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A COMPARISON OF THE [illegible] AND

O[illegible] OF [illegible]

[illegible]

[illegible] IN THE UNITED STATES.

A Thesis Submitted to

The Faculty of The

Michigan Agricultural College

by

Wesley Fuller Malloch

Candidate for the Degree

Bachelor of Science

June, 19[illegible]1

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P R E F A C E

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PREFACE.

The preparation of this paper has been undertaken in order to present in a concise form information concerning large steam turbines manufactured in the United States. It is felt that it will supply useful information in a ready form for comparison, thereby serving as a possible guide to engineers interested in steam turbine design and operation.

The material for this paper has been obtained from bulletins and confidential data sheets furnished by manufacturers, data supplied by operating companies and engineers, as well as from the latest available textbooks on the subject, articles in current technical periodicals and from the proceedings of various national engineering societies. This has been supplemented by knowledge gained from personal investigation and experience.

Since the present tendency in the design of steam turbines seems to be toward ever-increasing unit sizes and since the smaller machines have become so numerous as to types and designs, from the practical viewpoint it has been considered desirable to limit the discussion to those machines of 5,000 kw. rated capacity and over with more particular reference to those units built in sizes of 20,000 kw. and over.

Acknowledgement is made to the following concerns whose officials have kindly furnished information for the preparation of this report:

Allis-Chalmers Mfg. Co.,
General Electric Co.,
Westinghouse Electric & Mfg. Co.,
Detroit Edison Co.,
Commonwealth Edison Co., Chicago.

L I S T O F I L L U S T R A T I O N S.

T A B L E   O F   C O N T E N T S

LIST OF ILLUSTRATIONS.

(Concluded)

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I N T R O D U C T I O N

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A bibliography of the trade publications, text books, technical bulletins and periodicals which have been used as sources of material is appended at the end of this Report.

INTRODUCTION

There are at the present time but three manufacturers of steam turbines in the United States whose machines fall within the limits of this paper. They are the Allis-Chalmers Manufacturing Company, Milwaukee, Wisconsin, The General Electric Company, Schenectady, N. Y., and the Westinghouse Electric & Manufacturing Company, Pittsburgh, Pennsylvania.

The machines may be classified under two headings, namely; the reaction type and the impulse type, or, more specifically, the Parsons-reaction and the Curtis-impulse turbines. There have been various modifications and improvements have been introduced in the development of the present types but fundamentally they may be classified as above.

The Parsons-reaction turbine was invented in England by the Hon. Sir Charles Algernon Parsons in 1884 and is built in this country under American patent rights secured by the American manufacturers from the inventor.

The Curtis-impulse turbine was an American invention patented by Mr. C. G. Curtis in 1896.

The steam turbines manufactured by the Allis-Chalmers Manufacturing Company are of the Parsons-reaction type. Although up to the present time this company has built no units larger than 10,500 kw. rated capacity, it is now in a position to offer machines in sizes up to 30,000 kw. and has had under development a [illegible]0,000 kw. unit. Allis-Chalmers machines are of the single-cylinder single-flow type as shown in Fig. 1, and have only reaction blading although a few of the larger

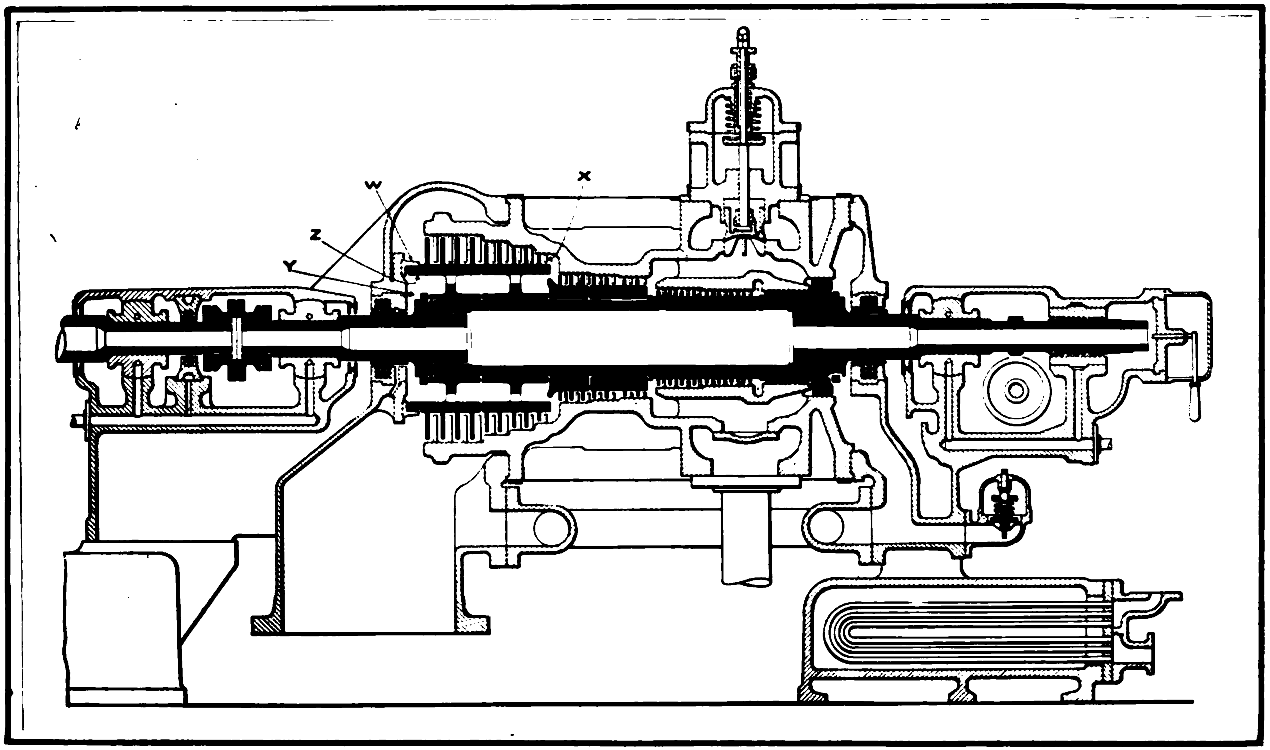

Fig. 1

Cross-section of Allis-Chalmers Turbine

machines have been designed with double-flow expansion in the low-pressure end. In the 20,000 kw. units being developed the low-pressure end is of the parallel-flow type in which the flow of the steam after it leaves the intermediate stage is divided so as to flow in the same direction along the shaft but half of the steam flows through one set of low-pressure blades while the other half flows in the same direction through a similar set of low-pressure blades farther along the shaft.

The General Electric Company is the only American manufacturer of large Curtis impulse turbines. These machines have been built in a large number of sizes and in single units of as high as 45,000 kw. capacity. Most of these turbines, even including the largest and most recent 45,000 kw. units, are of the single-cylinder single - flow type although they have been built employing double-flow expansion in the last pressure stage. When double-flow expansion is used a row of low-pressure nozzles is provided for each direction and a row of stationary and two rows of moving blades are located in the pressure stage at the exhaust side of each of these low-pressure nozzle sets. A cross-section of a recent 50,000-kw. General Electric turbine is shown in Fig. 2.

The pioneer in the field of large steam-turbine manufacture in the United States was the Westinghouse Electric & Manufacturing Company. It was this Company which really began the serious manufacture of large units. The early machines were of the single-cylinder single-flow type but as the size increased the Westinghouse Engineers, believing that greater reliability and economy could be obtained by dividing the expansion in several cylinders, developed, in addition to the single-cylinder single-flow types, steam turbines of two and three cylinders. These machines have been built both tandem-compound and cross-compound. In the tandem-compound units the high-pressure and low-pressure elements are mounted on shafts in the same line and coupled directly to one another. The elements are housed in separate cylinders. The steam, after it has expanded in the high-pressure blading is carried over from the high-pressure cylinder through a larger receiver-pipe connection to the low-pressure double-flow elements where it is expanded to the exhaust pressure. A cross-section of a 35,000 kw. Westinghouse tandem-compound turbine installed at the Northwest Station of the Commonwealth Edison Company in Chicago is shown in Fig. 3. The cross-compound units might well be considered as two or three separate turbines depending on whether there is one or two low-pressure cylinders. Each cylinder has its own spindle to which a separate generator is direct-connected. The high-pressure and low-pressure turbine elements are not mechanically connected. In this case, as in that of the tandem-compound units, the steam is first expanded in the high-pressure cylinder and is conveyed through receiver pipes to the low pressure elements. The following figures give information regarding the Westinghouse tandem-compound and cross-compound turbines:

	Weight	Length	Width	Height	Rating
Tandem	1,200,000	72ft.9in.	20ft.9in.	20ft.9½in.	35,[illegible]
Cross-compound	1,360,000	47ft.8in.	42ft.2in.	18ft.9½in.	47,[illegible]

"The cost per kilowatt of the two sizes may be assumed to be practically identical. The steam end of the tandem machine

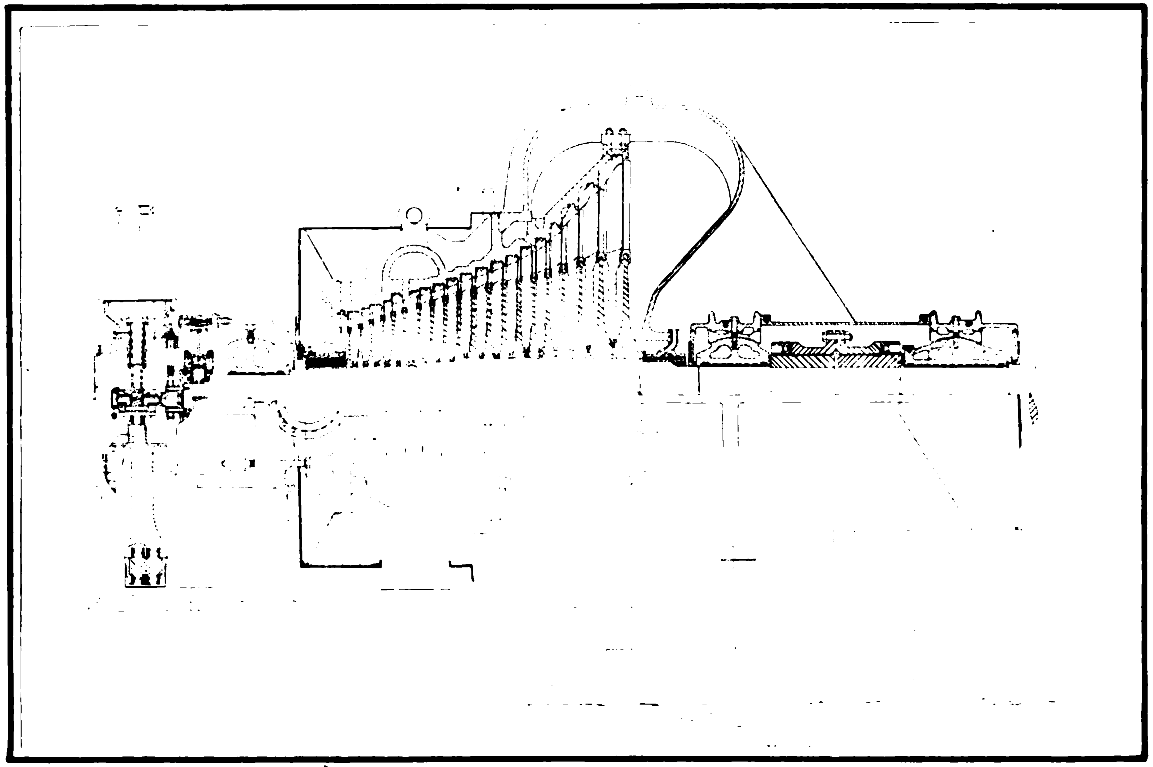

Fig. 2

Section of 30,000-Kw. General Electric Turbine

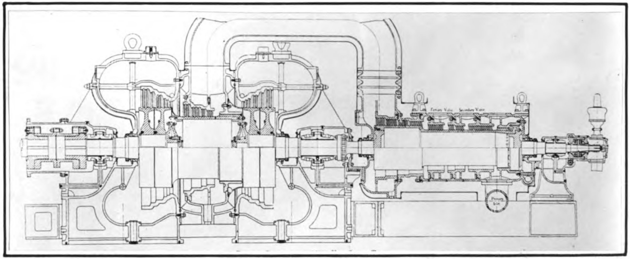

Fig. 3

Cross-section of 35,000-Kw. Westinghouse Tandem-Compound Turbine

is somewhat more expensive, while the two generators on the cross-compound will exceed the cost of the single generator about enough to equalize."

Fig. 4 shows cross-section views of the two cylinders of a [illegible],000-kw. Westinghouse cross-compound turbine and Figs. 5 and 6 are plan views of two three-cylinder cross-compound units.

The same company has also developed units in which the high-pressure elements are of the impulse type and the expansion is completed in double-flow reaction blading. These machines are of the single-cylinder construction.

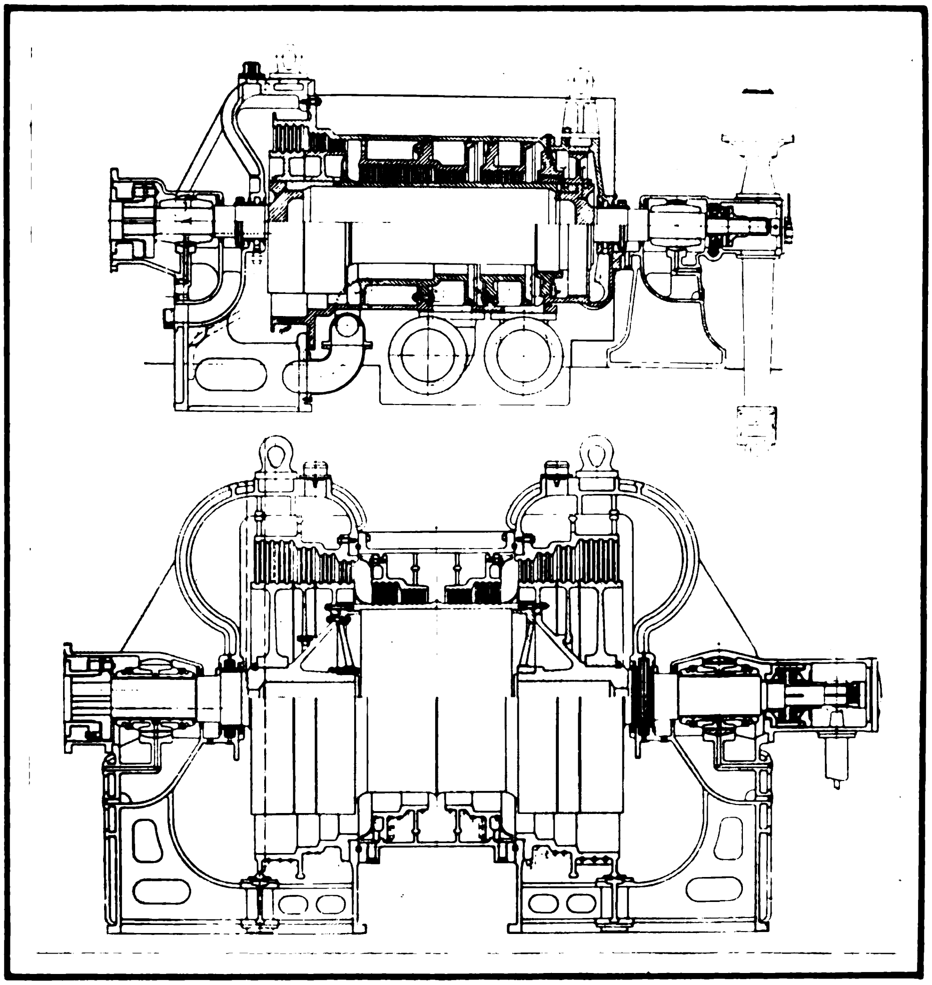

Fig. 4

Cross-sections of Two Cylinders of a 30,000-Kw. Westinghouse Cross-Compound Turbine

PERFORMANCE

Kw. Load	Steam Press. Lbs. Gage	Superheat Degrees F.	Vacuum In.Hg.	Lbs.per Kw.-Hr.	Eff. Ratio
26740	209	108.5	28.862	11.47	75.51

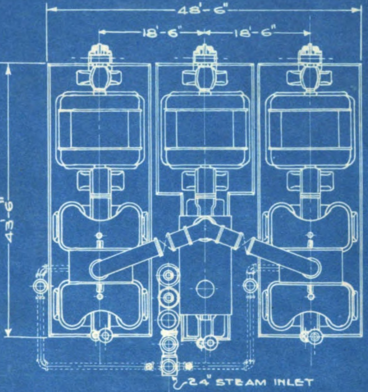

FIG. 5

70,000-KW. THREE-CYLINDER CROSS-COMPOUND STEAM TURBINE,
INTERBOROUGH RAPID TRANSIT CO., NEW YORK

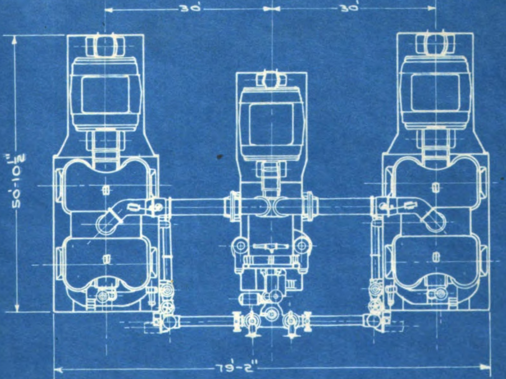

FIG. 6

60,000-KW. THREE-CYLINDER CROSS-COMPOUND STEAM TURBINE,
DUQUESNE LIGHT CO., COLFAX POWER STATION

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PART I.

COMPARISON OF STRUCTURAL DETAILS.

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B L A D I N G

The two main types of steam-turbine blading are impulse and reaction blading. The Westinghouse and the General Electric turbines employ impulse blading. All General Electric turbines have the impulse blading while the Westinghouse machines use it only in the combination machines where the high pressure stages are of the impulse type.

The method employed by the General Electric Company for securing the small and medium-sized impulse blades is shown in Fig. 7. The blades are machined at their root so that they will accurately fit the dovetailed slot machined in the periphery of the disc. At a point on the periphery an opening large enough to admit the root of one blade to the slot is prepared and all blades for a single row are introduced through this opening and then slid around to their proper position in the disc. After all blades in one row have been inserted the opening through which they were introduced to the slot is closed up by inserting a spacing block and fastening it. After the blades have been assembled a flat shroud ring is fitted over the projections at their tips and riveted in place. The function of this ring is to stiffen the complete row and reduce vibration and to assist somewhat in retaining the steam flow in its proper path.

The larger blades which are sometimes two feet and more in length in the General Electric machines are secured in the manner shown in Fig. 9. In this case the blades are forked at the root and the blades and periphery of the discs are accurately machined to give a tight fit when the blades

STEAM TURBINE IMPULSE BLADING

GENERAL ELECTRIC COMPANY

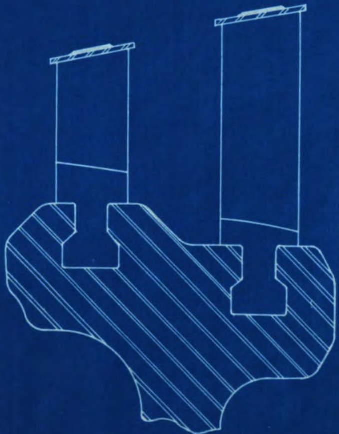


FIG. 7.

WESTINGHOUSE ELECTRIC & MFG. CO.

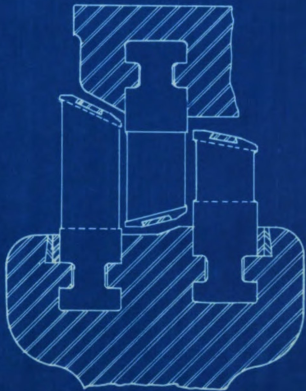


FIG. 8.

are inserted.

The Westinghouse impulse blades are inserted as shown in Fig. 8. After the blades have been inserted wedges are driven in at the sides to insure the blades being tightly held in the slot and to prevent any vibration stresses on the reduced section at the root of the blade. The shroud ring of the Westinghouse impulse blades is formed integral with the blades. At the top of the back of each blade there is a projection which fits tightly into the front of the adjacent blade. After all of the blades in a row have been assembled in place, a groove is turned in the shrouding and a steel strip is welded into the periphery to give a rigid construction to resist vibration.

The impulse blades of the Westinghouse turbines are made of electric furnace nickel steel having a composition of 5% Ni. and 0.08% C. This metal has great mechanical strength and anti-erosive qualities.

It will be noted that whereas the root section of the General Electric impulse blades of small and medium sizes is reduced at the periphery of the disc, the root section of the Westinghouse impulse blades has its full section carried well below the periphery. It is claimed that the latter construction reduces the liability to failure by vibration at the reduced section. No case of such failure in impulse blades of these smaller sizes in recent years has come to the attention of the writer, so that this claim cannot be substantiated or refuted here.

The reaction blades of the Westinghouse turbines are made of tapering cross-section, increasing towards the root, with the idea of reducing the vibration stresses throughout, their length. This is done by an upsetting process in which the blade is held firmly by its upper portion in an upsetting machine and a die, having the same cross-section as the finished blades, is brought up against the bottom, upsetting it and adding about 40% to its area. This operation also forges a foot at the bottom of the blade which is used to hold it in position in the groove of the spindle as shown in Fig. 10. This forged foot fits into a supplementary groove cut in the floor of the main groove. Dovetailed packing pieces of soft iron are then placed between the blades above these forged feet. In the larger sizes, wedges are driven in at the outlet sides of the blades for the purpose of forming a rigid interlocking system.

Reaction blading of the Westinghouse turbines has no shroud ring. In order to reduce and prevent as far as possible harmful vibration of the blades in the steam current with the subsequent failures, a lashing wire is employed. This wire has a special cross-section and is used as shown in Fig. 10. The lashing is placed a short distance from the tip of the blade in an effort to eliminate the low harmonics. After the blades have been properly spaced the tail of the comb is clinched so that the wire forms a clinch and tie between every two blades. Since the coefficients of expansion of the blades and spindle are not the same, the lashing is not continuous but the blades are tied together in groups. While this practically eliminates the vibration of the blades, individually it does not prevent some slight vibration of the entire group. This, however, is not serious as the vibration

STEAM TURBINE BLADING

GENERAL ELECTRIC CO. LARGE IMPULSE BLADING

FIG. 9.

WESTINGHOUSE REACTION BLADING

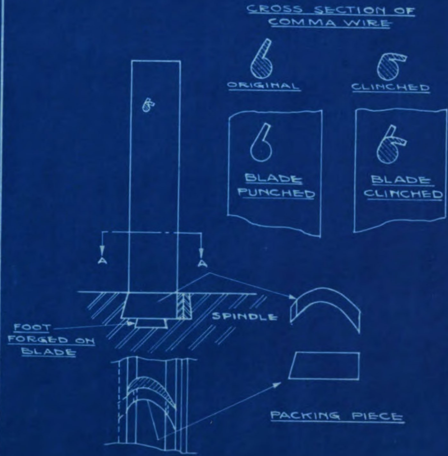


FIG. 10

stresses are reduced due to increase [illegible] period.

The reaction blades of [illegible] turbines are made of bronze, having the following composition:

Cu.	97 - 98	per cent
Sn.	2 - 3	" "
P.	0.03 - 0.07	per cent

"This metal is used for blades because of its anti-erosive and anti-corrosive qualities, and its ability to withstand vibration without fatigue."

"Where centrifugal stresses are high and mechanical strength is of prime importance, as in the low-pressure section of turbines, drop forged electric furnace nickel (low per centage) steel is used in reaction blades."

Except in the very smallest sizes the Allis-Chalmers Manufacturing Company employs a cast foundation ring to hold the reaction blading in its turbines. In this type of construction, the blading material is drawn in long strips and cut to the desired lengths. The blading sections are formed by casting the foundation ring material around the ends of the blades and the blading section is not reduced except for a small notch in the end of the blade where it does not affect the strength. The blading is not distorted in any way during the operation and consequently has its full cross-section and strength at any point to resist vibration. The construction of Allis-Chalmers reaction blading is shown in Fig. 11. The faces of the foundation rings are parallel with the blading and the grooves in the spindle are undercut to receive a projection machined on the foundation ring. The foundation ring is then firmly locked in the spindle groove by means of caulk-

STEAM TURBINE BLADING

ALLIS-CHALMERS REACTION BLADING

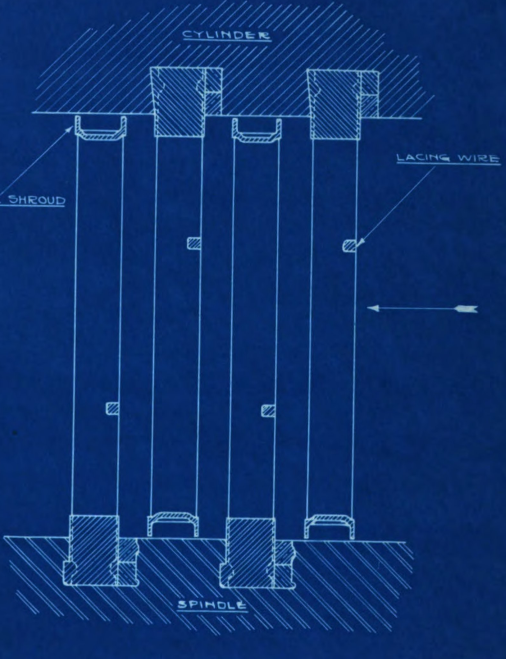


FIG. 11.

ing strip and the resulting construction stands at right angles to the spindle body so that no straightening is required and bending of blading during assembling is avoided.

The tips of the blades are further held by a channel shaped shroud brazed to them which besides greatly adding to the stiffness of the blade structure serves to a certain extent as a baffle construction preventing the leakage of the steam around the ends of the blades. In some of the most recent machines the Allis-Chalmers Manufacturing Company have employed a new type of shroud ring similar to the channel shroud except that one of the sides of the channel is bent down flat. It is believed that this change will also aid in greatly decreasing steam leakage around the ends of the blades.

In the larger sizes of blades a rectangular lacing strip is employed to aid in reducing the vibration. This strip is also brazed to the blades. Its most advantageous position has been determined by extended research and experiment for the different sizes of blading and types of construction.

The material used in the construction of Allis-Chalmers reaction blading is a copper nickel alloy which has been employed by this concern ever since it started to build steam turbines. This alloy contains approximately 80% copper and 20% nickel and is practically free from iron, zinc and other undesirable foreign substances.

S P I N D L E

In general it may be said that the shaft or spindle of the Curtis impulse turbine as manufactured by the General Electric Company is considerably shorter than the spindles of either the Westinghouse of Allis-Chalmers reaction turbines of equal capacity. This is true due to the fact that the steam is completely expanded in nozzles in the former case and as higher velocities are used a smaller number of rows of blades is necessary while in the latter machines about 80 rows of blades, 40 fixed and 40 moving, are required to expand the steam from 100 lbs. initial pressure to a 28 inch vacuum.

The spindle of a large General Electric turbine consists of a central shaft on which are mounted disc wheels carrying the blades in their periphery. There is a single wheel for each pressure stage and where there are two velocity stages in one pressure stage the rim of the wheel is enlarged to carry the two rows of moving blades. The discs or wheels of these turbines are usually made of forged steel and increase in thickness as they approach the hub. The wheels are pressed onto the shaft and keyed in place. A good idea of the rotor or spindle construction of these large units may be gained from Fig. 2.

The rotors of Westinghouse and Allis-Chalmers reaction turbines are built up of two shaft ends, a central body or barrel and various spindle rings and balance pistons as will be noted from Figs. 1, 3, and 4.

Westinghouse rotors are built up of hollow steel

shafts or drums which are machined both inside and outside. The shaft ends are constructed separately and are enlarged or flanged at one end. This end is carefully turned and the shaft ends are pressed into the ends of the rotor barrel. The diameter of this central barrel or drum corresponds to the root diameter of the smallest rings of blading. For the rows of blading of larger root diameter and for the balance pistons and dummy packing, separate steel rings which have been carefully balanced are pressed and keyed to the central body and the blade channels are cut in them.

The rotor of the Allis-Chalmers turbine is constructed in a somewhat similar manner. The shaft ends are formed from steel forgings and the spindle body is a hollow shaft forging. The inside of the ends of the spindle body and the shaft ends where they fit into the spindle are turned with a taper of 0.005" per inch. The spindle ends are forced into the body and held in place by a number of stud bolts passing through the flanges on the spindle ends and into the spindle body itself. The grooves to receive the blading are not cut into the spindle body itself but in the case of all of the larger Allis-Chalmers turbines spindle rings are provided in which the blading grooves are cut. These spindle rings are bored and turned from solid steel forgings and are all individually balanced before the rotor is assembled both before and after the blading has been inserted. The outside of the spindle body is turned with a slight taper and the rings, which are bored on the inside with a corresponding taper, are forced into position and secured in place with two keys, diametrically opposite. When all rings and balance pistons are in place on the spindle the entire spindle is heated and stop and shrink rings are inserted as shown at A, Fig. 12. The stop rings are in halves and fit in a recess in the flange of the spindle end. The stop ring is prevented from coming out by means of a shrink ring, which in turn cannot come off owing to the outside diameter of the stop ring being tapered slightly inward. In order to avoid trouble from irregular expansion of the spindle body on account of quick changes of temperature due to changes of load, holes are drilled at the center of the spindle as shown at B, Fig. 12 to admit steam to the center of the spindle thus making the temperature inside and outside the spindle the same at all times and tending to equalize the expansion of the spindle and the outside of the rings.

The standard specifications for Allis-Chalmers spindle rings and shaft ends are as follows:

Spindle Rings:

Ultimate tensile strength ...	65,000 lbs. per sq. in.
Elastic Limit	32,500 lbs. per sq. in.
Elongation in 2 inches	25%
Contraction	35%

Spindle Ends:

Ultimate tensile strength ...	75,000 lbs. per sq. in.
Elastic limit	37,500 lbs. per sq. in.
Elongation in 2 inches	23%
Contraction	35%

In extra large rings or in rings where exceptionally high stresses are likely to be encountered special chrome vanadium rings of the following characteristics are used:

Ultimate tensile strength ...	85,000 lbs. per sq. in.
Elastic Limit	50,000 lbs. per sq. in
Elongation in 2 inches	22%
Reduction of area	45%

STEAM TURBINE SPINDLE

ALLIS-CHALMERS MFG. CO.

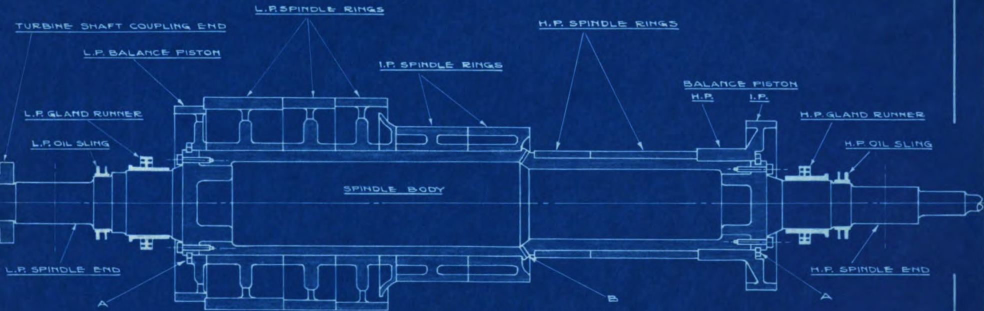


FIG. 12.

WESLEY E MALLOCH - JUNE 4 1921

Great care is taken to allow an ample margin of safety and in all cases spindles are tested at 25% over-speed before leaving the shops.

It is stated by the manufacturers that the deflection of these spindles is extremely small and seldom exceeds 0.007".

B E A R I N G S.

On all three types of turbines the bearings used consist of a babbitt-lined cylindrical shell. At the top and bottom and at each side of this shell steel blocks are fitted into grooves with liners between them and the bearing shell. The outside of these blocks is turned spherical and fits into spherical recesses in the pedestal which supports the bearing. The blocks serve as the supports for the bearing shell in the pedestal and permit movement of the spindle so that it may revolve more nearly about its center of gravity than about its geometrical center thus reducing the stresses that would be caused were the bearings constrained. Adjustment in erecting and overhauling the machine is obtained by changing the sheet steel liners under the four steel blocks. Oil is supplied at the bottom thru a central passage from which it is conducted to the ends of the bearing by suitable grooves in the babbitt lining. These bearings are split longitudinally and the two halves are held together by thru bolts. Fig. 13 shows four views of a Westinghouse bearing of this type while Fig. 14 consists of two sectional views of an Allis-Chalmers bearing in its pedestal.

B A L A N C E   P I S T O N S.

No balance pistons are employed on General Electric impulse turbines. The reason for this is that expansion of the steam for each stage is entirely completed in the preceding nozzle and there is no pressure drop within the stage itself. This results in the same pressure existing on both sides of each wheel and no unbalanced thrust of the axial component

STEAM TURBINE BEARINGS

WESTINGHOUSE SELF-ALIGNING BEARING

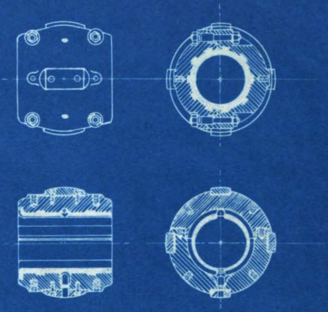


FIG. 13

ALLIS-CHALMERS BEARING AND PEDESTAL

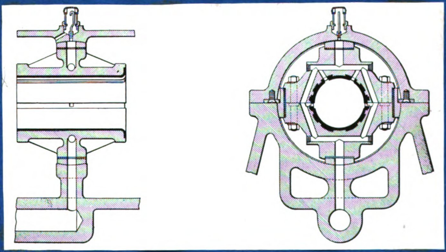


FIG. 14

of the steam jets striking the moving blades or buckets which can be readily taken care of by a single thrust bearing.

In the large Westinghouse turbines a small balance piston consisting of a collar containing grooves of dummies similar to those shown in Fig. 17 is fitted on the shaft on the opposite side of the inlet belt to the first row of high-pressure blading. Any thrust not taken up by this piston is taken care of by the thrust bearing. In the Allis-Chalmers machine the balance pistons are located as shown in Fig. 12. The high-pressure and intermediate-pressure pistons at the high-pressure end balance the end thrust due to the action of the steam on the high-pressure and intermediate-pressure blading and low-pressure balance piston at the exhaust end takes care of the end thrust due to the action of the steam on the low-pressure blading. The location of the low-pressure balance piston at the low-pressure end of the spindle rather than its incorporation in a larger piston next to the intermediate-pressure balance piston at the high-pressure end of the spindle eliminates the necessity for a large-diameter piston at the high-temperature end of the spindle and does away with troublesome leakage due to the warping of the large diameter piston. The area against which the steam pressure acts in the low-pressure piston is the solid area below the cored openings shown in this piston in Fig. 12. The steam is permitted to pass from the space between the intermediate and low-pressure spindle rings thru cored openings in the latter and thus the same pressure which is exerted against the low-pressure blading in an axial direction reacts between the turbine end-wall and the effective area of the balance piston.

G L A N D S A N D L A B Y R I N T H P A C K I N G.

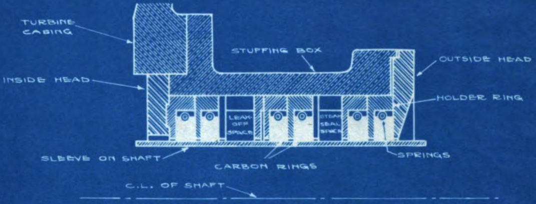
In order to seal the ends of the turbine spindle and to prevent the outleakage of steam at the high-pressure end and the in-leakage of air at the exhaust end it is necessary to provide some sort of packing. Here, due to the high speed of the spindle, it would be impracticable to utilize solid packing as is used on steam engine piston rods. Various types of packing are used to overcome this difficulty.

The General Electric Company uses carbon packing quite extensively on its larger turbines. This consists of a series of carbon rings built up of segments encircling the shaft and held against it by springs, so that any wear of the packing rings is immediately and evenly taken up. The carbon rings fit snugly in metal holder rings to minimize leakage over and around the packing rings. The rings are fitted in groups, as shown in Fig. 15, and the space between groups used to collect the steam leaking by the rings from the interior of the turbine at the head or to supply steam for sealing when installed at the exhaust end. Carbon packing, being able to adjust itself to any movement of the shaft either axially, caused by excessive end thrust, or radially due to extreme vibration, is not injured as quickly thereby as labyrinth packing.

The General Electric Company also used what is known as labyrinth packing for its spindle glands. This packing consists of a series of alternate rings on the shaft and on the inside of the gland designed so as to cause the steam to flow in a

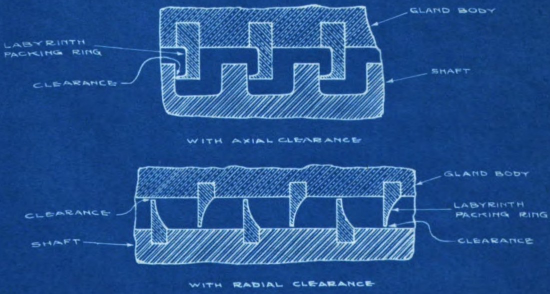
STEAM TURBINE SHAFT GLANDS AND PACKING

GENERAL ELECTRIC CO.



CARBON PACKING SHAFT GLAND

FIG. 15



LABYRINTH PACKING

FIG. 16

long winding path through the gland whereby it is throttled at each constriction in the path, with a reduction in pressure, so that starting with high pressure at the inside end of the gland, the steam escaping at the outer end will have only a few pounds pressure and it may easily be collected and piped elsewhere. If this type of gland seal is used on the exhaust end, steam at a very slight pressure may be supplied at the outer end of the gland and escape through the packing into the turbine, being gradually reduced in pressure until the exhaust vacuum is reached. Labyrinth packing of this type is shown in Fig. 16. Low side-clearance is used where the difference in expansion between the body and the shaft is very slight or negligible and the radial-clearance packing is used where this difference is large and would likely cause dangerous rubbing. Drain pipe connections are provided at the bottom of the gland casing in the case of both the labyrinth and carbon packing to draw off any condensate that may form.

The Westinghouse Electric and Manufacturing Company employs a water-seal gland in connection with labyrinth packing to seal the ends of the turbine casing where the spindle shaft passes through. In this case a bronze gland-water impeller or runner is shrunk onto the shaft and revolves in a gland casing to which water is supplied. The high speed of the spindle causes the impeller to build up a ring of water within the shell of the gland due to centrifugal force and in this way a seal is provided which will resist a pressure of more than 30 pounds per square inch. In connection with the water-seal gland labyrinth packing is also provided as shown in Fig. 17 so that in the case of the high-pressure end the steam

STEAM TURBINE SPINDLE GLANDS AND PACKING

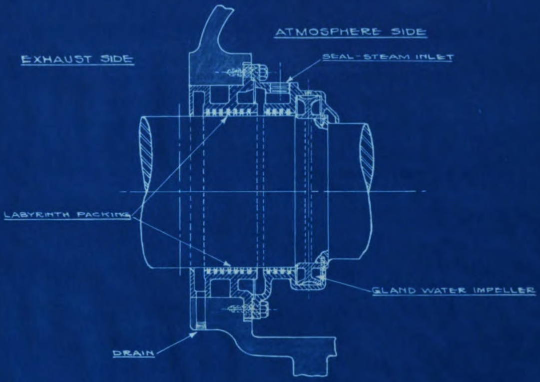


FIG-17

LABYRINTH AND WATER-SEAL GLAND COMMONLY USED ON WESTINGHOUSE LARGE STEAM TURBINES

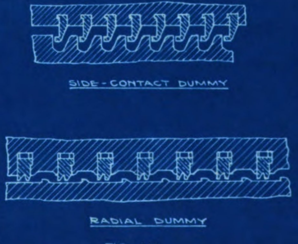


FIG-18

SECTIONAL VIEWS OF DUMMIES

may be throttled down to a low enough pressure for the gland water seal to be effective. At the exhaust end, steam may be admitted near the middle of the packing to form a seal for creating the vacuum when starting.

Dummy packing strips of both the axial and radial type are used on the balance pistons of the Westinghouse turbines. Sections of each type are shown in Fig. 18.

In the Allis-Chalmers turbines a water seal is also provided which is of somewhat similar construction as will be seen by reference to Figs. 19 and 20.

Where the low-pressure balance piston is located at the exhaust end of the turbine, a slightly different type of gland is necessary at the low-pressure end owing to the difference in pressure at the two ends of the cylinder. As will be noted by referring to Fig. 1, the pressure at the gland at the high-pressure end is that of the exhaust, while at the low-pressure end it is that of the intermediate stage. As it is necessary for balancing purposes that the pressures on both ends be the same, a series of rings having small radial clearances are furnished in the low-pressure gland casing forming a labyrinth packing between the intermediate and low-pressure steam spaces as shown in Fig. 19. Fig. 20 shows the corresponding high-pressure end gland casing and Fig. 21 shows sectional views of Allis-Chalmers labyrinth packing of both the radial-clearance and side-clearance types.

It will be noted by reference to Fig. 21 that on the low-pressure balance piston where the difference in expansion between the spindle and the cylinder is likely to be more marked, the radial-clearance type of packing is used

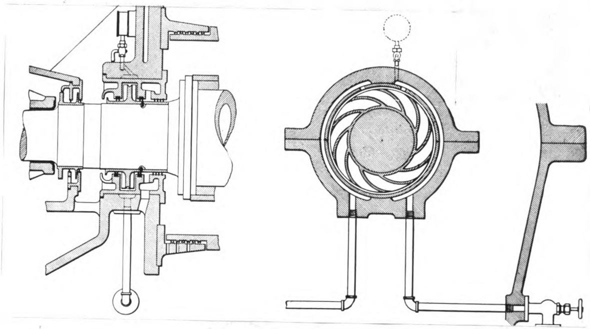


Fig. 19

Exhaust End Seal of Allis-Chalmers Turbine

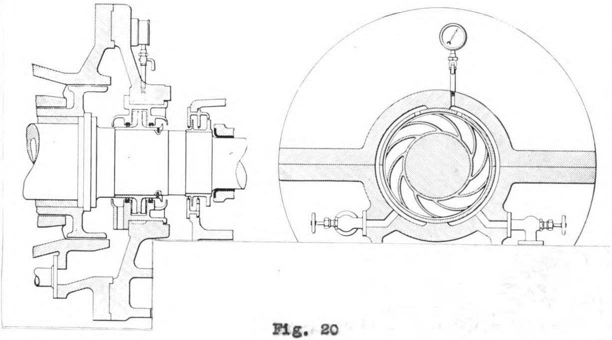


Fig. 20

High-Pressure End Seal of Allis-Chalmers Turbine

STEAM TURBINE DUMMY PACKING

ALLIS-CHALMERS MFG. CO.

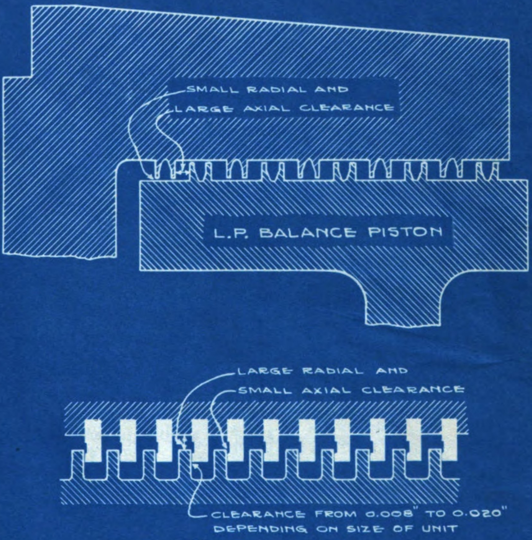


FIG. 21

whereas, on the high-pressure balance piston, where the piston is relatively near to where the thrust bearing is attached to the structure and where consequently the difference in expansion is almost negligible, the side-clearance type of packing is used.

T H R U S T   B E A R I N G S.

The General Electric Company employs a collar type thrust bearing on its turbines.

Both the Westinghouse Electric and Manufacturing Company and the Allis-Chalmers Manufacturing Company employ the Kingsbury type of thrust bearing. A cross-section view of this bearing as employed on the Westinghouse turbines is shown in Fig. 22. The bearing consists of an outer cage whereby connection is made through an adjusting nut with the turbine structure and a collar fitted to the shaft against which bearing surfaces press. The bearing surfaces are stationary and are divided into a number of segments each centrally pivoted on a self, aligning ring so that any individual segments may assume any angle it pleases, thus permitting the oil film to be of wedge-like form. The segments press against both sides of the collar so as to confine axial motion in either direction and are themselves confined within the cage. They consist of blocks of steel with babbitt faces which bear against the steel collar. An adjusting worm is provided to turn the previously mentioned adjusting nut, thereby moving the cage axially and causing a corresponding movement of the entire

STEAM TURBINE THRUST BEARING

KINGSBURY TYPE

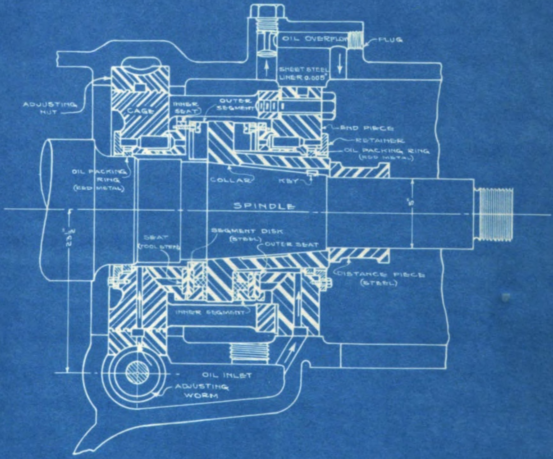


FIG. 22

turbine spindle or shaft for adjustment when desired. This is a very effective type of bearing as it permits the segments to incline ver y slightly so that as the oil is drawn across their faces and between them and the collar the film thickness decreases and the load is distributed over the entire surface.

C Y L I N D E R.

As will be noted to reference to Fig. 2, the cylinder of large General Electric Company impulse turbines consists of a large cylindrical central casting carrying the nozzle diaphrams, to which is bolted the exhaust chamber. In some of these machines the low-pressure end is made of cast iron and is rigidly bolted to the concrete foundation and the high-pressure section is made of cast steel and is bolted to the high-pressure end of the low-pressure section. The entire cylinder is hung free between the low-pressure casing and the bearing at the high-pressure end of the turbine. This allows the cylinder to expand freely in any radial direction while at the high-pressure end the bearing is held in guides in such a way that it can slide longitudinally under varying temperatures.

Large Westinghouse turbines employ cast steel for the high-pressure cylinder. The high-pressure cylinder is so constructed that blading rings are bolted to it in order that complicated steel castings may be avoided. The highe pressure cylinder is supported at three points, one under the governor or thrust end, and one on each side of the exhaust near the center line. In the more recent two and three

cylinder machines the low-pressure cylinder consists of a main casing and the inner cast steel section. The staionary single-flow reaction blading is carried in the cast steel section, independent from the main casing and is made of steel. The double-flow blading is carried in the exhaust ends which are bolted to the central portion. Two exhausts are provided for the low-pressure cylinder, one at each end. If two low-pressure cylinders are used, four exhausts will be employed. Four supports are used for the low-pressure elements and are applied near the center line at each side of the exhaust chambers. The entire cylinder is free to expand axially in both directions, sliding on these supports, the turbine being anchored to the inboard generator pedestal. Radial and axial stays are provided in the exhaust chambers to produce rigidity and to minimize the possibility of distortion and sympathetic vibration. After the exhaust ends and inner cast-steel section of the low-pressure cylinder are bolted together the turbine may be opened up along the longitudinal joint but the upper part of the exhaust chambers and the inner casing are lifted as one piece and are not dismantled. The entire low-pressure cylinder is constructed of steel so that in case the high-pressure element is out of order the low-pressure element or elements may be operated on steam from the main.

The Allis-Chalmers turbines are of the single-cylinder construction in which the high-pressure, high-temperature end is constructed of cast steel and the low-pressure end is constructed of cast iron. Large flanges are cast on the lower half of the high-pressure and low-pressure ends and by means

of these flanges the entire cylinder is supported from and between the outboard and inboard turbine pedestals, respectively. The inboard pedestal is firmly bolted to the bedplate of the turbine and the outboard pedestal is held in guides on the bedplate which allow the entire cylinder to expand freely in an axial direction and cause the pedestal to slide. Steam belts or channels are cored around the cylinder at the point of steam inlet and at the by-pass valve opening. The high-pressure and low-pressure ends are provided with flanges through which through-bolts pass and hold them securely together. The entire cylinder is split longitudinally and when once erected the high-pressure and low-pressure sections are never separated on the circumferential flange.

N O Z Z L E S A N D N O Z Z L E B L O C K S.

In the first stage of General Electric turbines the nozzles are generally grouped in blocks evenly distributed about the edge of the diaphram and admitting steam to only a portion of the periphery. As stages further along in the turbine are reached it is necessary to employ full peripheral admission to handle the large volume of steam and nozzle plates of the desired shape are cast integral with the diaphrams.

Where the Westinghouse turbines employ impulse blading for the high-pressure steam nozzle blocks are used to give partial-peripheral admission. Due to its ability to withstand the high temperature of high-pressure superheated steam cast bronze is used for these parts of the turbine.

Its composition is as follows:

Cu.	. . . .	78.85 per cent
Sn.	. . . .	10.25 per cent
P.	. . . .	1.05 per cent
Pb.	. . . .	9.85 per cent
		100.00 per cent

G O V E R N O R A N D G O V E R N O R V A L V E S.

The governor used on present large General Electric turbines consists of a weight governor actuated by centrifugal force. The governor is driven through a worm on the high-pressure end of the turbine shaft and a worm wheel on the vertical governor spindle and through a horizontal lever controls the position of a pilot valve admitting oil to one side or the other of a small piston located in a hydraulic cylinder. The piston of this cylinder is connected to a piston rod on one end of which is a rack engaging a gear on the end of a horizontal shaft carrying a number of cams set at different angles. The follower to each cam controls a valve admitting steam to a nozzle in the first pressure stage of the turbine. As the speed of the turbine drops below normal with an increase of load the governor acts on the horizontal lever in such a manner as to move the stem of the pilot valve and admit oil to one side of the piston in the hydraulic cylinder at the same time relieving the pressure on the other side. This causes the piston to move the rack and rotate the cam shaft opening the valves successively until all have been opened when the by-pass valve opens to admit

steam to further stages in the turbine. When the turbine overspeeds the pilot valve moves so as to admit oil to the opposite side of the piston in the hydraulic cylinder and to relieve the existing pressure thus causing the rack to rotate the cam-shaft in the opposite direction and close the valves admitting steam to the first stage nozzles. By having a number of valves controlled by the governor and governing apparatus in this manner the effect of throttled steam is practically eliminated as all but one or two nozzles receive the full steam pressure rather than having one partially-opened throttle-valve supplying all nozzles at a reduced pressure due to throttling. This tends to give the turbine good economy at all loads. Oil for the operation of the hydraulic gear is supplied to the cylinder from the main oil pump which is driven by the main turbine shaft through the lower end of the governor spindle. A pressure of from 70 to 80 pounds per square inch is maintained in this line.

Connected to the horizontal lever connecting the motion of the main governor stem with the pilot valve is a rod which connects with a spring-loaded dash-pot for the purpose of [illegible] the governor action being too sensitive. The force required to move the pilot valve is varied by varying the compression on the spring thus requiring a higher speed of the turbine if the load on the turbine is increased or a lower speed if the load on the turbine is decreased to make the effect of the governor felt at the pilot valve. In this manner the speed for which the governor is to operate can be varied. Mounted on the governor housing is a small motor which by means of a worm and worm wheel raises or lowers

a motor [illegible] for changing the speed for the purpose of synchronizing the unit. This [illegible] is a synchronizing motor and is controlled from the main switch-board.

The [illegible] turbine employs a governor of the ball lever type. It is driven from the main shaft through a worm gear, and is claimed to be unusually powerful. The ball levers and the links connecting these levers to the governor sleeve, are all pivoted on hardened special steel knife edges, to eliminate friction and disturbances, and all wearing parts of the governor are provided with forced lubrication to insure against wear. The main spring surrounds the spindle and bears directly on the governor sleeve. A small auxiliary spring, with a manually and electrically operated tension gear for making small speed adjustments while running, is connected to the governor linkage. It is used in synchronizing the alternators or in distributing the electrical load among them. The governor employs an oil relay mechanism for operating the steam inlet valves. In this system the governor controls the position of a valve on the oil cylinder through a linkage so that with increased speed oil is admitted under pressure beneath a piston and allowed to run out from above the piston so that the inlet valves are closed and when the speed drops below that for which the governor is to regulate oil is admitted to the top of this piston under pressure and released from the bottom thus opening the inlet valves. The general practice is to build the steam chest with two valves under governor control, the first called the "Primary" admitting steam to one group of nozzles; and to the first row of blading in the case of a complete reaction turbine, the "Secondary" automatically opening upon demand after the piston of the oil cylinder has moved so as to have opened the primary valve to its maximum height so as to admit steam to a further stage in the turbine blading.

In turbines using the oil relay the circulating pump maintains a pressure higher than required for the lubricating system, the oil required for the latter passing through a reducing valve to the lubricating system. The oil pressure in the hydraulic cylinder operates the steam inlet valves, the only work being imposed on the governor being to operate the small relay valve controlling the operating piston. Oil for the hydraulic cylinder is supplied at a pressure of 50 pounds per square inch. By means of a cam and vibrator rod the relay linkage is provided with a fixed oscillation so that it is always in motion and ready to assume a new position without having to overcome the friction of rest. This oscillation is so slight that it is not sufficient to cause any fluctuation in steam flow, but this feature combined with the powerful governor gives sensitive regulation, as any change in position of governor weights immediately produces the proper change in steam flow irrespective of slight inaccuracies of adjustment and reasonable wear of the linkage.

Allis-Chalmers turbines are also governed by means of an oil relay cylinder. The governor is a spring-loaded governor in which the movement of the weights is horizontal. The horizontal movement of the weights with variations of

speed is transmitted to the governor sleeve and a stem which acting on a lever and a series of links produces a slight movement in the stem of the relay valve. A change in the position of this admits oil under pressure to the interior of the valve and causes the valve to move, in turn uncovering and opening various ports in the relay valve cylinder thereby varying the admission and discharge of the oil to the relay cylinder itself which is set on the steam chest directly over the admission valve and has in it a piston directly connected to the upper end of the valve stem. On this stem is a fixed collar to which is connected one end of a long lever, the other end of which through a series of links causes a movement in main [illegible] or lever to the relay valve stem and causing the relay valve to return to its neutral position when the movement of the oil-cylinder piston has been completed. Synchronizing is done by changing the position of the fulcrum of the main governor lever either by turning a small hand wheel or by means of an electric synchronizing motor controlled from the main switchboard and a small oil-filled and spring-loaded dash pot connected to the outer end of this lever retards its motion sufficiently to keep it from undue variation at constant load. A collar is fixed to the valve stem so that when the main inlet valve has been opened to its maximum height this collar engages a sliding collar to which is connected a bell crank which through a lever and another bell crank opens the main overload valve

on the top of the turbine cylinder thus admitting live steam to an intermediate stage of the turbine and keeping the speed up under overload. The oil for operating the relay cylinder is supplied at a pressure of about [illegible]0 pounds per square inch by the main oil pump.

The materials used for valves and seats on Allis-Chalmers turbines are as follows:

For dry saturated steam up to and including 200 pounds gage pressure - Cast Iron.

For superheated steam up to 400°F. and for dry saturated steam between 201 pounds gage and 250 pounds gage inclusive - Nickel Bronze.

For superheated steam between 401°F. and 475°F. inclusive - Nickel Bronze.

For superheated steam 476°F. and above - Nickel Bronze.

S A F E T Y   S T O P.

The safety or emergency stop of the General Electric turbines consists of a steel ring placed around the main shaft between the turbine and the generator. This ring, which is held in position on the shaft by study bolts, is placed in a slightly eccentric position, and the centrifugal force due to this unbalancing is counteracted by a helical spring. When the speed increases, the centrifugal effort overcomes the spring and the ring moves into a still more eccentric position so that it strikes a bell-crank lever, which trips, by means of a simple auxilliary mechanism and tension rod, the throttle valve on the main steam supply pipe.

In the Westinghouse safety stop a hole is bored on a diameter of the shaft near the high pressure end and a pin governor weight counteracted by an adjustable spring is inserted. At excessive speed the centrifugal force throws a lever connected to an auxilliary valve on the relay oil cylinder. This opens the ports admitting and discharging oil from the hydraulic cylinder mention previously in such a manner that, regardless of the action of the main governor, the oil cylinder piston will act positively to close all valves admitting steam to the turbine.

The emergency stop governor of Allis-Chalmers turbines is located at the end of the shaft and consists of a fly-weight governor which acts upon a rod set into a hole drilled axially in the end of the shaft. The rod is held in its normal position by means of a spring and when the turbine shaft has reached an excessive speed the fly weights open up and force the rod outward. It comes in contact with a trigger at the end of the shaft housing and allows a trip weight to fall and the momentum of this weight acting through suitable levers releases a trigger holding in compression a heavy spring with which the main throttle valve is loaded, thus allowing the spring to close the throttle valve, effectually shutting off steam to the turbine. A hand lever is provided which allows the operator to close down the unit by means of the trip mechanism, should an occasion arise when quick action is necessary.

T H R O T T L E   V A L V E.

In addition to the admission valves controlled by the governor in all of these turbines they are fitted with hand valves in the main steam line which must be first opened before steam can get to the admission valves. In the Allis-Chalmers turbines this throttle valve is located in a steam chest directly under the main admission valve and its oil cylinder. The valve is opened against a heavy spring which would tend to close the valve should anything go wrong with the valve stem and which is released by the safety over-speed devide to automatically close the steam supply to the turbine. The Westinghouse turbines also have a spring-loaded stop-valve admitting steam to the steam chest containing the primary and secondary admission valves and when the safety stop trips this valve is also tripped to close under the action of the springs.

S T E A M   C H E S T.

In the General Electric turbines the steam supply is carried directly to the turbine throttle which admits it through a strainer to the nozzle chamber at the high-pressure end of the turbine.

The Westinghouse Electric and Manufacturing Company employs a steam chest which is separate from and attached to the turbine cylinder and is connected to it by suitable piping.

The steam chest is mounted on heavy springs in order to relieve the strains on the piping or on the main cylinder due to unequal expansion. After passing through the throttle valve the steam passes through a cylindrical strainer in the steam-chest housing and thence to the governor-controlled admission valves.

The steam chest of Allis-Chalmers turbines is also a separate structure from the main turbine cylinder. It is mounted on the bed-plate of the turbine and connected to the turbine itself by one or two large U-bends passing below the base. This connection takes up any strains due to differential expansion. The steam chest contains a strainer through which the steam must pass before reaching the throttle valve. The governor-controlled admission valve is located directly above the throttle valve and its hydraulic cylinder is supported on the steam chest structure.

EXHAUST CONNECTION.

Recent practice of the General Electric Company in connecting the turbine exhaust to the condenser has been to rigidly bolt the exhaust flange of the turbine to the flange of the condenser and to support the condenser on heavy springs to take up excessive stresses due to expansion thus relieving the turbine cylinder of strain.

The Westinghouse turbines have been connected to the condenser flanges through suitable expansion joints as well as by rigid connection between the exhaust and the condenser with the latter supported on springs. A recent installation of a 75,000-kw., cross-compound unit had the turbine and condenser each supported firmly on their own foundations and connection made between them by means of a molded rubber connection about two feet long suitably braced from within to prevent its collapse and water-sealed at the points where it is connected to the turbine and condenser flanges respectively.

Exhaust connections on Allis-Chalmers turbines are made directly with the condenser flanges through special copper expansion joints.

L U B R I C A T I N G S Y S T E M.

In all three types of turbines lubrication is by oil under pressure which in addition to lubricating the moving parts carries off the heat from the bearings. Pressure is maintained by a rotary pump directly connected to the lower extremity of the governor spindle and driven from the main turbine shaft. This pump draws its supply from the oil reservoir located in the base of the turbine in each case and supplies it to the system at the pressure required to operate the hydraulic governor gear. As this pressure is normally considerably higher than that necessary for the lubrication system the oil for lubrication is passed through pressure-reducing valves where its pressure is reduced to that desired for lubrication.

The approximate oil pressures maintained at the bearings and in the hydraulic valve gear of these turbines are as follows:

Turbine Make	Oil Pressure in Lbs. per Sq. in.	
	Bearings	Hydraulic Gear
Allis-Chalmers	5 - 10	70
General Electric	7 - 9	60 - 70
Westinghouse	5 - 8	50

After passing through the pressure-reducing valve the oil is piped to the bottom of the bearings and flows up through and around the journals. In the Allis-Chalmers bearing a vent is provided at the top of the bearing and an inverted U-shaped tube is inserted. The other end of the U-tube is left open and the oil after coming through the bearing is forced through this tube from which it drains into the base of the pedestal. A cap which is glass-enclosed on two sides is placed over the tube in this way providing a sight oil-vent through which the oil leaving the bearings must pass and through which any air in the oil may escape. It also serves the purpose of showing the operating engineer whether or not the bearings are receiving their proper oil supply since being located at the top of the bearing the oil must first flow through the bearing and a flow from the sight oil vent indicates that the bearing is receiving oil. The thrust bearing receives its supply in a similar manner and here again in the Allis-Chalmers turbines a sight oil vent is provided.

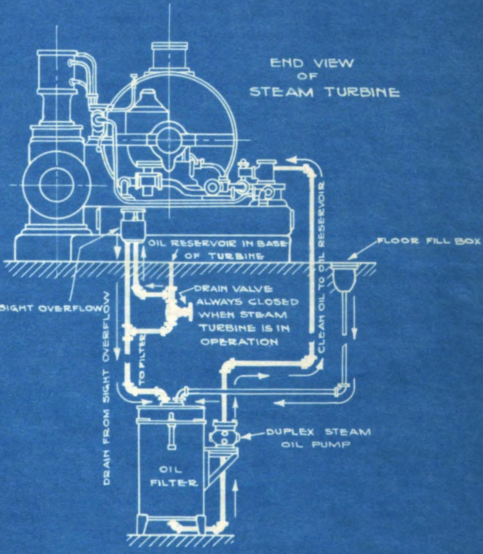
Since in turbines the oil is used not only for a lubricant but also as a conveyer of the heat generated at the bearings it must be cooled before it can be again used for this purpose. The General Electric cools the bearings themselves by circulating water through the shells and babbitt linings while both the Westinghouse Electric & Manufacturing Company and the Allis-Chalmers Manufacturing Company have separate oil coolers in the bases of their turbines. These coolers consist of cast iron boxes in which are placed a large number of thin metal tubes. The oil from the bearings is passed through these tubes on its way to the reservoir in the base of the turbine and cooling water is circulated about them in the containing box.

Experience has shown that the best results are obtained with an oil temperature of between 100°F. and 140°F. as it leaves the bearings. At this temperature the oil is, however, likely to turn acid and consequently animal or vegetable oils are seldom used. Even with mineral oils a large amount of air, impurities, and moisture are picked up in passing through the lubricating system so that if left unchanged and unpurified the oil will become so impure and emulsified that its effectiveness as a lubricant will be greatly diminished and bearing troubles are likely to arise. Two methods are used to overcome this.

First, a large reservoir is provided in the turbine base where the oil can collect and settle and a partial lubrication system is used. The principal is the same in any case and can be best illustrated by Fig. [illegible] which shows the use of a Richardson-Phoenix oil filter in the partial oil-purification system furnished by the Allis-Chalmers Manufacturing Company with all of its recent large turbines.

STEAM-TURBINE LUBRICATION

PARTIAL OIL-PURIFICATION



R-P OIL FILTER AS USED WITH
ALLIS-CHALMERS TURBINE

OVERFLOW GAUGE MAINTAINS CONSTANT OIL LEVEL IN TURBINE RESERVOIR. OIL FLOWS TO FILTER BY GRAVITY, IS PURIFIED AND PUMPED BACK INTO THE SYSTEM AGAIN - ALL AUTOMATICALLY.

FIG. 23

installation. [illegible] bottom of the reservoir in the turbine [illegible] allows the dirtiest oil to [illegible] the oil filter by gravity. [illegible] oil has collected [illegible] the filtered oil back into the [illegible]. This only filters a small [illegible] of the total supply but tends to purify the dirtiest oil and thus [illegible] of the oil in the reservoir.

The other method of purification is known as batch-filtration. In this process all of the oil is drained from the turbine base and a new supply put in. The old oil is then run through large oil filters which are a part of the plant equipment and allowed to rest in large tanks for a long period. This allows the air to escape and any impurities that have passed the filter to settle out besides causing the oil to regain practically all of its original lubricating qualities. Then when the supply of oil in the turbine is again dirty the two are again interchanged. This results in a big saving in make-up oil.

Oil strainers are fitted over the intakes of the oil pumps to prevent any foreign matter in the turbine from getting to the bearings.

In the Westinghouse and Allis-Chalmers machines the oil pressure in the lubricating system is maintained constant by means of spring loaded pressure valves which remain closed as long as the pressure is right but which allow oil to escape to the reservoir thus relieving the pressure if too great. In the General Electric turbines the pressure is maintained by compressed air which partly fills an air chamber in the pipe line.

Auxilliary oil pumps are provided to supply oil to the bearings and hydraulic gear when starting or in case anything happens to the main oil pump. On the Allis-Chalmers machines a small impulse turbine with a vertical spindle is used to drive the auxilliary pump and is so arranged that it will start automatically should the oil supply fall below a certain predetermined pressure. The General Electric Company and the Westinghouse Electric & Manufacturing Company have used small turbine-driven pumps in some cases and in other cases double-acting plunger pumps for auxilliaries.

B E D P L A T E S.

In each of the above classes of turbines the bearing pedestals and cylinders as the case may be are supported upon heavy cast-iron bedplates, strongly ribbed to withstand vibration and to furnish a rigid base to which the various turbine parts can be fastened to hold them in fixed relation with one another. These bedplates are bolted securely to the foundations and in some cases portions of them are filled with concrete to reduce vibration and to provide additional stability.

C O U P L I N G.

The shaft of the turbine is connected to the shaft of the generator in Westinghouse units by means of a pin drive coupling in which circular driving pins having considerable overhang are employed to connect the coupling sleeve to the turbine shaft coupling end and to the generator shaft

coupling end respectively. The overhang allows considerable flexibility of the pin itself, that is, they may deflect slightly without strain. No breakage has occurred with this design.

The Allis-Chalmers Manufacturing Company employs an all metal claw type coupling for this purpose. Due to the fact that this company employs a method of lubricating the flat contact surfaces which is patented by them they are able to use this type of coupling successfully where other turbine builders attempting to use this type of coupling in the past have failed.

The General Electric Company uses a pin-connected coupling similar to that employed by the Westinghouse Company to connect the turbine and generator shafts.

-ooOoo-

PART II.

ORIGINAL HISTORIES

AND

CHARACTERISTICS.

-ooOoo-

OPERATING HISTORIES AND CHARACTERISTICS.

It seems that information concerning the operation of the various turbines whose structural details have been compared in Part I of this report are logical at this time. Although difficulty has been experienced in securing as much of such information as was desired, yet considerable has been collected and is here included.

INSTALLATIONS.

It was not until the year 1905 that machines of 5,000 kw., were generally manufactured and it has been only recently, since about 1913, that units of 20,000 kw., capacity and over have been installed in any appreciable numbers.

Table I gives a number of central-station system capacities and large unit installations as of May 1, 1919.

During 1920 the following large units were put into operation:

Springdale Station, West Penn Power Company
20,000-kw. Westinghouse units.

Delaware Station, Philadelphia Electric Company
30,000-kw. General Electric units.

West End Plant, Union Gas and Electric Company, Cincinnati.
25,000-kw. General Electric units.

Cheswick Power Co., Cheswick, Pa.
60,000-kw. Westinghouse units.

T A B L E I.

C[illegible]TRAL-STATION S[illegible] LARGE UNIT

INSTALLATIONS AS OF MAY 1, 191[illegible]

(From the Electrical World, Vol. 7[illegible], No. 21, May 24, 191[illegible])

Company and Location	Total Generating Capacity Kva.	Capacity in 20,000 Kva. and larger Kva.	Per Cent of Total Kva.	Capacity of Largest Unit Kva.	Per Cent of Total Kva.
Buffalo General Elec. Co., Buffalo, N. Y.	105,555	105,555	100.0	[illegible]	76.8
Con. Gas, El. Lt. & Pr. Co., Baltimore, Md.	81,500	4[illegible],000	4[illegible].1	20,000	2[illegible]
Boston Elev. Ry. Co., Boston, Mass.	12[illegible],500	[illegible]5,000	23.5	35,000	[illegible].5
Edison Electric Illg. Co., Boston, Mass.	145,000	50,000	[illegible]	50,000	[illegible].8
Alabama Power Co., Birmingham, Ala.	140,[illegible]	58,[illegible]	41.6	[illegible]	[illegible]
Edison Electric Illg. Co., Brooklyn, N. Y.	121,500	52,000	42.7	30,000	24.7
Bklyn. Rapid Transit Co., Brooklyn, N. Y.	170,850	51,000	[illegible]	30,000	21.5
Commonwealth Edison Co., Chicago, Ill.	4[illegible],510	227,910	[illegible].7	35,[illegible]	7.1
Cleveland Electric Illg. Co., Cleveland, Ohio	208,000	150,000	72.1	[illegible]	15.[illegible]
Union Gas & Elec. Co., Cincinnati, Ohio	[illegible]	[illegible]	[illegible]	25,000	[illegible]
Northern Ohio Traction Co., Cuyahoga Falls, Ohio	67,000	4[illegible],444	66.5	22,[illegible]	[illegible]
Detroit Edison Company, Detroit, Michigan.	193,000	105,000	54.4	45,000	[illegible]
Pennsylvania R.R. Co., Long Island City, N.Y. ..	78,000	41,100	52.7	21,1[illegible]0	27.1
Twin City Rapid Transit Co., Minneapolis, Minn.	65,000	20,000	30.8	20,000	[illegible]0.8

T A B L E I ([illegible])

Company and Location	Total Kva.	Kva.	Kva.	Kva.	K[illegible].
Moline & Rock Is. Mfg. Co. Moline, Ill.	50,600	[illegible]0,000	[illegible].6	[illegible],000	[illegible]
Interborough Rapid Tran. Co. New York City	[illegible]89,000	256,000	65.8	70,000	1[illegible]
New York Edison Co., New York City	[illegible]86,000	111,000	[illegible].8	[illegible]	1[illegible].[illegible]
Public Service Elec. Co., Newark, N. J.	265,100	105,000	[illegible].0	[illegible]	15.0
United El.Lt. & Power Co., New York City	1[illegible]4,900	65,900	[illegible].8	[illegible],900	[illegible].7
Philadelphia Electric Co., Philadelphia, Pa.	279,700	153,900	55.1	35,000	1[illegible]
Narragansett El. Ltg. Co., Providence, R. I.	85,500	67,500	78.9	47,500	[illegible]5.5
Duquesne Light Co., Pittsburgh, Pa.	168,000	47,200	[illegible]	47,200	[illegible]
N.Y.C.R.R. Co., Port Morris & Yonkers, N.Y.	60,000	20,000	[illegible].5	20,000	[illegible]
Reading Transit & Light Co. Reading, Pa.	25,000	25,000	100.0	25,000	100.0
Union El.Lt. & Pwr. Co., St. Louis, Mo.	83,000	25,000	30.1	25,000	[illegible].1
United Electric Co., Springfield, Mass.	45,000	20,000	44.4	20,000	44.[illegible]
Toledo Ry. & Light Co., Toledo, Ohio	83,000	45,750	47.0	25,500	26.7
Worcester Elec. Light. Co., Worcester, Mass.	43,000	20,000	46.5	20,000	46.5
Wheeling Electric Co., Wheeling, W. Va.	69,000	60,000	87.0	20,000	43.5

Within the past year the following large units have been installed:

Colfax Station, Dusquesne Light Company,

60,000-kw., Westinghouse Unit.

59th Street Station, Interborough Rapid Transit Company. New York City,

30,000-kw., General Electric Unit.

Connors Creek Station, Detroit Edison Company,

30,000-kw.,,General Electric Unit.

Delaware Station, Philadelphia Electric Company,

30,000-kw., General Electric Units.

Following is a list of Allis-Chalmers turbines of 7,500 kw., capacity and over that have been put in operation since 1917:

Universal Portland Cement Company, Buffington, Indiana,

2 - 7,500 M, 80% P.F., 1500 r.p.m. Units.

U. S. Gas Filling Plant, Edgewood, Maryland,

7,500 M, 80% P.F., 1500 r.p.m. Unit.

Columbus Power Co., Columbus, Georgia.

7,500 M, 80% P.F., 1800 r.p.m. Unit.

Public Service Electric Company, Perth Amboy, N. J.,

10,000 M, 80% P.F., 1800 r.p.m. Unit.

City of Cleveland, Ohio.

10,000 M, 80% P.F., 1800 r.p.m. Unit.

Goodyear Tire & Rubber Company, Akron, Ohio.

2 - 10,000 M, 80% P.F., 1800 r.p.m. Units.

Niagra, Lockport & Ontario Power Company, Lyons, N. Y.,

12,000 M, 80% P. F., 1500 r.p.m. Unit.

Edison Electric Illuminating Company, Brooklyn, N. Y.

12,500 M, 100% P.F., 1500 r.p.m. Unit.

San Joaquin Light & Power Company, Bakersfield, Cal.,

12,500 M, 100% P.F., 1800 r.p.m. Unit.

O P E R A T I O N.

General Electric Company.

In general the large unit installations of the General Electric Company seem to have operated fairly well although trouble has been experienced with wheel discs and diaphrams and in some cases with shafts and casings.

On Feb. 14, 1917, trouble arose in a 35,000-kw., turbine installed in the O Street Station of the Boston Elevated Railway Company in Boston. This machine was a 20-stage, horizontal, single-cylinder unit. At this time the 18th diaphram became distorted; that is, it deflected at its edge in the direction of the 18th wheel, rubbed the buckets where they join the wheel and stripped the buckets from the 18th and 19th wheels seriously damaging the 18th and 19th diaphrams. This happened when the machine was being given trial runs. Rubbing began and the throttle was tripped, after which the damage to the buckets and diaphrams followed. When the buckets let go the speed was below the normal 1500 r.p.m., perhaps 1000 or 1200 r.p.m.

"After the accident of February 14, 1917, the capacity was reduced to 20,000 kw., from March 17 to May 23, while repair parts were being made, by locking closed the secondary valve, which admits steam to the 7th stage. The repair parts in place and the machine in service, annoyance was given because the machine would not carry the load with its swings of 2500 kw., above the rated 35,000-kw., under the operating conditions. When the swings came, the cycles dropped from the normal 25 to 24. The purchaser was most anxious that the turbine carry the swings, and it was suggested that nineteen 1-1/8-in. holes be drilled in the eighth diaphram in front of the eighth wheel. The holes were drilled to allow high-pressure steam to that stage. The turbine then carried the swings.

"The machine was designed for 200 lb. gage pressure at the turbine throttle, 200 degrees F., superheat and 29 in. vacuum at 30 in. barometer. There was a pressure drop of 4 pounds in the steam line between the boilers and the throttle, or from 200 pounds to 196 pounds.; the drops through the governor valves was also slightly more than normal. The builder states that on August 15 last (August 15, 1917), with 188.7 pounds gage pressure at the throttle, 132°F. superheat and 28.7 in. vacuum, the turbine carried 36,500-kw., and that based on these figures the capacity would be 39,000-kw., under contract conditions."

On February 14, 1918 a second accident completely wrecked the turbine. At the time of the accident the turbine was carrying 32,000-kw., when the failure of another machine of 10,000-kw. at the Central Station threw the additional

load on the machine which tended to throw all the load which was dropped when the [illegible] occurred by opening wide its secondary valve. The sudden impact of the steam in the lower stages probably distorted or increased the distortion of the 18th wheel. At any rate the buckets from the 18th wheel broke off identically as the buckets a year previous. These buckets fouled the diaphragms and as a result the last three wheels and diaphragms were wrecked and thrown in pieces through the casing and against the cylinder with such force as to completely wreck the turbine.

The presumable cause of the accident was that a cast-iron diaphragm in the 18th stage became distorted and fouled the 18th wheel, breaking off the buckets, after which the buckets and diaphragms from the 18th stage on to the last or 20th wheel, were destroyed by the diaphragms becoming loose from their fastenings and dropping down on the rotating shaft. The diaphragms, being made of cast-iron, were not designed for the high centrifugal stresses set up in them when they began rotating with the rapidly revolving shaft and consequently it was only a matter of a few seconds when they burst, throwing pieces in all directions through the turbine cylinder and exhaust end and over the walls of the turbine room itself.

There was a similar failure of a 20,000 kw. unit at the Northwest Station of the Commonwealth Edison Company in Chicago some few months later. In this case the damage was confined to the turbine itself, however. It is interesting to note that failure occurred in exactly the same place;

that is, at the 18th wheel. The wheel rubbed, loosening the blades and destroying the diaphrams and wheels on through the 20th stage.

At the same station when one of these machines was taken down for its customary overhauling a large crack was found in the shaft.

The Detroit Edison Co., too has experienced some difficulty with these units. During the summer of 1920 the semi-steel high pressure casing of a 45,000-kw., unit gave way making it necessary to take the unit out of service completely for several months until repairs could be made. The machine is again in operation and is carrying its load daily.

The same company has experienced some difficulty with General Electric machines of 20,000-kw., capacity due to the diaphrams distorting and the blading being fouled. In one case it became necessary to remove three wheels and keep the machine on the line with the wheels out. This cut the capacity of the turbine to between 16,000 and 17,000-kw., and considerably increased the water rate.

During 1920 a 25,000-kw., single-cylinder horizontal General Electric turbine at the West End Station of the Union Gas and Electric Company, Cincinnati, Ohio, operating with steam at a pressure of 234 lbs. per sq. in. gage (249 lbs. per sq. in., abs.) with a total steam temperature of 595°F. (approximately 195°F. superheat) and exhausting into a vacuum of 28.855 in. Hg. carried a load of 20,708-kw., at a water rate of 10.46 lbs. per kw. hr. This is equivalent to an efficiency ratio, of 77%.

WESTINGHOUSE ELECTRIC & MFG. COMPANY.

In discussing the operating history of their various turbine installations the engineers of the Westinghouse Electric & Manufacturing Company make use of the following two factors:

RELATIVE CAPACITY AVAILABILITY or merely the CAPACITY AVAILABILITY which is the ratio of the time that turbine is available for use to the total number of hours that it has been installed.

If operative at only part capacity, credit is given for the proper percentage of availability. Shut-downs of less than 24 hours for minor repairs, inspection, etc., are not considered as loss of availability, but any shut-downs exceeding 24 hours occasioned by mechanical failures or manufacturers request for inspection, whether turbine or generator are recorded as outage periods.

ECONOMIC AVAILABILITY which is the ratio of the Rankine cycle efficiency actually obtained over a range of from 50% to full load, to the efficiency at the particular point or load at which maximum economical operation obtains. The proximity of the availability curve to the 100% line when operating normally, thus indicates the flatness of the turbine's performance curve throughout its working range.

The Westinghouse installation of three 30,000-kw., two-cylinder, cross-compound units at the 74th Street Plant of the Interborough Rapid Transit Company in New York City is an interesting one. The first unit was started December [illegible]th, 1914; the second, February 24th, 1915; and the third, July [illegible]th,

1915. These units operate with steam at 200 lbs. steam pressure and 150 deg. F. superheat and exhaust into a vacuum of 29 inches referred to 30 inches. The load factor is approximately 75% and the maximum load that has been carried is 32,000-kw., All three units are in daily operation at an average of 16 to 20 hours per day, their operating record covering a period of 3-1/2 to 4 years. Between the time that steam was turned on and the end of December, 1918 the outages were comparatively few. On Nos. 1 and 3 there were quite minor outages, involving nothing more than inspection, adjustment and minor repairs. No. 2 unit, a duplicate of the other two has been somewhat less fortunate. Three outages were for inspection and repairs while four others were due to trouble with labyrinth packing, the exigencies of the service requiring the unit to be continued in operation with the packing and corresponding stationary blade elements removed until the unit could be spared for permanent repairs. It was finally determined that this trouble was due to distortion of the machine caused by insufficient flexibility of the high-pressure piping. The following table gives the average Relative Capacity Availability and the average Economic Availability for the three units from the day steam was first turned on to the end of December, 1918:

Unit No.	Relative Capacity Availability Per Cent.	Economic Availability Per Cent.
1	97	95
2	85	86
3	96	94

On September 14, 1917 a 30,000-kva. Westinghouse tandem-compound unit, operating with steam at [illegible] lbs. pressure and 200° superheat and discharging into a 29-inch vacuum, was started at the Northwest Station of the Commonwealth Edison Company in Chicago. This unit has been running about 90% of the total hours from the date of starting. It ran from October 24th, 1917 to January 1st, 1918, a period of 68 days, without shutting down, when it was taken off to clean the condensers. Ordinarily it is shut down at week-ends for eight to ten hours for condenser cleaning. It has carried up to 30,000-kw., but is usually operated near its most efficient point of about 25,000 kw. A few hours after the unit was put into service the labyrinth packing on the low-pressure element failed. The manufacturers believe that this was caused by buckling of the turbine cylinder due to rigid piping connections between the two surface condensers, preventing the condensers translating with the turbine as the temperature increased. The machine being urgently needed, temporary repairs were made, the packing being removed, also the spindle holding ring, the stationary ring being trued up for temporary use. The machine has been operating in this condition up to the present time at a slightly lower efficiency. Now the unit has been overhauled and the permanent repair parts of an improved design put in. These parts have been on hand for some time but until now the unit could not be spared long enough for them to be installed.

A duplicate of the previous unit was installed in the Northwest Station of the Commonwealth Edison Company and

started operation on September [illegible], 1918. It operated at an average load of 25,000 kw. with a maximum daily load of 30,000 kw. The operation log shows the unit to have been in almost daily operation, with the exception of one delay occurring about ten days after first starting. This was the burning out of the high-pressure labyrinth packing, due to improper adjustment by the manufacturers. The permanent repair to the spindle packing was made locally, the high cylinder strips being shipped by the manufacturers and permanently applied in the following April. During the first [illegible] months the unit was available for service [illegible]% of the time and in that period actually operated 6,[illegible] hours. It was recently shut down after a continuous run of 112 days and 18 hours, carrying an average load of 25,985 kw., or a total for the run of over 65,000,000 kw. hours.

A 30,000-kw. single-cylinder Westinghouse turbine was put in operation at the Gold Street Station of the Edison Electric Illuminating Company of Brooklyn, N. Y. on October 6, 1917. The unit operates at a load factor of about 75% and has carried maximum loads of 30,000 kw. During the first 15 months of service, out of [illegible] total hours it ran 7540 hours and 51 minutes, or about 75% of the time. From all causes related to the unit it has been out of service [illegible] hours and 55 minutes, or an availability for service of about 97%. Of this outage 227 hours were consumed in replacing the surge tank and cooler in the oiling system, the original ones having defective material. This leaves 91 hours outage in 15 months due to mechanical troubles which the manufacturers state were, principally, minor troubles with the oil pump. This represents

the largest-sized turbine that the Westinghouse engineers have built of the one-cylinder design, and represents, with the present knowledge, about the maximum physical dimensions which they consider feasible in a single cylinder structure.

A similar Westinghouse unit is in operation at the Kent Avenue Station of the Brooklyn Rapid Transit Company, Brooklyn, N. Y. The Kent Avenue Station contains, besides this 30,000-kw. unit, three 7,500-kw., four 12,500-kw., and one 20,000-kw. units. On a twenty-four hour run with the large unit carrying 40% of the total output of the station, the station coal consumption is reduced between 75 and 100 tons as compared with the same load carried with the large machine shut down. This amounts in a fuel saving of from 8 to 10%. The machine began its regular operation December 24, 1917 and except for minor adjustments, operated until January 13, 1918, when it was shut down for repairs to the condenser and balancing turbine and generator. From February 15 until July 8, it was in regular operation, except for minor adjustments and repairs to auxilliaries. On the latter date, the machine was opened up for inspection due to observed reduced capacity. Two rows of spindle blades and two rows of stationary blades in the high-pressure section were found damaged, evidently due to foreign matter. One six-inch blade in the intermediate section was found broken below the second lashing wire and it was plainly defective. The lashing wire was found broken in a number of places. A number of rows of labyrinth packing strips were found to be badly corroded and were repaired. The machine was closed up without replacing the high-pressure blading which had been damaged. From

July 23 until October 18, the unit was in regular operation, except on September 19, when the collector rings became loose and were temporarily repaired so that the machine was put in operation the same day. The outage on October 18 was caused by a thrust bearing burning out, damaging the gland runners and gland casings. At that time six or seven were defective blades were discovered. The machine was repaired and resumed operation on December 7 but after a few hours the thrust bearing burned out again causing some damage to the gland casings. It was found that the generator bearings were also wiped. This repeated trouble caused a further investigation. The outboard pedestal is insulated to prevent eddy currents from passing through the shaft and bedplate. It was found that this insulation at one of the dowel bolts had become grounded, suggesting the theory that this bearing trouble had been caused by the carbonizing of the oil due to electric action. The repairs were made again and the pedestal properly insulated. The machine was put in operation January 8 and has continued to give uninterrupted service except for brief intervals required to make the gland seals tight. The log record shows the unit to have been in service 5120 hours out of 9764, during which time about one-half of the outages were due to mechanical troubles.

A 47,500-kva. two-cylinder cross-compound unit has been installed at the Brunot's Island Station of the Duquesne Light Company, Pittsburgh, Pa., and operates in conjunction with five other units of 17,000 kw. each. The initial steam pressure is 175 lbs. with 100°F. superheat and the exhaust is at 28.5 inches vacuum. The unit was started December 15, 1917

and operates on an average load of [illegible],000 kw. Its highest hourly output has been 45,000 kw. and its highest peak has been 50,000 kw. The longest continuous run has been for 633 hours and 30 minutes. The effect of this large unit upon the station coal consumption has been frequently observed. A load of 60,000 kw. carried by the 30,000-kw. and three of the 17,000-kw. units showed a reduction in coal of [illegible]% as compared with the same load carried on the five 17,000-kw. units.

One of the most interesting of the large Westinghouse installations is that of a 60,000-kw., three-cylinder unit, shown in plan in Fig. 5, at the 74th Street Station of the Interborough Rapid Transit Company, New York City. Steam is used at 205 lbs. gauge pressure and 150°F. superheat and is exhausted into a vacuum of 23.0 inches referred to 30 inches. The unit comprises one high-pressure element and two low-pressure elements all running at 1500 r.p.m. The first low-pressure element was started on April 11, 1918; the high-pressure element on September 20, 1918; and the second low-pressure element on October 11, 1918.

The first low-pressure element was operated temporarily, according to plans, and independently, on the regular station steam pressure reduced through the governor-controlled inlet valve, which valve had been supplied for the low-pressure turbine for this purpose. When operating thus independently, the low-pressure element showed a water rate at 30,000 kw. of 14.25 pounds. With the high-pressure and one low-pressure, the rate at the most efficient load of 30,000 kw. is 12.0 pounds. With all three elements operating, the rate at 40,000 kw. is 10.75 pounds, and at 60,000 kw., 11.32 pounds.

All rates [illegible]. These water rates are [illegible] being corrected to [illegible]. The operating [illegible] favor-ably upon the flexibility of the unit. They find that it handles [illegible] flexibility as three small units. If an electrical disturbance should open the circuit breaker of any one circuit, that element would automatically shut down without disturbing the other two. Similarly, if any one turbine should develop mechanical trouble, the tripping of its automatic stop mechanism, by hand, will open its circuit breaker and that element will be brought to rest. In case of trouble with any one part of the unit, 20,000 kw. may be generated with one low-pressure, 30,000 kw. with the high-pressure and one low-pressure, or 45,000-kw., with the two low-pressure elements.

There were a number of outages of this machine during the first year of operation. They were as follows:

October 22nd, 1918 - High-pressure element out due to defect in expansion joint. Temporary repair required 9 days. This joint, furnished by the turbine manufacturers, plainly was weak, and a joint of more adequate design was later installed. Unit was put back in commission with the maximum load limited to 45,000-kw.

November 1st, 1918 - Right-hand low-pressure, out 13 days due to some broken blades. Investigation showed a number of blades broken due to poor soldering of the lashing wire, permitting the blades to vibrate and ultimately to break. Unit put back in service with two rows of 18-in. blading removed.

November 2nd, 1918 - Left-hand low-pressure, out 15

[illegible] builders' request, to balance spindle.

December 14th, 1918 - Entire unit down less than one day to install new expansion joint on high-pressure turbine.

December 16th, 1918 - High-pressure turbine taken out of service owing to accident to labyrinth packing. Repaired and put in service February 11th.

The cause of this accident was ascribed to the following circumstances:

Tests were being carried out on the back pressure valve leading from high-pressure element to atmosphere.

The method of conducting these tests was to pass high-pressure steam through the high-pressure element, the latter standing still, in that way trying out the back pressure valve under various pressures up to about 60 lbs. gage. These tests were conducted for several hours up to the time the machine was needed for service. Shortly after starting the high-pressure element, injury resulted. It seemed quite clear that with the turbine standing still and subjected to the high steam pressure for a considerable period, the result was an uneven heating and consequent distortion which caused the injury when it was hurriedly started.

December 30, 1918 - Right-hand low-pressure had blade trouble requiring replacing of considerable intermediate and some low-pressure blading. The repair could only be partly made, due to war conditions; some of it being deferred to a later time. The machine, however, was put back in service March [illegible], 1919. The same condition was ascribed for these broken blades that caused the previous blade breakage, namely, defective soldering. The manufacturers believe that subsequent improvements have removed this cause of trouble.

March 7th, 1919 - [illegible] at request of builder to complete [illegible].

July 9th, 1919 - Right-hand low-pressure, [illegible] service to [illegible]. [illegible] again in service August 13.

August 24th, 1919 - High-pressure, [illegible] out for [illegible]. [illegible] in service August [illegible], 1919.

September [illegible], 1919 - High-pressure, [illegible] out for less than [illegible] day in order to [illegible] new governor.

November 20th, 1919 - Entire unit out for one day and high-pressure element out for four days, [illegible] and [illegible] valves.

December 24th, 1919 - Entire unit out for less than one day, and high-pressure and right-hand low-pressure out for four days, [illegible] joints.

January 2, 1920 - High-pressure and left-hand low-pressure out for two days [illegible] joints.

From October 11, 1919 when the last low-pressure element of the unit was put into operation, [illegible] the entire unit, up to the middle of February, 1920 the average capacity availability of the unit was 77.[illegible]% while the average economic availability during the same period was 9[illegible].1%.

In regard to the [illegible] trouble [illegible] the [illegible] labyrinth packing as evidenced by the above [illegible], the manufacturer [illegible]:

"A word about [illegible] labyrinth packing. [illegible] to reduce leakage. It is used [illegible] all types of turbines. [illegible]

packing on the periphery of the [illegible] is used to counterbalance [illegible] turbine [illegible]. Theoretically the [illegible] should be [illegible] to with-stand the action of the steam, but [illegible] [illegible]. In the above [illegible], [illegible], [illegible] to [illegible] distortion of the [illegible]. We now [illegible] material [illegible] will not cause injury to [illegible] parts in case of a rub, [illegible] believe has the [illegible] durability."

Allis - Chalmers Manufacturing Company.

The writer [illegible] direct data available as to operating history of large Allis-Chalmers turbines, [illegible], the manufacturers have very [illegible] Table II which [illegible] the steam consumption of their [illegible]-kw. [illegible] designed for 80[illegible] P.P. and [illegible] r.p.m. [illegible] conditions. The curves in Figs. 24 and 25 [illegible] this data.

In addition to the above, Table III [illegible] the steam consumption of a [illegible]-kw. Allis-Chalmers [illegible] the Municipal [illegible] Plant of the City of Cleveland, Ohio. The data is [illegible] curves [illegible] the results of the official economy tests made under the direction of Professor [illegible] J. Thomas, of Johns-Hopkins University. The water rate [illegible] steam consumption curves [illegible] plotted in Fig. 26.

TABLE II. - STEAM CONSUMPTION [illegible] 5000-KW. ALLIS-CHALMERS
[illegible] REACTION [illegible] FOR 80% P.F. AND 1800 R.P.M.

Turbines designed for one of different steam condition.

The vacuum in each case is 28-1/2 in. Hg. referred to 30 in.

For 28 in. vacuum referred add 5%.
For 29 in. " " deduct 2%.

Gauge Pressure Lbs. per sq. in.	Superheat Degs. F.	Steam Consumption Lbs. of steam per Kw. - Hr.		
		Half Load	3/4 Load	Full Load
150	0	16.6	15.5	15.2
175	0	16.2	15.1	14.9
200	0	15.8	14.8	14.4
225	0	15.5	14.5	14.1
150	100	15.6	14.6	14.2
175	100	15.2	14.1	14.0
200	100	14.9	13.9	13.4
225	100	14.7	13.8	13.2
150	150	15.2	14.2	13.7
175	150	14.8	13.8	13.4
200	150	14.5	13.6	13.1
225	150	14.3	13.4	12.9

STEAM CONSUMPTION CURVES

AT FULL LOAD

FOR

5000-KW., 80% P.F., 1800 R.P.M. ALLIS-CHALMERS-PARSONS

STEAM TURBINES

DESIGNED FOR EACH DIFFERENT STEAM CONDITION

VACUUM IN EACH CASE - 28½ IN. REF.

FOR 28-IN. VACUUM REF. ADD 5%

FOR 29-IN. VACUUM REF. DEDUCT 2%

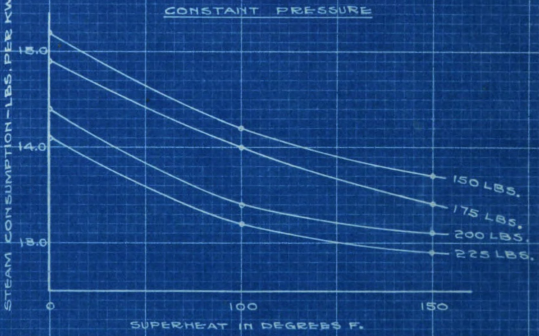


FIG. 24

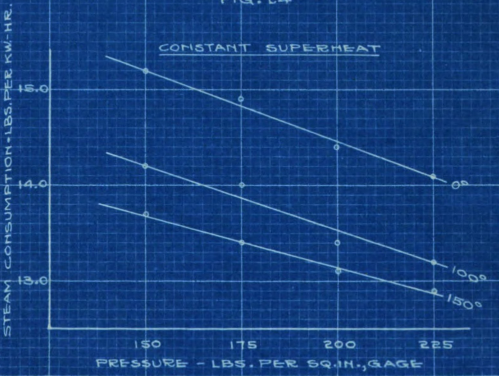


FIG. 25

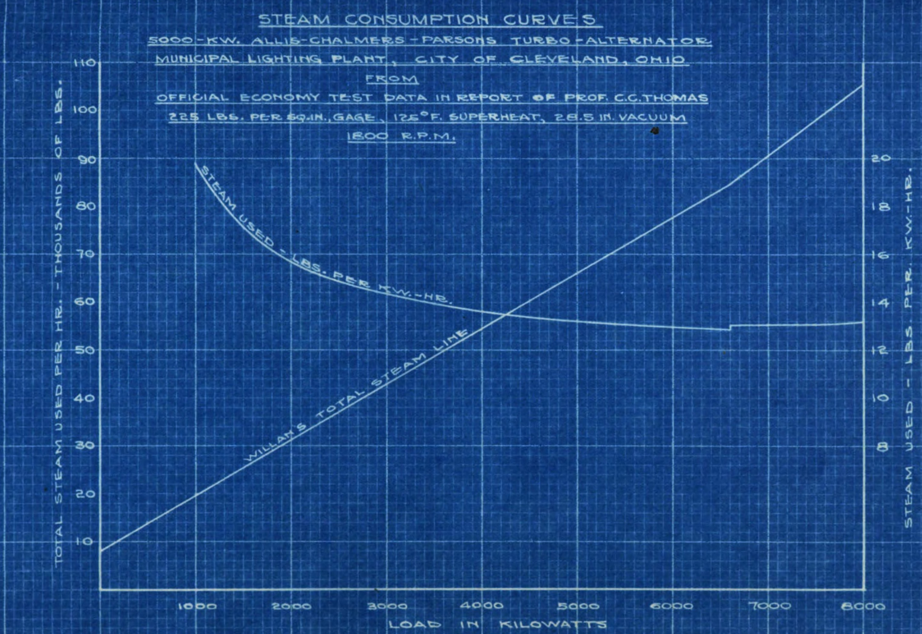

STEAM CONSUMPTION CURVES
5000-KW. ALLIS-CHALMERS-PARSONS TURBO-ALTERNATOR
MUNICIPAL LIGHTING PLANT, CITY OF CLEVELAND, OHIO
FROM
OFFICIAL ECONOMY TEST DATA IN REPORT OF PROF. C.C. THOMAS
225 LBS. PER SQ.IN. GAGE, 125°F. SUPERHEAT, 28.5 IN. VACUUM
1800 R.P.M.
TOTAL STEAM USED PER HR. - THOUSANDS OF LBS.
10
20
30
40
50
60
70
80
90
100
110
STEAM USED - LBS. PER KW.-HR.
8
10
12
14
16
18
20
STEAM USED - LBS. PER KW.-HR.
WILLAN'S TOTAL STEAM LINE
1000
2000
3000
4000
5000
6000
7000
8000
LOAD IN KILOWATTS

FIG. 26

COMPARISON.

At the Annual Meeting of the American Society of Mechanical Engineers in December, [illegible] - Messrs. H. G. Stott and R. J. S. Pigott, Jr., reported upon efficiency tests of one of three 30,000-kw., three-cylinder cross-compound units installed at the 74th Street Station of the Interborough Rapid Transit Company of New York City. The steam pressure at the throttle for these tests was [illegible] lbs. per sq. in., abs. the steam being superheated [illegible]°F., and exhausted into a vacuum of [illegible] in. Hg., referred to 30 in.

At the Spring Meeting of the American Society of Mechanical Engineers held at Chicago, May 23 to 26, [illegible] Mr. Herbert B. Reynolds presented a report upon the efficiency tests of one of the three 30,000-kw. General Electric straight impulse turbines installed at the 59th Street Station of the same company, the Interborough Rapid Transit Company, in New York City. The normal steam pressure at the throttle was 225 lbs. per sq. in., abs. the steam being superheated [illegible]°F., and exhausted into a vacuum of [illegible] in. Hg. The results of this test are particularly valuable inasmuch as they are on a large turbine of the same size as the Westinghouse unit previously tested by Messrs. Stott and Pigott and as both reports contain complete correction curves for initial conditions of steam pressure and superheat as well as for vacuum, the results of one test can be readily transformed to the conditions of the other and a direct comparison can be made.

Tables IV, V, and VI contain test data for the tests on both turbines, taken directly from the curves contained in the

reports. The correction factors for pressure, superheat, and vacuum have been taken from the correction curves of the reports in each case and the original data have been transferred from those obtained to those under which the other machine was tested in each case. Comparative curves have been plotted from these tables and are shown in Fig. 17.

TABLE IV. - STEAM CONDITIONS.

Turbine	Pressure lbs. per sq. in. abs.	Superheat Degs. F.	Vacuum In. of Hg. 30-in. Bar.
General Electric	225	150	29
Westinghouse	215	120	29

TABLE V. - PER CENT CORRECTION

	Pressure	Superheat	Net
For transferring General Electric data to Westinghouse test conditions;	-0.2%	-0.3%	-0.5%
For transferring Westinghouse data to General Electric test conditions:	0.2%	2.4%	2.6%

TABLE VI. - CORRECTED VALUES FOR TURBINE [illegible] WATER RATES.

Average Net Output 1000 Kw.	General Electric Turbine		Westinghouse Turbine	
	Water Rate Lb. per Kw. Hr.	Corrected Water Rate	Water Rate Lb. per Kw. Hr.	Corrected Water Rate
14	11.75	11.70	--	--
15	11.62	11.57	--	--
16	11.50	11.45	11.85	12.17
17	11.39	11.34	11.75	12.06
18	11.30	11.24	11.67	11.98
19	11.22	11.17	11.58	11.89
20	11.15	11.10	11.52	11.82
21	11.10	11.05	11.48	11.78
22	11.06	11.01	11.45	11.75
23	11.04	10.99	11.44	11.74
24	11.05	10.99	11.43	11.73
25	11.08	11.03	11.37	11.68
26	11.10	11.05	11.28	11.58
26.5	--	--	11.27	11.57
27	11.12	11.07	11.28	11.59
28	11.15	11.10	11.[illegible]	11.6[illegible]
29	11.19	11.15	11.44	11.74
30	11.24	11.19	11.45	11.75
31	11.26	11.20	11.45	11.75
32	11.29	11.25	11.39	11.69
33	11.30	11.24	--	--

COMPARATIVE WATER-RATE CURVES

OF

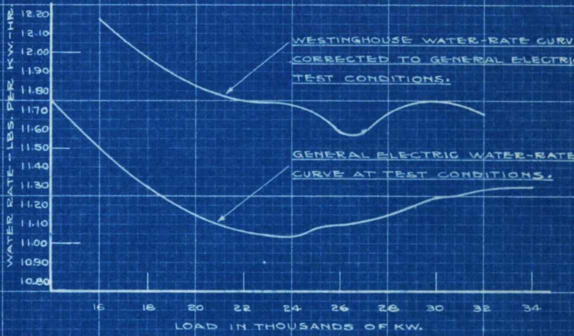
A 30,000-KW. CROSS-COMPOUND WESTINGHOUSE-PARSONS STEAM TURBI

AND

A 30,000-KW. SINGLE-CYLINDER GENERAL ELECTRIC-CURTIS STEAM TURBI

GENERAL ELECTRIC TEST AT

225 LBS. ABS., 150°F. SUPERHEAT, 29-IN. VAC.



WESTINGHOUSE TEST AT

215 LBS. ABS., 120°F. SUPERHEAT, 29-IN. VAC.

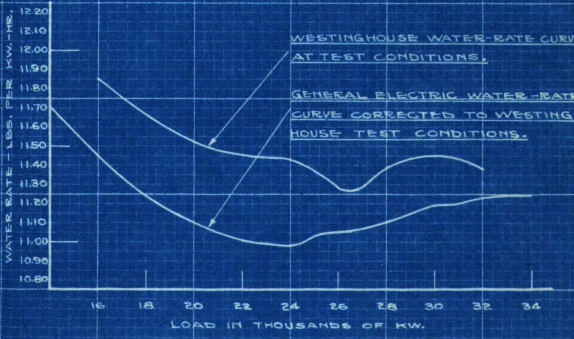


FIG. 27

Mr. [illegible], Chief of [illegible], [illegible] Development, Brooklyn, N. Y. [illegible] report of [illegible] the follow-ing [illegible] of Table VI.:

"[illegible], super-heat variation [illegible] variation, ... which are used to calculate the last three columns (i.e., [illegible] data sheet in-cluded [illegible] report), the values in [illegible] plotted, ... [illegible] tion upon which [illegible]. [illegible] results of which [illegible]. [illegible] after correction [illegible] displayed features [illegible] or the [illegible]; [illegible] therefore [illegible], [illegible] possible to determine [illegible] correction curves from the turbine it-self or from a turbine of [illegible], [illegible] turbine of manufacture [illegible] referred to [illegible] have displayed features [illegible] ....

"That [illegible] no attempt was made to establish the precise characteristics of the [illegible] test data [illegible], be-cause by the conditions [illegible] pres-sure, superheat, and vacuum [illegible] actual test results [illegible] performance of the turbine [illegible] condit-ions is to be determined [illegible]; [illegible] ter-mining [illegible] the performance of the [illegible]

definite contract conditions."

Following is a comparison of the efficiency ratios based on the Rankine cycle and the thermal efficiencies of a Westinghouse and an Allis-Chalmers Parsons reaction turbine. The Westinghouse turbine is one installed in 1925 and is capable of being operated at full load of either 5500 or 7500 kilowatts. The Allis-Chalmers turbine is the one, installed in the Municipal Lighting Plant of the City of Cleveland, which has been previously described. In comparing these performances, it must be borne in mind that the efficiency ratio cannot be used as a direct comparison, as the same turbine will give a higher efficiency ratio with higher superheat. In this instance the efficiency ratios include generator losses.

Allis-Chalmers 5000-kw., 80% P.F., 1800-r.p.m. unit;

Most efficient load	-- 6600 kw.
Steam consumption	-- 12.82 lbs. per kw.-hr. at most efficient load.
Steam Pressure	-- 225 lbs. per sq. in., Gage
Superheat	-- 125°F.
Vacuum	-- 28.5 in. Hg. ref. to 30 in.

$$\text{Efficiency Ratio} = \frac{3,415}{12.82(1275 - 921)} = 75.3\%$$

Westinghouse 5500 or 7500-kw. unit:

Rated capacity	-- 5500 and 7500 kw.
Steam consumption	-- 15.21 lbs. per kw.-hr. at 9,805-kw. load
Steam Pressure	-- 177.6 lbs. per sq. in., Gage
Superheat	-- 96.0°F.
Vacuum	-- 27.21 in. Hg. ref. to 30 in.

$$\text{Efficiency ratio} = \frac{3,415}{15.21\ (1254 - 951)} = 74.1\%$$

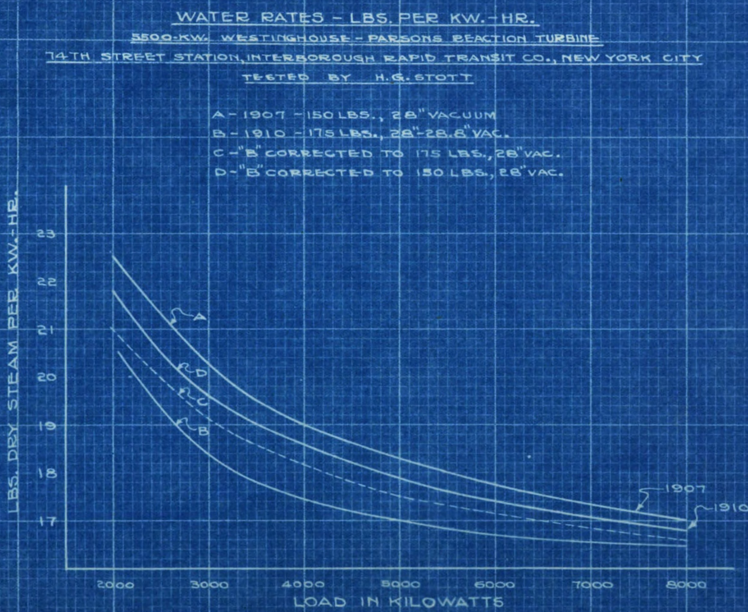

WATER RATES - LBS. PER KW.-HR.
5500-KW. WESTINGHOUSE - PARSONS REACTION TURBINE
74TH STREET STATION, INTERBOROUGH RAPID TRANSIT CO., NEW YORK CITY
TESTED BY H.G. STOTT
A - 1907 - 150 LBS., 28" VACUUM
B - 1910 - 175 LBS., 28"-28.8" VAC.
C - "B" CORRECTED TO 175 LBS., 28" VAC.
D - "B" CORRECTED TO 150 LBS., 28" VAC.
LBS. DRY STEAM PER KW.-HR.
23
22
21
20
19
18
17
A
D
C
B
1907
1910
2000
3000
4000
5000
6000
7000
8000
LOAD IN KILOWATTS

FIG. 28

In Fig. 28 are shown graphically the results of two series of tests conducted on a 5500-kw. Westinghouse turbine installed in the 74th Street Station of the Interborough Rapid Transit Company, New York City and are interesting from the view-point of the matter of permanency of efficiency. At the time as indicated on the chart three years elapsed between the two tests and at the time of the last test the unit had been in service five years and two months, and its total output had been 168,614,075 kilowatt-hours, or 70% of the total number of hours multiplied by the rated capacity of the unit. The last test, far from indicating any deterioration in efficiency, shows even better results than the one made three years earlier. The tests were made by Mr. H. G. Stott.

A comparison of the data obtained on these two units is of interest in indicating the change in power plant operating conditions. In 1907 it was common practice to build boilers for 150 pounds pressure saturated steam and design condensers for 27-1/2 to 28 inches of vacuum, while modern practice in turbine plants is to install boilers designed for at least 200 pounds pressure and superheat of 150° and above and stations located on tide water generally endeavor to maintain 29 inches of vacuum for a greater part of the year.

The curve shown in Fig. 29 appeared in an article prepared by Mr. J. F. Johnson, Engineer in the Turbine Department of the Westinghouse Electric & Manufacturing Company. It shows the approximate water rates of different-size turbines at their most efficient loads in per cent of that of a 20,000-kw. unit.

APPROXIMATE WATER RATES OF DIFFERENT-SIZE TURBINES
AT MOST EFFICIENT LOADS

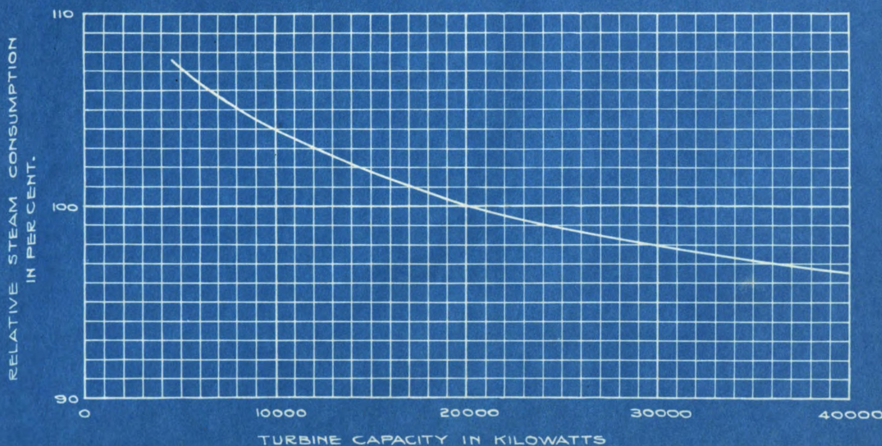


FIG. 29

J.F. JOHNSON IN ELECTRICAL WORLD, 72:26, DEC. 28, 1918

WESLEY F. MALLOCH - APRIL 22, 1921

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C O N C L U S I O N

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C O N C L U S I O N .

From a review of the comparisons made of the structural details of large steam turbines as manufactured in the United States today there are several details that stand out distinctly as characteristic of the various manufacturers.

The General Electric Company stands out as the only concern in the United States manufacturing large impulse turbines besides being the strong advocate of single-cylinder construction even in the largest units. It is [illegible] naturally quite difficult to [illegible] of the manufacturers of reaction turbines and the value of a comparison of the structural details of this type of turbine with those of the Westinghouse and Allis-Chalmers machines, other than being of interest, is doubtful.

[illegible] a comparison of the principal features of the Westinghouse and Allis-Chalmers turbines, especially in the turbines above the 5000-kw. limit there are several interesting facts. [illegible] in the method of fastening and lashing [illegible] wire [illegible] the blades at the blade tips, and the latter employ [illegible] shrouding rings and channel shrouds at the blade tips in addition to [illegible] lashing wire. Spindle construction varies [illegible] in that, whereas the Allis-Chalmers engineers employ a drum on which spindle rings are fitted to carry the blading, the Westinghouse engineers cut the grooves for the first rows of blading directly in the spindle drum and press disc wheels on the shaft ends to carry the last rows of the reaction blading. In the double-flow Westinghouse turbines it is customary to employ three balance pistons at the high-pressure end of the cylinder, which fact makes the third or low-pressure part of large size and increases the liability of warping, while the Allis-Chalmers engineers have patented the method of locating the low-pressure balance piston at the exhaust end of the spindle and have thereby avoided the necessity of a large disc in contact with the steam with consequent reduction of the liability of warping.

In contrast to the General Electric Company the Westinghouse Electric & Manufacturing Company does not approve of the practice of housing units of more than 10,000 kw. rating in a single turbine shell and has introduced the principle of multiple-cylinder construction in both the tandem and cross-compound arrangements.

In other details such as governing, gland sealing, bearings, etc., it will be noted that all three types of machines have considerable in common.

When comparing operating histories and characteristics it should be borne in mind that a successful operating history depends to as great if not to a greater extent upon the operating forces as upon the design of the units. To be sure there are cases where faulty design and construction have caused trouble but in criticising the designing engineers, it should always be borne in mind that especially in the larger and more recent units, the designer is entering upon an unknown field and is pioneering, basing the details of construction on what previous experience with smaller machines seems to indicate might be expected to hold for the larger units, and as long as units keep increasing in size this will be the case. After

more of the larger units have been manufactured the problem of their design should be but little more difficult than the present problems met with in the design of smaller units. Although the design principles inherent in Allis-Chalmers turbines seem very sound and excellent, it seems quite reasonable to say that the apparent lack of trouble due to faulty design is to a great extent due to the fact that as yet no exceptionally large turbines have been built by this company and if in incorporating new design and structural features in the larger units which they build they do not have troublesome experiences much the same as the Westinghouse and General Electric Engineers have had, theirs will indeed be the exception to the rule.

It would seem from a study of the present situation in the field of manufacture and operation of large steam turbines in the United States that the limit of successful increase in the size of single-cylinder units has been reached in the impulse turbines by the General Electric Company in its 45,000-kw., units and in the reaction turbines by the Westinghouse Electric & Manufacturing Company in its [illegible],000-kw. [illegible] double-flow units.

The fact that to date large steam turbines have been so eminently successful in this country is due to the skill, energy, [illegible], and [illegible] which characterize the [illegible] of the engineering profession in America and in criticising their works a thorough study of the facts in the case should be made and due credit should be given for increased knowledge gained even through misfortune and apparent disaster. Engineers themselves should also realize the inestimable value of disseminating [illegible]

this is possible without jeopardizing the interests of their firms or clients and serves to further the progress of engineering and with it the best interests of humanity.

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A P P E N D I X

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APPENDIX - I.

REACTION TURBINES.

In a reaction turbine the steam is allowed to expand continuously through rows of fixed and moving blades from inlet to exhaust pressure, a small amount of pressure drop occurring in each row of blades. The moving blades are driven partly by the impulse of the steam issuing from the fixed guide blades and by its expansion in its path through the blade channels. In this type of turbine there is a gradual pressure drop from the inlet to the exhaust pressure, the velocity energy due to the heat drop being absorbed by the moving blades.

IMPULSE TURBINES.

In an impulse turbine the steam in each stage is completely expanded from its initial pressure to the exhaust pressure of the stage in nozzles and no pressure drop takes place within the stage itself. In order to reduce the number of pressure stages the steam is allowed to expand to a relatively high velocity in one set of nozzles and this velocity is then absorbed by several rows of moving blades between each row of which is a row of stationary blades for reversing the direction of the flow of the steam.

APPENDIX - II.

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