Water Wheel

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SMITH-KAPLAN TURBINES

MCMXXX

S. MORGAN SMITH COMPANY
YORK, PENNSYLVANIA

Serial # 8659
H P 300
RPM 150
Head 15' 0"

SMITH-KAPLAN

Automatically Adjustable Blade Hydraulic Turbines

BULLETIN No. 123

Francis Type
300 H.P – R.P.M – 200 + Case + Gov. $10,000

Kaplan
Adjustable 300 H.P. R.P.M - 277 + Case + Gov $15,000

5500 with exciter

Gen @ 200
" @ 277 4585 "

S. MORGAN SMITH COMPANY

Main Office and Works: YORK, PENNSYLVANIA

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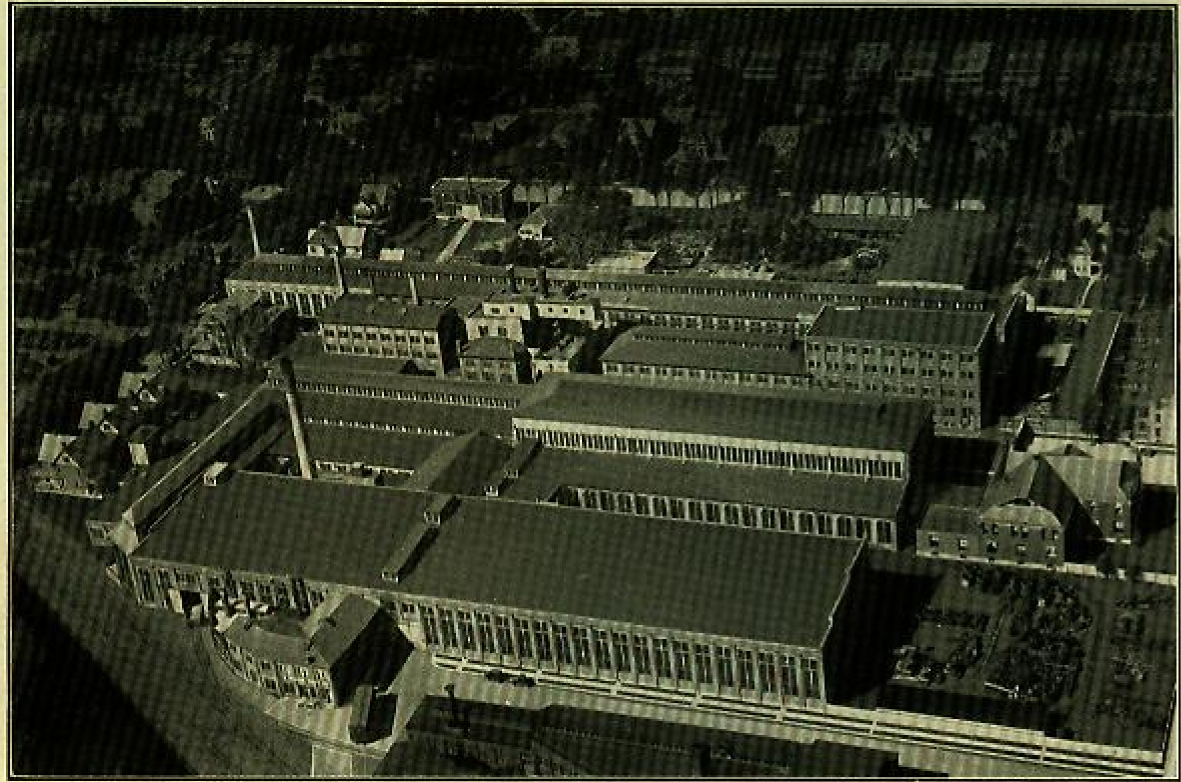
***Associated Company,* S. Morgan Smith-Inglis Co., Ltd., 14 Strachan Avenue, Toronto, Canada**

Where SMITH-KAPLAN Turbines Are Built



Aeroplane view of the plant of S. Morgan Smith Co., York, Pennsylvania; the Largest Plant in the World devoted exclusively to the manufacture of Hydraulic Turbines

Founded in 1877

A Bit of History Regarding The SMITH-KAPLAN Turbine

The introduction of the Kaplan Turbine represents a most important advance in the art of hydraulic turbine construction in the United States and Canada.

For this remarkable achievement, we are indebted to Prof. Dr. Victor Kaplan of Brunn, Checkoslavokia, who, since the beginning of this century, has designed hydraulic turbines along radically different lines, and who, after many experiments, developed the fundamentally new runner and gate case designs, which excell the performance of the Francis turbine at high specific speeds.

Today, the Kaplan turbine has been developed into a prime mover which has successfully withstood the most severe tests in actual service in many European and American hydro-electric installations. This development is the result of a series of exhaustive hydraulic laboratory tests carried out over a period of years by Dr. Kaplan and the J. M. Voith Co. in Heidenheim, Germany, a firm of world wide reputation as builders of hydraulic turbines for over sixty years. It is noteworthy, that in this rapid development there have been no disappointing failures and that all installations have gone into service without any particular difficulties.

The large number of orders placed with the Voith Co. in the relatively short space of five years, demonstrates conclusively that these high speed turbines have been accepted by engineers in charge of water power development. Up to the end of November, 1929, a total of 96 Kaplan adjustable blade turbines with a total of 231,000 horse power and 19 fixed blade turbines with a total horsepower of over 79,000 had either been built, or were under construction by the Voith Co.

In 1928 the rights under the Kaplan patents for the manufacture of adjustable and fixed blade turbines in the United States and Canada were acquired by the S. Morgan Smith Company,—and at the same time arrangements were made whereby the Voith Co. placed at our disposal the results of their tests and the benefits of their experience in designing and manufacturing such turbines. After acquiring these patent rights, we carried out complete and exhaustive tests in our hydraulic laboratory in order to confirm these designs and modify them to incorporate the knowledge gained from our own experience in designing and manufacturing hydraulic turbines since 1877.

Since beginning to manufacture under these patents, less than two years ago, we have been awarded contracts for sixteen adjustable blade turbines and twenty-seven fixed blade turbines.

Characteristics of the SMITH-KAPLAN Turbine

Kaplan turbines have a totally different form than Francis turbines. In the Kaplan turbine, a few wing-like runner vanes (or buckets) without the familiar rim around their outer ends are attached to a strong hub. This runner, (Fig. 1), therefore, resembles a ship's propeller rather than a Francis turbine.

The Kaplan turbine shows three important new characteristics secured and protected by many United States and foreign patents.

These characteristics are as follows:

1—*A vane-free transition space* between the wicket gates discharge and the runner entrance. The water leaving the gates is deflected in an axial direction in this transition space and flows axially through the runner.

2—*Wing Shaped runner vanes*, so spaced and proportioned that two adjacent vanes form a nozzle or double guidance for part of this radial extent and single guidance for the remainder.

3—*Adjustable runner vanes.* Prof. Kaplan was the first to adjust the runner vanes and the wicket gates simultaneously. In the closed position (Fig. 2, page 5) the whole surface of the vanes or buckets lie approximately at right angles to the shaft axis. In this position the discharge is a minimum and the runner develops the minimum power. With increasing wicket gate opening (increasing load) the vanes are opened so that the area of the water passage increases (Fig. 3). Each position of the runner vanes corresponds to a definite position of the wicket gates, and the correct relationship of these positions must be maintained if the efficiency at all rates of discharge is to be a maximum.

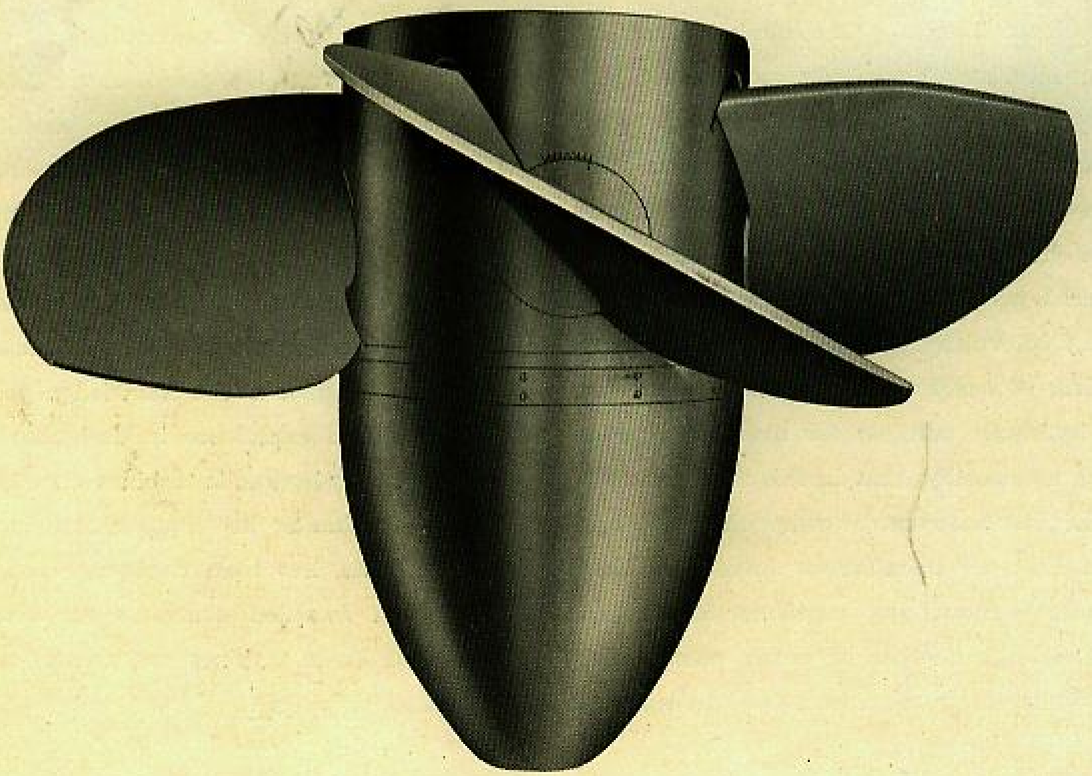


Figure 1

Smith-Kaplan adjustable blade runner

Advantages of the SMITH-KAPLAN Turbine

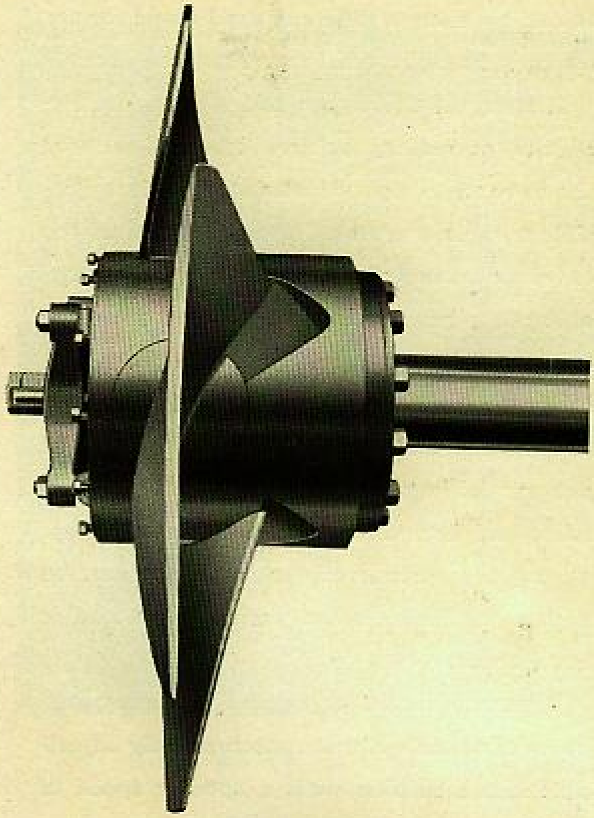


Figure 2
Runner with vanes in closed position

Modern operating practice requires that, at times of low load on hydro-electric plants, the generators be operated as synchronous condensers to improve the system power factor. Smith-Kaplan adjustable blade turbines have a distinct advantage in that the runner blades can be moved to the fully closed position during such operation, thus materially reducing the windage losses and consequently the power required to drive the synchronous condenser. Figure 2, above, clearly shows how the wind resistance is reduced when the blades are in the flat position.

The features of design and construction described previously give to the Smith-Kaplan turbine certain advantages that are responsible for its rapid adoption.

By reducing the number of blades and decreasing their area and also omitting the band around the blades, the friction of the water on the runner surfaces is greatly reduced. This reduction in friction means less loss through the runner with consequent higher efficiencies and higher specific speed. Francis turbines can be built with good efficiency at specific speeds up to 110 while Kaplan turbines show good efficiencies at specific speeds up to 170 for the fixed blade runners and up to 225 for the adjustable blade runners. This increase in specific speed makes it possible to use higher speed generators with a consequent reduction in the cost of the electrical equipment.

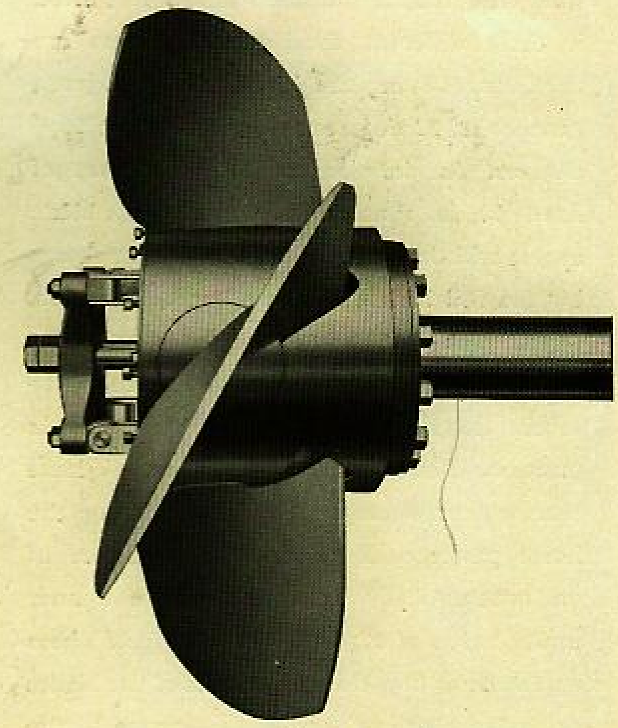


Figure 3
Runner with vanes in full load position

Advantages of the SMITH-KAPLAN Turbine

The simultaneous adjusting of the runner blades and wicket gates to maintain the best conditions of flow throughout the entire range of output results in the obtaining of exceptionally high part load efficiencies, thus securing very flat efficiency-load curves. Since the blade and gate angles and openings always have the correct relationship to each other, the Smith-Kaplan adjustable blade turbine operates with maximum smoothness and with minimum vibration and pitting.

Figure 4 shows a comparison of the efficiency-load curves of a Kaplan automatically adjustable blade runner with those of fixed blade runners at various heads and with different blade angles. The dotted curves show the performance of a fixed blade runner at different heads. The dash and dot lines show the results obtained at 26 feet head if three different fixed blade runners are used, one having the blades at 28 degrees, another at 22 degrees and the third at 16½ degrees. An infinite number of curves of fixed blade runners with different blade angles will develop the envelope curve shown by the full line for 26 feet head. Automatic adjustment of the blades and gates maintains the correct relationship between them to secure the highest efficiency for each blade position. Four such envelope curves have been drawn, using full lines, showing the horse power and efficiency performance of an automatically adjustable blade runner under heads of 17, 20, 23 and 26 feet. These curves show how the adjustment of the blades holds the efficiency of the turbine up to the maximum which could theoretically be obtained by using a different fixed blade runner for each special condition of load and head.

A study of this figure and a consideration of the operating features involved clearly shows that, as a practical matter, it is impossible to obtain even an approximation of the envelope curves with a hand operated adjustable blade runner requiring a shut down for each adjustment. In addition to the necessarily uneconomical operation of the non-automatic turbine, there is involved a substantial amount of increased physical labor and attendance and also loss of power during the periods of shutdown required to adjust the blades when variations in load or head occur.

Figure 5 shows a typical efficiency-load curve of a Smith-Kaplan automatically adjustable blade turbine with a specific speed of 161. Note the very flat curve with more than 85 per cent efficiency from 33 to 96 per cent load and more than 90 per cent efficiency from 43 to 75 per cent load.

Figure 6 on page 8 shows a comparison of a Smith-Kaplan automatically adjustable blade turbine, a fixed blade turbine and a high speed Francis turbine. This figure shows the marked advantage in efficiency of the adjustable blade turbine at all loads except in a very narrow range at about 90 per cent of full load capacity. The fixed blade and the Francis turbines attain very high efficiencies only at nearly full load and the part load efficiencies drop off very sharply. For the same full load capacity, a smaller adjustable blade turbine can be used and consequently it can be operated at a higher speed, thus per-

Advantages of the SMITH-KAPLAN Turbine

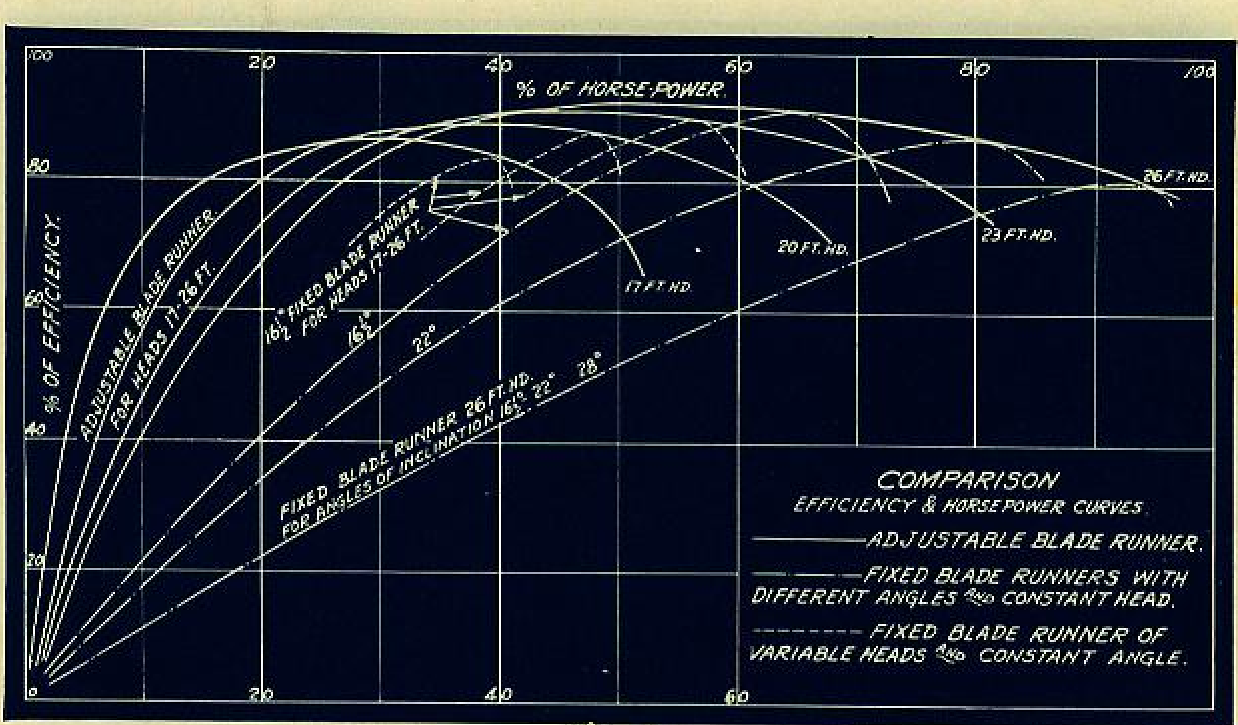


Figure 4
Comparison of efficiency. Load curves for fixed and adjustable blade turbines. These curves show how the automatic adjustable blade turbine curves are derived

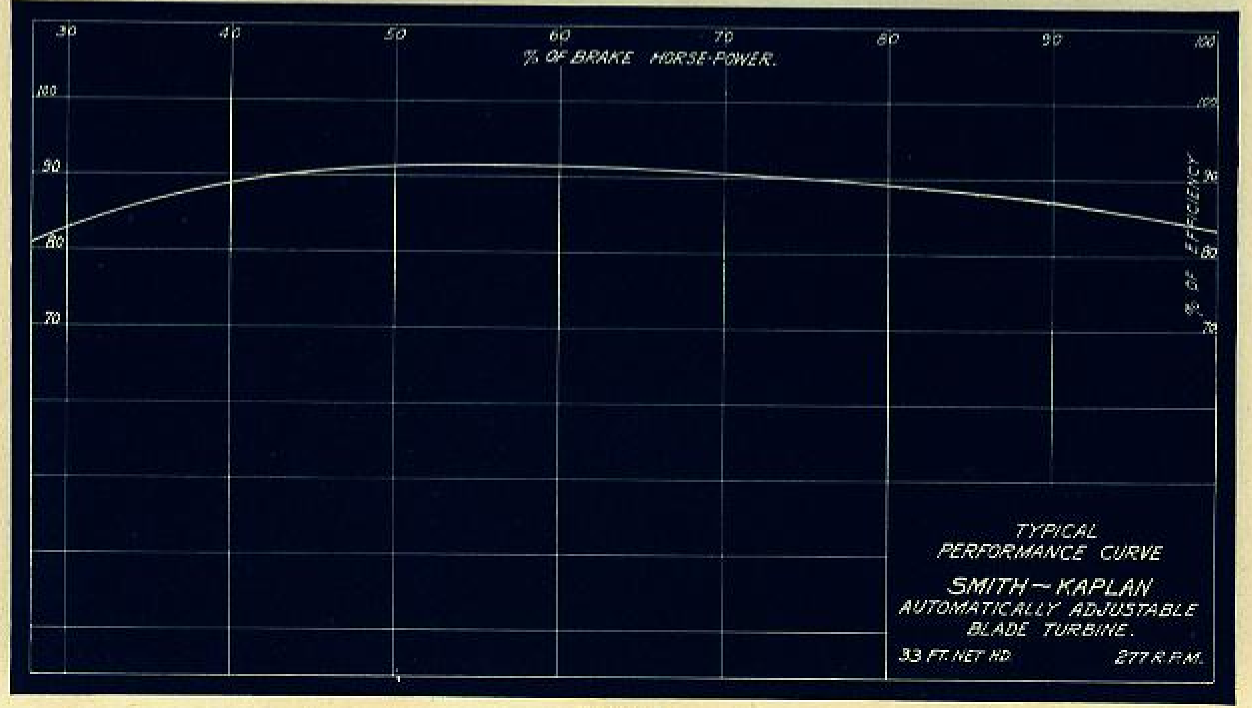


Figure 5
Typical efficiency curve of an automatically adjustable blade Smith-Kaplan turbine

Advantages of the SMITH-KAPLAN Turbine

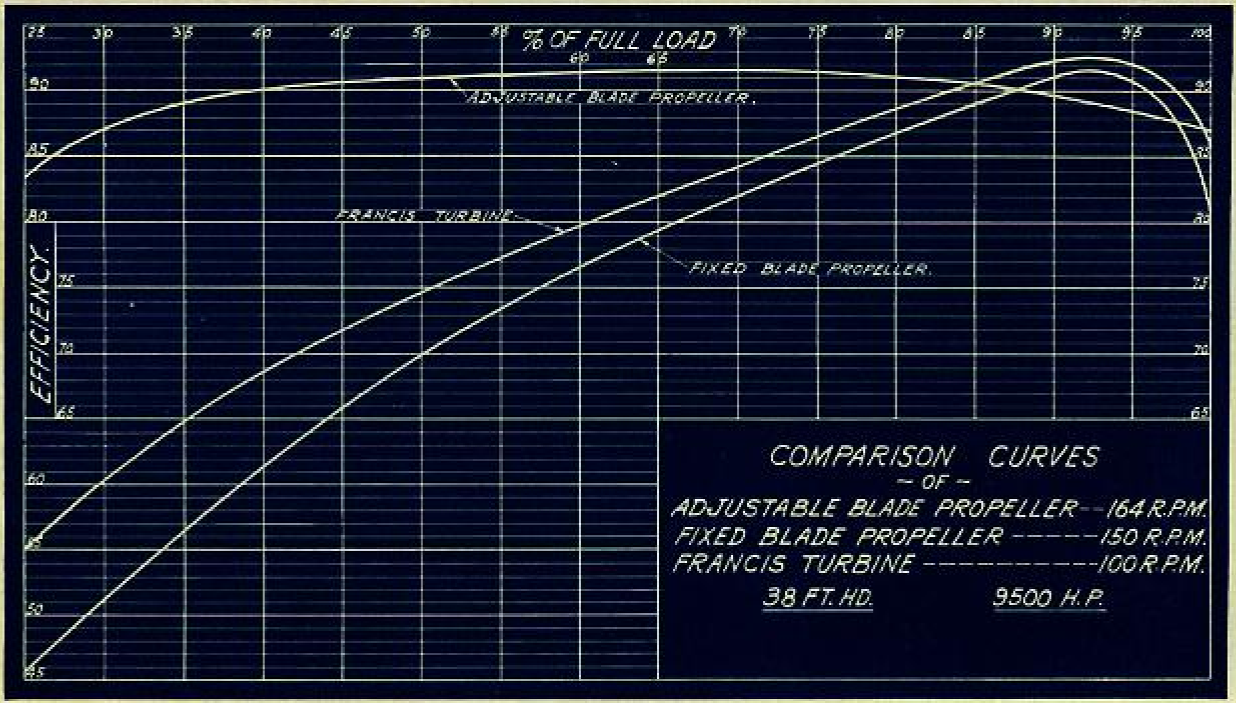


Figure 6

Comparison of high speed Francis, fixed and adjustable blade turbines

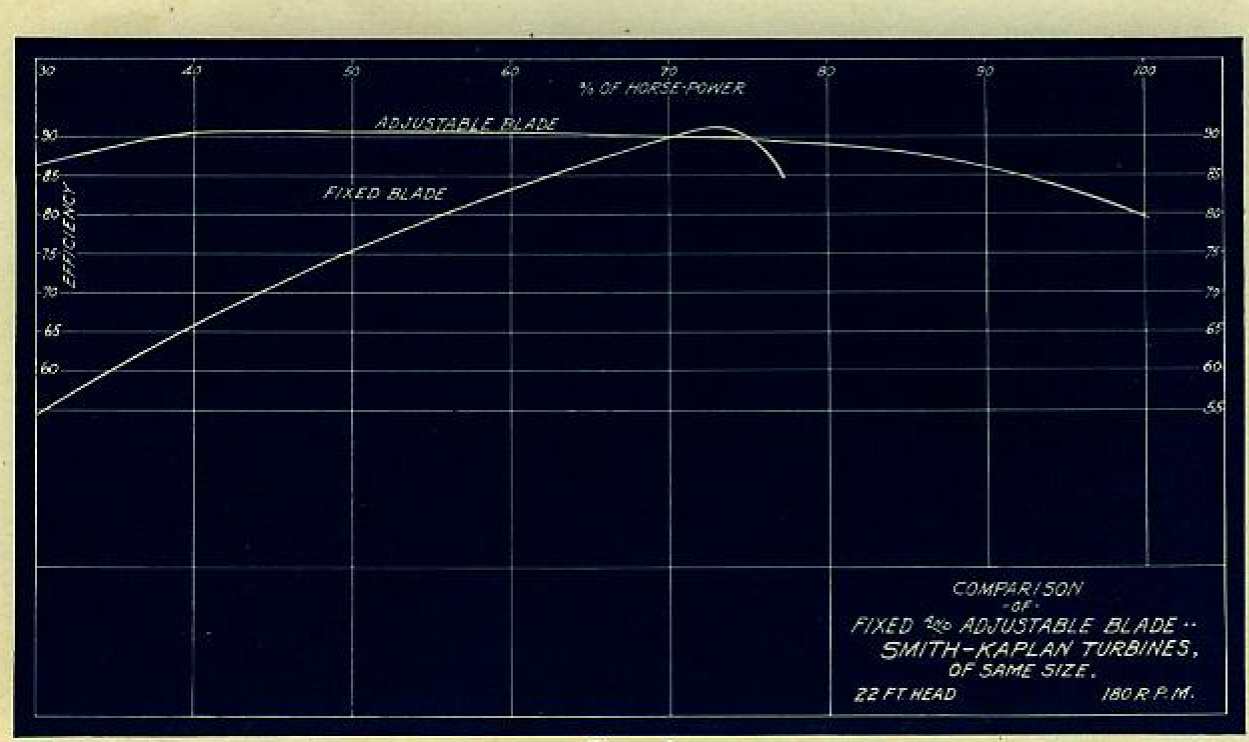


Figure 7

Curve showing total output gained by using an adjustable blade turbine instead of a fixed blade turbine. Both turbines have the same runner diameter and operate at the same speed

Advantages of the SMITH-KAPLAN Turbine

mitting the use of a smaller and cheaper generator. The higher the specific speed for the fixed blade and the Francis turbine, the faster the efficiency drops at part load. Therefore, with high specific speeds, the efficiency of these turbines attains satisfactory values only over a small change of output. Consequently such turbines can be considered only where they will be operated with loads varying over a short range at near full capacity.

The automatic Smith-Kaplan adjustable blade turbine may be designed and selected to provide a liberal overload capacity. The turbine is very flexible in this respect, and the excess horsepower for short peak loads or for low head flood conditions can be provided with slightly less than normal load economy,—and usually with little or no reduction in efficiency at low gate openings. Figure 7 shows the overload capacity gained by substituting an automatically adjustable blade runner for a fixed blade runner of the same size and speed.

Figure 8 shows the possibility of reducing the number of units in a power house without reducing the total capacity by using adjustable blade instead of fixed blade runners. This curve shows that two adjustable blade units could be substituted for five smaller fixed blade turbines and the efficiency at any discharge would be higher than if fixed blade units were used. The use of the two adjustable blade units results in material reductions in the cost of the mechanical and electrical equipment and also reduces the size and consequentially the cost of the power house itself.

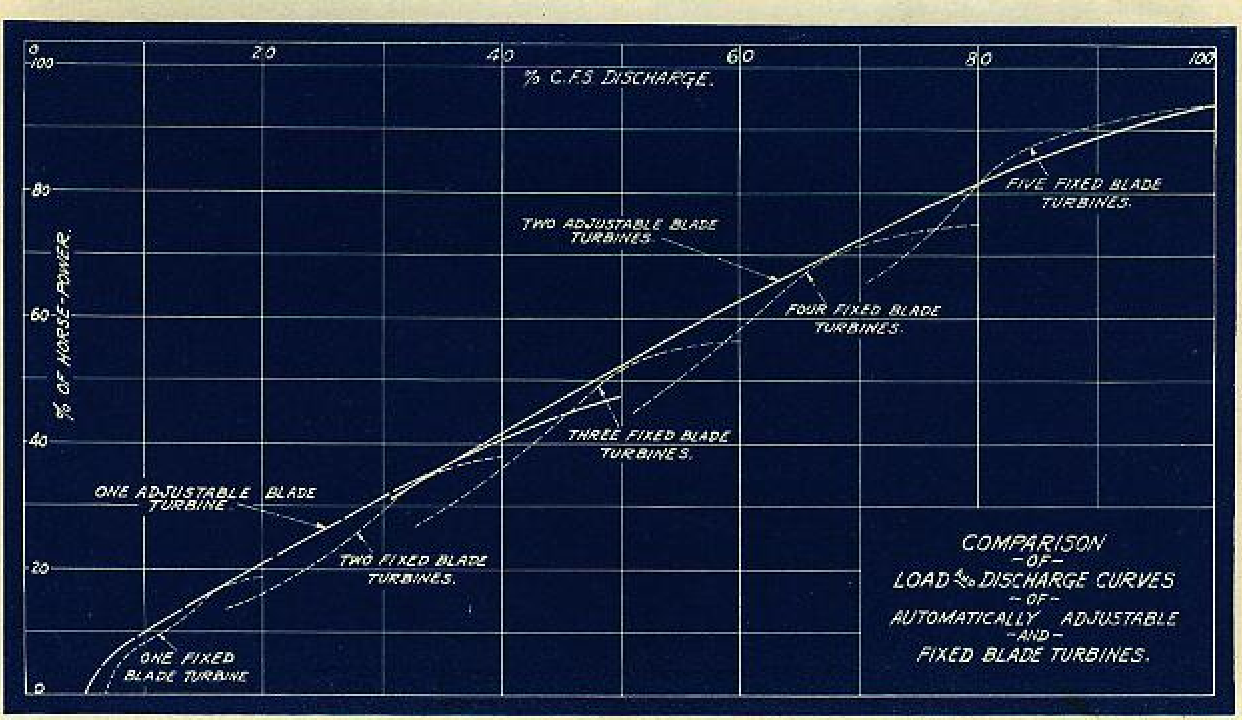


Figure 8

Curves showing substitution of two adjustable blade units for five fixed blade turbines

Construction of the Adjustable Blade Runner of the SMITH-KAPLAN Turbine

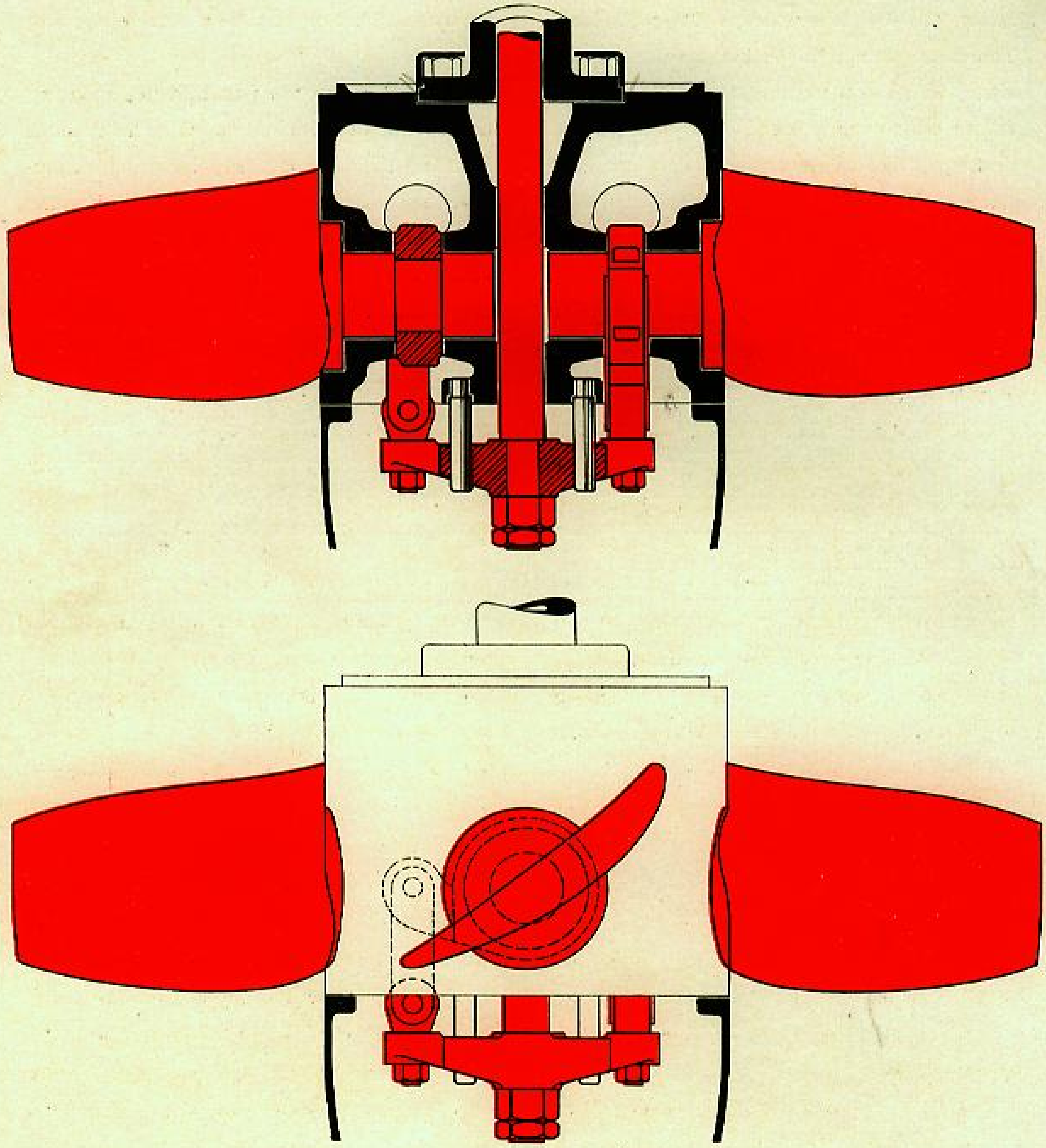


Figure 9

Construction of the Adjustable Blade Runner of the SMITH-KAPLAN Turbine

The adjustable blade Smith-Kaplan turbine is constructed in the same manner as an ordinary wicket gate turbine except for the shape of the top plate and the construction of the runner and shaft. The top plate is shaped so as to form the vane-free transition space between the wicket gates and the runner in which the direction of flow of the water is changed from radial to axial.

The construction of the runner hub which carries the movable blades requires special attention due to the relatively small space available. All of the operating connections for moving the vanes must be contained inside the single piece hub casting (see Fig. 9) and must be of such form that they will stand up indefinitely under the most severe service requirements without any adjustments. By very carefully utilizing every cubic inch of space a design has been developed which has proved eminently satisfactory and reliable in the many plants already built and in operation over a period of years. The stresses are held within very conservative limits to guarantee freedom from excessive strains and deformation and to reduce the possibility of wear to the absolute minimum. Careful inspection of the Kaplan turbines already in operation for several years reveals no signs of wear.

The hub is bored out and bushed with bronze to receive the trunions of the runner vanes. A crank is keyed to each trunion and clamped to secure the runner vane against lateral displacement. These cranks, which stand normal to the shaft axis in their mid-position, are connected to a sliding cross by means of links and eye-bolts. The cross is carried on a sliding regulating rod which operates inside the hollow turbine shaft. This regulating rod is guided in bronze bushings and moves axially in the shaft to operate the runner vanes through the agency of the sliding cross, the links and the cranks. The eye-bolts and cranks are bushed with high grade bronze. The cross slides on keys which prevent any motion except in an axial direction.

In Figure 9 on page 10, the upper view shows a cross-section through the hub of a Smith-Kaplan adjustable blade runner and the lower cut shows an outside view of the hub with the lower section removed. The moving parts, consisting of the regulating rod, the sliding cross and the link connection to the crank on the runner vane trunion are clearly shown in color.

Figure 10 on page 12 shows a runner hub in the shop before assembly. The bearings for the runner vane trunions are clearly shown. An individual vane and the lower hub section are also illustrated. Figure 11 gives a view of the hub with the sliding cross in place and an individual vane with the crank, link and eye-bolt partially assembled.

Construction of the Adjustable Blade Runner of the SMITH-KAPLAN Turbine

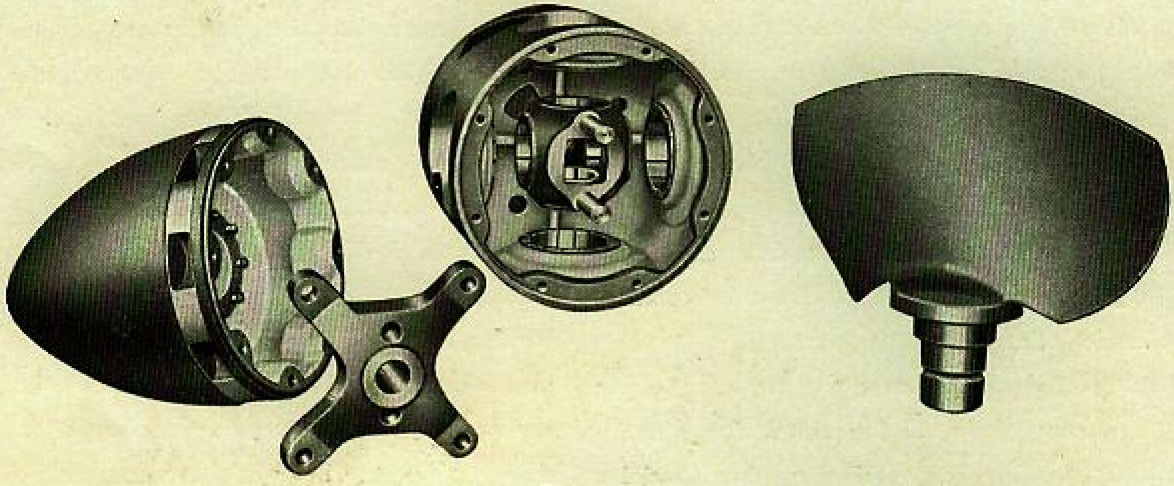


Figure 10

In order to provide constant lubrication for the moving parts in the hub, vertical shaft turbines have the hub filled with a heavy-bodied oil, which is supplied through the hollow turbine shaft, by means of openings located at a convenient height for refilling. Horizontal shaft turbines are filled with light grease for lubrication, with provision for refilling by means of a grease compressor. Each runner vane trunion is packed against leakage where it goes through the hub body, so that the oil loss due to leakage is eliminated. This packing is so arranged, that it, in combination with the inside oil pressure (partly static due to the head in the hollow shaft and partly in centrifugal head due to the rotation), prevents the seepage of water and sand or other impurities into the hub. A brass pipe plug is provided in the lower hub section for draining the oil if necessary.

The runner vanes and hub are made of cast steel. Great care is used to finish the vanes to templates, so that they will have the correct form and degree of smoothness required to offer the least disturbance to the flow of water through the turbine.

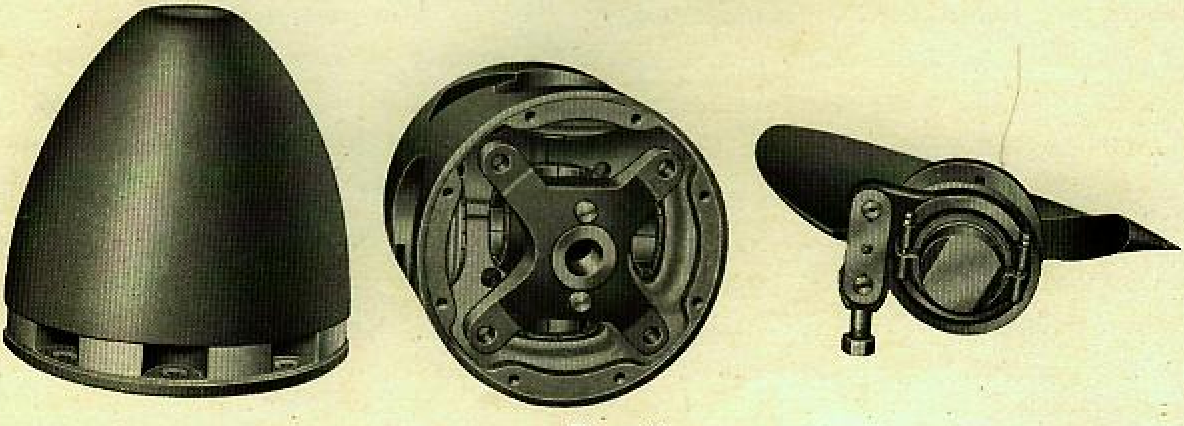


Figure 11

Regulation of the SMITH-KAPLAN Automatically Adjustable Blade Turbine

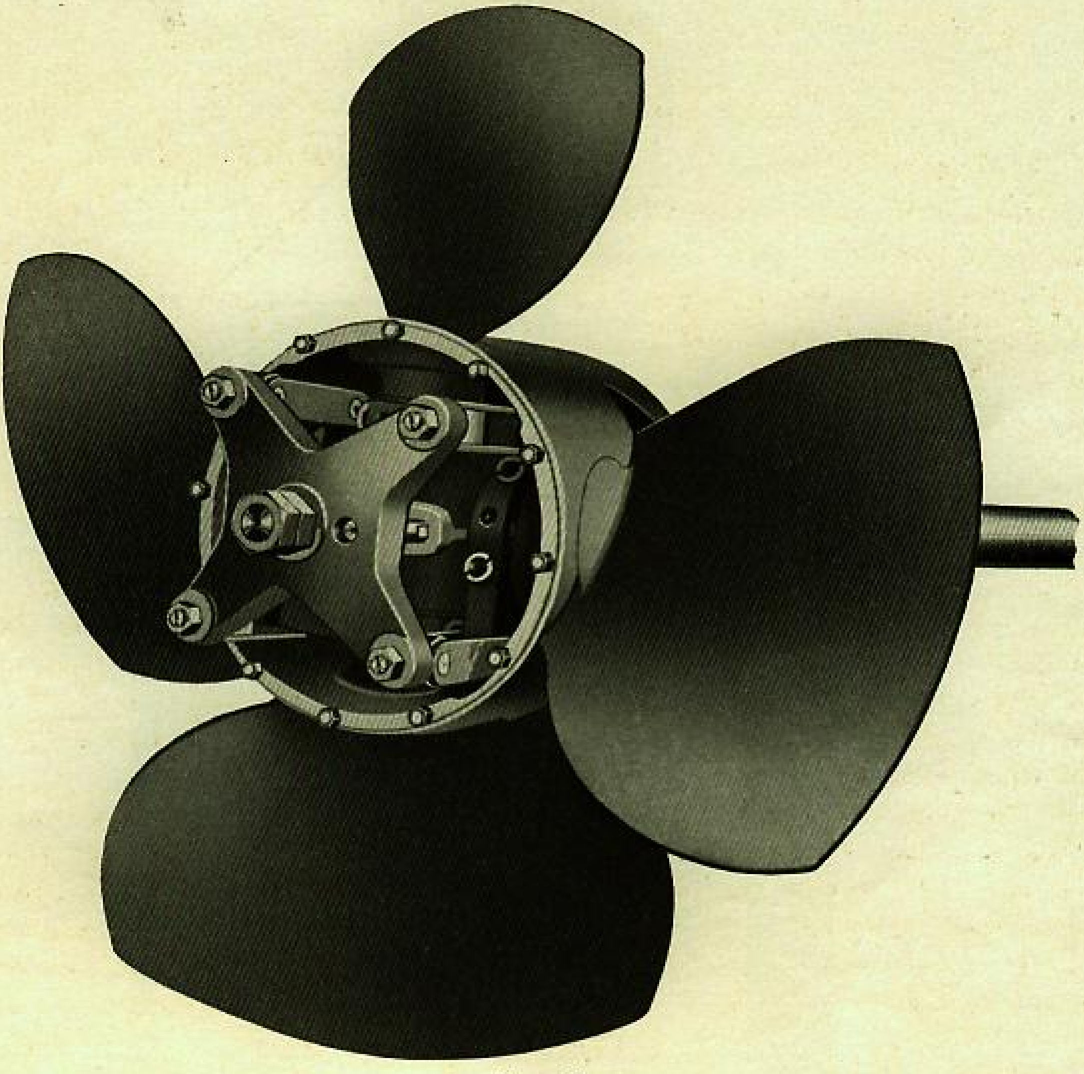


Figure 12

As has already been mentioned, to secure maximum efficiency, the runner vanes, as well as the wicket gates, must be adjusted with changing load conditions. Therefore, the movements of the gate control system and the runner vane control system must be *synchronized at all times,* so that for every gate position there is a definite runner vane position. This can only be accomplished when the gates and runner each have their own servo-motor and distributing valve. The regulating rod in the hollow turbine shaft is moved axially by a servo-motor (Figure 15, page 15) which is arranged between the flanges of the turbine and generator shafts and is rigidly connected to them, so that it revolves with the shaft. The servo-motor piston is directly connected to the upper end of the regulating rod which communicates the piston movements to the runner vanes. The servo-motor is operated by oil supplied under pressure from above, through two pipes arranged concentrically within the hollow generator shaft.

Open Flume Setting of SMITH-KAPLAN Turbine

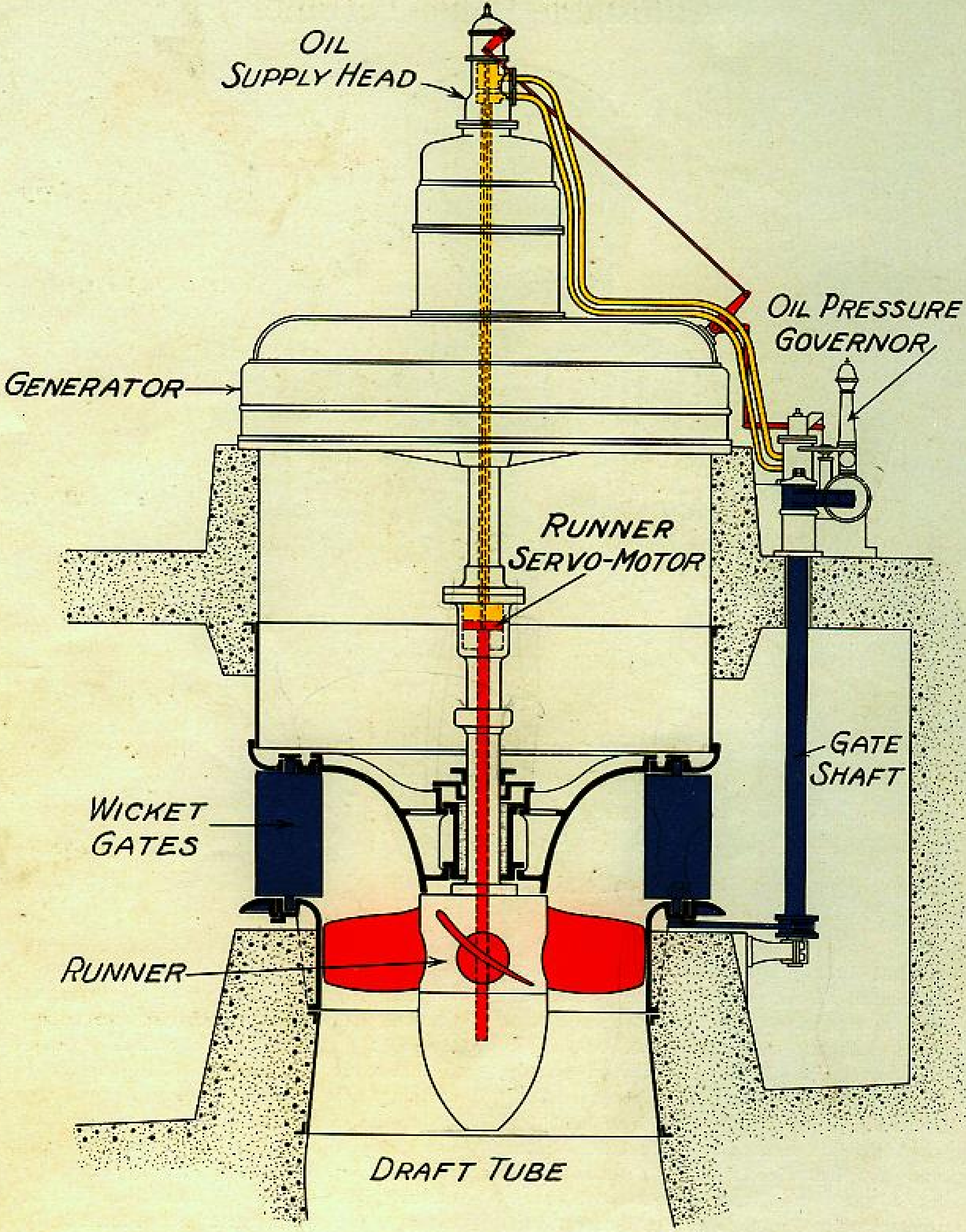


Figure 13

Regulation of the SMITH-KAPLAN Automatically Adjustable Blade Turbine

Figure 14 Oil supply head

The inner pipe carries oil to the lower side of the piston, and is rigidly connected to the same, moving upward and downward with the piston. The governor compensating mechanism is connected to the upper end of this pipe. The two pipes to the servo-motor terminate in two distributing chambers arranged one on top of the other, and mounted on top of the generator. These chambers receive the oil from the governor and collectively form the Oil Supply Head. See Figure 14. Special provision is made to prevent any oil leakage over the generator.

Figures 13 and 15 show schematically the regulating mechanism.

The governor itself is a simple speed governor which operates the wicket gates in the usual manner, either through a

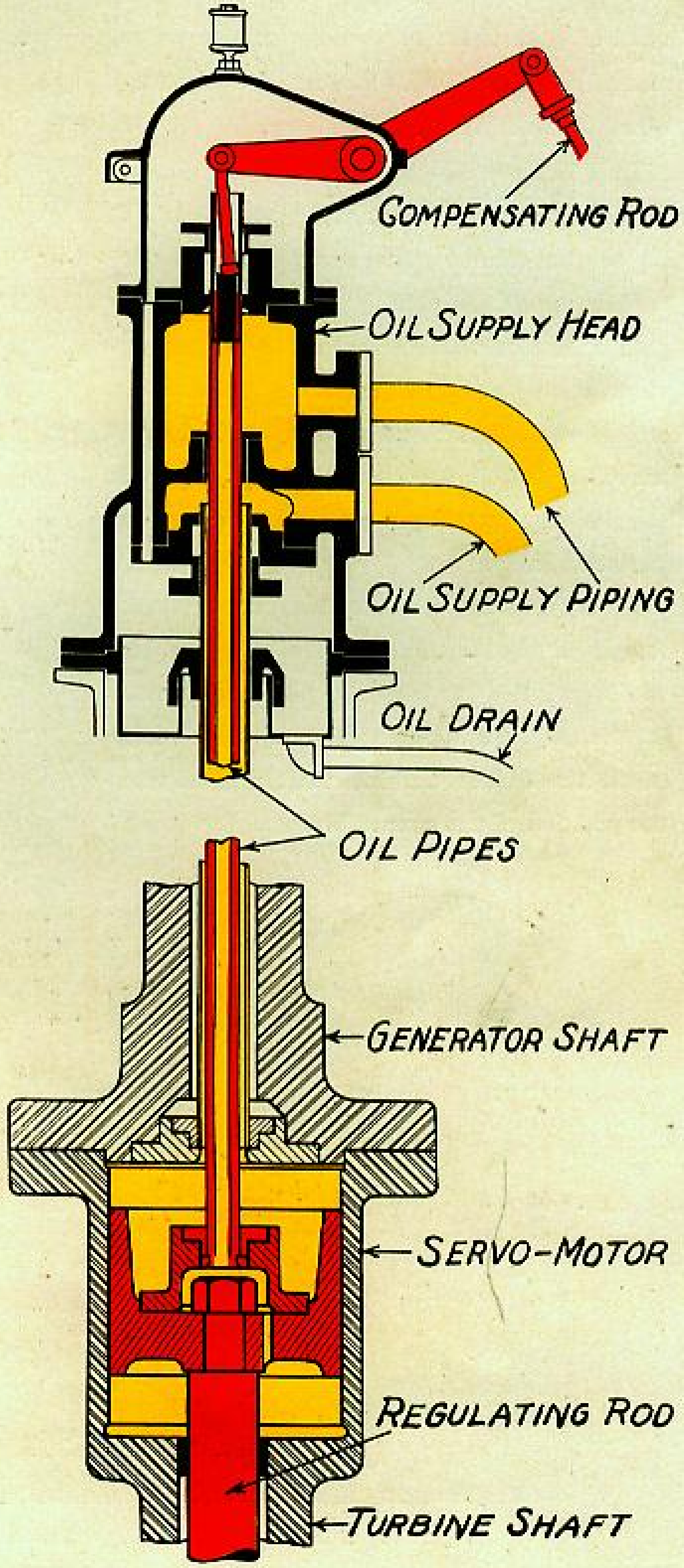


Figure 15

Regulation of the SMITH-KAPLAN Automatically Adjustable Blade Turbine

vertical gate shaft or through servo-motors and push and pull rods connected to the turbine gate shifting ring.

In addition this governor has a second distributing valve controlling the flow of oil to the runner vane servo-motor in the turbine shaft. A cam is connected to the gate operating mechanism and to the runner vane compensating connections in such a way that the gates and runner vanes always move in the definite relationship required to give the maximum efficiency for every variation in load.

Figure 17 shows the runner servo-motor forged in the coupling end of the turbine shaft and the servo-motor piston mounted on the end of the regulating rod which slides inside the hollow turbine shaft and adjusts the position of the runner blades.

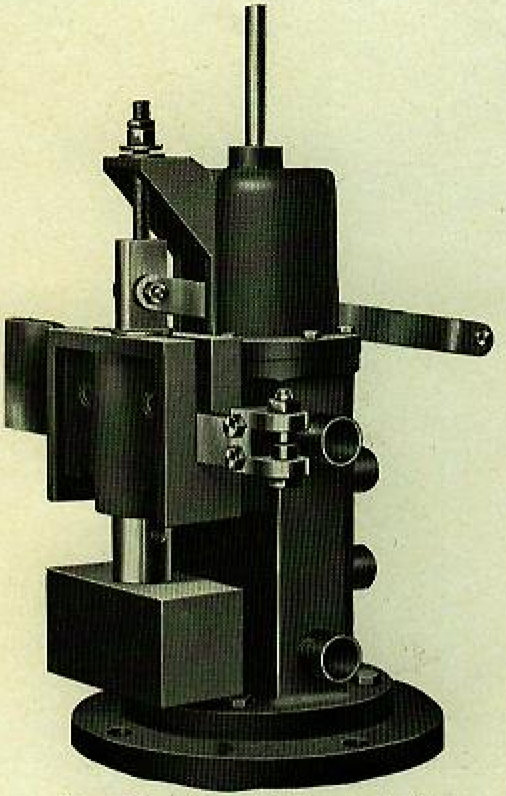


Figure 16 Runner blade control valve

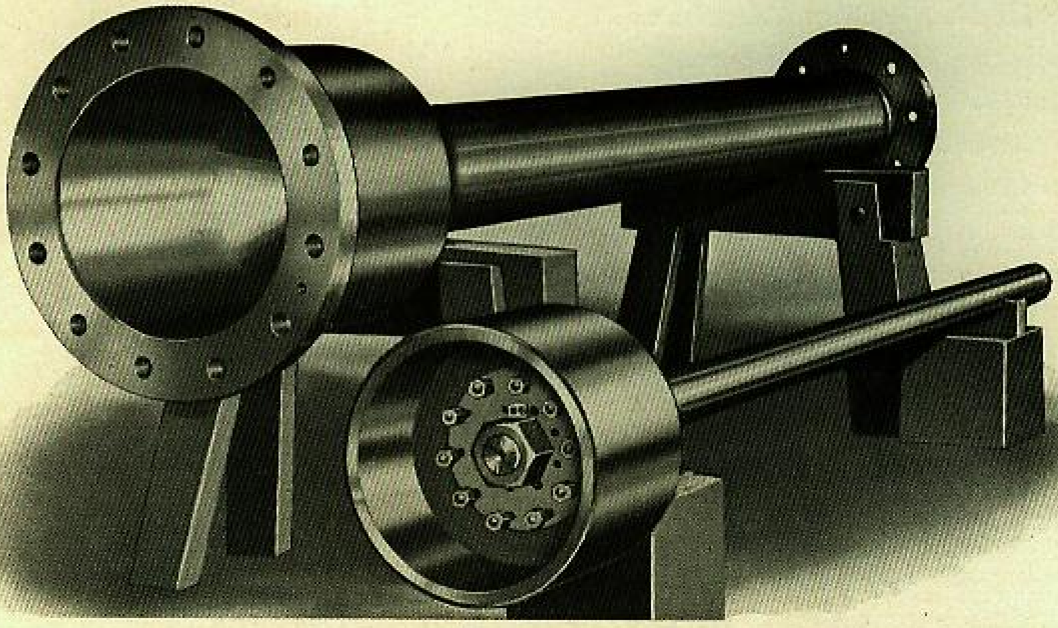


Figure 17 Runner servo-motor in turbine shaft and piston on regulating rod

Field of Use for the SMITH-KAPLAN Turbine

With hydraulic turbines of such high speed as the Kaplan turbine, direct connection of the turbine to the generator is possible under very low heads, since the rotational speed is high enough to utilize commercial sizes of high speed generators, thus reducing the cost of the electrical generating equipment. As a class Kaplan turbines are essentially low and medium head machines. However the head under which they may be used is constantly increasing and heads up to 66 feet may now be developed with perfect safety.

The installation of a Kaplan adjustable blade turbine is particularly advantageous where the quantity of water varies greatly. On account of its high part load efficiency, an adjustable blade turbine delivers much more power in times of low water than a fixed blade or Francis type turbine. Thus the total annual kilowatt-hour output available is greatly increased. The realized increase is greater than the computed gain, as in actual plant operation the Francis units are not started and stopped in accordance with the envelope of the individual efficiency curves.

Another and important advantage of the automatically adjustable vane turbine is that it may be readily selected and designed so that substantial overload capacity is available at all heads. This is a valuable feature at normal heads since the excess capacity can be used to carry peak loads—and this advantage can be obtained with negligible reduction of efficiency. During low head periods the gates and buckets are opened wide, thus developing greatly increased output as compared with a Francis or fixed blade axial flow turbine.

Fixed blade Kaplan turbines, on account of their narrow operating range at high efficiency, can only be considered in comparison with adjustable blade turbines when they can be constantly operated at nearly full load. This condition applies only where such machines are used to carry base load and are tied in electrically with a large system so that other units may be used for regulating purposes.

Where there is a large quantity of water to be handled, a number of fixed blade turbines may be installed and only as many units operated as the immediate quantity of water justifies. Even in this case the total yearly output can be increased by using one or more automatically adjustable blade turbines for regulating purposes.

SMITH-KAPLAN Turbine Settings

The vertical shaft type of setting is always to be preferred for Kaplan turbines, although these turbines may be used with horizontal shaft settings where the shaft is only a short distance above tail water. Where the tail water variations are great and the capacities are large, vertical settings should always be used. This type of setting offers the most favorable hydraulic conditions with consequent higher efficiency and the least space requirements and the minimum cost of construction. It also permits the generator to be installed at any desired elevation to eliminate the possibility of flooding.

With these turbines the allowable draft head decreases with increasing head and increasing specific speed. Consequentially this feature must be carefully considered in designing the setting or uneven operation and also pitting may result in the turbine. The operation of this turbine is also very dependent on the design of the draft tube. For small units we recommend a straight conical tube but this type of tube can only be used in cases where the excavation cost will permit. For all medium and large size turbines we recommend the elbow type draft tube in order to secure the length necessary to regain the energy from the turbine discharge with the minimum amount of excavation. This elbow type of draft tube, as developed by our engineers is the result of years of study and hundreds of tests in our hydraulic laboratory. This tube reduces excavation to a minimum, provides maximum support for the superstructure, simplifies and cheapens the form work, has no underhanging parts requiring expensive reenforcing, and enables the turbine to develop maximum efficiency.

The water is generally supplied to the runner through an open flume or a concrete scroll casing and, sometimes, through a plate steel pressure case or spiral casing. Open flume settings are usually chosen for both small vertical and horizontal shaft turbines, and for low heads, also for the larger turbines. This type of setting is shown in Fig. 13, page 14, which illustrates a turbine with inside gate control mechanism and the runner servomotor mounted in the shaft. Larger units in concrete scroll cases are built with outside gate mechanism and the gates and runner vanes operated by servomotors as shown in Fig. 18, page 19.

Scroll Case Setting of SMITH-KAPLAN Turbine

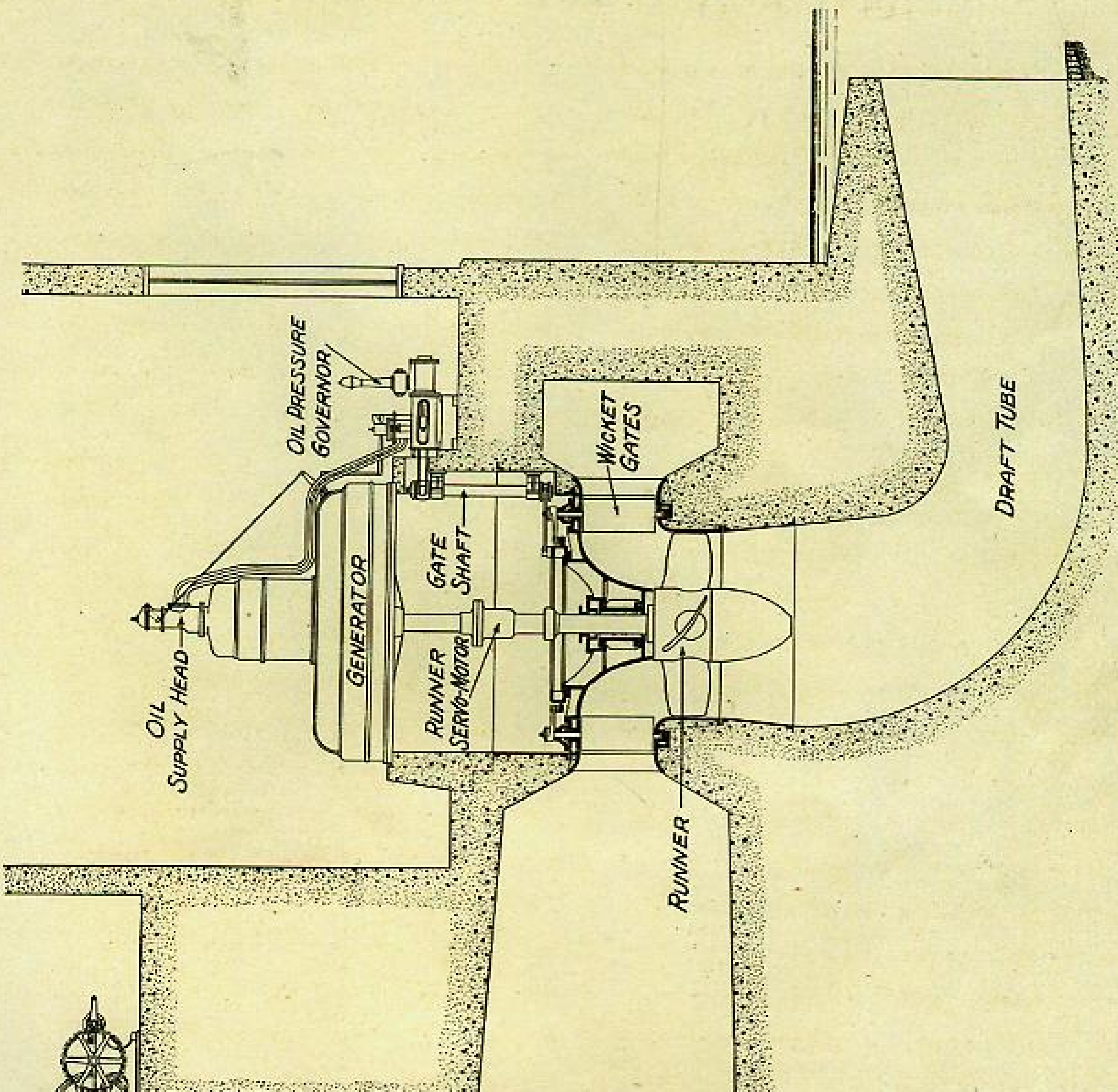


Figure 18

Installation View of SMITH-KAPLAN Turbine Showing Servo-Motor in Shaft

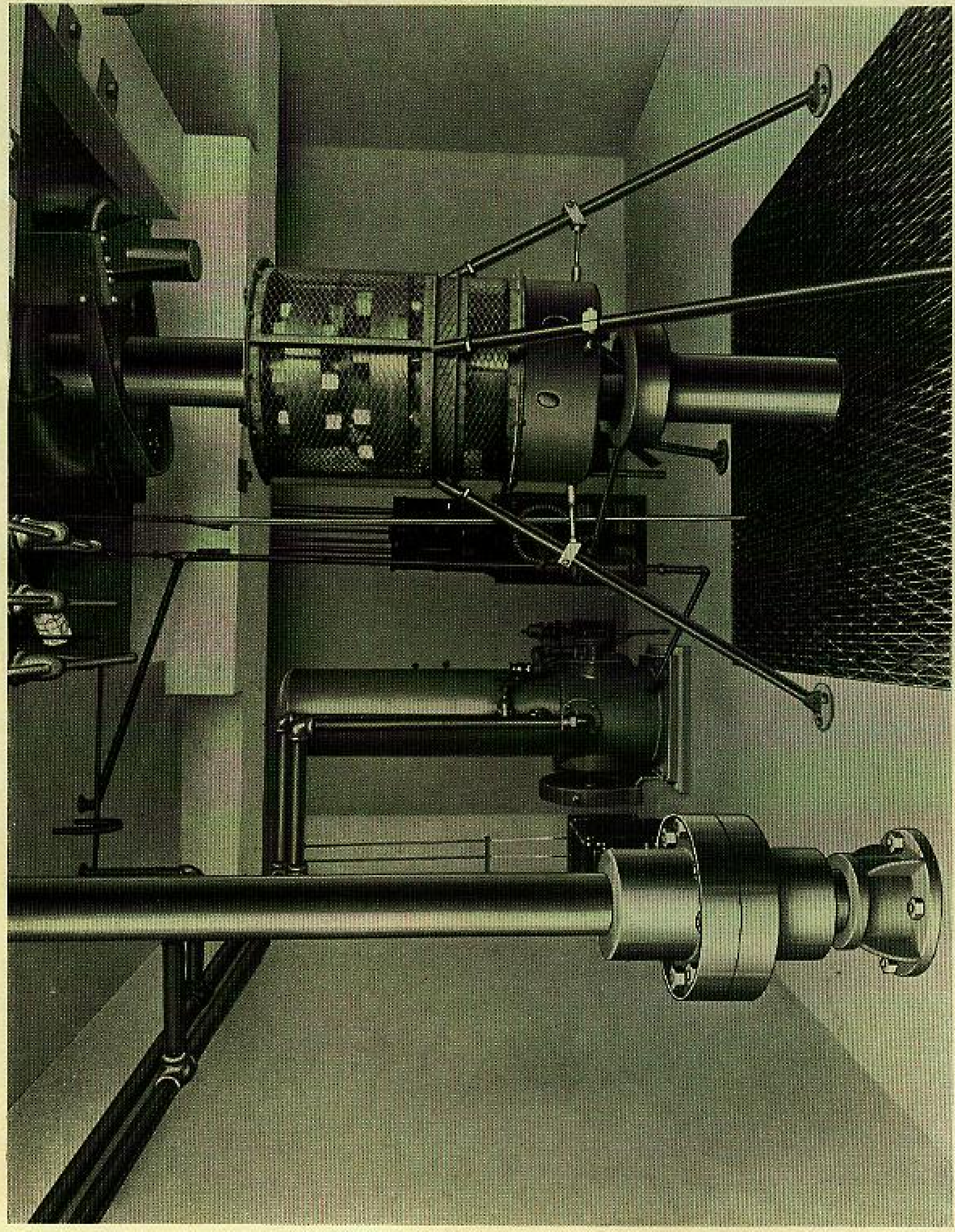


Figure 19

Installation View of SMITH-KAPLAN Turbine Showing Generator with Oil Supply Head

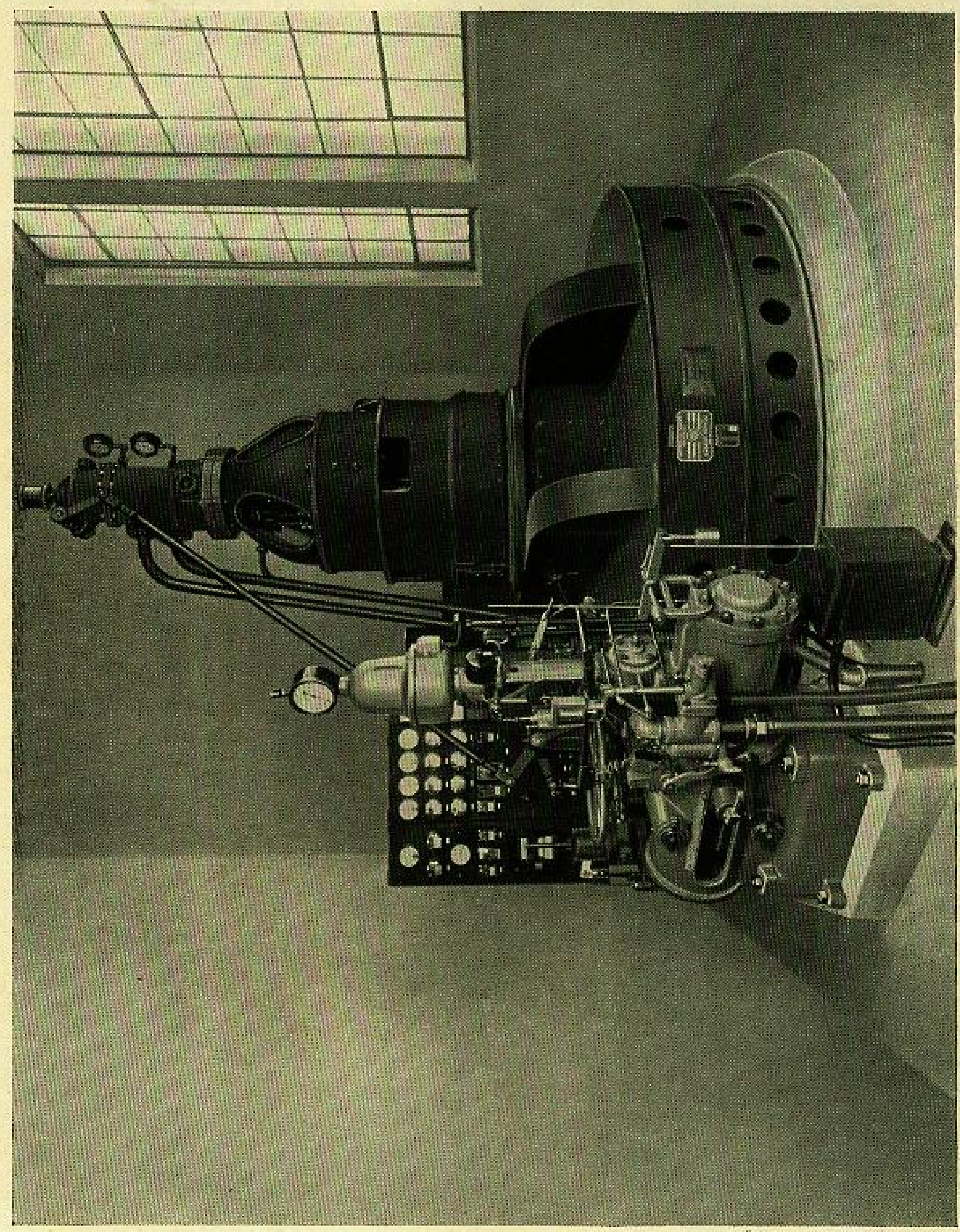


Figure 20

SMITH-KAPLAN Turbine Installations

The following list shows the sixteen Smith-Kaplan adjustable blade turbines installed or in process of manufacture on December 31, 1929. The total rated capacity of these turbines at the normal heads is 37,366 horse power.

Company	Plant	State	No. Units	Date Purchased	Head	Speed	H.P. Per Unit
Metropolitan Edison Co.,....	York Haven,	Pa.	1	7/19/28	26′	200	2,970
Central Pr. & Lt. Co.,......	Devils River #9,	Tex.	1	8/29/28	33′	277	1,900
Wisconsin Pr. & Lt. Co.,......	Rockton,	Ill.	1	10/ 8/28	10½′	100	750
Nova Scotia Pr. Comm.,.......	Tusket Falls,	N. S.	3	11/ 1/28	20′	225	1,052
Utilities Pr. & Lt. Co........	Valentine,	Neb.	1	4/22/29	29′	600	320
Wheatsworth, Inc.,...........	Hamburg,	N. J.	1	5/17/29	29′	600	310
Metropolitan Edison Co.,....	York Haven,	Pa.	3	7/ 8/29	26′	200	2,970
Connecticut River Dev. Co.,	McIndoes,	Vt.	2	9/17/29	29′	150	5,120
Utilities Pr. & Lt. Co.,......	Lebanon,	Mo.	2	10/ 7/29	40′	327	2,030
San Joaquin Lt. & Pr. Co.,	Merced Falls,	Cal.	1	11/22/29	26′	128.6	4,750

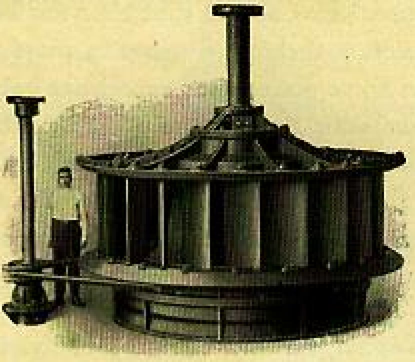
Of the turbines listed above, only one, and this the first one, is of the manually adjustable type. It is interesting to note that the Metropolitan Edison Company purchased first a fixed blade, then a manually adjustable, and now has on order, as shown above, three fully automatic, adjustable, axial flow turbines. A thorough study of the results actually obtained in place with the fixed blade and the manually adjustable blade turbines shows conclusively that turbines with fully automatically adjustable blades are advantageous even in the twenty-unit plant at York Haven.

In addition to the adjustable blade turbines, our company has built or now has on order 72 fixed blade turbines developing a total of 216,658 horse power.

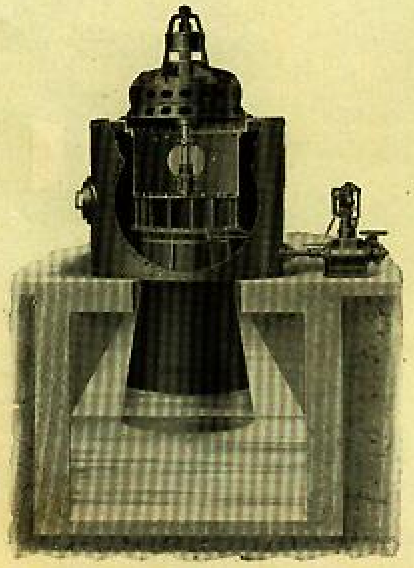
Included in this number are turbines with runners ranging from 30 to 200 inches in diameter operating under heads of from 8 to 66 feet and developing from 100 to 37,500 horse power per unit. These turbines have been installed in all parts of the United States and Canada and are supplying power for public utilities, municipal plants, paper mills, industrial plants and flour mills.

SMITH Reaction Turbines and Accessories

In addition to the Smith-Kaplan turbine, we also design and build reaction turbines of any capacity from 5 h.p. to 90,000 h.p., for heads of from 4 ft. to 850 ft., in types of settings to suit the particular requirements of each installation. Efficiencies of up to 94% have been obtained in actual field tests.

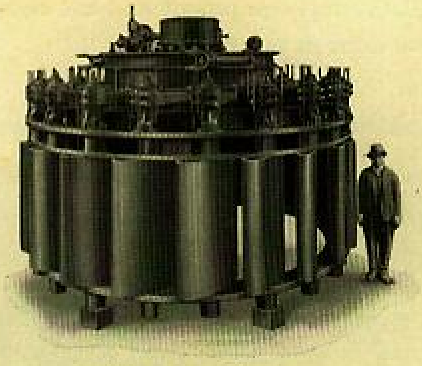


Standard single vertical turbine for open flume settings



Vertical self-contained hydro-generating unit with the turbine mounted in a plate steel pressure case and direct connected to a generator mounted on the case head

For small installations we manufacture a standard turbine which is adaptable for heads up to 40 ft., and with capacities up to 1,500 h.p. These may be had in either vertical or horizontal settings and in single or multiple runner designs.

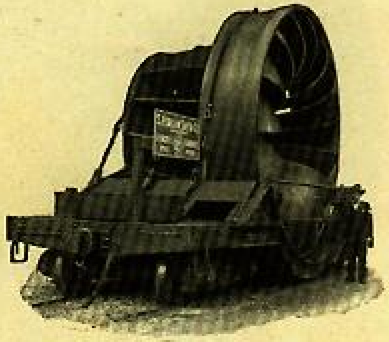


30,000 h.p. turbine case

For larger units and for higher heads we have developed a great number of patterns and designs covering practically every possible combination of turbines in vertical or horizontal and in either open flume or scroll case settings.

We also build governors, Gibbs thrust bearings, roller dams, gate, butterfly and Dow valves, head and sluice gates of various types, and gate hoists.

Write for bulletins covering these products and for our engineers' recommendations.



Turbine runner on one of our special cars

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