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Author of "Twentieth Century Hand Book for Steam Engineers and
Electricians," "Modern Locomotive Engineering,"
"Modern Steam Boilers" and "Catechism
for Engineers and Electricians."

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INTRODUCTION

The rapid increase within recent years, in the number of installations of steam turbines for power purposes, renders it absolutely necessary that the engineer who is in charge of, or is confronted with a possibility of being placed in charge of a steam turbine plant, should make himself thoroughly acquainted with the principles controlling the action of steam turbines; also the details connected with their care, and successful operation. This knowledge he can obtain by a close study of the following pages, in which are set forth in plain, simple language the underlying principles of the turbine, and its advantages as a prime mover. The book also contains descriptions in detail of the several different types of steam turbines that have, on account of their merits come to be standard in this country. Each type is clearly illustrated and explained. There is also a plain and forcible discussion of methods used in the disposal of the exhaust steam of steam turbines, much of which will also apply to reciprocating engines, and this in itself will prove to be of great benefit to the student engineer, for the reason that in many steam plants conditions exist which call for a complete working knowledge of both the Turbine, and the Reciprocating types of prime movers, due to the fact that both types of engines are often being operated by the same firm or corporation. In addition to the foregoing matter, there is also a complete list of questions and answers pertaining to the principles of steam turbines, and their operation and management, all of which will be found to be of inestimable value to the student seeking knowledge along this line.

The Steam Turbine

Although the turbine principle of utilizing the heat energy in steam and converting it into useful work has been experimented upon for many years, it is only since the inauguration of the twentieth century that steam turbines have been brought to the front as efficient power producers.

The piston of the reciprocating engine is driven back and forth by the static expansive force of the steam, while in the steam turbine not only the expansive force is made to do work, but a still more important element is utilized, viz., the kinetic energy, or heat energy latent in the steam, and which manifests itself in the rapid vibratory motion of the particles of steam expanding from a high, to a low pressure, and this motion the steam turbine transforms into work.

Notwithstanding the fact that much has been said and written during the past four years regarding the steam turbine, the machine is to-day a mystery to thousands of engineers, not because they do not desire information upon the subject, but because of a lack of opportunities for obtaining that information. The author therefore considers that a space devoted to this subject would no doubt be of benefit to his readers.

The steam turbine is simple and compact in design, having few working parts as compared with the reciprocating engine, and any engineer who is capable of operating and caring for an engine of the latter type, can also run and take care of a steam turbine. But, as in the case of the

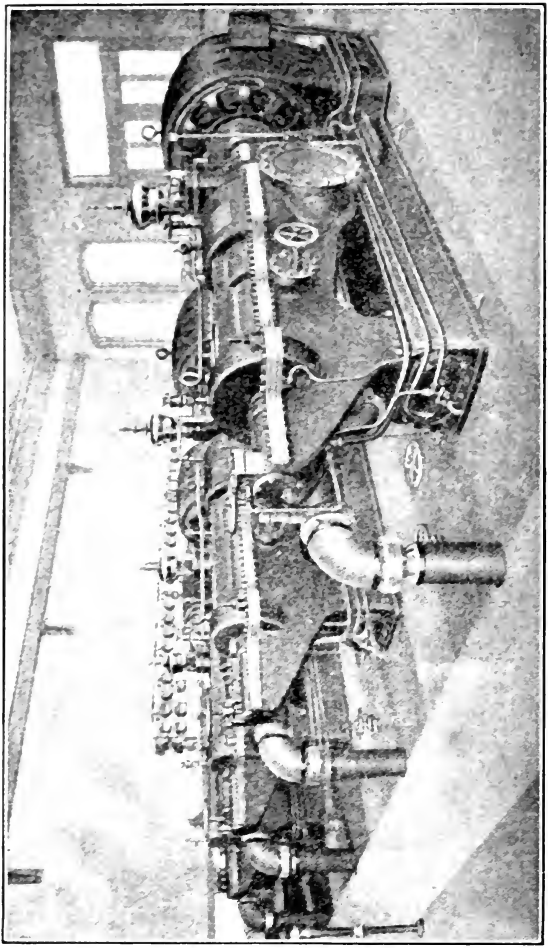


FIG. 235

FOUR WESTINGHOUSE-PARSONS STEAM TURBINES reciprocating engine, the engineer in charge of a turbine plant should be familiar with the interior construction of the machines under his charge, and he should know what to do, and what to avoid in order to keep them in continual and efficient operation.

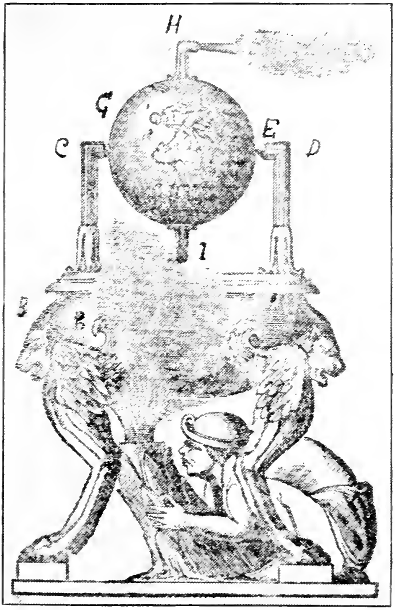


Fig. 236

The steam turbine in principle, and even in type is not new, being in fact the first heat motor of which we have any record in steam engineering.

One of the earliest descriptions of a device for converting the power of steam into work was recorded by Hero, a learned writer who flourished in the city of Alexandria in Egypt, in the second century before Christ. Hero describes a machine called an Aeolipile or "Ball of Aeolus," illustrated in Fig. 236. B is the boiler under which a fire was made. G is a hollow metallic globe that revolved on trunnions C and D, one of which terminated in a pivot at E, while the other was hollow and conveyed the steam generated in the boiler B to the interior of the globe or ball, from which it escaped through the hollow bent tubes H and I, and the reaction of the escaping steam caused the globe to revolve. This was the first steam turbine, and it worked on the reaction principle.

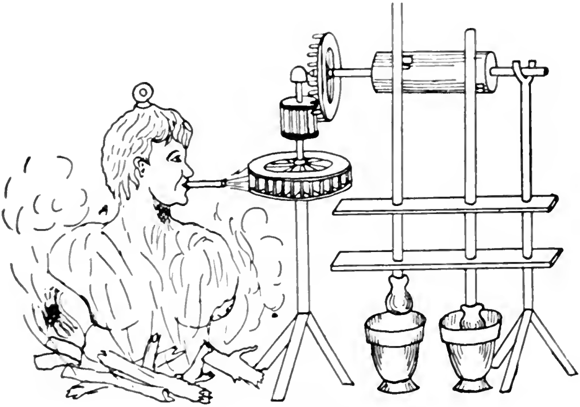


FIG. 237

Many centuries later, in the year A. D. 1629, Branca, an Italian, described an engine which marks a change in the method of using the steam. Branca's engine consisted of a boiler A, Fig. 237, from which the steam issued through a straight pipe, and impinged upon the vanes of a horizontal wheel carried upon a vertical shaft, causing it to revolve. This device was the germ of the impulse turbine, and these two principles, viz., reaction and impulse, either one or the other, and sometimes a combination of both, are the fundamental principles upon which the successful steam turbines of the present age operate.

Steam expanding through a definite range of temperature and pressure exerts the same energy whether it issues from a suitable orifice or expands against a receding piston.

Two transformations of energy take place in the steam turbine; first, from thermal to kinetic energy: second, from kinetic energy to useful work. The latter alone presents an analogy to the hydraulic turbine.

The radical difference between the two turbines lies in the low density of steam as compared to water, and the wide variation of its volume under varying temperatures and pressures.

A cubic foot of steam under 100 lbs. pressure, if allowed to discharge into a vacuum of 28 inches, would attain a theoretical velocity of 3,860 feet per second and would exert 59,900 ft. lbs. of energy.

A law of turbo-mechanics specifies that in order to obtain the highest efficiency in the operation of turbines (whether water or steam) the relation between bucket speed and fluid speed, (steam in this case), should be as follows:

For purely impulse wheels, bucket speed equals one-half of jet speed.

For reaction wheels, bucket speed equals jet speed.

Assuming the velocity of the jet of steam issuing from the nozzle to be 4,000 feet per second, this would mean a peripheral speed of 2,000 feet per second for an impulse wheel, and for a wheel 1 foot in diameter the speed would be 38,100 R. P. M. But such a speed is beyond the limits of strength of material, and the speed of steam turbines is accordingly kept within the bounds of safety, and strength of material.

Form of Blade.—The blades or buckets should be of such form, and curvature as will permit the steam to expand to the desired final, or terminal pressure with the smallest possible friction and eddy current losses. As to directing the flow in the desired course, the direction of exit from the guide, and rotating wheel is of the greatest importance. In order to get the desired angle, the last part of the blade should be kept straight, at least to the foot of the perpendicular dropped from A_1, or the length A B in Fig. 238. From there on, the channel should lead in easy curvature to the angle a_1. The construction according to a in Fig. 238 would obviously be too sharp, and would cause the steam stream to separate from the wall.

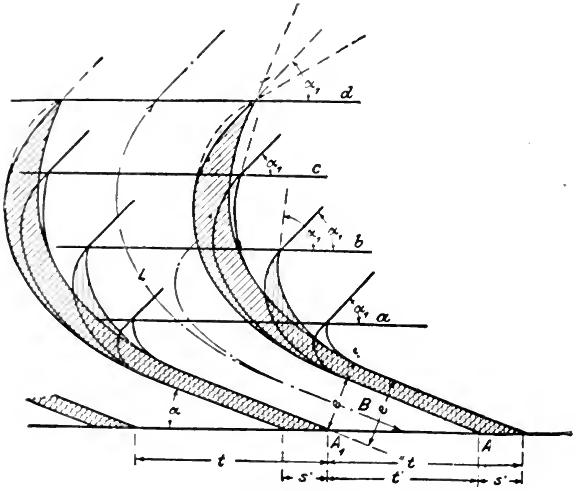


FIG. 238

The construction according to b would suffice, and the wheel radius would depend, above all, upon how far we wish to diminish the shock at entrance. For the profile b the angle a_1 is taken as the slope of the blade back, from which we obtain for the guiding blade surface the somewhat large angle a_1'. This would be more favorable with c, and d, but the latter would obviously give a needlessly long steam path. Besides, a pointing of the blade such that a_1 is half of a_1', as is shown dotted at d, could be considered just as correct as the first mentioned. By drawing the absolute steam path and finding the decrease of peripheral speed, we get useful results concerning the regularity of delivering work.

The proper length of the channel, or steam path can only be determined by practical experience, and with a given curvature the ratio of length to breadth can be considered fairly constant.

Stuffing Boxes.—The stuffing boxes are the most important and delicate part of the steam turbine. As they are subjected to high temperature on account of their proximity to the steam space, the problem of getting rid of their own heat of friction becomes all the more difficult. The advantage of the stuffing box used on reciprocating engines, where the rod for part of the time is exposed to the air, and cools at least its surface by radiation, cannot be considered with the rotating shaft. Water-cooling may be an effective means, but creates considerable loss by condensation in the surrounding steam spaces.

The majority of designers get around this difficulty by avoiding contact between packing and shaft, and secure tightness only by the least possible clearance. This is the principle of the so-called "labyrinth stuffing box" that was first generally used by Parsons. This is shown in Fig. 239, in which A is the shaft, B the stuffing box. The rings

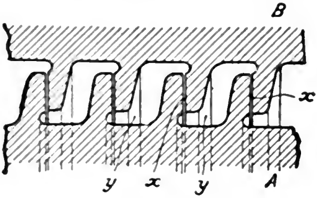


Fig. 239

LABARYNTH STUFFING BOX

on both parts form alternately a narrow space x, and a large space y. The velocity of the steam flowing through this narrow space is destroyed by eddy-currents in the large space, so that for further velocity, a part of the drop in pressure is utilized. With a large number of rings, and with very small spaces x, the loss is greatly decreased.

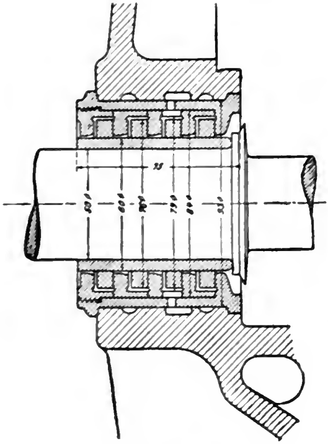


Fig. 240

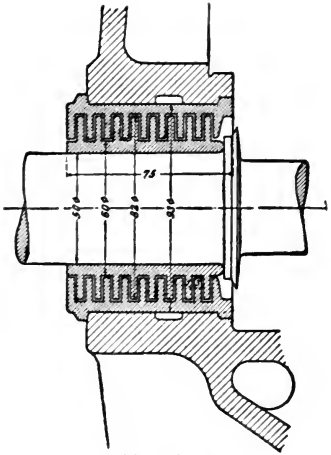


Fig. 241

It also seems to have a favorable influence when the steam in leaving this narrow space flows radially inwards, that is, it helps to overcome its centrifugal force.

Fig. 240 shows the stuffing box of a *Schulz* turbine. No provision is here made for enlarged spaces, but the necessary throttling is accomplished by the great length of the labyrinth path. The designer hoped to limit his clearance to 1 mm. (0.039 in.). The outer box is made in two parts.

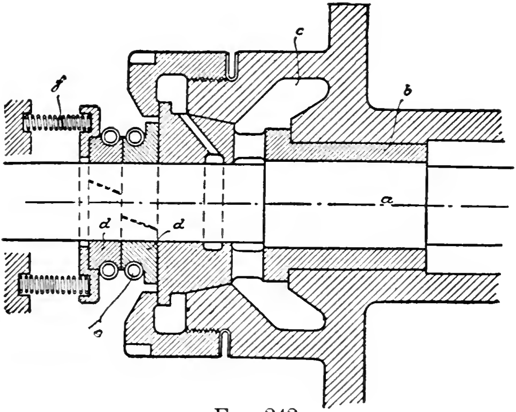


FIG. 242

Fig. 241 shows a stuffing box by the same designer, built of rings, in which the inner rings are loose, but are made with a neat fit.

The Rateau stuffing box is shown in Fig. 242. The main part consists of the shaft, a, enclosed by a close fitting box b, of suitable metal. The steam leaking through this space flows into chamber c, where a constant pressure of about 12 lbs. absolute is maintained by a reducing valve. From the valve the steam is led to a condenser. Chamber c, is kept steam tight from the outside by two bronze rings

d. d. each made in three parts, which are held against the shaft with slight pressure by the spiral springs e. A pressure in an axial direction is caused by springs f. The chambers of all the stuffing boxes of the turbine are connected together. Thus a portion of the steam that leaves the high pressure chamber will be drawn into the low pressure side. When running light, partial vacuum exists in all the stuffing boxes, the reducing valve allowing live steam to enter, thus preventing air from being drawn in.

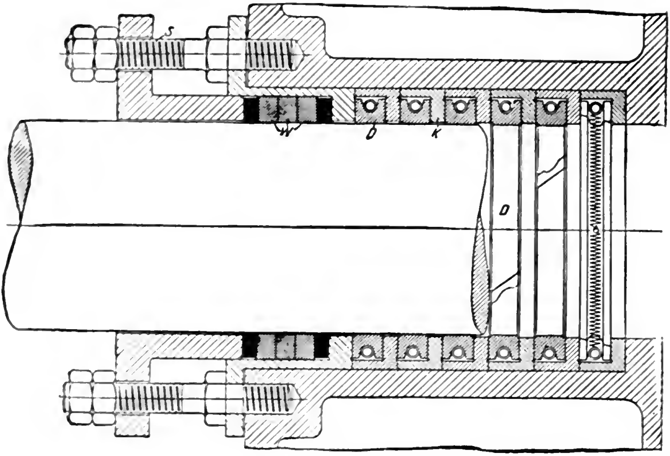


FIG. 243

Steam is led in Figs. 240 and 241 through the ring passages, and excludes thereby the air, so that the vacuum does not suffer.

The construction of a turbine stuffing box as steam tight as that of the steam engine is still an unsolved problem. For this reason we might add the excellent stuffing box of Schwabe, that is used in steam-engine work, shown in Fig. 243. This consists of a large number of rings D made in three parts, held together by a circumferential spiral spring. These rings (for the steam engine) press on one another, and should either not touch the shaft at all, or with only the slightest pressure. With turbines, the soft packing at the outer end will of course be omitted, and the rings must be prevented from turning, and so constructed as to be tight against either pressure or vacuum. The inside and outside ends of the box are provided with means for oiling.

The Regulation of the Steam Turbine.—The regulation in the majority of different systems is acomplished by simple throttling, thus decreasing, at the very beginning, the available work of the steam, and consequently the economy of the turbine. The loss is measured by the product of the increase of entropy and the absolute temperature of the exhaust steam, which can easily be determined from the entropy tables.

The ideal conditions would be to constantly work with a full initial pressure, and to make all cross-sections of steam passages suitable to the power required. Constructively; this idea is most easily applicable to the single stage impulse turbine, in which the nozzles are opened or closed one after another by means of a regulator.

The following description of the construction, and principles controlling the action of the leading types of steam turbines manufactured in the United States is presented, with the hope that it may prove to be not only interesting, but instructive as well, to the student.

It may be said in general of the steam turbine, that it has passed the experimental stage, and has come to the front as an efficient power producer, having a bright future before it. It has solved the problem of using superheated steam, owing to the absence of all rubbing parts exposed to the steam. This permits the use of steam of high temperature, thus making it possible to realize the advantages of economical operation.

The Westinghouse-Parsons Steam Turbine

The Westinghouse-Parsons Steam Turbine operates on both impulse and reaction principles, and by a system of compounding, which will be explained later on, the peripheral velocity of the machine has been so reduced as to bring it within practical limits, while at the same time the power value of the steam is utilized to a high degree of efficiency.

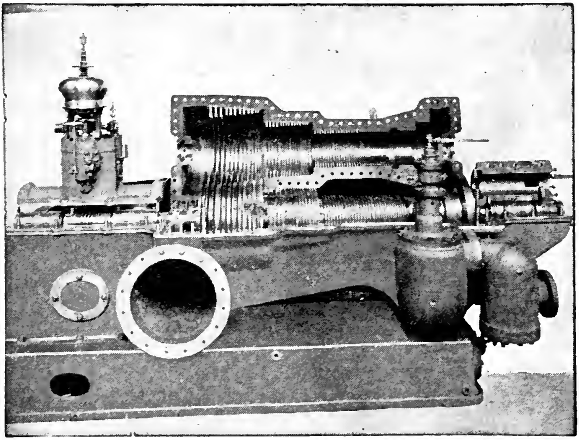


FIG. 244

The speed of the Westinghouse-Parsons turbine varies from about 750 R. P. M. for a 5,000 K. W. machine, to 3,600 R. P. M. for a 400 K. W. turbine.

The Westinghouse-Parsons turbine is fundamentally based upon the invention of Mr. Charles A. Parsons, who, while experimenting with a reaction turbine constructed along the lines of Hero's engine, conceived the idea of combining the two principles, reaction and impulse, and also of causing the steam to flow in a general direction parallel with the shaft of the turbine. This principle of parallel flow is common to all four types of turbines, but is perhaps more prominent in the Westinghouse-Parsons, and less so in the De Laval.

Fig. 235 shows a general view of four Westinghouse-Parsons steam turbines, and Fig. 244 shows a 600 H. P. machine with the upper half of the cylinder, or stator as it is termed, thrown back for inspection. Fig 245 is a sectional view of a Westinghouse-Parsons turbine, and it will be noticed that there are three sections or drums, gradually increasing in diameter from the inlet A, to the third and last group of blades. This arrangement may be likened in some measure to the triple compound reciprocating engine.

Fig. 246 shows the complete revolving part of a 3,000 H. P. turbine. Its weight is 28,000 lbs., length over all 19 feet 8 inches, and 12 feet 3 inches between bearings; the largest diamater, 6 feet.

By reference to Fig. 244 it will be seen that the inside of the cylinder is studded with rows of small stationary blades, and that the rotor or revolving part of the machine is also fitted with rows of small blades, similar in shape and dimensions to the stationary blades. When the upper half of the cylinder is in position, each row of stationary blades fits in between two corresponding rows of moving blades. This arrangement may perhaps be better

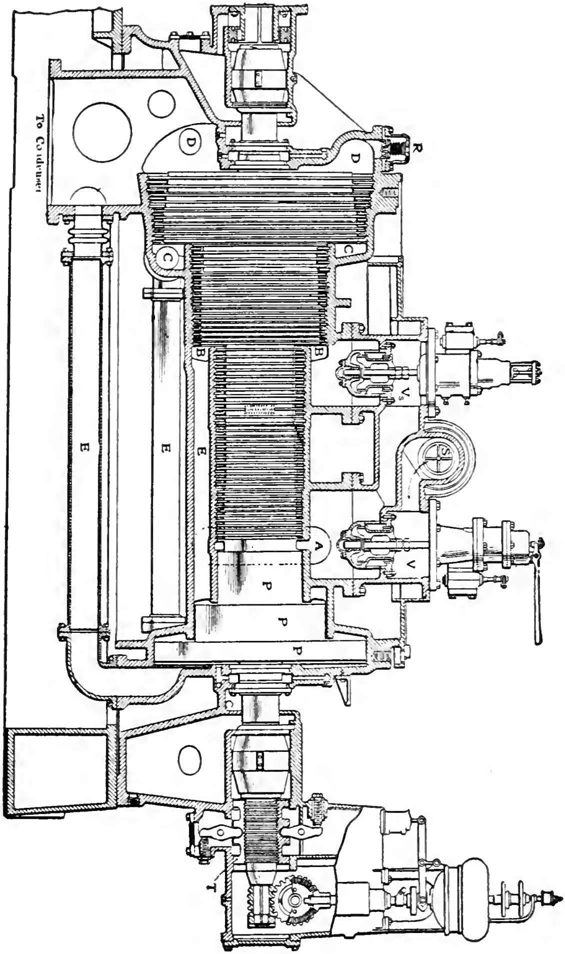


FIG. 245

SECTION OF STANDARD WESTINGHOUSE SINGLE FLOW TURBINE understood by reference to Fig. 247, which illustrates the relation of the stationary blades to the moving blades when in position, and also shows by the arrows the course of the steam and its change of direction caused by the stationary blades.

For the purpose of explanation the moving blades or vanes may be considered as small curved paddles projecting from the surface of the rotor, and there is a large number of them, as for instance, taking a 400 K. W. machine, there are 16,095 moving blades and 14,978 stationary blades, a total of 31,073.

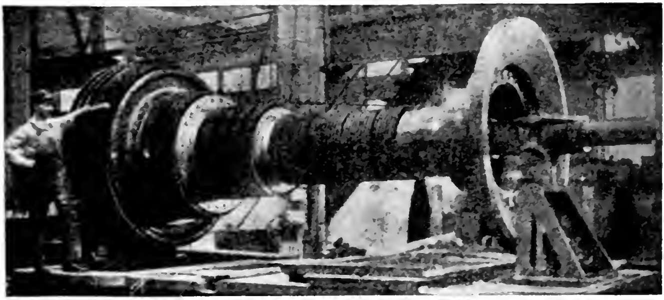


FIG. 246

The stationary vanes, as previously explained project from the inside surface of the cylinder. Both stationary and moving vanes are similar in shape, and are made of hard drawn material, and they are set into their places and secured by a caulking process. The blades vary in size from 1½ to 7 in. in length, according to where they are used. Referring to Fig. 244, it will be observed that the shortest blades are placed at what might be termed the steam end of each section or drum of the rotor and cylinder, and that their length gradually increases, corresponding with the increased volume of steam, until a mechanical limit is reached, when a new group of blades begins on a succeeding drum of larger diameter. Referring to Fig. 247, which is a sectional view of four rows of blades, it will be noticed that all the blades, whether stationary or moving; have the same curvature. Also that the curves are set opposite each other. The reason for this will be apparent as the diagram is studied. The steam at pressure P first comes in contact with row 1 of stationary blades. It expands through this row, and in expanding the pressure falls to P′.

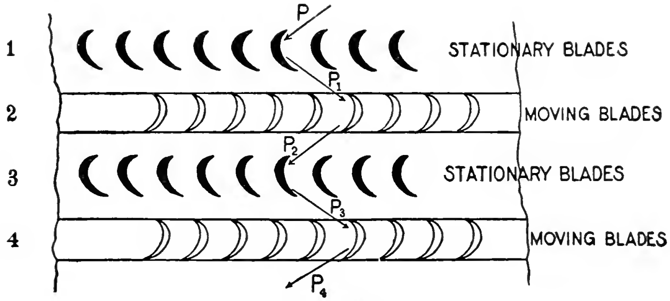


FIG. 247

The energy in the steam is converted into velocity, and it impinges upon row 2 of moving blades, driving them around in their course by impulse. A second expansion now occurs in row 2, and again the energy is converted into velocity, but this time the reaction of the steam as it leaves the blades of row 2 also tends to impel them around in their course. The moving blades thus receive motion from two causes—the one due to the impulse of the steam striking them, and the other due to the reaction of the steam leaving them.

This cycle is repeated in rows 3 and 4, and so on throughout the length of the rotor until the exhaust end is reached.

It should be noted that the general direction taken by the steam in its passage through the turbine is in the form of a spiral or screw line about the rotor. The clearance between the blades as they stand in the rows is ⅛ in. for the smallest size blades and ½ in. for the larger ones, gradually increasing from the inlet to the exhaust. In the 5,000 K. W. machine the clearance at the exhaust end between the rows of blades is 1 in. It will thus be seen that there is ample mechanical clearance, also allowance for lateral motion for adjustment of the rotor, although this is very slight, as the rotor is balanced at all loads and pressures by the balancing pistons PPP, Fig. 245, to which reference is now made. These pistons revolve within the cylinder, but do not come in mechanical contact with it; consequently there is no friction. The diameter of each piston corresponds to the diameter of one of the three drums.

The steam entering the chamber A through valve V presses against the turbine blades and goes through doing work by reason of its velocity. It also presses equally in the opposite direction against the first piston P, and so the shaft or rotor has no end thrust. On leaving the first group of blades and striking the second group the pressure in either direction is again equalized by the balance port E allowing the steam to press against the second balance piston P. The same event occurs at group three, the steam acting upon the third piston P.

The areas of the balancing pistons are such that, no matter what the load may be, or what the steam pressure or exhaust pressure may be, the correct balance is maintained and there is practically no end thrust. Below is shown a pipe E connecting the back of the balancing pistons with the exhaust chamber. This arrangement is for the purpose of equalizing the pressure at this point with the pressure in the exhaust chamber.

It might be thought that the blades, on account of their being so light and thin, would wear out very fast, but experience so far shows that they do not. This may be accounted for in two ways. First, the reduction of the velocity of the steam, the highest velocity in the Parsons turbine not exceeding 600 ft. per second; secondly, the light steam thrust on each blade, said to be equal to about 1 oz. avoirdupois. This is far within the bending strength of the material. A steam strainer is also placed in the admission port, to prevent all foreign substances from entering the turbine.

A rigid shaft and thrust or adjustment bearing accurately preserves the clearances, which are larger in this turbine than in other types, owing to the fact that the entire circumference of the turbine is constantly filled with working steam when in operation.

The bearings shown in Fig. 245 are constructed along lines differing from those of the ordinary reciprocating engine. The bearing proper is a gun metal sleeve, see Fig. 248, that is prevented from turning by a loose-fitting dowel. Outside of this sleeve are three concentric tubes having a small clearance between them. This clearance is kept constantly filled with oil supplied under light pressure, which permits a vibration of the inner shell or sleeve and at the same time tends to restrain or cushion it. This arrangement allows the shaft to revolve about its axis of gravity, instead of the geometrical axis, as would be the case if the bearing were of the ordinary construction. The journal is thus to a certain degree a floating journal, free to run slightly eccentric according as the shaft may happen to be out of balance.

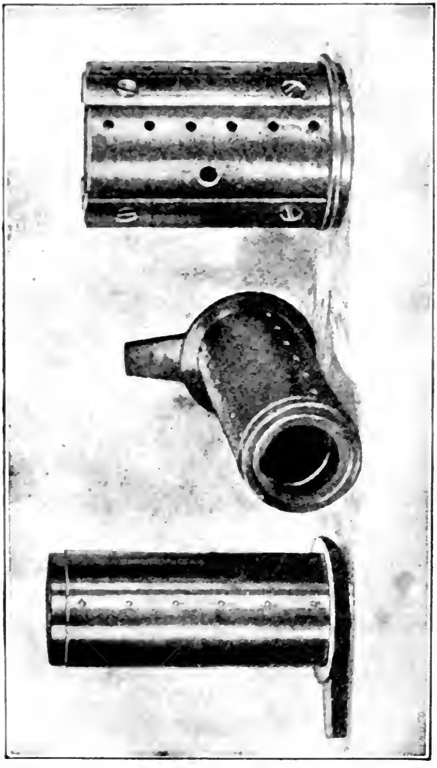


FIG. 248

A flexible coupling is provided, by means of which the power of the turbine is transmitted to the dynamo or other machine it is intended to run. The oil from all the bearings drains back into a reservoir, and from there it is forced up into a chamber, where it forms a static head, which gives a constant pressure of oil on all the bearings. A secondary valve is located at Vs, by means of which high pressure steam may be admitted to the steam space E on the same principle that high pressure steam is admitted to the low pressure cylinder of a compound engine. This valve opens automatically in cases of emergency, such as overload, failure of the condenser to work, etc.

The shaft, where it passes through either cylinder head, is packed with a water seal packing, consisting of a small paddle wheel attached to the shaft, which, through centrifugal action, maintains a static pressure of about 5 lbs. per sq. in. in the water seal, thus preventing all leakage while at the same time it is frictionless.

Governor.—The speed of the Westinghouse-Parsons turbine is regulated by a fly ball governor constructed in such manner that a very slight movement of the balls serves to produce the required change in the supply of steam. Fig. 249 is a diagram of the governor mechanism. The ball levers swing on knife edges instead of pins. The governor works both ways, that is to say, when the levers are oscillating about their mid position a head of steam corresponding to full load is being admitted to the turbine, and a movement from this point, either up or down, tends to increase or to decrease the supply of steam.

Referring to Fig. 249, B is a piston directly connected to the admission valve. Steam is admitted to this piston under control of the pilot valve A, which has a slight but continuous reciprocating motion derived from the eccentric rod C, and the function of the governor is to vary the plane of oscillation of this valve, thus causing it to admit more or less steam to piston B. The admission valve, being actuated exclusively by piston B, is thus caused to remain open for a longer or shorter period of time, according to the load upon the turbine.

The vibrations of the admission valve, although very slight, are continuous and regular, about 165 per minute, and are transmitted primarily by means of an eccentric, the rod of which is shown at C, Fig. 249.

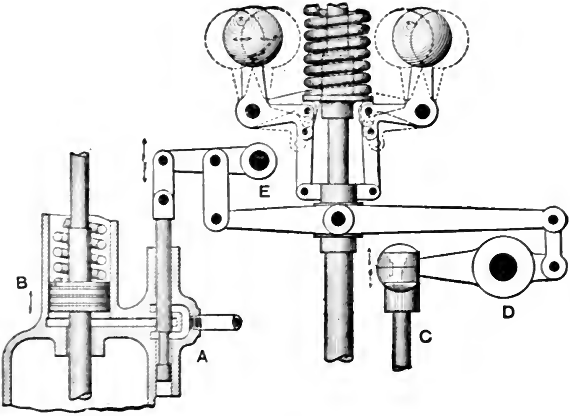


Fig. 249

The governor sleeve is used as a floating fulcrum, and the points D and E are fixed. By means of this very ingenious device the steam is admitted to the turbine in puffs, either long or short, according to the demand for steam. At full load the puffs merge into an almost continuous blast. When the load has increased to the point where the valve is wide open continuously, a full head of steam is being admitted. Beyond this the secondary valve comes into action, thus keeping the speed up to normal.

The rotor requires perfect balancing to insure quiet running, but this is easily accomplished in the shop by means of a balancing machine used by the builders.

Steam turbines generally show higher efficiency in the use of steam than reciprocating engines do, and this fact is due to three leading causes. First, it is possible with the turbine to use highly superheated steam which, owing to the difficulties attending lubrication, could not be used in the reciprocating engine. Second, a larger proportion of the heat contained in the steam is converted into work, for the reason that the steam is allowed to expand to a much lower pressure, and into a higher vacuum. In addition to this, the velocity of the expanding steam is utilized in a much higher degree in the turbine as compared with the reciprocating engine. Third, mechanical friction or lost work is reduced to the minimum. Under test a 400 K. W. Westinghouse-Parsons steam turbine, using steam at 150 lbs. initial pressure and superheated about 180°, consumed 11.17 lbs. of steam per brake horse power hour at full load. The speed was 3,550 R. P. M. and the vacuum was 28 in.

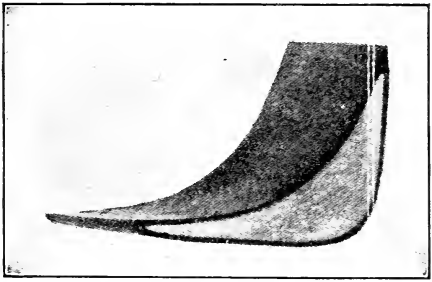


FIG. 250
NEW BLADING MATERIAL

With dry saturated steam the consumption was 13.5 lbs. per B. H. P. hour at full load, and 15.5 lbs. at one-half load.

A 1,000 K. W. machine, using steam of 150 lbs. pressure and superheated 140°, exhausting into a vacuum of 28 in., showed the very remarkable economy of 12.66 lbs of steam per E. H. P. per hour.

A 1,500 K. W. Westinghouse-Parsons turbine, using dry saturated steam of 150 lbs. pressure with 27 in. vacuum, consumed 14.8 lbs. steam per E. H. P. hour at full load, and 17.2 lbs. at one-half load.

The Westinghouse machine company have recently introduced a new blade material which is now used in all Westinghouse turbines. It is a copper-coated steel blade, or, as designated by the builder, "Monnot metal," in which the copper coating (seen in Fig. 250) is chemically welded to the steel so thoroughly that the blades can be drawn to the desired shape from the original ingot, without weakening the union between the copper and steel. The process of drawing makes the copper coating somewhat thicker at the inlet and outlet edges of the blade, though the remaining portions of the blade surfaces are coated with an absolutely uniform thickness of copper. The only portion of the blade where steel is exposed, is the small surface of the tip of the blade where, however, corrosion is the least detrimental, for should the tips corrode, the copper coating would still remain intact, thus leaving the working blade surfaces untouched and the blade clearances unaltered.

Figs. 251 and 252 show sectional elevations of the double flow type of steam turbines now being manufactured by the Westinghouse company, in addition to the standard single flow turbine already described.

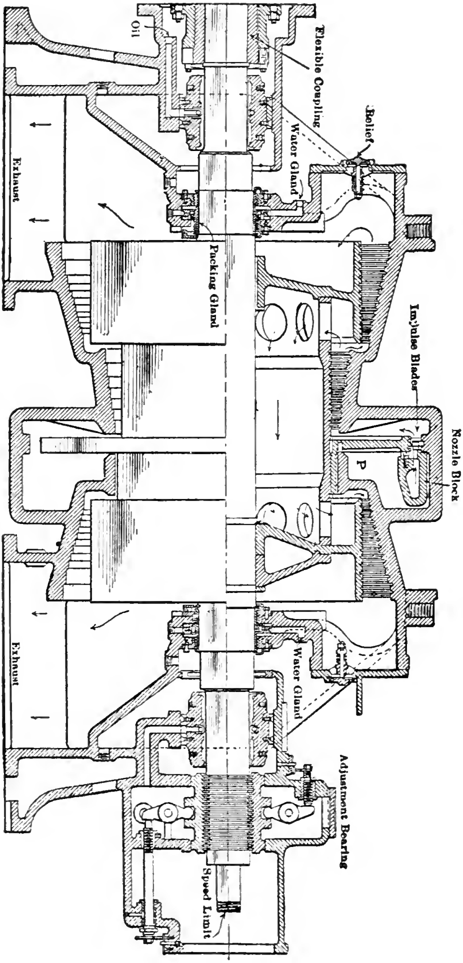


Fig. 251
SECTION OF WESTINGHOUSE DOUBLE FLOW TURBINE

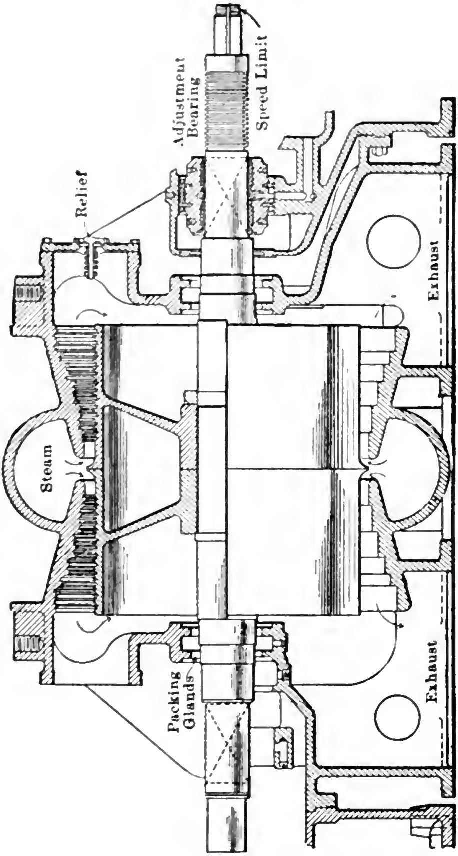


Fig. 252

WESTINGHOUSE DOUBLE FLOW LOW-PRESSURE TURBINE

Sectional Elevation

Fig. 251 shows the machine as adapted for using steam of high initial pressure, in fact an impulse turbine, in which the steam admitted first to the nozzle block, is expanded in nozzles arranged about the periphery, and impinges upon the impulse buckets of the central rotation wheel. There are two rows of moving blades upon the impulse wheel, with an intermediate set of reversing blades as shown. Issuing from the delivery side of this wheel with its velocity energy practically all abstracted, the steam passes, as shown by the arrow, to an intermediate set of Parsons blading. As this blading has no counterpart upon the other side of the turbine, the pressure upon it must be counterbalanced, and this is done by making the extension of the hub by which the impulse wheel is keyed to the shaft, into a piston or dummy of the mean diameter of the intermediate stage, as shown at P. After passing the intermediate stage the steam divides, one portion passing directly to the low-pressure blading at the left, while the rest passes through the hollow shell of the rotor to the similar pressure blades upon the right. As these sections are equal and symmetrical they counterbalance each other, so that no further dummies are required than the small one already referred to.

For regulating the steam supply in accordance with the load, two methods other than that of simple throttling with its sacrifice of temperature head are available.

The admission area may be varied by the cutting in and out of nozzles.

The duration of the time of admission through a constant area may be varied.

The first is the Curtis method, impracticable for a full-admission turbine like the Parsons: the second, that which has been developed by the Westinghouse engineers for the Parsons as they build it. The adoption of the partial admission for first stage in the double flow machine gave the

Westinghouse designers their option of the two methods, but they have preferred to continue the variable duration puff system, already described in connection with single flow machines. A disadvantage of the variable nozzle method of regulation is, that if the area of the nozzles of the succeeding stages is correctly proportioned to pass along the steam admitted by a certain number of primary nozzles, it will be too great when fewer nozzles are in action, and too small when there are more. This will result in a considerable variation of the pressure in the succeeding stages, and of the pressure ratios of expansion and jet velocity acquired in those stages, and interfere with the designer's intention with regard to the distribution of work and the relation of blade to jet velocity. This could be overcome only by adjusting the nozzles of the succeeding individual stages in harmony with those of the initial stage.

If, on the other hand, the passages through the turbine are permanently arranged in the correct relation to each other, this relation will persist whether the flow is continuous or intermittent, and the energy developed can be regulated to the demand by making the flow more nearly continuous, as the load approaches the rated capacity of the machine. So far as the change in initial pressure due to the alternate letting on and shutting off of the steam is concerned, theory indicates, and experiment proves that where the expansion in each stage is but a small part of the total range, as in the Parsons turbine, the initial and terminal pressures of each stage rise and fall, resulting in a fairly constant pressure ratio at each successive expansion; in other words, for small ranges, and throttle governing, the nozzle and blade areas are reasonably correct through a wide range of load and pressure distribution. For this reason the impulse section of the Westinghouse turbine, doing, say, only one-fifth of the total work, is properly proportioned for a wide range in load and may be governed without resorting to intermediate nozzle control, and without sacrifice of economy and fractional loads.

Advantage Gained.—The balancing pistons have been reduced to a minimum. In the single-flow types the high-pressure dummy occupies fully one-half of the total dummy piston length on the shaft, while the low-pressure piston is 2½ times the high-pressure diameter.

A reduction of nearly 50 per cent in shaft span between bearings. Owing to the rotor construction a better loading of the shaft is also obtained: that is, the rotor weight is transmitted to the shaft at points nearer the bearings than in the single-flow rotor, where the weight is largely distributed.

An increase to about double rotative speed made possible by the reduction in shaft span and loading: that is, to a general greater rigidity of the double-flow construction.

A reduction of about 70 per cent in the bulk of the main parts of the machine with practically the same output.

Internal cylinder stresses due to high-pressure and high-temperature steam are avoided by isolating the incoming steam within separate nozzle chambers, so that the main body of the turbine is subjected to steam having not much over 75 pounds gauge pressure with practically no superheat.

The bulk of the low-pressure stage is better distributed and the length of the low-pressure blades greatly reduced by subdividing this stage into two parts located at opposite ends of the rotor.

As will be plain from what has preceded, the advantages sought in this form of turbine are constructional and mechanical rather than economic. For high-pressure work the standard Westinghouse-Parsons single-flow turbine will be built up to capacities of 3,000 kilowatts; above 5,000 kilowatts all units will be built upon the double-flow principle. The latter construction will also be used for the low-pressure turbines to which it is so admirably adapted, as shown in Fig. 252, which is a section of the Westinghouse low-pressure, double-flow, steam turbine designed for utilizing the exhaust steam from non-condensing reciprocating engines. Fig. 253 shows a view of a double-flow steam turbine without the generator attached.

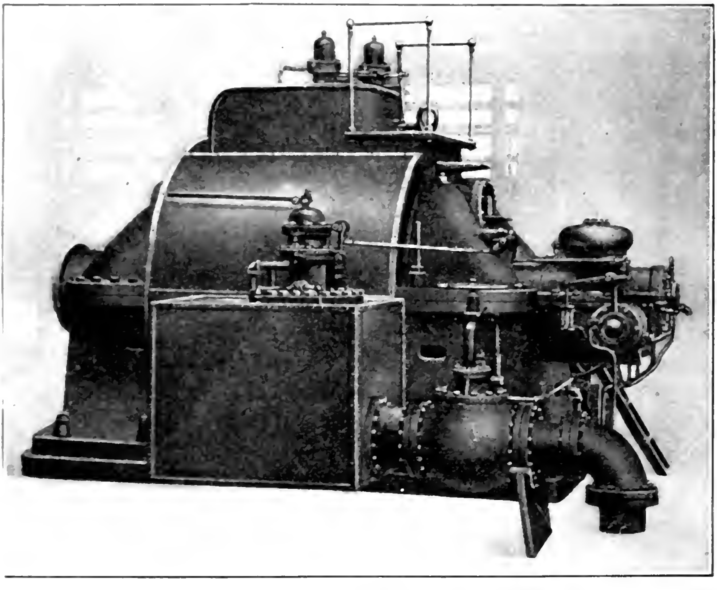


FIG. 253

3,000 K. W. WESTINGHOUSE DOUBLE FLOW STEAM TURBINE

The Curtis Steam Turbine

In the Curtis turbine the heat energy in the steam is imparted to the wheel, both by impulse and reaction, but the method of admission differs from that of the Westinghouse-Parsons, in that the steam is admitted through expanding nozzles in which nearly all of the expansive force of the steam is transformed into the force of velocity. The steam is caused to pass through one, two, or more stages of moving elements, each stage having its own set of expanding nozzles, each succeeding set of nozzles being greater in number and of larger area than the preceding set. The ratio of expansion within these nozzles depends upon the number of stages, as, for instance, in a two-stage machine, the steam enters the initial set of nozzles at boiler pressure, say 180 lbs. It leaves these nozzles and enters the first set of moving blades at a pressure of about 15 lbs., from which it further expands to atmospheric pressure in passing through the wheels and intermediates. From the pressure in the first stage the steam again expands through the larger area of the second stage nozzle to a pressure slightly greater than the condenser vacuum at the entrance to the second set of moving blades, against which it now impinges, and passes through still doing work, due to velocity and mass.

From this stage the steam passes to the condenser. If the turbine is a four-stage machine and the initial pressure is 180 lbs., the pressure at the different stages would be distributed in about the following manner: Initial pressure, 180 lbs.; first stage, 50 lbs.; second stage, 5 lbs.; third stage, partial vacuum, and fourth stage, condenser vacuum.

Fig. 254 gives a general view of a 5,000 K. W. turbine and generator. The generator is shown at the top, while the turbine occupies the middle and lower section. A portion of the inlet steam pipe is shown, ending in one nozzle group at the side. There are three groups of initial nozzles, two of which are not shown. The revolving parts of this unit are set upon a vertical shaft, the diameter of the

FIG. 254

5,000 K. W. CURTIS STEAM TURBINE DIRECT CONNECTED TO 5,000 K. W. THREE-PHASE ALTERNATING CURRENT GENERATOR shaft corresponding to the size of the unit. For a machine having the capacity of the one illustrated by Fig. 254 the diameter of the shaft is 14 in.

The shaft is supported by, and runs upon a step bearing at the bottom. This step bearing consists of two cylindrical cast iron plates, bearing upon each other and having a central recess between them into which lubricating oil is forced under pressure by a steam or electrically driven pump, the oil passing up from beneath. A weighted accumulator is sometimes installed in connection with the oil pipe as a convenient device for governing the step bearing pumps, and also as a safety device in case the pumps should fail, but it is seldom required for the latter purpose, as the step bearing pumps have proven, after a long service in a number of cases, to be reliable. The vertical shaft is also held in place and kept steady by three sleeve bearings, one just above the step, one between the turbine and generator, and the other near the top. These guide bearings are lubricated by a standard gravity feed system. It is apparent that the amount of friction in the machine is very small, and as there is no end thrust caused by the action of the steam, the relation between the revolving and stationary blades may be maintained accurately. As a consequence, therefore, the clearances are reduced to the minimum.

The Curtis turbine is divided into two or more stages, and each stage has one, two or more sets of revolving blades bolted upon the peripheries of wheels keyed to the shaft. There are also the corresponding sets of stationary blades, bolted to the inner walls of the cylinder or casing. As in the Westinghouse-Parsons type, the function of the stationary blades is to give direction to the flow of steam.

Fig. 255 illustrates one stage of a 500 K. W. turbine in course of construction. It will be observed that there are three wheels, and that in the spaces between these wheels the stationary buckets or vanes are placed, being firmly bolted to the casing. Fig. 256 shows sections of both revolving and stationary buckets ready to be placed in position. The illustration in Fig. 255 shows the lower or last stage. The clearance between the revolving and stationary blades is from $\frac{1}{32}$ to $\frac{1}{16}$ in., thus reducing the wasteage of steam to a very low percentage. The diameters of the wheels vary according to the size of the turbine, that of a 5,000 K. W. machine being 13 ft.

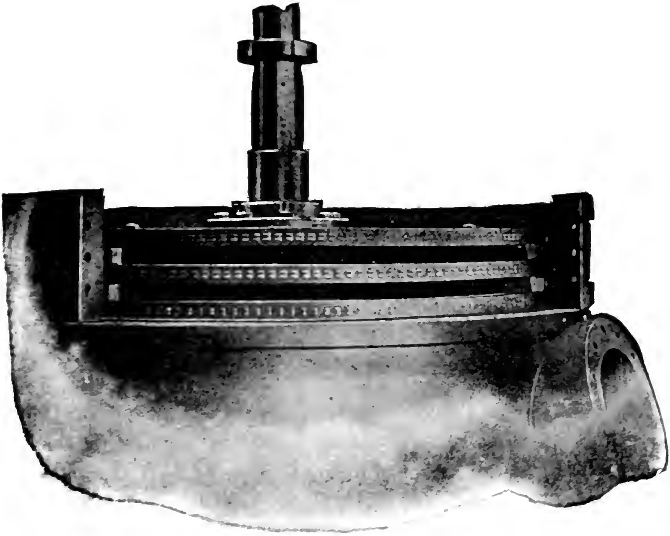
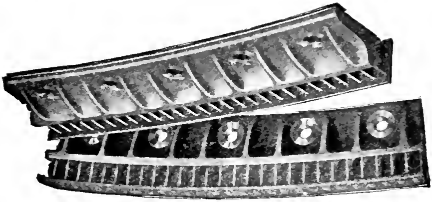
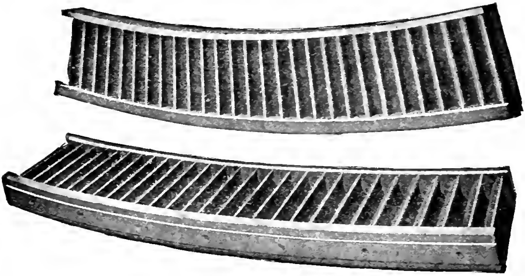


FIG. 255

500 K. W. CURTIS STEAM TURBINE IN COURSE OF CONSTRUCTION



REVOLVING BUCKETS FOR CURTIS STEAM TURBINE



STATIONARY BUCKETS FOR CURTIS STEAM TURBINE
FIG. 256

FIG. 257
NOZZLE

Fig. 257 shows a nozzle diaphragm with its various openings, and it will be noted that the nozzles are set at an angle to the plane of revolution of the wheel.

Fig. 258 is a diagram of the nozzles, moving blades and stationary blades of a two-stage Curtis steam turbine. The steam enters the nozzle openings at the top, controlled by

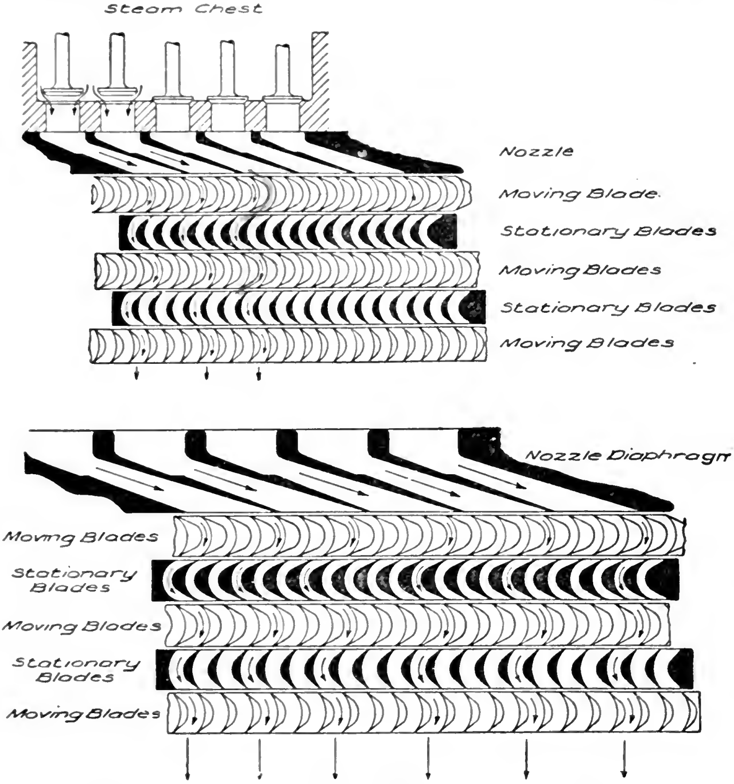


FIG. 258

DIAGRAM OF NOZZLES AND BUCKETS IN CURTIS STEAM TURBINE

the valves shown, the regulation of which will be explained later on. In the cut Fig. 258 two of the valves are open, and the course of the steam through the first stage is indicated by the arrows. After passing successively through the different sets of moving blades and stationary blades in the first stage, the steam passes into the second steam chest. The flow of steam from this chamber to the second stage of buckets is also controlled by valves, but the function of these valves is not in the line of speed regulation, but for the purpose of limiting the pressure in the stage chambers, in a manner somewhat similar to the control of the receiver pressure in a two-cylinder or three-cylinder compound reciprocating engine.

The valves controlling the admission of steam to the second, and later stages differ from those in the first group in that they partake more of the nature of slide valves and may be operated either by hand, or automatically: in fact, they require but very little regulation, as the governing is always done by the live steam admission valves.

Action of the Steam in a Two-stage Machine.—As previously stated, the steam first strikes the moving blades in the first stage of a two-stage machine at a pressure of about 15 lbs. above atmospheric pressure, but with great velocity. From this wheel it passes to the set of stationary blades between it and the next lower wheel. These stationary blades change the direction of flow of the steam and cause it to impinge the buckets of the second wheel at the proper angle.

This cycle is repeated until the steam passes from the first stage into the receiving chamber, or steam chest for the second stage. Its passage from this chamber into the second stage is controlled by valves, which, as before stated, are regulated either by hand, or automatically. The course of the steam through the nozzles and blades of the second stage is clearly indicated by the arrows, and it will be noted that steam is passing through all the nozzles.

At this point it might be well to consider the question which no doubt arises in the mind of the student in his efforts to grasp the underlying principles in the action of the steam turbine. Why is it that the impingement of the steam, at so low a pressure, against the blades or buckets of the turbine, imparts such a large amount of energy to the shaft?

The answer is, because of velocity, and a good example of the manner in which velocity may be made to increase the capacity of an agent to do work is illustrated in the following way: Suppose that a man is standing within arm's length of a heavy plate glass window and that he holds in his hand an iron ball weighing 10 lbs. Suppose the man should place the ball against the glass and press the same there with all the energy he is capable of exerting. He would make very little, if any, impression upon the glass. But suppose that he should walk away from the window a distance of 20 ft. and then exert the same amount of energy in throwing the ball against the glass, a different result would ensue. The velocity with which the ball would impinge the surface of the glass would no doubt ruin the window. Now, notwithstanding the fact that weight, energy and time involved were exactly the same in both instances, yet a much larger amount of work was performed in the latter case, owing to the added force imparted to the ball by the velocity with which it impinged against the glass.

Speed Regulation.—The governing of speed is accomplished in the first set of nozzles, and the control of the admission valves here is effected by means of a centrifugal governor attached to the top end of the shaft. This governor, by a very slight movement, imparts motion to levers, which in turn work the valve mechanism. The admission of steam to the nozzles is controlled by piston valves, which are actuated by steam from small pilot valves which are in turn under the control of the governor Fig. 259 shows the form a governor for a 5,000 K. W. turbine, and Fig. 260 shows the electrically operated admission valves for one set of nozzles.

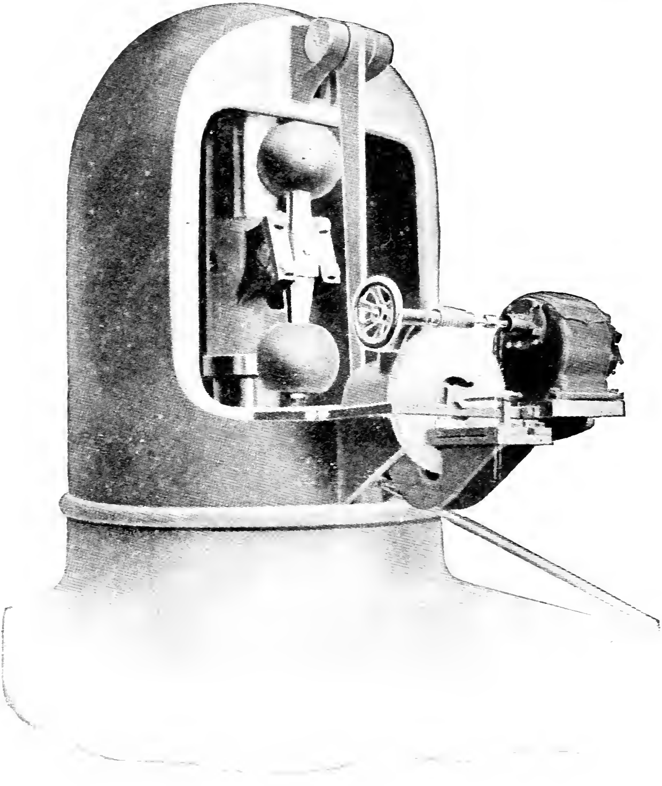


FIG. 259

GOVERNOR FOR 5,000 K. W. TURBINE

Speed regulation is affected by varying the number of nozzles in flow, that is for light loads fewer nozzles are open, and a smaller volume of steam is admitted to the turbine wheel, but the steam that is admitted impinges the moving blades with the same velocity always, no matter whether the volume be large or small. With a full load and all the nozzle sections in flow, the steam passes to the wheel in a broad belt and steady flow.

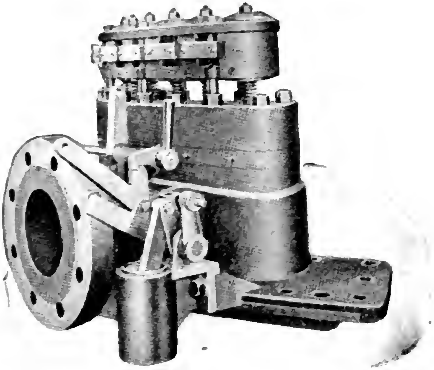


FIG. 260
ELECTRICALLY OPERATED VALVE

In addition to the method just described, of actuating the addmission valves by steam, the General Electric Company, manufactures of the Curtis Turbine, have recently introduced a system of hydraulicaly operated valves for speed regulation.

These valves are also of the poppet type, and each is closed by a helical spring in compression. In the closed position they are held tight by steam pressure, against which they are opened! The valves on one machine are all duplicates, and are opened in rotation by cams (one for each valve) mounted on a shaft, each cam being given in succession an angular advance over its predecessor. This cam shaft is rotated by the piston in a hydraulic cylinder, the cylinder being mounted either on the generator or valve casing.

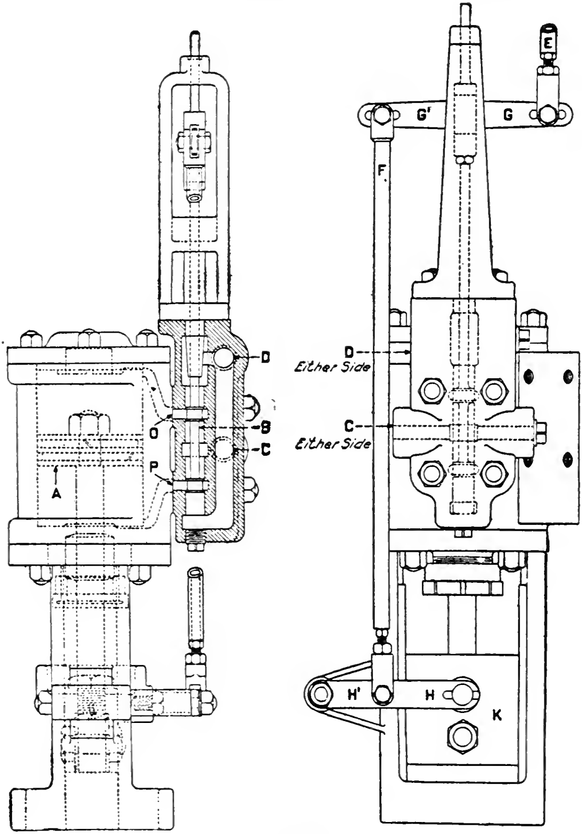


Fig. 261

The valves open gradually: that is there will be throttling on the opening, or closing valve, before the next one in either side is opened or closed, so that the exact amount of steam required can be admitted for any definite load. Fig. 261 shows a section of the hydraulic cylinder, and controlling valve. The position of piston A is controlled by a balanced piston valve B. The liquid under pressure is admitted at C, and discharged at D. The rod E is connected with the governor, and rod F with the piston rod.

Operation.—The rod E receives its motion from the governor, and occupies a fixed position for any given speed between the limits through which the governor is designed to operate. The lever arms G and G′, and H and H′ are so proportioned that the piston A will occupy a definite fixed position to correspond with any position of rod E.

Therefore as the crosshead K transmits its motion through connecting rod N: (see Fig. 262) to the crank L on the cam shaft M, there will be a fixed number of valves open for any position of the governor. While the turbine is operating at a fixed speed, the piston valve will occupy a central position, closing both ports O and P. When there is a drop in speed, the governor causes rod E to move down, thus opening part O to discharge, and port P to admit liquid under piston A which them moves upwards, opening more valves to satisfy the demand for steam. In moving up the piston transmits its motion through rod F to the piston valve B, restoring it to the central position. When operating on a fixed, or slightly varying load, the main piston should not continuously move over a distance greater than that corresponding to the lap of the piston valve, and under no condition of governing should the main piston continually travel back and forth over a dis-

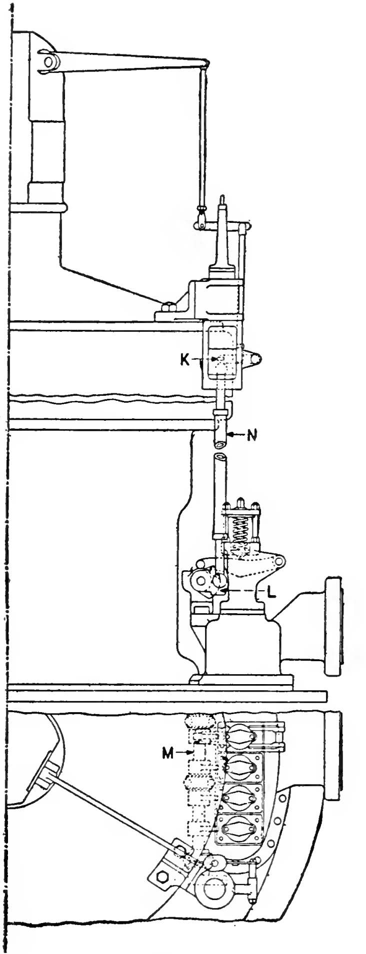


Fig. 262

tance greater than this. Any larger movements should only occur when greater or less power is demanded for considerable variation in load. Any continuous opening and closing of the valves during a steady load is an indication of excessive friction in the governor rigging, or piston valve, and it should be eliminated as soon as possible.

It is essential that the pistons on the piston valve B, Fig. 261 be reduced in diameter at their centers $\frac{1}{32}$ in. as indicated in the illustration. If this is not done it may be responsible for sticking of the piston valve, thereby interfering with the satisfactory regulation of the machine.

For different machines the connections may be altered, and in some the operation is reversed, by crossing the ports, so that the piston A will move in the same direction as the piston valve B, and in the application of the gear to later machines of large capacity, it has been found advisable to place the cylinder horizontal, operating crank shafts of valve casings by means of rack and pinion with bevel gear transmission, or with racks operating directly on pinions on cam shafts, but the principle of operation is the same, only modified in application to suit particular cases.

Adjustment.—With the piston A, and the piston valve B, both in their mid positions, the rod F should be of such a length that the lever G will be horizontal. The connecting rod N is adjusted so that with piston A at the extreme end of its up stroke, all the steam valves are open, and the first one just ready to close. With the piston A in this position (i. e., at the extreme end of its stroke,) and the governor at the low speed position, the rod E should be adjusted so that the piston valve B, will be in its mid position.

Precautions.—(1) It is absolutely essential that all connections between governor and valve be entirely free from friction.

(2) The piston valve B must move freely for the whole length of its stroke, so that if the rod E be disconnected from the arm G, the valve will drop of its own weight, either with pressure on or off.

(3) There must be absolutely no binding at any of the joints through the whole travel.

(4) The liquid used must be entirely free from dirt, or grit, of any nature.

(5) On the main steam valves: in the closed position, when the roller has ridden off of the cam, it must not press on the cam shaft, as this will prevent valve seating properly.

(6) The piston valve and bore must be perfectly round and absolutely straight, or an excessive leakage will be established on one side of the valve, causing it to bind.

(7) The pressure exerted by the main valve springs in the open position must be in excess of that sufficient to overcome steam pressure on rod, and any friction that may exist in packing.

(8) The plate below main valve springs must be a sliding fit in guides at all temperatures.

(9) Care must be taken in the adjustment of the length of the rods E and F, that in no position of the governor, or piston, can the piston valve become jammed at the end of its stroke.

(10) A heavy oil must not be used or the action will be sluggish.

Piping.—Fig. 263 shows a diagram of piping for a machine using oil to operate the valves. This is supplied by the same pumps that furnish lubrication for the guide bearings. A relief valve R, is adjusted to the desired pressure for operating the gear. When the speed is constant and the valve not taking any oil, the excess supplied by pumps will be discharged through this relief valve.

The special reducing valve shown in Fig. 264, and at S, Fig. 263, is provided to control the amount of oil supplied to the bearings.

This valve can be closed, or adjusted over a wide range, by altering the effective length of baffler.

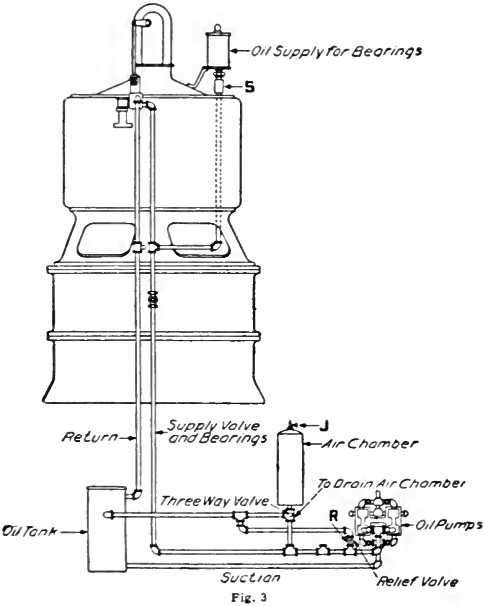


FIG. 263

Referring to Fig. 263, the tank marked "air chamber" is provided in order to give a reserved capacity of oil should the pumps for any reason stop, and also to form an air cushion on the system. The valve at the top of this tank should be kept closed, and the oil allowed to compress the air contained in the tank, and from time to time the tank should be completely emptied and refilled with air. The emptying can be easily accomplished by opening the three-way valve to discharge to the oil tank. This need not interfere with the operation of the machine. After the air chamber is emptied, valve J should be closed, and the three-way valve open to admit oil to the chamber.

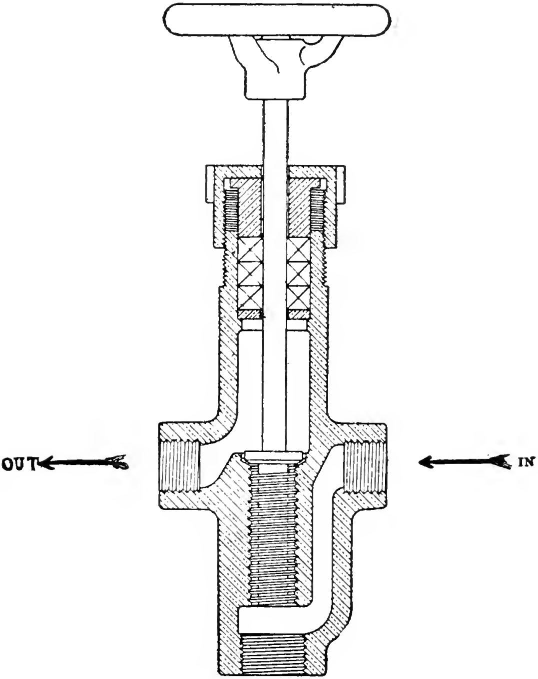


Fig. 264

In installations where oil is used for the turbine step bearing, oil for the operating gear and bearings may be taken from the high pressure pipe line, on the pump side of the step baffler, through a reducing valve. The piping system remains as shown diagramatically in Fig. 263 except for change in source of supply of operating fluid.

In case the station installation includes an air compressor, this equalizing tank may be piped in the system, the connection being made on the side of the tank (as provided for). The refilling of the tank is thus much simplified, and its capacity for emergency operation greatly increased.

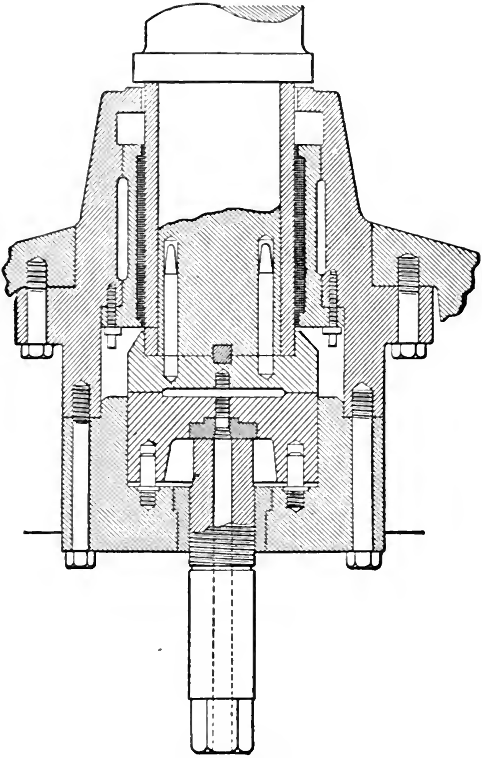


Fig. 265

Care should be taken to insure tightness of both valve controlling air supply to tank, and pet cock at the top.

Step Bearing.—Fig. 265 is a section through the cast iron step blocks. The lower block in the illustration has two holes drilled in it to match the two dowel pins seen projecting from the other block. There is another hole through the center of the lower block threaded for ¾″ pipe—The step lubricant (oil or water) is forced up through this hole, and out between the raised edges in a film, thus floating the rotating elements of the turbine on a frictionless disk of lubricant. The upper side of the top step block is counterbored to fit the lower end of the turbine shaft, in which there is also a slot for the reception of a key that is fitted across the top end of the step block.

The counterbore centers the block, the dowel-pins guide the key into the slot, and the key causes the block to turn with the shaft. These are all close fits, and when it becomes necessary to remove the block for inspection or repairs, it must be pulled off by means of a screw introduced into a threaded hole in the under side of the lower block. The whole is supported by. and rests upon a large screw that passes up through a block of cast-iron which has a threaded bronze bushing that forms the nut for the screw. The large block termed the cover plate is held to the base of the turbine by eight 1½ inch cap screws. A good idea of the construction may be gained by reference to Fig. 266 which is a section of the lower portions. It will be noticed that the ¾ in. oil supply pipe passes up through the entire length of the large step supporting screw. and connects with the oil passage through the lower step block.

Clearance.—With the Curtis turbine, the matter of clearance is very important. There must be no rubbing contact between the revolving and stationary buckets. Neither must there be too much clearance. Provision is therefore made for inspection, and adjustment of the clearance in the following manner. A two inch hole is drilled and tapped into each stage, sometimes opposite a row of moving blades and sometimes opposite the stationary blades.

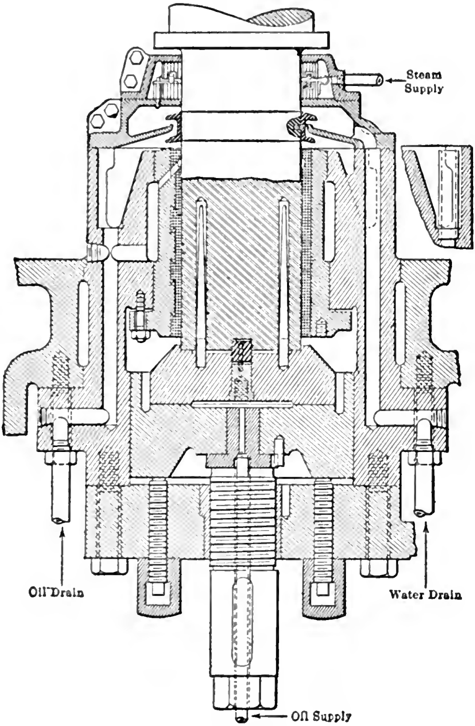


Fig. 266

Two inch plugs are screwed into these holes, to be removed when an inspection is to be made. The clearance is not uniform in all the stages, but is least in the first stage, and greatest in the last. The clearances in each stage of a 1500 K W machine for instance are as follows: 1st stage 0.06 to 0.08, 2nd stage 0.08 to 0.1, 3d stage 0.08 to 0.1, 4th stage 0.08 to 0.2.

These clearances are measured by clearance gages, which are tapering slips of steel about 1½-in. wide accurately ground and graduated by markings, the difference in thickness of the gage between graduations being 0.001-in., the graduations being ½-in. apart.

When it is desired to measure the clearance, one of the 2 inch plugs is taken out, and a clearance gage which has previously been rubbed with red lead is inserted between the revolving and stationary buckets as far as it will go, and then pulled out.

The red lead marking on the gage will show how far it went in, and the nearest graduation in thousandths of an inch will show the clearance, after noting which, the red lead is rubbed on the gage again, and it is tried on the other side, and if there is any difference either high or low it is corrected by placing the wheel as nearly in the middle of the clearance space as possible, which is done by means of the step supporting screw shown in Fig. 266.

The clearance may be adjusted while the machine is running at full speed in the following manner: turn the step supporting screw until the wheels are heard or felt to rub slightly, then mark the screw, and turn it in the opposite direction until the wheels rub again. After marking the screw at this point, it should be turned back half way between the two marks.

This method of adjusting the clearance requires great skill, and experience, and it would seem that the gage method is to be preferred for safety.

Packing.—The shaft of the Curtis turbine is packed with carbon packing, where it passes through the top head of the wheel case. This packing consists of blocks of carbon made into rings, each ring consisting of three segments which break joints. These rings are fitted to the shaft with a slight clearance, and soon get a smooth polish which is not only frictionless but steam tight. The rings are held close to the shaft either by light springs, or the pressure of the steam in the case.

The Baffler.—This is a device for restricting the flow of water, or oil to the step and guide bearing. Its most important function is to steady the flow from the pump, and maintain a constant oil film as the pressure varies with the load, and in cases where several machines are operating on the same step-bearing system, the baffler fixes the flow to each machine. The amount, and pressure of oil or water required to float a turbine, and lubricate the guide bearing depend upon each other, and also upon the condition of the step bearing. Usually from 4½ to 5½ gallons per minute flowing under a pressure of from 425 to 450 lbs. per sq. in. is found to be correct for a 1500 K W machine; of course larger machines require a heavier pressure. The area of the step bearing must be considered also. The principle upon which the baffler operates is as follows: into the barrel or body of the device is inserted a plug which is simply a square threaded worm, the length of which, and the distance it enters the barrel of the baffler determining the amount of flow. The more turns that the water must pass, the less will be the flow.

The De Laval Steam Turbine

The De Laval steam turbine, the invention of Carl De Laval of Sweden, is noted for the simplicity of its construction and the high speed of the wheel—10,000 to 30,000 R. P. M. The difficulties attending such high velocities are, however, overcome by the long, flexible shaft and the ball and socket type of bearings, which allow of a slight flexure of the shaft in order that the wheel may revolve about its center of gravity, rather than the geometrical center or center of position. All high speed parts of the machine are made of forged nickel steel of great tensile strength. But one of the most striking features of this turbine is the diverging nozzle, also the invention of De Laval.

It is well known that in a correctly designed nozzle the adiabatic expansion of the steam from maximum to minimum pressure will convert the entire static energy of the steam into kinetic. Theoretically this is what occurs in the De Laval nozzle. The expanding steam acquires great velocity, and the energy of the jet of steam issuing from the nozzle is equal to the amount of energy that would be developed if an equal volume of steam were allowed to adiabatically expand behind the piston of a reciprocating engine, a condition, however, which for obvious reasons has never yet been attained in practice with the reciprocating engine. But with the divergent nozzle the conditions are different.

Referring to Fig. 267, a continuous volume of steam at maximum pressure is entering the nozzle at E, and, passing through it, expands to minimum pressure at F, the temperature of the nozzle being at the same time constant, and equal to the temperature of the passing steam. The principles of the De Laval expanding nozzle are in fact more or less prominent in all steam turbines. The facilities for converting heat into work are increased by its use, and

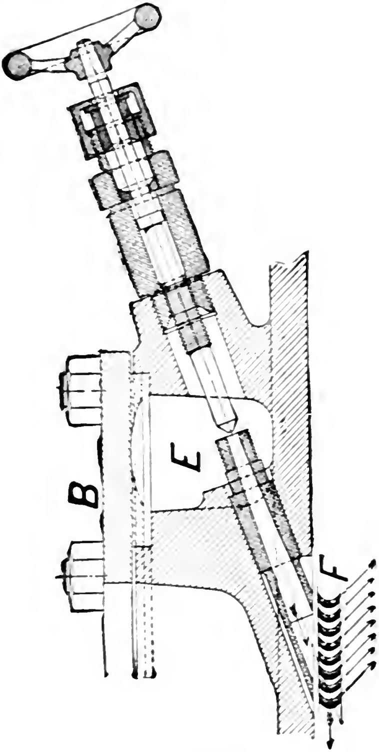


Fig. 267
DE LAVAL NOZZLE

the losses by radiation and cooling influences are greatly lessened.

The De Laval steam turbine is termed by its builders a high-speed rotary steam engine. It has but a single wheel, fitted with vanes or buckets of such curvature as has been found to be best adapted for receiving the impulse of the steam jet. There are no stationary or guide blades, the angular position of the nozzles giving direction to the jet. Fig. 268 shows the form of wheel and the nozzles. The nozzles are placed at an angle of 20° to the

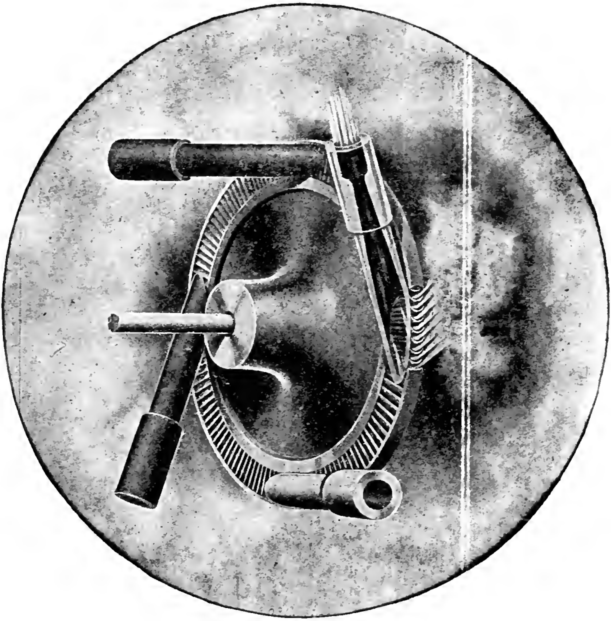


Fig. 268

THE DE LAVAL TURBINE WHEEL AND NOZZLES

plane of motion of the buckets, and the course of the steam is shown by the illustration. ← in. page 66)

The heat energy in the steam is practically devoted to the production of velocity in the expanding or divergent nozzle, and the velocity thus attained by the issuing jet of steam is about 4,000 ft. per second. To attain the maximum of efficiency the buckets attached to the periphery of the wheel against which this jet impinges should have a speed of about 1,900 ft. per second, but, owing to the difficulty of producing a material for the wheel strong enough to withstand the strains induced by such a high speed, it has been found necessary to limit the peripheral speed to 1,200 or 1,300 ft. per second.

Fig. 269 shows a De Laval steam turbine motor of 300 H. P., which is the largest size built up to the present time, its use having been confined chiefly to light work.

The turbine illustrated in Fig. 269 is shown directly connected to a 200 K. W. two-phase alternator. The steam and exhaust connections are plainly shown, as also the nozzle valves projecting from the turbine casing. The speed of the turbine wheel and shaft is entirely too high for most practical purposes, and it is reduced by a pair of very perfectly cut spiral gears, usually made 10 to 1. These gear wheels are made of solid cast steel, or of cast iron with steel rims pressed on. The teeth in two rows are set at an angle of 90° to each other. This arrangement insures smooth running and at the same time checks any tendency of the shaft towards end thrust, thus dispensing with a thrust bearing.

The working parts of the machine are clearly illustrated in Fig. 270, and a fairly good conception of the assembling

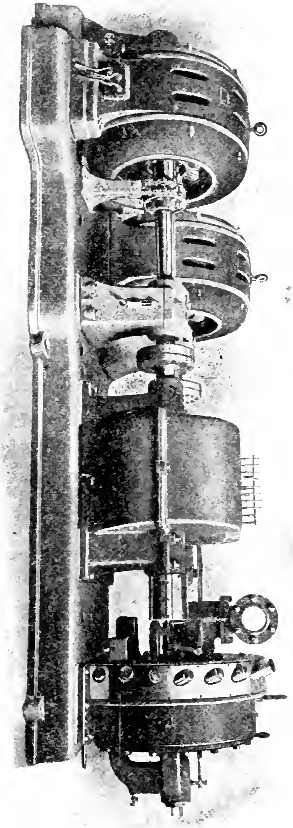


FIG. 269

of the various members, and especially the reducing gears, may be had by reference to Fig. 271, which shows a 110

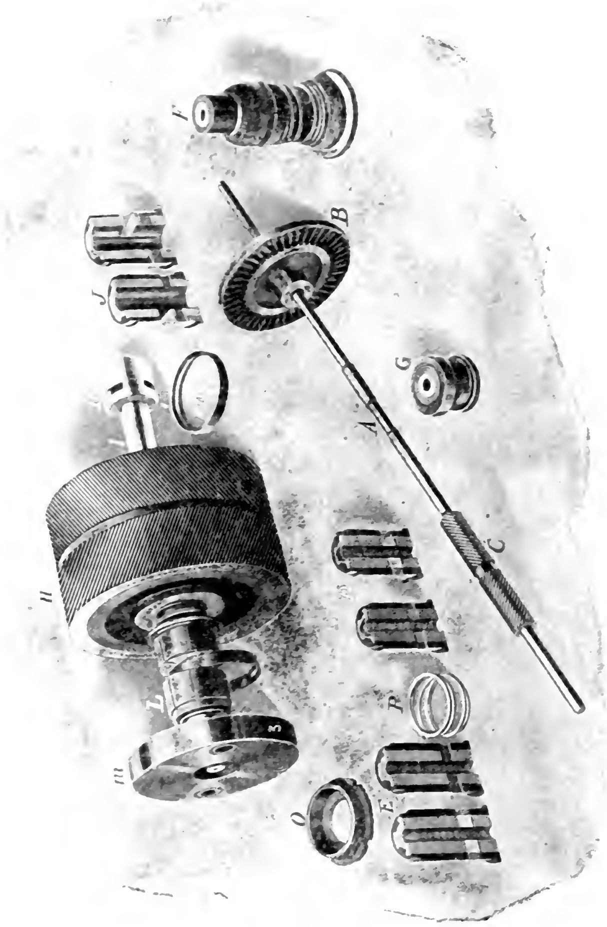


Fig. 270

H. P. turbine and rotary pump with the upper half of the gear case and field frame removed for purposes of inspec-

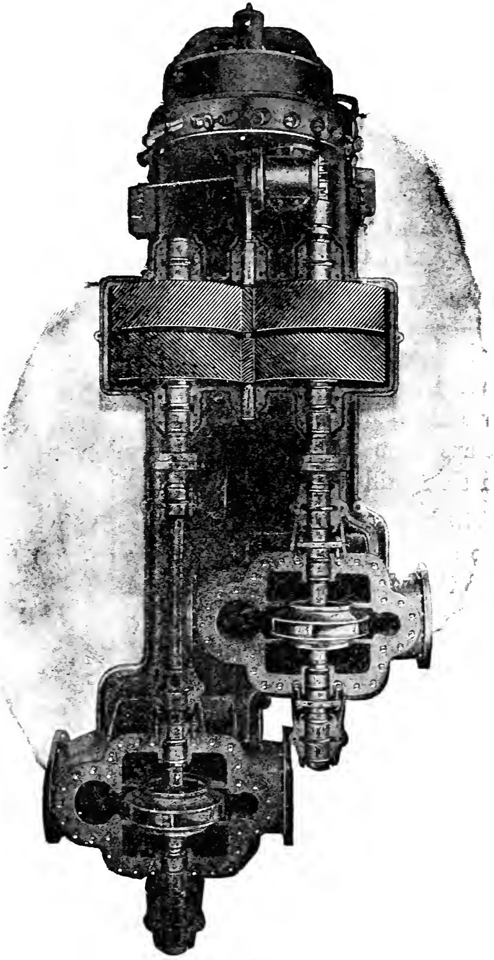


FIG. 271

tion. The slender shaft is seen projecting from the center of the turbine case, and upon this shaft are shown the small pinions meshing into the large spiral gears upon the two pump shafts.

Referring to Fig. 270, A is the turbine shaft, B is the turbine wheel, and C is the pinion. As the turbine wheel is by far the most important element, it will be taken up first. It is made of forged nickel steel, and it is claimed by the builders, the De Laval Steam Turbine Co., of Trenton, New Jersey, that it will withstand more than double the normal speed before showing any signs of distress. A clear idea of the construction of the wheel and buckets may be had by reference to Fig. 268. The number of buckets varies according to the capacity of the machine. There are about 350 buckets on a 300 H. P. wheel. The buckets are drop forged, and made with a bulb shank fitted in slots milled in the rim of the wheel.

Fig. 272 is a sectional plan of a 30 H. P. turbine connected to a single dynamo, and Fig. 273 is a sectional elevation of the same.

The steam, after passing the governor valve C, Fig 273, enters the steam chamber D, Fig. 272, from whence it is distributed to the various nozzles. The number of these nozzles depends upon the size of the machine, ranging from one to fifteen. They are generally fitted with shut-off valves (see Fig. 269) by which one or more nozzles can be cut out when the load is light. This renders it possible to use steam at boiler pressure, no matter how small the volume required for the load. This is a matter of great importance, especially where the load varies considerably, as, for instance, there are plants in which during certain hours of the day a 300 H. P. machine may be taxed to its utmost capacity and during certain other hours the load on the same machine may drop to 50 H. P. In such cases

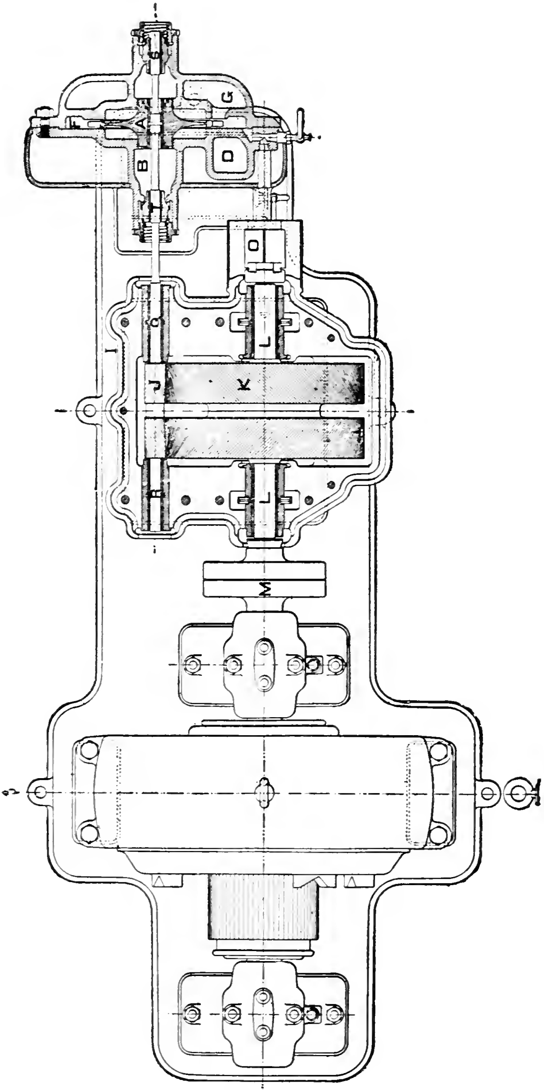


FIG. 272

the number of nozzles in action may be reduced by closing the shut-off valves until the required volume of steam is admitted to the wheel. This adds to the economy of the machine. After passing through the nozzles, the steam, as elsewhere explained, is now completely expanded, and in impinging on the buckets its kinetic energy is transferred to the turbine wheel. Leaving the buckets, the steam now passes into the exhaust chamber G, Fig. 272, and out through the exhaust opening H, Fig. 273, to the condenser or atmosphere as the case may be.

The gear is mounted and enclosed in the gear case I, Fig. 272. J is the pinion made solid with the flexible shaft and engaging the gear wheel K. This latter is forced upon the shaft L, which, with couplings M, connects to the dynamo, or is extended for other transmission.

O, Fig. 273, is the governor held with a taper shank in the end of the shaft L, and by means of the bell crank P operates the governor valve C. The flexible shaft is supported in three bearings, Fig. 272. Q and R are the pinion bearings and S is the main shaft bearing which carries the greater part of the weight of the wheel. This bearing is self-aligning, being held to its seat by the spring and cap shown.

T, Fig. 272, is the flexible bearing, being entirely free to oscillate with the shaft. Its only purpose is to prevent the escape of steam when running non-condensing, or the admission of air to the wheel case when running condensing. The flexible shaft is made very slender, as will be observed by comparing its size with that of the rotary pump shaft in Fig. 271. It is by means of this slender, flexible shaft that the dangerous feature of the enormously high speed of this turbine is eliminated.

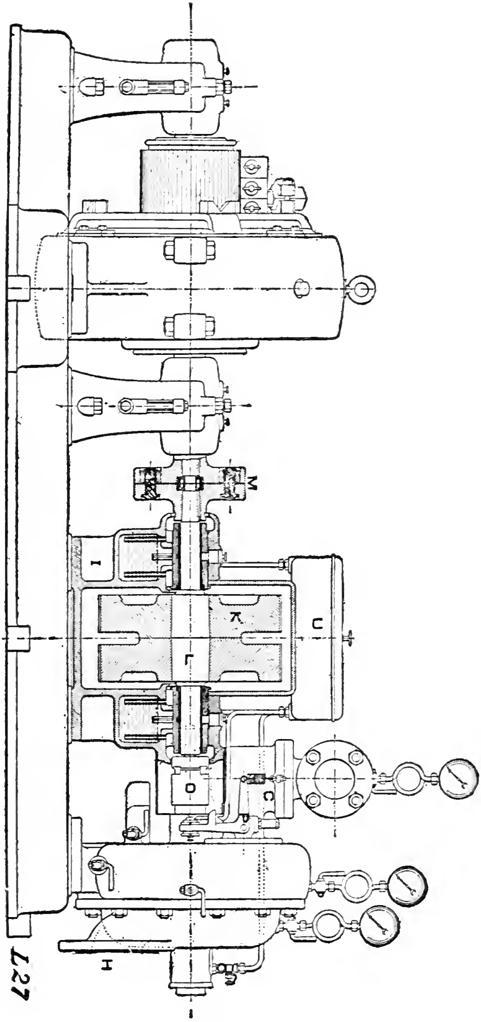


Fig. 273

The governor is of the centrifugal type, although differing greatly in detail from the ordinary fly ball governor, as will be seen by reference to Fig. 274. It is connected directly to the end of the gear wheel shaft. Two weights B are pivoted on knife edges A with hardened pins C, bearing on the spring seat D. E is the governor body fitted in the end of the gear wheel shaft K and has seats milled for the knife edges A. It is afterwards reduced in diameter to pass inside of the weights and its outer end is threaded to receive the adjusting nut I. by means of which the tension of the spring. and through this the speed of the turbine, is adjusted. When the speed accelerates, the weights, affected by centrifugal force, tend to spread apart, and pressing on the spring seat at D push the governor

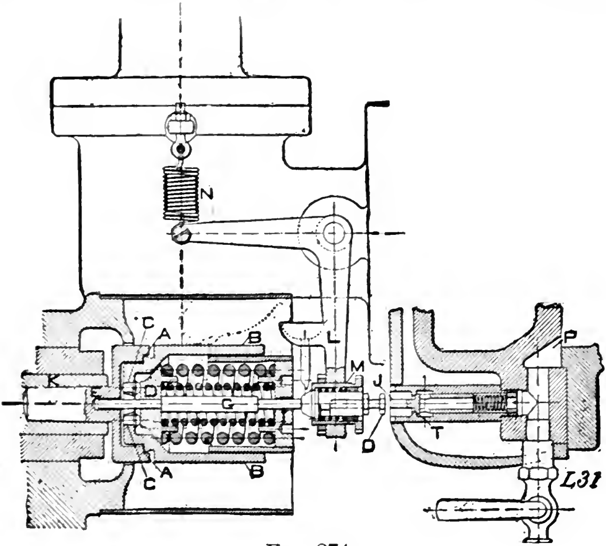


FIG. 274

pin G to the right, thus actuating the bell crank L and cutting off a part of the flow of steam.

It has been found necessary with this turbine, when running condensing, to introduce a valve termed a vacuum valve, also controlled by the governor, as it has been found that the governor valve alone is unable to hold the speed of the machine within the desired limit. The function of the vacuum valve is as follows: The governor pin G actuates the plunger H, which is screwed into the bell crank L, but without moving the plunger relative to said crank. This is on account of the spring M being stiffer than the spring N, whose function is to keep the governor valve open and the plunger H in contact with the governor pin. When a large portion of the load is suddenly thrown off, the governor opens, pushing the bell crank in the direction of the vacuum valve T. This closes the governor valve, which is entirely shut off when the bell crank is pushed so far that the screw O barely touches the vacuum valve stem J. Should this not check the speed sufficiently, the plunger H is pushed forward in the now stationary bell crank, and the vacuum valve is opened, thus allowing the air to rush into the space P in which the turbine wheel revolves, and the speed is immediately checked.

The main shaft and dynamo bearings are ring oiling. The high-speed bearings on the turbine shaft are fed by gravity from an oil reservoir, and the drip oil is collected in the base and may be filtered and used over again.

The fact that the steam is used in but a single stage or set of buckets and then allowed to pass into the exhaust chamber might appear at first thought to be a great loss of kinetic energy, but, as has been previously stated, the static energy in the steam as it enters the nozzles is converted into kinetic energy by its passage through the divergent nozzles, and the result is a greatly increased volume of steam leaving the nozzles at a tremendous velocity, but at a greatly reduced pressure—practically exhaust pressure—impinging against the buckets of the turbine wheel and thus causing it to revolve.

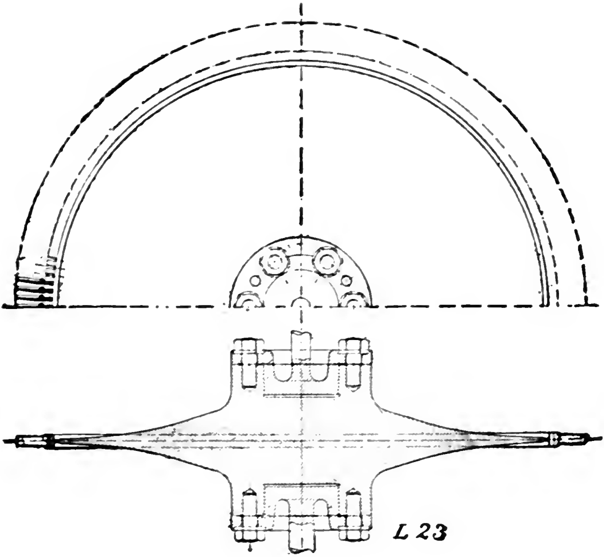


FIG. 275

Efficiency tests of the De Laval turbine show a high economy in steam consumption, as for instance, a test made by Messrs. Dean and Main of Boston, Mass., on a 300 H. P. turbine, using saturated steam at about 200 lbs. pressure per sq. in. and developing 333 Brake H. P., showed a steam consumption of 15.17 lbs. per B. H. P., and the same machine, when supplied with superheated steam and carrying a load of 352 B. H. P., consumed but 13.94 lbs. per B. H. P. These results compare most favorably with those of the highest type of reciprocating engines.

Fig. 275 shows a cross section of a 300 H. P. De Laval wheel, showing the design necessary for withstanding the high centrifugal stress to which these wheels are subjected. All De Laval wheels are tested to withstand the centrifugal stress of twice their normal velocity without showing signs of fatigue.

A characteristic feature of the De Laval steam turbine is that none of its running parts are subject to the full pressure of the steam, as the steam is fully expanded in the nozzle before it reaches the turbine wheel. This feature, which will not be found in *any other* heat motor, is of great value and promising future in the direction of using high pressures with resultant increase in economy of fuel. The restriction as to the steam pressure that can be used is found only with the boiler, and as far as the steam turbine itself is concerned, it has been operated successfully with a pressure as high as 3,000 lbs. per square inch.

Allis-Chalmers Steam Turbine

Fig. 276 shows a general view of the Allis-Chalmers steam turbine, and although it is essentially of the "Parsons" type, still there are a number of modifications in details of construction, as compared with the Westinghouse-Parsons steam turbine, some of which, no doubt may be considered as adding to the efficiency, and durability of the machine.

Fig. 277 is a sectional view of the "elementary" Parsons type of steam turbine, and its various parts are described as follows:

Main bearings, A and B. Thrust bearing, R. Steam pipe C. Main throttle valve, D, which is balanced, and operated by the governor. Steam enters the cylinder through passage E, passes to the left through the alternate rows of stationary and revolving blades, leaving the cylinder at F and passes into the condenser, or atmosphere through passage G. H, J and K are the three steps or stages of the machine. L, M and N are the three balance pistons. O, P and Q are the equalizing passages, connecting the balance pistons with the corresponding stages.

Fig. 278 shows a sectional veiw of the "Parsons" turbine with the Allis-Chalmers modifications. L and M are the two balance pistons at the high pressure end. Z is a smaller balance piston placed in the low pressure end, yet having the same effective area as did the larger piston N shown in Fig. 277. O and Q are the two equalizing passages for pistons L and M. Passage P is omitted in this construction, and balance piston Z is equalized with the third stage

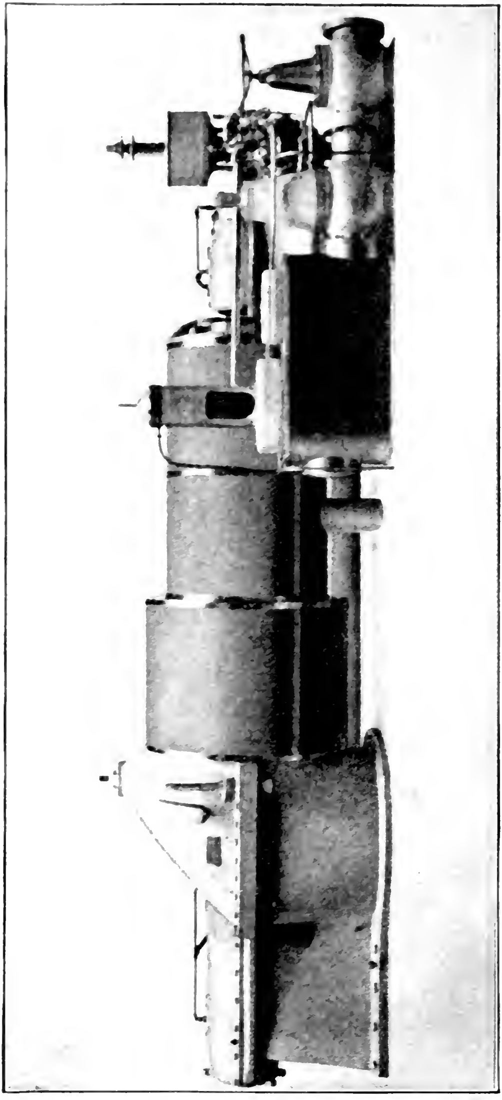


FIG. 276

THE ALLIS-CHALMERS STEAM TURBINE

pressure at Y. Valve V is a by-pass valve to allow of live steam being admitted to the second stage of the cylinder in case of a sudden overload. This by-pass valve is the equivalent of the by-pass valve used to admit live steam to the low pressure cylinder of a compound reciprocating engine. Valve V is arranged to be operated, either by the governor or by hand, as the conditions may require. Frictionless glands made tight by water packing are provided at S and T where the shaft passes out of the cylinder. The shaft is extended at U and connected to the generator shaft by a flexible coupling.

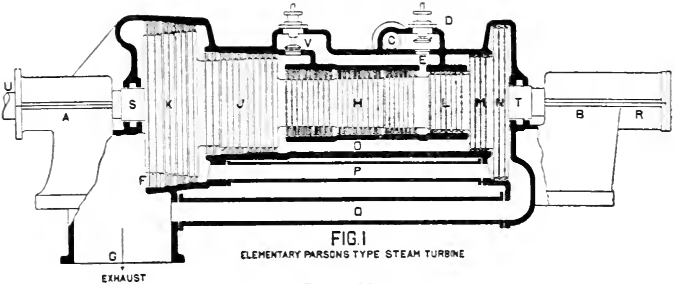


FIG. 277

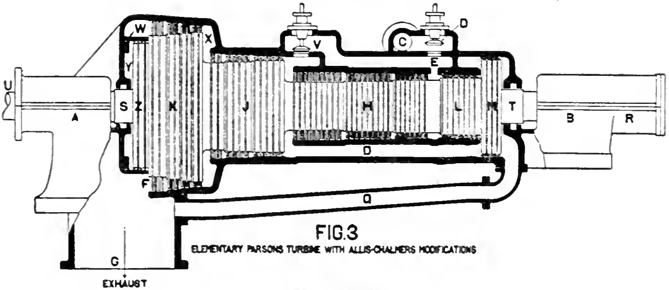


FIG. 278

The action of the steam, and the general arrangement of the stationary, and moving blades is practically the same in the two turbines, with the exception that, in the larger sizes of the Allis-Chalmers turbine the "balance" pistons for neutralizing the end thrust, are arranged in a different manner, the largest one of the three pistons (piston N—Fig. 277) is replaced by a smaller balance piston.

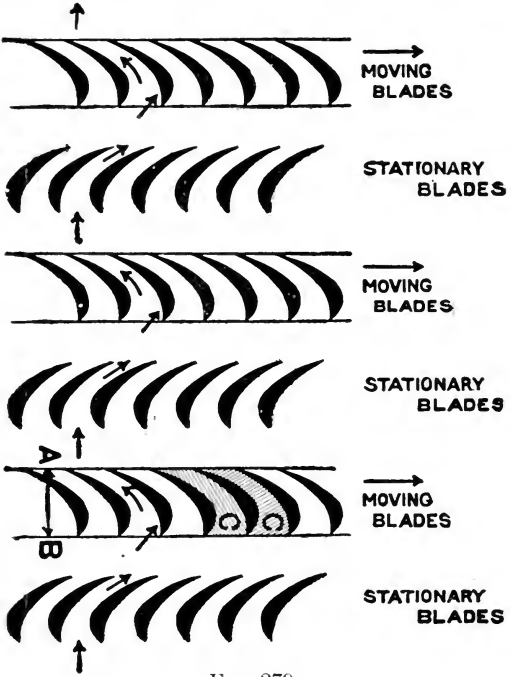


FIG. 279
Showing Arrangement of Blading and Course of the Steam in Parsons Steam Turbine

This piston presents the same effective area for the steam to act upon, as did the larger piston, for the reason that the working area of the latter in its original location consisted only of the annular area included between its periphery and the periphery of the next smaller piston. The pressure of the steam is brought to bear upon this equalizing piston in its new position, by means of passages or ports through the body of the rotor, connecting the third stage of the cylinder with the supplementary cylinder, in which the piston revolves. Fig. 279 shows the arrangement of blading, the course of the steam being indicated by the arrows. The clearances between the edges of the revolving and stationary blades, as shown in the cut are relatively out of proportion to the actual clearances allowed.

This clearance is preserved by means of a small thrust-bearing provided inside the housing of the main bearing.

This thrust-bearing can be adjusted to locate and hold the rotor in such a position as will allow sufficient clearance to prevent actual contact between the moving and stationary blades, and yet reduce the leakage of steam to a minimum.

The method by which the blades are fitted to and held in the rotor and cylinder of the Allis-Chalmers steam turbine is as follows: Each blade is individually formed by special machine tools, so that its root or foot is of an angular, or dove-tail shape, and at its tip there is a projection. In order that the roots of the blade may be firmly held in position, a foundation ring, A, Fig. 280, is provided, which after being formed to a circle of the proper diameter, has slots cut in it by a special milling machine.

These slots are formed of dove-tail shape to receive the roots of the blades, and are at the same time accurately spaced, and inclined so as to give the required pitch and angles to the blades.

The foundation rings are also of dove-tail shape in cross-section, those holding the stationary blades are inserted in dove-tail grooves in the cylinder and those holding the revolving blades being pressed into the rotor or spindle.

The rings are firmly held in their places by key-pieces driven into place and upset into under-cut grooves, thus positively locking the whole structure together, and making it practically impossible for a blade to get out of place.

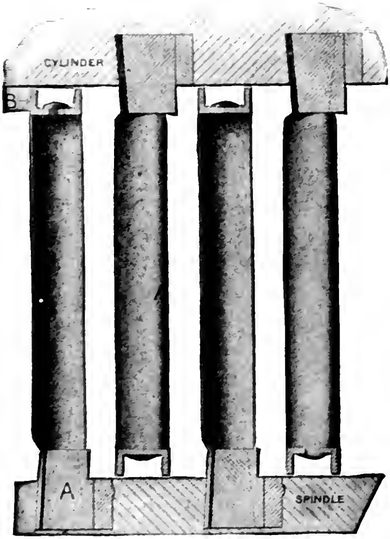


FIG. 280

The tips of the blades are held and firmly bound together by a shroud-ring, B, Fig. 280.

The shroud-rings are made channel-shape, in cross-section, the flanges being made thin in order to prevent dangerous heating in case of accidental contact with either the walls of the cylinder or the surface of the rotor.

The bearings of this turbine are of the self-adjusting ball and socket type, designed for high speed. Shims are provided for proper alignment. The lubrication of the four bearings, two for the turbine, and two for the generator, is accomplished by supplying an abundance of oil to the middle of each bearing and allowing it to flow out at the ends where it is caught, passed through a cooler, and pumped back to the bearings.

The fact that the oil is supplied in large quantities to the bearings does not involve a heavy oil bill.

The journals are practically floating on films of oil, thus preventing that "wearing out" of the oil that occurs when it is supplied in small "doses."

The governor is driven from the turbine shaft by means of cut gears working in an oil-bath.

The governor operates a balance throttle valve by means of a relay, except in very small sizes in which the valve is worked direct.

In order to provide for any possible accidental derangement of the main governing mechanism, an entirely separate safety, or over-speed governor is furnished. This governor is driven directly by the turbine shaft without the intervention of gearing, and is so arranged and adjusted that if the turbine should reach a predetermined speed above that for which the main governor is set, the safety governor will come into action and trip a valve, shutting off the steam and stopping the turbine. A strainer is provided through which the steam is passed before admission to the turbine.

For connecting the rotors of the turbine and generator a special type of flexible coupling is used to provide for any slight inequality in the wear of the bearings, to permit axial adjustment of the turbine spindle, and to allow for differences in expansion. This coupling is so made that it can be readily disconnected for the removal of the turbine spindle, or of the revolving field of the generator. Provision is made for ample lubrication of the adjoining faces of the coupling. The coupling is enclosed in the bearing housing, so that it is completely protected against damage, and cannot cause injury to the attendants.

Waste of heat by radiation is prevented in the following manner:

The hot parts of the turbine, up to the exhaust chamber are covered with an ample thickness of non-conducting material and lagged with planished steel.

For large Allis-Chalmers turbines the bedplate is divided into two parts, one carrying the low-pressure end of the turbine and the bearings of the generator, the other carrying the high-pressure end of the turbine. The turbine is secured to the former, while the latter is provided with guides which permit the machine to slide back and forth with differences of expansion caused by varying temperature, at the same time maintaining the alignment.

Fig. 281 shows the spindle, or rotor of the Allis-Chalmers turbine. The rings which carry the blades are pressed on the shaft. Fig. 282 illustrates the blades as they appear when fitted on to the rotor. The shroud ring protecting the tips of the blades is also shown in place. Fig. 283 shows another view of the blade construction. This is a half-ring of blades inserted in the foundation ring before being placed upon the rotor.

Fig. 284 shows several rows of stationary blades as they appear, fitted in the cylinder of an Allis-Chalmers steam turbine.

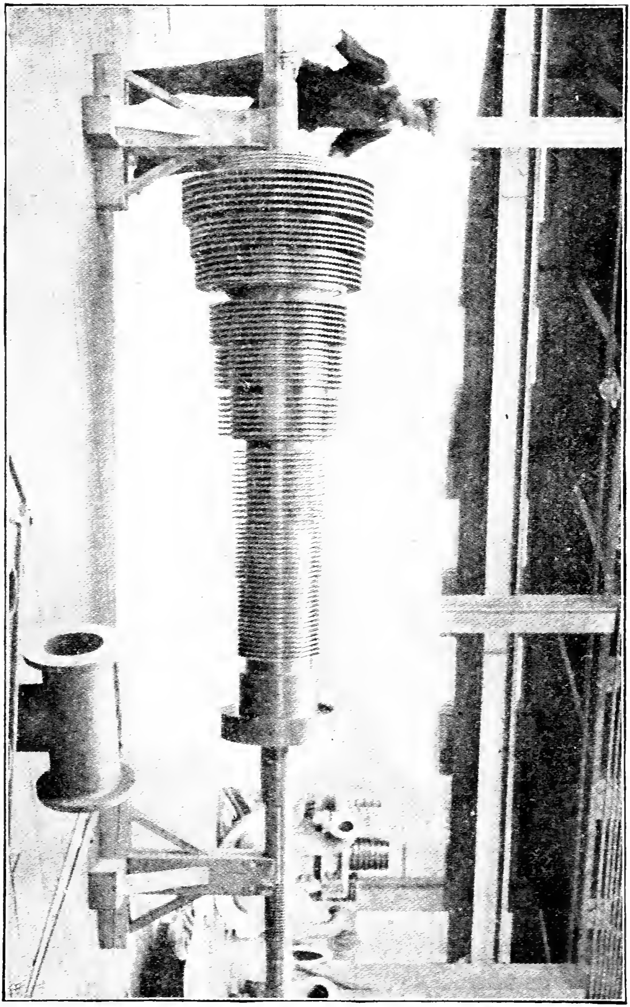


Fig. 281

ROTOR OF ALLIS-CHALMERS STEAM TURBINE

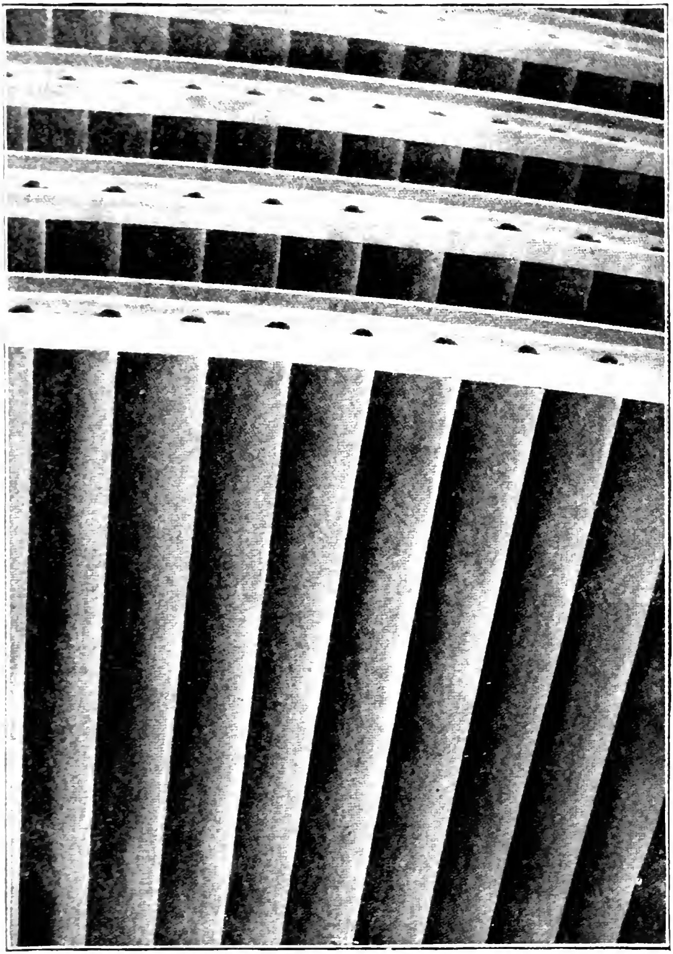


FIG. 282

Starting Up.—As a rule in preparing to start a steam turbine, especially one of the "Parsons," type, the first move is to open the throttle slightly, to allow as much steam as possible to flow through the turbine without causing it to start. This requires but a few seconds, and about an equal period of time is required to start the auxiliary oil pump. The inlet valve is always left open to the surface condensers, so they are always full of water. The outlet valve is quickly opened a certain number of turns, which is known to be sufficient for all purposes, and this is easily done before the moderate amount of steam flowing through has had time to heat the condenser unduly. By this time the oil is sufficiently high in the reservoir to permit the turbine to be started very slowly, and it doubtless warms up rather more evenly when turning over than when standing. When the oil has reached its normal level in the reservoir, the turbine is given more steam, and the field cut in.

The principal precautions to be observed are, not to start without properly warming up, also to be certain that the oil is circulating freely through the bearings.

The vacuum should not be on until the water glands seal, and care should be taken not to run on vacuum without a load on the turbine.

If a turbine vibrates objectionably when started after a moderate time has been allowed for warming, say 6 minutes for a 500-kilowatt, 10 minutes for a 2000-kilowatt, and 15 or,perhaps 20 minutes for larger sizes, it is highly probable that there is something structurally wrong with it, and any longer period will do but little, if any, good; furthermore, it will be subject to mysterious "spells" or "fits" of vibration upon changes of load or vacuum.

In Operation.—The throttle, and inlet gages should be closely watched, to see that neither the pressure, nor the steam temperature varies much. The vacuum should also

FIG. 283

be kept constant, as well as the water glands, and those pressures indicated by the oil gages. The temperature of the oil flowing to and from the bearings should not exceed 135° Fahr.—.

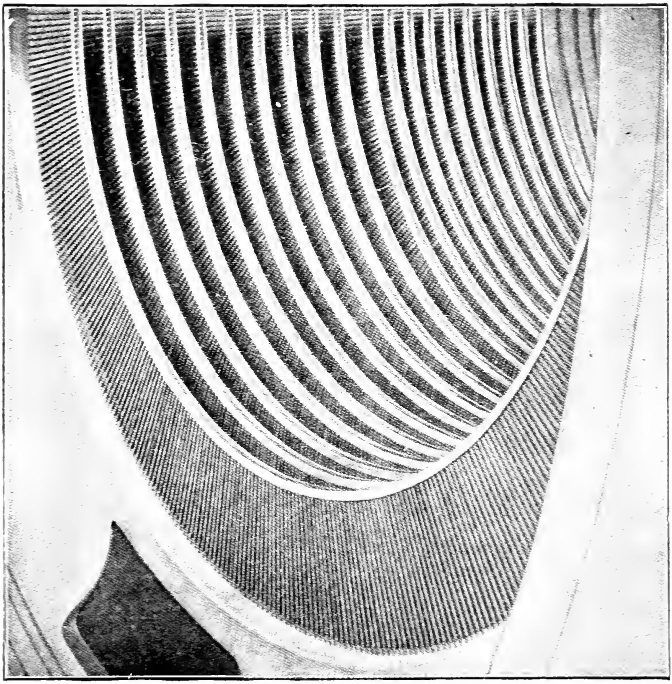


FIG. 284
Shows a Number of Rows of Stationary Blades Fitted in the Cylinder of an Allis-Chalmers Steam Turbine

The governor parts also should be oiled at regluar intervals.

Stopping the turbine is practically the reverse of starting, the successive steps being as follows: starting the auxiliary oil pump, freeing it of water and allowing it to run slowly; removing the load gradually; breaking the vacuum when the load is almost zero, shutting off the condenser injection and taking care that the steam exhausts freely into the atmosphere; shutting off the gland water when the load and vacuum are off; pulling the automatic stop to trip the valve and shut off steam and, as the speed of the turbine decreases, speeding up the auxiliary oil pump to maintain pressure on the bearings; then, when the turbine has stopped, shutting down the auxiliary oil pump, turning off the cooling water, opening the steam chest drains and slightly oiling the oil inlet valve-stem. During these operations the chief particulars to be heeded are: not to shut off the steam before starting the auxiliary oil pump nor before the vacuum is broken, and not to shut off the gland water with vacuum on the turbine. The automatic stop should also remain unhooked until the turbine is about to be started up again.

General Suggestions.—Water used in the glands of the turbine must be free from scale-forming impurities, and should be delivered at the turbine under a steady pressure of not less than 15 pounds. The pressure in the glands will vary from 4 to 10 pounds. This water may be warm. In the use of water for the cooling coils and of oil for the lubricating system, nothing more is required than ordinary good sense dictates. An absolutely pure mineral oil must be supplied, of a nonfoaming charcter, and it should be kept free through filtering from any impurities.

These suggestions apply more particularly to steam turbines of the "Parsons" type, exhausting into condensers. For turbines built to be run non-condensing the portion relating to vacuum does not of course apply.

Hamilton-Holzwarth Steam Turbine

In order to thoroughly understand the underlying principles of the steam turbine, and the action of the steam within it, one must get definitely fixed in his mind this fact, viz., that there is no similarity between it and the reciprocating engine, and the action of the steam upon the piston in driving it back and forth. In fact, there is more similarity between the reciprocating engine and the rotary engine than there is in the case of the turbine. In the rotary engine the steam pushes a piston in the same manner as it does in the reciprocating engine, with the exception that the piston of the rotary engine travels entirely around the shaft, while the piston of the reciprocating engine travels back and forth in a straight line motion. It will be much easier to get a clear idea of the action of the turbine if one will for the time being drop all knowledge he may have of reciprocating and rotary engines. He will then be able to more readily grasp, and better understand the action of the steam turbine.

One of the most comprehensive, and at the time most simple explanations of the action of the steam upon the blades of the turbine, and also upon the piston of the reciprocating engine, in both of which cases rotary motion is produced, but in two different ways, is given by Hans Holzwarth. He says: "Take a large wheel which is fastened to a vertical shaft. Grasp this wheel at the rim at a certain point, and walk continuously around the shaft, always retaining the hold, like a horse walking around a capstan fastened to a bar or pole which he pulls after him.

Or stand still in a certain spot and take the wheel by the rim and cause it to revolve (like opening and closing a valve by hand), by changing hands so that the whole rim is constantly revolving."

The first illustration clearly explains the manner in which the shaft of the reciprocating engine is caused to revolve, by means of the static expansion force of the steam acting upon the crank pin, through the medium of the piston, piston rod, cross head, and connecting rod. In the second illustration, in which the man turns the wheel by simply standing still in one place, and causing the wheel to revolve by grasping the rim and giving it a push, first with one hand, and then with the other, we have a simple explanation of how the steam causes the shaft of the turbine to revolve, by a constant series of pushes, or impulses against the movable blades that are key seated to the drum, which in turn is keyed to the shaft, the moving blades representing the rim of our wheel.

Every one knows that in order to be able to turn the aforesaid wheel the man must have a good floor to stand upon, and he must also have a good foothold on the floor, because he exerts the same amount of pressure on the floor, that he exerts against the rim of the wheel. This explains why there must be stationary blades, as well as revolving blades in a turbine.

The actual pressure exerted upon any single blade in a turbine is in reality very light. Take, for example, a 300 K. W. Westinghouse turbine. There are altogether in a machine of this size 31,073 blades, of which 16,095 are moving blades. The pressure that each blade exerts in turning the shaft is a little over one ounce, but owing to the large number of blades, and the velocity of the steam, the power is developed.

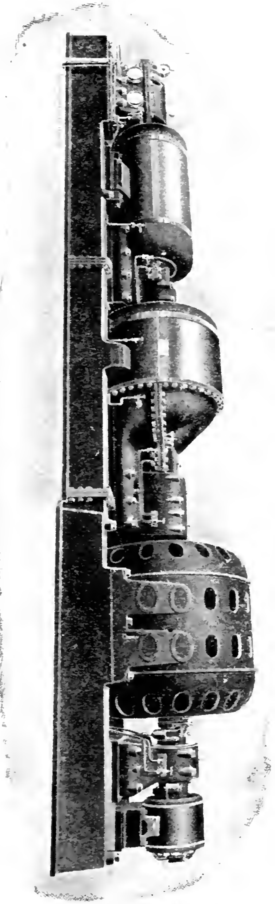


FIG. 285

HAMILTON-HOLZWARTH STEAM TURBINE

The Hamilton-Holzwarth steam turbine resembles in many respects the Westinghouse-Parsons turbine, prominent of which is that it is a full stroke turbine: that is, the steam flows through it in one continuous belt, or veil in a screw line, the general direction being parallel with the shaft. But unlike the Parsons type, the steam in the Hamilton-Holzwarth turbine is made to do its work only by impulse, and not by impulse and reaction combined. The smaller sizes are built in a single casing or cylinder, but for units of 750 K. W. and larger there are two parts, viz., high and low pressure, thus resmbling in some respects a compound reciprocating engine.

The Hamilton-Holzwarth steam turbine is based upon and has been developed from the designs of Prof. Rateau, of Paris, and is being manufactured in this country by the Hooven-Owens-Rentschler Co., of Hamilton, Ohio. It is horizontal, and placed upon a rigid bed plate of the box pattern. All steam, oil and water pipes are within and beneath this bed plate, as are also the steam inlet valve and the regulating and by-pass valves.

There are no balancing pistons in this machine, the axial thrust of the shaft being taken up by a thrust ball-bearing. The interior of the cylinder is divided into a series of stages by stationary discs which are set in grooves in the cylinder, and are bored in the center to allow the shaft, or rather the hubs of the running wheels that are keyed to the shaft, to revolve in this bore.

Clearance.—The clearance allowed is as small as practicable, as it is in this clearance between the revolving hub and the circumference of the bore of the stationary disc that the leakage losses occur. It should be noted that between each two stationary discs there is located a running wheel, and that the clearance between the running vanes and the stationary vanes is made as slight as is consistent with safe practice: otherwise leakage would occur here also, and besides this there would be a distortion of the steam jet and entrainment of the surrounding atmosphere, resulting in a rapid decline in economy if the clearance between the stationary and moving elements was not reduced to as small a fraction as possible.

As before stated, the stationary discs are firmly secured to the interior walls of the casing. At intervals on the outside periphery of these discs are located the stationary, or guide vanes. These are made of drop forged steel. They are set in a groove on the outside edge of the disc and fastened with rivets. Both disc and vanes are then ground, giving the vanes the profile that they should have for the most efficient expansion of the steam. After this is done a steel ring is shrunk on the outside periphery of the vanes and the steam channels in the disc. These discs are then placed in the grooves in the casing at regular intervals, and in the spaces between them are the running wheels.

The casing is divided into an upper and lower half. The running wheels are built with a cast steel hub having a steel disc riveted on to each side, thus forming a circumferential ring space into which the running vanes are riveted. A thin steel band or rim is tied on the outer edge of the vanes, thus forming an outer wall to the steam channels and confining the steam within the vanes. These vanes are also milled on both edges, on the influx, and efflux side of the wheel, thus forming them to the shape corresponding to the theoretical diagram.

In all steam turbines one of the main requisites for a quiet-running machine is that the revolving element or rotor shall be perfectly balanced. The rotary body of the Hamilton-Holzwarth turbine consists of a plurality of running wheels, each one of which is balanced by itself before being placed upon the shaft. All the bearings are lubricated in a thorough manner by oil forced up into the bottom bushing or shell under slight pressure. Flexible couplings are used between the high and low-pressure shafts, and for connecting the turbine shaft to the generator shaft or other shaft to be driven. By means of the thrust ball-bearing on the exhaust end of the turbine the shaft may be adjusted in an axial direction in such a manner as to accurately preserve the desired position of the running wheels.

Fig. 285 shows a general view of the Hamilton-Holzwarth turbine, and the action of the steam within the machine may be described as follows: After leaving the steam separator that is located beneath the bed plate, the steam passes through the inlet or throttle valve, the stem of which extends up through the floor near the high-pressure casing and is protected by a floor stand and equipped with a hand wheel, shown in Fig. 285. The steam now passes through the regulating valve. From this valve it is led through a curved pipe to the front head of the high pressure casing or cylinder. In this head is a ring channel into which the steam enters, and from which it flows through the first set of stationary vanes. In these vanes the first stage of expansion occurs.

Construction of the Stationary Blade.—A stationary blade is constructed in the following manner: A circular cast-iron disc a, Fig. 286, has a bore b corresponding to the diameter of the shaft, with the necessary clearance. On the outer circumference of this disc there is cut a groove c. The stationary guides, consisting of a vane of proper curvature and the adjoining piece, are of drop-forged steel, milled on all sides of the adjoining piece which fits into the circular groove c. These vanes are arranged all around the circumference so that one adjoining piece touches another and they are held in place and fastened securely, by rivets e, to the disk. The outer circumference of these vanes is turned off to the right size, and then a steel ring f is shrunk over them. This shrunk ring projects into the grooves of the housing.

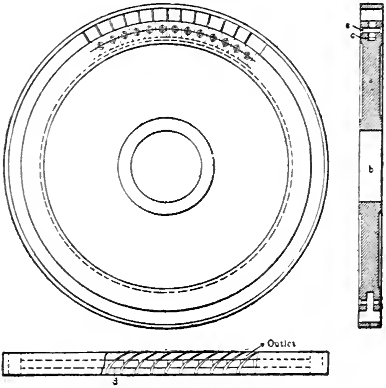


FIG. 286

The Running Wheel.—While in the stationary blade the weight is not of great importance, in the running wheel it is very essential to reduce the weight as much as possible. It will be readily understood that the lighter the running wheels are, the less the bearings will have to support, and therefore the shorter they may be constructed, and the better they will work. Furthermore, by keeping down the weight of the running wheel the shaft diameter is kept within small limits. This determines the bore of the stationary blade, and with that the circular space between the bore of the stationary blade and the shaft can be kept within small limits: therefore in the construction of this running wheel every dead and unnecessary weight is avoided.

The running wheel is made up as follows: A steel hub or spider a, Fig. 287, has a bore b fitting closely to the shaft diameter. On both side of the hub are riveted steel discs c. The groove on the outer circumference of the steel disc is turned out and forms a receptacle for the running vanes. The running vane itself consists of the properly curved blade, with an adjoining piece made in one section of drop-forged steel. The adjoining piece is finished and fits closely into the grooves of the steel disc. The running vanes are held in place and rigidly connected to the steel discs by rivets d, so that the centrifugal force of each vane is taken up by a rivet and transmitted through the rivet to the steel disc. The outer edge f of the vane is turned off and thus provided with an annular groove forming a receptacle for the steel band g, which is tied all around the wheel. It is held in place and secured to the

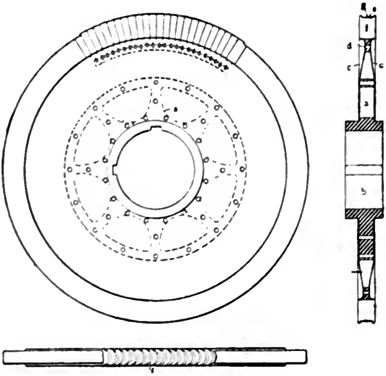


FIG. 287

vanes by riveting over the projecting ends of the vanes. The ends of the band are brazed together.

Reference to Fig. 288, which is a vertical section of this turbine, will serve to make more clear the action of the steam within the machine. The turbine casing a, is made of cast iron of cylindrical shape, and split in the horizontal axis, into the upper half, a, and the lower half, b. In the horizontal points the two halves are bolted together steam tight. The lower half, b, is cast together with the pedestal, c, which is the support for the low pressure bearing, d, and the groove, e, for the stuffing box, f. The outlet opening, g, is arranged in the lower half, b. This lower half is supported on pads of the bed plate, h, with two feet extending on the sides, and fastened thereto. The front head, i, is bolted steam tight to the flange, k, on the front side of the casing. In front of the head, i, is located the regulating mechanism pedestal, l, which combines the high pressure bearing with the housing for regulating mechanism, n, and housing, o, for the governor, p. A live steam pipe, g′, is connected to an inlet valve, r, and this to a main regulating valve, s, to the inlet flange of the front head, i. The passage of the steam into this front or high pressure head has already been referred to. In the grooves cut in the housing are the stationary blades, t, and in the space between the two following stationary blades is the running wheel, u. All running wheels fit on the shaft, v, and are keyed to the shaft. The shaft, v, is supported in the high pressure bearing, m, on one end, and in the low pressure bearing, d, on the other end. The low pressure bearing has an arrangement which allows the adjustment of the shaft, v, lengthwise in the direction of the turbine. On the outer end of the shaft is the coupling, w, keyed to the

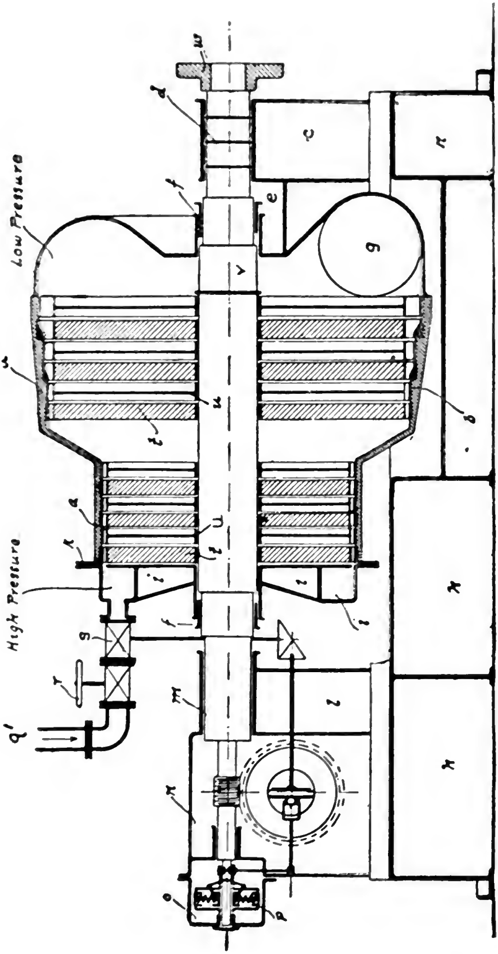


FIG. 288
HAMILTON-HOLZWARTH STEAM TURBINE
Sectional Elevation

shaft. This coupling allows connection to be made to the generator, pump, or blower, which is to be driven by the turbine.

The flow of the steam from the inlet valve, r, to the exhaust outlet, g, and the manner of the working of the steam in the turbine is as follows: The steam passing through the main regulating valve, s, enters the circular channel of the front head, i, and from here it flows through a circular slot to the first stationary blade, t. Opposite this circular slot is arranged a multitude of vanes, x, Fig. 289,

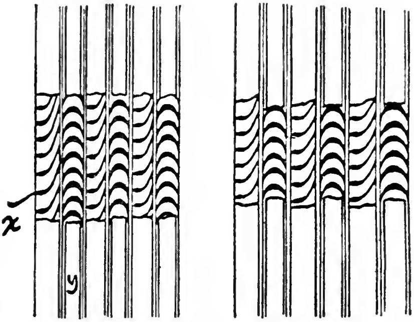


FIG. 289

which give the steam the right expansion in the right direction. With this velocity attained in the stationary blades, the steam impinges upon the vanes, u, of the first running wheel, and the bore of the housing can be kept within larger limits, because the steam flowing through the vanes is prevented from flowing rapidly outward by means of a band secured around the outer circumference of the running wheel.

The running vanes conform in section somewhat to the Parsons type, but the action of the steam upon them, and also within the stationary vanes is different. The expansion of the steam, and consequent development of velocity takes place entirely within the stationary vanes, which also change the direction of flow of the steam, and distribute it in the proper manner to the vanes of the running wheels, which, according to the claims of the makers, the steam enters and leaves at the same pressure, thus allowing the wheel to revolve in a uniform pressure.

In the low-pressure casing, which is larger in diameter than the high-pressure, the steam is distributed in the same manner as it is in the high-pressure casing. There is, however, in the front head of the low-pressure casing an additional nozzle through which live steam may be admitted in case of overload. The design of this nozzle is such that the live steam entering and passing through it, and controlled by the governor exerts no back pressure on the steam coming from the receiver, but, on the contrary, its action is similar to the action of an injector, that is, it tends to suck the low-pressure steam through the first set of stationary vanes of the low-pressure turbine.

The first stationary disc of the low-pressure turbine has guide vanes all around its circumference, so that the steam enters the turbine in a full cylindrical belt, interrupted only by the guide vanes. To provide for the increasing volume as the steam expands in its course through the turbine, the areas of the passages through the distributers and running vanes must be progressively enlarged. The gradual increase in the dimensions of the stationary vanes permits the steam to expand within them, thus tending to maintain its velocity, while at the same time the vanes guide the steam under such a small angle that the force with which it impinges the vanes of the next running wheel is as effective as possible. The curvature of the vanes is such that the steam while passing through them will increase its velocity in a ratio corresponding to its action.

The purpose of the stationary discs is, as has been stated, to distribute the steam to the running wheel. They also take the back pressure of the steam as it impinges the vanes of the running wheels, thus in a sense acting as balancing pistons.

The governor is of the spring and weight type, adapted to high speed, and is designed especially for turbine governing. It is directly driven by the turbine shaft, revolving with the same angular velocity. Its action is as follows: Two discs keyed to the shaft drive, by means of rollers, two weights sliding along a cross bar placed at right angles through the shaft and compressing two springs against two nuts on the cross bar. Every movement of the weights, caused by increasing or decreasing the angular velocity of the turbine shaft, is translated by means of levers to a sleeve which actuates the regulating mechanism. These levers are balanced so that no back pressure is exerted upon the weights. The whole governor is closed in by the discs, one on each side, and a steel ring secured by concentric recesses to the discs. In order to decrease the friction within the governor and regulating mechanism, thrust ball-bearings and frictionless roller-bearings are used.

As previously stated, the regulating valve is located beneath the bed plate. One side of it is connected by a curved pipe with the front head of the high-pressure cylinder, and the other side is connected with the inlet valve. The regulating valve is of the double-seated poppet valve type. Valves and valve seats are made of tough cast steel, to avoid corrosion as much as possible, and the valve body is made of cast iron.

Immediately below the regulating valve and forming a part of it in one steam chamber is located the by-pass regulating valve. Thus the use of a second stuffing box for the stem of this valve is avoided. The function of this valve is to control the volume of the live steam supply that flows directly to the by-pass nozzles in the front head of the low-pressure casing. This valve is also a double-seated poppet valve.

The main regulating valve is not actuated directly by the governor, but by means of the regulating mechanism. The construction and operation of this regulating mechanism is as follows: The stem of the regulating valve is driven by means of bevel gears by a shaft that is supported in frictionless roller-bearings.

On this shaft there is a friction wheel that the governor can slide across the face of a continuously revolving friction disc by means of its sleeve and bell crank lever. This revolving disc is keyed to a solid shaft which is driven by a coupling from a hollow shaft. This hollow shaft is driven by the turbine shaft through the medium of a worm gear. The solid shaft, with the continuously revolving friction disc, can be slightly shifted by the governor sleeve so that the two friction discs come into contact when the sleeve moves, that is, when the angular velocity changes. If this change is relatively great, the sleeve will draw the periodically revolving friction disc far from the center of the always revolving one, and this disc will quickly drive the stem of the regulating valve and the flow of steam will thus be regulated. As soon as the angular velocity falls below a certain percentage of the normal speed, the driving friction disc is drawn back by the governor, the regulating valve remains open and the whole regulating mechanism rests or stops, although the shaft is still running.

Should the angular velocity of the shaft reach a point 2.5 per cent higher than normal, the governor will shut down the turbine. If an accident should happen to the governor, due to imperfect material or breaking or weakening of the springs, the result would be a shut-down of the turbine.

In order to change the speed of the turbine while running, which might be necessary in order to run the machine parallel with another prime mover, a spring balance is provided, attached to the bell crank lever of the regulating mechanism. The hand wheel of this spring balance is outside of the pedestal for regulating mechanism and near the floor-stand and hand wheel. With this spring balance the speed of the turbine may be changed 5 per cent either way from normal.

All the bearings of the turbine are thoroughly lubricated with oil forced under pressure by the oil pump driven by means of worm gearing by the turbine itself. After flowing through the bearings the oil is passed through a filter, and from thence to the oil tank located within the bed plate, from whence it is taken by the oil pump. All revolving parts are enclosed, and the principal part of the regulating mechanism operates in a bath of oil.

The Stuffing-Box.—An effective means of packing a swiftly revolving shaft is a long sleeve surrounding the shaft with a very small radial clearance. The reason for this will be found in the throttling action of the steam particles revolving with the shaft. These steam particles have a tendency to fly outwardly and so prevent the steam from passing axially through the small clearance between the shaft and the sleeve. The reader will readily understand that it would not be practical to use such a long sleeve in the construction of a steam turbine, as this arrangement would considerably increase the length of the free shaft. For the reason that the deflection of the shaft depends upon the third power of the free length of the shaft, it is absolutely necessary to restrict this free length as much as possible.

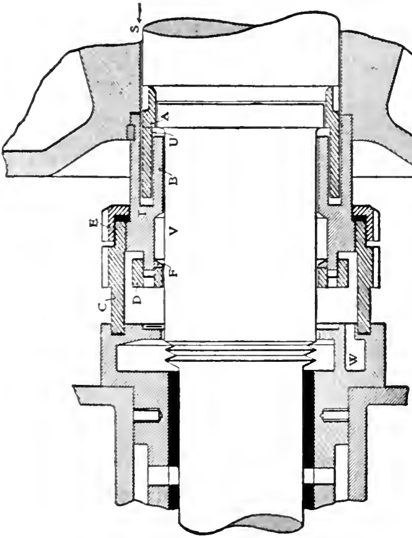


FIG. 290

In the Hamilton-Holzwarth turbine, use is made of the telescopic idea; that is the entire length of the sleeve is split into several parts, and these single parts are shifted together. In Fig. 290 the ring A screwed upon the shaft projects axially into a groove of the ring B, and revolves within it. The ring B does not move at all, but is held in place, and pressed tightly against the turbine casing by means of the ring C which presses against the bushing of the bearing. By screwing the ring C on the ring B, both rings are forced axially in opposite directions. From the casing S the steam seeking to escape, flows axially to T. From there it flows back to U, and then forward to V, being very much throttled in the process. The ring B has an annular groove which must be packed with soft packing. Any accumulating water is collected in the chamber W, in the bushing of the bearing, from whence it is properly drained. The ring E serves only the purpose of tightening the threads between rings C and B.

The Rateau Steam Turbine

The Rateau turbine is purely an impulse turbine, using wheels of thin plates pressed into a slightly conical form. These are mounted on a common shaft, and separated from each other by division walls. The first wheels have partial peripheral admission, so that the peripheral velocity may be high from the very beginning without using too short blades. The guide blades are set into division walls, and the rotating blades are bent from a single piece of bronze, or steel plate, and are riveted to the double turned rim of the wheel-disc. The shaft bearings were originally built as part of the cover of the turbine, but now are made independent. At the low pressure end the shaft is made steam tight by means of a simple stuffing box, into which sufficient water is allowed to flow to secure steam tightness. As the same pressure exists on both sides of each rotating wheel, the axial thrust has only the small value due to the pressure on the area of the end of the front journal.

Fig. 291 shows a sectional view of the machine, in which it is to be noted that the wheel discs are riveted to their hubs.

Fig. 292 shows a view of the turbine with generator, and oil equipment. The construction of the wheels, and division walls can easily be seen in Figs. 293, 294 and 295. The construction according to the latter figure, with division walls made in sections is preferred, because after taking away the casing cover, all the interior parts are easily accessible.

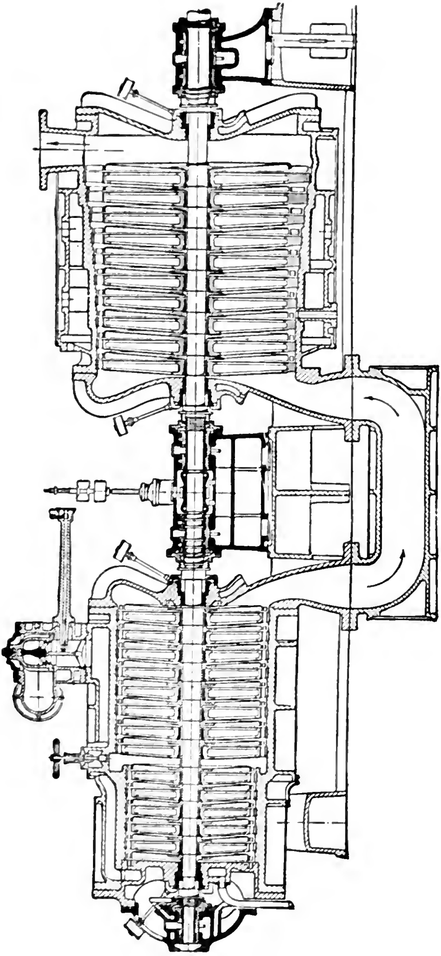


FIG. 291

The most recent Rateau turbine is of the action type, that is to say, expansion of the steam is fully carried out in

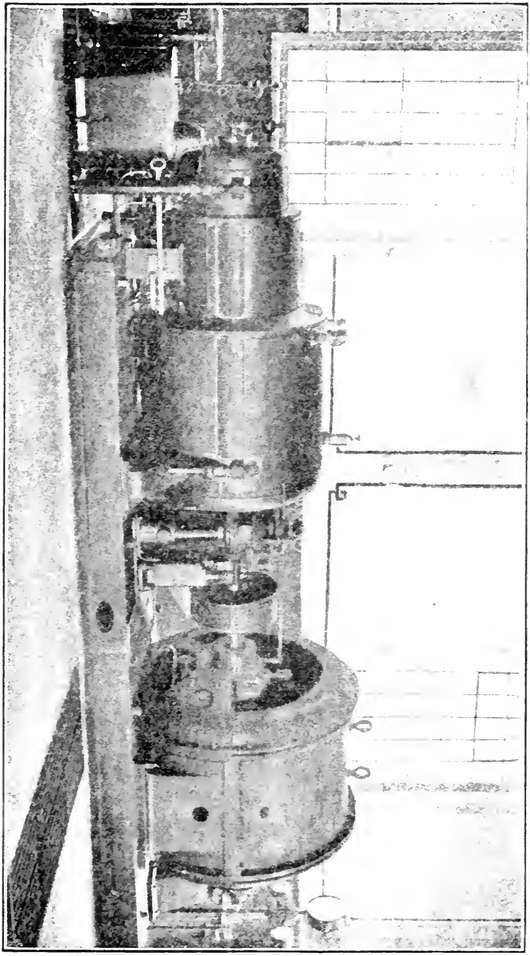


FIG. 292

the distributor for each group consisting of a distributor and one moving wheel. The steam therefore acts by its velocity and not by its pressure. These turbines are moreover multicellular, that is to say, they consist of a certain number of elements, each element comprising one distributor and one moving wheel.

This turbine has been developed by the firm of Sautter-Harlé, of Paris, France, from designs by Prof. A. Rateau, who is also the inventor of the Rateau steam regenerator, through which the exhaust from non-condensing reciprocating engines may be passed to a low-pressure turbine, thus resulting in the development of power from steam which otherwise would be wasted. A very complete and

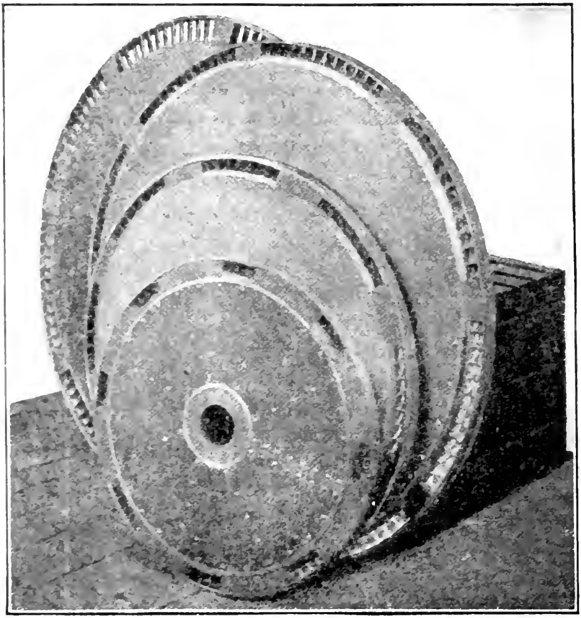


Fig. 293

successful installation of this character has been in operation for some time at the extensive steel works of the International Harvester Company at Chicago, Ill., and judging from the results of an exhaustive series of tests conducted by Mr. F. G. Gaesch, and published in the June, 1907, issue of "Power," the system possesses considerable merit. The following description of the installation at the Harvester Company's plant, is supplied by courtesy of the Western Electric Co., of Chicago.

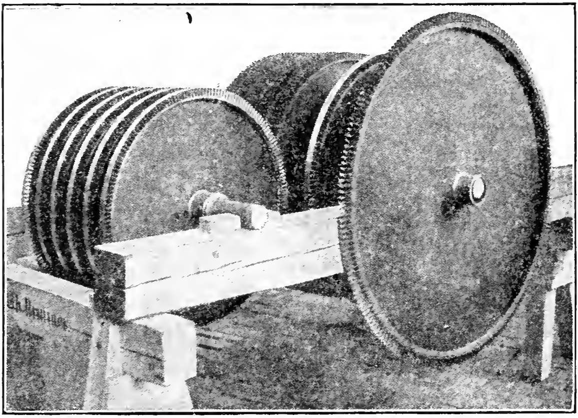


Fig. 294

The Steam Regenerator, or accumulator, consists of a cylindrical wrought-steel shell $\frac{3}{8}$ of an inch in thickness, 11 feet 6 inches in diameter, and 30 feet long, having a central horizontal diaphragm which divides the regenerator into two similar compartments. In each compartment there are six elliptical tubes or steam-distributing conduits, A, Fig. 296, which extend from end to end in pairs, and are so placed as to leave spaces, B, between them. (The sectional view is from another installation and only shows four tubes.) Baffle plates, C, are arranged above the space between each pair of tubes. The spaces surrounding the conduits, and, under certain conditions, even the conduits themselves, are filled with water to the extent that the top of the latter is usually submerged three or four inches. The sides of the conduits are perforated with a great many $\frac{3}{4}$-inch holes to allow of the lateral escape of steam through the water, with, occasionally, a further escape from the bottom openings. A large baffle plate in the upper steam space serves for a perfect separation of entrained moisture from the steam. The steam enters by the pipe shown at the left hand of the side elevation, passes to the interior of the elliptical tubes, and escapes into the spaces through the perforations. The circulation of the water takes place in the direction of the arrows: the baffle plates placed above each pair of tubes prevent the water from being thrown

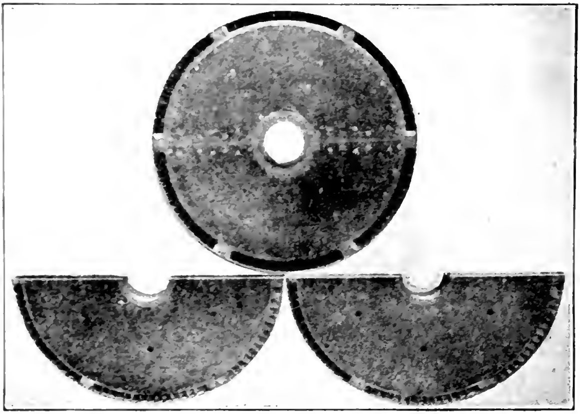


FIG. 295

into the steam space. This flow of steam gives an extreme degree of steam saturation to the water; and the slight back pressure which at first might be expected, owing to the head of water above the rows of perforations, is thereby reduced to insignificant proportions.

When the supply of steam from main engine ceases, the water liberates part of the heat it has absorbed, and an even flow of low-pressure steam is given off, while the steady demand of the turbine reduces the pressure in the accumulator, causing the steam still retained in the tubes to escape, maintaining the circulation of the water, and facilitating the liberation of the steam. Experience has shown that the whole of the contained water participates in the regenerative action. The steam is taken from the top of the accumulator to the turbine, and the pressure can be regulated by the relief valve shown. The water level is maintained constant by a ball float contained in a small tank arranged at the back of the regenerator. Generally there is a slight overflow at all times, representing among other things the "make up" from the exhaust steam supply. The regenerator at this plant has a capacity of 55 tons of water, sufficient by actual test to deliver all the steam for a 50 per cent overload on the turbine for a period of 430 seconds. At full load this would correspond to a period of 390 seconds. The regenerator or accumulator is fitted with the following accessories: First, an adjustible relief valve, which regulates the limits of pressure in the accumulator, and allows the steam to escape when the turbine is stopped, or working on a light load: it also prevents back pressure in the cylinders of the reciprocating engine.

This valve may be connected to the condenser so that in case the turbine is shut down for a period, the main engines may have the benefit of the vacuum.

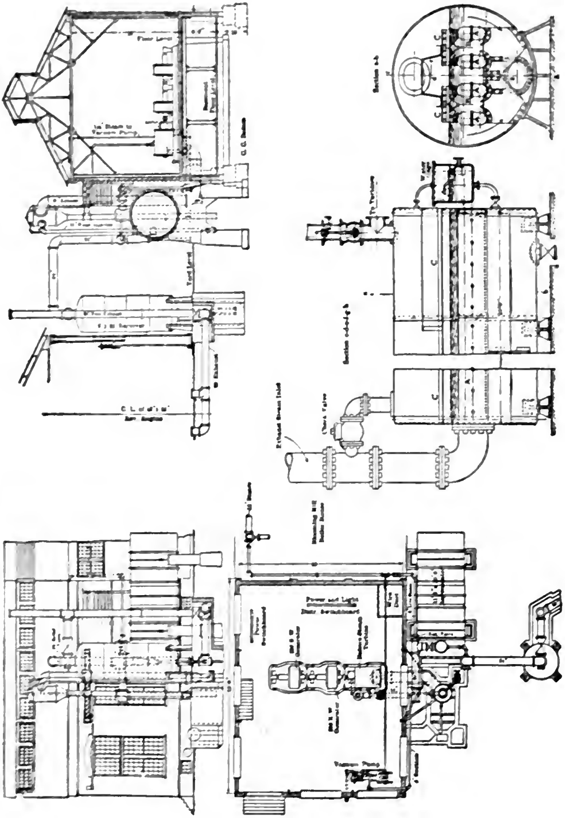


FIG. 296

PLAN AND ELEVATION OF LOW-PRESSURE TURBINE INSTALLATION, WITH TRANSVERSE AND LONGITUDINAL SECTIONS OF REGENERATOR

Second, a non-return water valve, necessary with water accumulators, to prevent any possibility of reflux of water toward the main engines during periods of stoppage.

Third, automatic level regulators, and gauge glasses, and automatic drains.

Fourth, piping beginning at the inlet of the receiving drum, including the steam header and mains from the regenerator to the turbine, the exhaust piping from the turbine, and condenser, and the piping between the condenser and air pump.

Fifth, a vertical receiving drum 9 feet in diameter, and 22 feet long, with baffle plates, and separating chambers, the function of which is to allow the ready escape of steam from the main engines without increase of back pressure on the system. The expansions allowed in this drum conduce to a more even flow of steam in the steam regenerator.

Sixth, a 30-inch barometric condenser of the Alberger type, complete with air cooler, exhaust entrainer, expansion joint, and an air pump 8x6x12 inches.

The exhaust steam from a 42x60 McIntosh & Hemphill, rolling mill engine, passes through the regenerator and into a Rateau low-pressure turbine, to the shaft of which is connected two direct current generators, each of 250 K. W. capacity, at 250 volts, and designed so that they may be operated in parallel. The bearings are of the ring oiled reservoir type, with water jackets. The plant is designed with a view of adding another similar unit, but the evidence of the tests shows that a 750 K. W. unit can be operated with the steam that is available, without allowance for the steam (about 6,000 lbs. per hour) that is available from auxilliary machinery.

Part of these auxiliaries already exhaust into an open feed water heater, but the steam regenerator, constituting a perfect feed heating device, can more appropriately receive all the steam from the auxiliaries, with the advantage of some addition to the capacity of the turbine equipment.

Fig. 297 shows a view of the regenerator and attached equipment.

The leading objects of the tests made by Mr. Gaesch were, first to determine the steam consumption of the turbine per unit of power, and second, to measure the actual amount of steam available for the use of the turbine as delivered from the main engine.

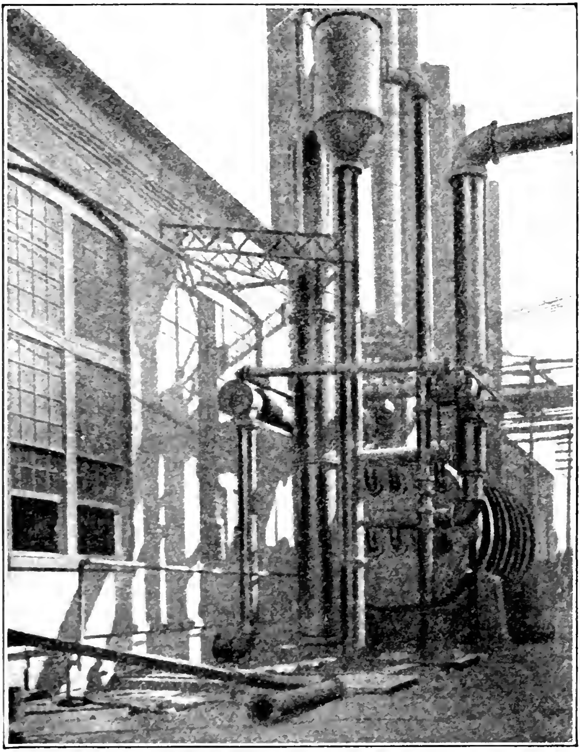


FIG. 297

RATEAU REGENERATOR, AND ATTACHED CONDENSER

Space prohibits a detailed description of the method of conducting the tests, and the results derived therefrom.

The average brake horse power developed by the turbine according to the report of one of the tests was 544 with a steam consumption per B. H. P. per hour of 37 lbs. The average steam pressure at the turbine was 16.6 lbs. absolute. The average I. H. P. of the main engine during the same test was 820, with a steam consumption of 61.2 lbs. per I. H. P. per hour. The total weight of steam available per hour from regenerator to turbine was 56,100 lbs.

The main engine, the dimensions of which have already been given, was a reversing rolling mill engine. The stuffing box used in the Rateau turbine is clearly illustrated in Figs. 240 to 243.

The Reidler-Stumpf Steam Turbine

This turbine is manufactured in Germany and its essential characteristics are the peculiarly formed, parallel return buckets derived from the Pelton water wheel, also the rectangular nozzles that allow a homogeneous jet of steam to be directed against the wheel. Fig. 298 shows a view of one of the wheels, and Fig. 299 shows sections of a bucket, and nozzle.

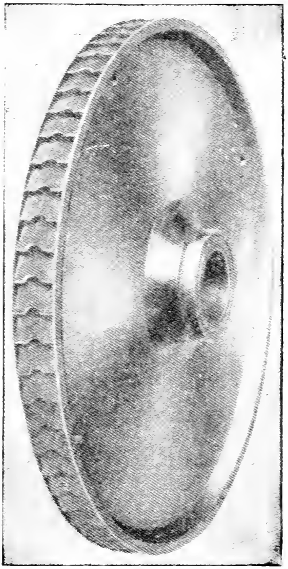


Fig. 298

The buckets are worked out of a solid forged wheel with a milling cutter, consequently they are very strong, and durable.

The steam jet enters the bucket C from the nozzle B, and is deflected through an angle of 180 degrees, the direction of its exit being parallel to that of its entrance, as shown by the arrows (Fig. 299).

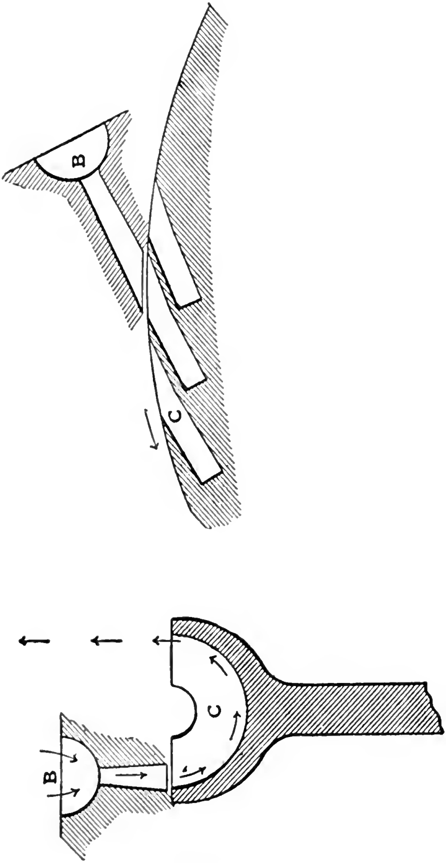


Fig. 299

This type of wheel has but a one-sided discharge—Fig. 300 shows another type of this turbine, in which the sta-

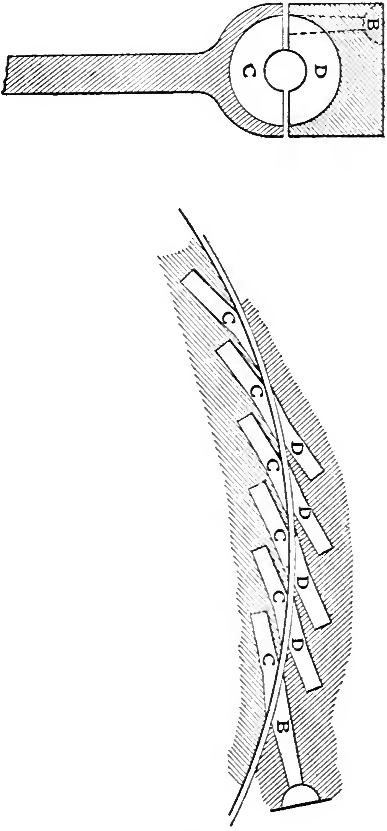


Fig. 300

tionary buckets D, of the reverse guide are opposed to the rotating buckets C of the wheel in such a manner as to form a continuous closed cylinder in which the steam in its course through the wheel continually whirls or spirals around and around. With this type of turbine the steam enters the bucket wheel from the nozzle as shown in Fig. 299, but instead of escaping after it has passed once through the bucket, it is caught by the guide or stationary bucket and returned to the wheel, this process being repeated again and again until practically all of the energy in the steam has been abstracted.

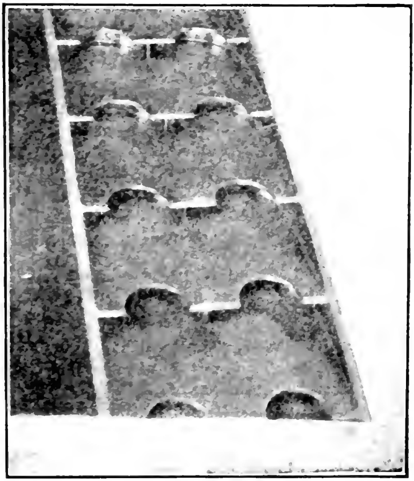


FIG. 301

Fig. 301 shows a portion of the rim of this style of wheel with its symmetrical double buckets. The steam jet is split into two symmetrical parts by the sharp middle partition. The direction of flow of the two steam streams is now reversed, and they are returned to the middle plane of the wheel by the reverse blades, and again brought to the wheel as a united jet. Nearly the entire periphery has primary, or secondary admission, and as a result of this the fan work of the idle blades is reduced to a minimum.

Disposal of the Exhaust Steam of Steam Turbines

As in the case of the reciprocating engine, the highest efficiency in the operation of the steam turbine is obtained by allowing the exhaust steam to pass into a condenser, and experience has demonstrated that it is possible to maintain a higher vacuum in the condenser of a turbine than in that of a reciprocating engine. This is due, no doubt, to the fact that in the turbine the steam is expanded down to a much lower pressure than is possible with the reciprocating engine.

The condensing apparatus used in connection with steam turbines may consist of any one of the modern improved systems, and as no cylinder oil is used within the cylinder of the turbine, the water of condensation may be returned to the boilers as feed water. If the condensing water is foul or contains matter that would be injurious to the boilers, a surface condenser should be used. If the water of condensation is not to be used in the boilers, the jet system may be employed. Another type of condenser that is being successfully used with steam turbines is the Bulkley injector condenser.

Among the steam turbines that were on exhibition at the St. Louis exposition in 1904 the Westinghouse-Parsons and the General Electric Curtis turbines were each equipped with Worthington surface condensers, fitted with improved auxiliary apparatus consisting of dry vacuum pumps, either horizontal of the well-known Worthington type, or rotative motor-driven, a hot well pump, and a pump for disposing of the condensed steam from the exhaust system. The two latter pumps were of the Worthington centrifugal type. The Hamilton-Holzwarth turbine was equipped with a Smith-Vaile surface condenser, fitted with a duplex double-acting air pump, a compound condensing circulating pump, and a rotative dry vacuum pump, motor-driven. The vacuum maintained was high, 28 to 28.5 in.

As an instance of the great gain in economy effected by the use of the condenser in connection with the steam turbine, a 750 K. W. Westinghouse-Parsons turbine, using steam of 150 lbs. pressure not superheated and exhausting into a vacuum of 28 in., showed a steam consumption of 13.77 lbs. per B. H. P. per hour, while the same machine operating non-condensing consumed 28.26 lbs. of steam per B. H. P. hour. Practically the same percentage in economy effected by condensing the exhaust applies to the other types of steam turbines.

With reference to the relative cost of operating the several auxiliaries necessary to a complete condensing outfit, the highest authorities on the subject place the power consumption of these auxiliaries at from 2 to 7 per cent of the total turbine output of power. A portion of this is regained by the use of an open heater for the feed water, into which the exhaust steam from the auxiliaries may pass, thus heating the feed water and returning a part of the heat to the boilers.

A prime requisite to the maintenance of high vacuum, with the resultant economy in the operation of the condensing apparatus, is that all entrained air must be excluded from the condenser. There are various ways in which it is possible for air to find its way into the condensing system. For instance, there may be an improperly packed gland, or there may be slight leaks in the piping, or the air may be introduced with the condensing water. This air should be removed before it reaches the condenser, and it may be accomplished by means of the "dry" air pump.

This dry air pump is different from the ordinary air pump that is used in connection with most condensing systems. The dry air pump handles no water, the cylinder being lubricated with oil in the same manner as the steam cylinder. The clearances also are made as small as possible. These pumps are built either in one or two stages.

A barometric or a jet condenser may be used, or a surface condenser. The latter type lessens the danger of entrained air, besides rendering it possible to return the condensed steam, which is pure distilled water, to the boilers along with the feed water, a thing very much to be desired in localities where the water used for feeding the boilers is impregnated with carbonate of lime, or other scale-forming ingredients.

In comparing the efficiency of the reciprocating engine and the steam turbine it is not to be inferred that reciprocating engines would not give better results at high vacuum than they do at the usual rate of 25 to 26 in., but to reach and maintain the higher vacuum of 28 to 28.5 in. with the reciprocating engine would necessitate much larger sizes of the low-pressure cylinder, as also the valves and exhaust pipes, in order to handle the greatly increased volume of steam at the low pressure demanded by high vacuum.

The steam turbine expands its working steam to within 1 in. of the vacuum existing in the condenser, that is, if there is a vacuum of 28 in. in the condenser there will be 27 in. of vacuum in the exhaust end of the turbine cylinder.

On the other hand, there is usually a difference of 4 or 5 in (2 to 2.5 lbs.) between the mean back pressure in the cylinder of a reciprocating condensing engine, and the absolute back pressure in the condenser.

It therefore appears that the gain in economy per inch increase of vacuum above 25 in. is much larger with the turbine than it is with the reciprocating engine. Mr. J. R. Bibbins estimates this gain to be as follows: between 25 and 28 in. there is a gain of 3½ to 4 per cent per inch of increase, and at 28 in. 5 per cent. These results have been obtained by means of exhaustive tests conducted by Mr. Bibbins. Other high authorities on the steam turbine all agree as to the great advantages to be derived by incurring the extra expense of erecting a condensing plant that is capable of maintaining the high vacuum necessary to high efficiency.

Another method by which the steam consumption of the turbine may be materially decreased, and a great gain in economy effected is by superheating the steam. The amount of superheat usually specified is 100°, and the apparatus employed for producing it may be easily mounted in the path of the waste gases. The steam may thus be superheated without extra cost in fuel, and an increase of 8 to 10 per cent in economy effected. The independent superheater requires extra fuel and labor, and the gain in this case is doubtful, but there can be no question as to the wisdom of utilizing the waste flue gases for superheating the steam.

As previously stated, the steam turbine is peculiarly adapted for the use of highly superheated steam, and high vacuum, and in these two particulars it excels the reciprocating engine. At the present time many large plants are equipped with turbine engines that are giving the best of results, and the outlook for the future employment of this type of power producer is certainly very promising.

Surface Condensers.—The demand for efficient service in the production of power by both the reciprocating engine, and the steam turbine has resulted in bringing to bear upon the design of the surface condenser, some of the thought, study and experiment which have heretofore been expended upon the other factors of the power plant. Up to within the past few years the surface condenser consisted principally of an indiscriminate collection of tubes within a metal box, with a flood of water following what happened to be the path of least resistance, with tubes subjected upon the steam side to a shower of water of condensation, keeping the steam from contact, and with pockets and quiet corners for steam and air and water, with an air-pump large enough for whatever happened, and little attention paid to the getting of the air into it, the surface condenser has satisfied the moderate demands of the past, and awaited the demands created by the turbine, and the strenuous central station man for scientific treatment along rational lines.

In a condenser taking care of 200,000 pounds of steam per hour, over 55 pounds of water are made upon the tubes per second. If this has to drip down over the bank below the point at which it is formed, it can readily be seen that the lower tubes are going to be busy cooling off feed-water instead of condensing steam, and that the greater rate of condensation will occur upon the upper tubes. By arranging the tubes in banks, the condensation from each of which is quickly drawn to the side and disposed of, by leading the steam to a positive and rapid flow among these tubes in a direction counter to the flow of the water, so that the final contact of the condensed steam and air is with the coolest water, and by subdividing the flow so that the circulating water travels positively and rapidly past every square foot of the cooling surface, the condenser is made to condense eighten or twenty instead of six pounds of steam per hour per square foot of surface. The significance of this, not only in first cost and space occupied, but in maintenance charges where, as in some of the large stations upon the Atlantic seaboard, tubes have to be renewed once in about three years, is easy to appreciate, and it is not the tube which is condensing lots of steam, but rather that which is loafing in an air pocket or an eddy, that is the most likely to corrode.

Notwithstanding the liability to corrosion of the tubes of surface condensers, many of the large engine plants, and practically all steam turbine plants have been equipped with surface condensers. This is due largely to the saving effected by returning the pure water of condensation to the boilers. But unless the condenser tubes are closely watched for signs of corrosion, there is danger of having in the course of time a mixture of cylinder oil and condenser leakage along with the water of condensation, which would be a very undesirable boiler feed. This applies to reciprocating engine plants. On the other hand a surface condenser in connection with a steam turbine is a better investment. The turbine water of condensation contains no lubricating oil and condenser leakage is the only source of trouble to be feared. To maintain this condenser leakage at the lowest practicable minimum is extremely important, as this will seriously affect (if the hot-well water is used for boiler feed) the percentage of corrosive and scale-forming elements fed into the boilers. Even under normal surface-condenser operation there is a small leakage, through the packing at the ends of the tubes, and to this is added leakage due to corrosion.

The danger of corrosion attacking the tubes of surface condensers is much greater in localities upon, or near the sea coast where the condensing water is largely impregnated with salt.

QUESTIONS AND ANSWERS.

446. Explain the chief points of difference between the action of the reciprocating steam engine, and the steam turbine.

Ans. The piston of the reciprocating engine is driven back and forth by the static expansive force of the steam; while in the steam turbine, not only is this static expansive force made to do work, but the velocity of the steam in expanding from a high, to a low pressure is also utilized in turning the rotor of the turbine.

447. What other important factors enter into the operation of a steam turbine?

Ans. The principles of reaction and impulse.

448. Name several of the more important advantages that the turbine has over the reciprocating engine.

Ans. First, highly superheated steam of a high initial pressure may be used in the turbine. Second, a larger proportion of the heat in the steam may be converted into work with the turbine. Third, there is much less friction with the turbine.

449. What is the most economical method of disposing of the exhaust steam from a turbine?

Ans. By allowing it to pass into a condenser.

450. Will the turbine expand the steam to as low a pressure as the reciprocating engine will?

Ans. Yes, and even lower.

451. What type of condensing apparatus is necessary with the steam turbine.

Ans. The same kind that is used on reciprocating engines.

452. How low will a well regulated turbine allow the steam to expand?

Ans. To within one inch of the vacuum existing in the condenser.

453. What is the theoretical velocity of steam under 100 lbs. pressure if allowed to discharge into a vacuum of 28 inches?

Ans. 3860 feet per second.

454. How many ft. lbs. of energy would one cubic ft. of steam thus exert?

Ans. 59,900 ft. lbs.

455. What is the ratio of bucket speed to jet speed for impulse wheels.

Ans. Bucket speed equals one-half of jet speed.

456. What should be the ratio between bucket speed and jet speed, for reaction wheels.

Ans. 1 to 1. That is, the two speeds should be equal.

457. What should be the form or curvature of the blades, or buckets?

Ans. They should be of such form as will permit expansion of the steam with the least amount of friction, or eddy currents.

458. How are the stuffing boxes of steam turbines usually kept cooled?

Ans. By means of water applied in various ways.

459. How is the speed of steam turbines usually regulated?

Ans. By simple throttling.

460. What are the ideal conditions under which a turbine should work?

Ans. A full initial pressure, and all cross sections of steam passages to be suitable to the power required.

461. Of what type is the Westinghouse-Parsons turbine?

Ans. It is both an impulse and reaction turbine.

462. How are the clearances between the blades preserved in this turbine?

Ans. By means of balancing pistons on the shaft.

463. What is the usual velocity of the steam in the Westinghouse-Parsons turbine?

Ans. 600 ft. per second.

464. How does the efficiency of steam turbines compare with that of reciprocating engines?

Ans. It is generally higher.

465. How is the heat energy in the steam imparted to the wheels of the Curtis turbine?

Ans. Both by impulse and reaction.

466. Describe the method of admission in the Curtis turbine.

Ans. The steam is admitted through expanding nozzles in which nearly all of the expansive force of the steam is transformed into the force of velocity. The steam is caused to pass through one, two, or more stages of moving elements, each stage having its own set of expanding nozzles, each succeeding set of nozzles being greater in number and of larger area than the preceding set.

467. What is the ratio of expansion in these nozzles?

Ans. The ratio of expansion within these nozzles depends upon the number of stages, as, for instance, in a two-stage machine, the steam enters the initial set of nozzles at boiler pressure, say 180 lbs. It leaves these nozzles and enters the first set of moving blades at a pressure of about 15 lbs.

468. In a four-stage machine, with 180 lbs initial pressure, what would be the pressures at the different stages?

Ans. First stage, 50 lbs.: second stage, 5 lbs.; third stage, partial vacuum, and fourth stage, condenser vacuum.

469. How are the revolving parts of the Curtis turbine supported?

Ans. Upon a vertical shaft, which in turn is supported by, and runs upon a step bearing at the bottom.

470. How is this step bearing lubricated?

Ans. Oil is forced under pressure by a steam or electrically driven pump, the oil passing up from beneath.

471. How is the speed of the Curtis turbine regulated?

Ans. By varying the number of nozzles in flow.

472. How are the clearances adjusted in the Curtis turbine?

Ans. By means of the large step screw at the bottom.

473. How is the shaft packed to prevent steam leakage?

Ans. With carbon blocks made into rings fitting the shaft.

474. What type of turbine is the De Laval?

Ans. It is purely an impulse wheel.

475. What is the speed of the wheel?

Ans. From 10,000 to 30,000 revolutions per minute.

476. How is the heat energy in the steam utilized in the De Laval turbine?

Ans. In the production of velocity.

477. What is the velocity of the steam as it issues from the expanding nozzles and impinges against the buckets?

Ans. About 4,000 ft. per second.

478. What is the usual peripheral speed of the wheel?

Ans. 1,200 to 1,300 feet per second.

479. Of what type is the Allis-Chalmers steam turbine?

Ans. It is essentially of the Parsons type.

480. How are the clearances between the revolving and stationary blades preserved?

Ans. By a thrust bearing.

481. What kind of bearings has the Allis-Chalmers turbine?

Ans. Self-adjusting ball and socket bearings.

482. What is the first move in preparing to start a steam turbine?

Ans. Open the throttle slightly and allow a small volume of steam to flow through in order to warm the turbine.

483. What should be done next?

Ans. Start the auxiliary oil pump.

484. What are the principal precautions to be observed when starting a steam turbine?

Ans. To see that the turbine is properly warmed, also to be certain that the oil is circulating freely through the bearings.

485. What type of turbine is the Hamilton-Holzwarth steam turbine?

Ans. It is an impulse turbine.

486. Describe in brief its construction?

Ans. There are no balancing pistons in this machine, the axial thrust of the shaft being taken up by a thrust ball-bearing. The interior of the cylinder is divided into a series of stages by stationary discs which are set in grooves in the cylinder and are bored in the center to allow the shaft, or rather the hubs of the running wheels that are keyed to the shaft, to revolve in this bore.

487. In what respect does this turbine resemble a compound reciprocating engine?

Ans. The steam is first admitted to the high pressure casing, and from there it passes into the low pressure casing, which is larger in diameter.

488. Describe the action of the steam upon the blades?

Ans. The expansion of the steam takes place entirely within the stationary blades, which also change the direction of its flow, distributing it to the running vanes.

489. What additional function do the stationary vanes perform?

Ans. They take the back pressure, thus acting as balancing pistons.

490. What type of governor has this turbine?

Ans. The spring and weight type.

491. How are the bearings lubricated?

Ans. The oil is forced into the bearings under pressure by an oil pump.

492. Of what type is the Rateau steam turbine?

Ans. It is an impulse turbine having wheels of thin plates, slightly conical.

493. How is the rotor balanced?

Ans. The same pressure exists on both sides of each rotating wheel.

494. Does the steam act by velocity or pressure?

Ans. By velocity in this case.

495. What are the essential features of the Reidler-Stumpf steam turbine?

Ans. The peculiar form of bucket, and the parallel return of the steam.

496. What is meant by parallel return of the steam?

Ans. The steam enters the buckets through nozzles, and is deflected through an angle of 180 degrees, thus leaving the rotating buckets in a direction parallel to that of its entrance.

497. Describe the action of the steam within the Reidler-Stumpf turbine.

Ans. Instead of escaping after having once passed through the buckets, it is caught by the guides or stationary buckets and returned to the wheel: this process being repeated again, and again until all of the energy in the steam has been made to do work.

498. How many types of this turbine are there?

Ans. Two, viz.: The single flow, and the double flow.

499. How is the highest efficiency obtained in the operation of the steam turbine?

Ans. By allowing the exhaust steam to pass into a condenser.

500. Is it possible to maintain as high vacuum with the turbine as with a reciprocating engine?

Ans. Experience demonstrates that a higher vacuum may be maintained in the condenser of a turbine than is possible with reciprocating engines.

501. What kind of condensing apparatus may be used with steam turbines?

Ans. Any one of the modern improved types.

502. What is required in order to maintain a high vacuum in any type of condenser?

Ans. That all entrained air be excluded.

503. How may this be accomplished?

Ans. By means of a dry air pump.

504. In what manner does the dry air pump differ from an ordinary air pump?

Ans. The dry air pump handles no water, and the clearances are made as small as possible.

505. To what extent does the steam turbine expand its working steam?

Ans. To within one inch of the vacuum existing within the condenser.

506. Is the steam turbine adapted to the use of superheated steam?

Ans. It is. Highly superheated steam may be used, and a high vacuum maintained.

507. Is the water of condensation from turbines desirable for boiler feed?

Ans. It is, for the reason that it contains no lubricating oil, and is a comparatively pure water.

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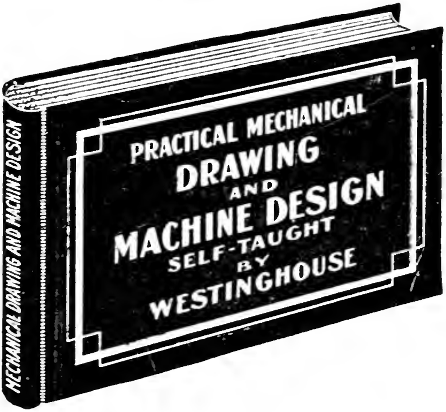

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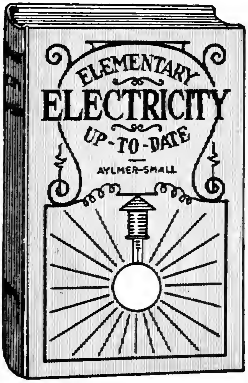

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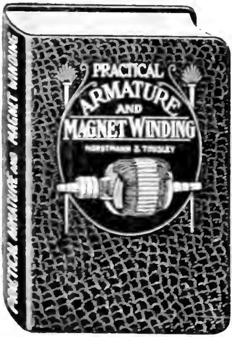

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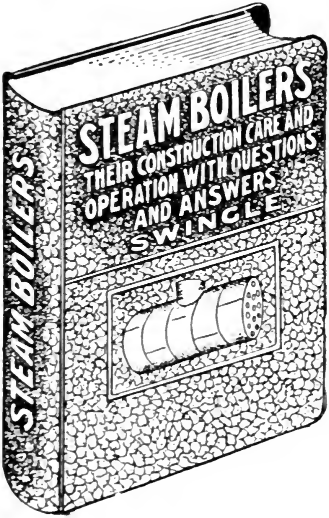

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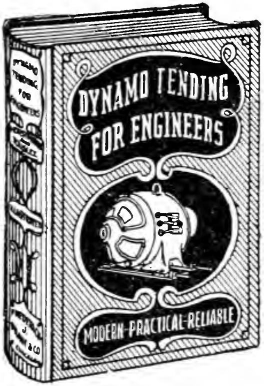

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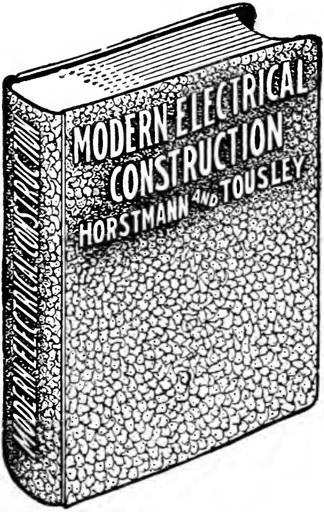

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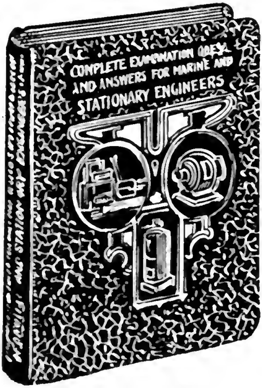
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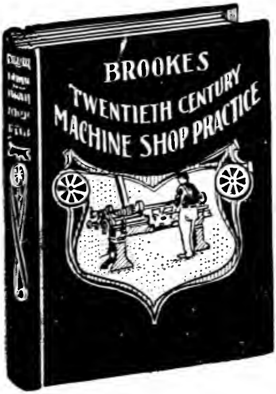
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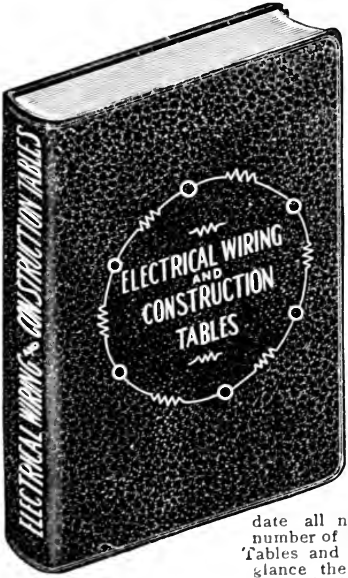
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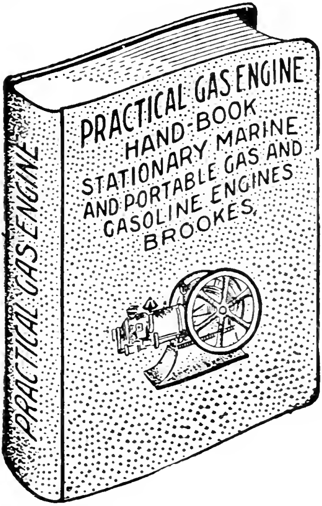

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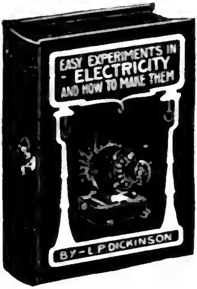

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