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THE MODERN DEVELOPMENT OF WATER POWER.

BY

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By ALPHONSE STEIGER, M.Inst.C.E.

The development of water power has entered into quite a new phase since the advent of long-distance power transmission by means of electricity and the application of the electric current to industrial purposes. Whereas formerly hydraulic power plants were installed for a specific purpose, say for driving the machinery in a factory, or a mine, or the pumping engines of some waterworks, and mostly on a small scale, the present tendency is to create large power centres from which the power is distributed over a whole district and supplied to factories or for lighting purposes, for working railways and tramways, or to be used in the most modern industry, that of electro-metallurgical work. The result of this remarkable development has been a complete revolution in the manufacture of water-turbines; types have changed and the capacity of single units increased from 400 or 500 H.P. (considered large some 20 years ago) to 15,000 and even 20,000 H.P., with a prospect of still larger units in future. Further, the constantly increasing demand for water power has increased its value, so much so that it has become an important object for the investment of capital. It is probably no exaggeration to state that up to the present over 500 million pounds sterling are invested in hydro-electric installations in different parts of the world and we hear constantly of new schemes and undertakings in this direction.

The available water power of Great Britain is variously estimated at from 500,000 to 1 million H.P., the former being a fair basis of calculation, as probably the higher figure would not be available all the year round. In order to show the value of this power, assume that the 500,000 H.P. has to be raised in steam boilers, reckoning that 3 lb. of coal is required to generate one B.H.P. per hour. If the price of coal is 10s. per ton, and taking 300 days of 12 working hours, the quantity of coal required will be $\frac{300 \times 12 \times 500,000 \times 3}{2240} = 2,410,000$ tons, valued at £1,205,000, the latter sum being equivalent to the interest at 5 per cent. on £24,100,000. If it should be asked what can be done with this power, it is only necessary to point to the manner in which water power has been utilised in countries which are, or soon will be, in direct competition with this country.

With this fact before us, it is to be regretted that progress has so far been very slow in Great Britain, although the large power plants at Foyers and at Kinlochleven should show to be devoid of all foundation the assertion (still frequently made) that there is no water power of any value in this country. This belief, and the indifference resulting from it as regards water power must inevitably have a serious effect on British industry, more especially on the iron and steel industry, in view of the rapidly increasing number of electric furnaces abroad, the products of which are being imported into this country. It may be mentioned that while Germany in 1911 had 26 electric furnaces for producing steel, of an aggregate capacity of 95·8 tons, France 24 electric furnaces of an aggregate capacity of 89 tons, the United States of America 12 electric furnaces of an aggregate capacity of 59 tons, Great Britain had, in the same year only 9 electric furnaces of an aggregate capacity of 27 tons. While, undoubtedly, the modern steam engines, steam turbines, gas, and oil engines are highly economical, the progress made in this direction does not entirely compensate for the increased price of coal, which has doubled during the last 20 years and is likely to increase still further, and it will be found that water is in most cases the cheapest source of power. A prominent English engineer said that by using fuel for generating power we "destroy capital." It is well to keep this truth before us. Water, on the other hand, is indestructible capital and in its eternal circulation, inexhaustible, but as a source of power its use is restricted by topographical, climatic and meteorological conditions, over which we have no control, and further, by the fact that it is a necessity for the existence of the human race in many ways and must, therefore, not be monopolised for one particular purpose.

Although the meteorological conditions differ according to the geographical situation and the topography of a country there is everywhere a certain irregularity in the water supply which is sometimes serious in its consequences in so far as an excess as well as a dearth of water results in the loss of valuable property. Provisions for a greater regularity of the water supply are therefore of the utmost importance, and are found partly in afforestation and partly in storage. Afforestation has been found such an effective means for the prevention, or at least, the diminution of the damage done by floods, that in many countries the Governments have introduced very stringent laws, according to which even private owners of wooded land are not permitted to cut down trees without replanting and eventually increasing the wooded area. Storage works have been carried out on a large scale for the exclusive purpose of irrigation in tropical countries like India and Egypt; similar works are now being carried out in Mesopotamia and are contemplated in South Africa and elsewhere. Their value for the cultivation of the adjoining land is incontestable but would be far greater if more foresight had been used in planning them. If, for instance, the large dam at Assuan had been combined with an hydraulic power plant, a large amount of power would now be available for irrigation by pumping in districts farther away from the river. In industrial and more developed countries the question is more one of protection of highly cultivated land against damage by floods and particularly of providing cheap power. Works of this kind were first called into being in France and Switzerland as a consequence of the devastation of large tracts of land by floods. In recent years we find a remarkable development in this direction in Germany, where whole valleys are closed by large dams, with the multiple object of protection against floods, of irrigation, of regulating the flow in rivers for navigation, for the supply of water to towns, and last, but not least, for generating power. It is a significant fact that some of the largest works of this kind are situated in Westphalia, the centre of the German coal-mining industry. Judging from the number of such works already carried out and those in course of construction, the financial results justify the large expenditure on them.

Of special interest is the development of hydraulic power in connection with the navigation of rivers. The value, and in these times of keen competition, the necessity of cheap transit is admitted and its appreciation borne out by the active interest taken by the Governments of several countries on the Continent in a scheme which is in course of realisation.

The author may be forgiven for mentioning this scheme, which is of the utmost importance to his native country, Switzerland. Although Switzerland is often called the country of hotel-keepers, those who know it more intimately know that she has a great and highly developed industry. Being situated in the heart of the European Continent, without direct access to the sea, without producing herself the raw material required for the various industries, and being surrounded by large countries with high tariffs, a wealth of raw material and possessing great seaports, Swiss industries labour under very great difficulties. The Rhine is the only river on which a goods traffic can be carried on to a limited extent as far as Basle. The scheme now is to make the Rhine navigable up to the Lake of Constance. The difference in level between that lake and Basle—a distance of about 80 miles—is 600 feet, including the Falls at Schaffhausen of a height of 66 feet which are already utilised to the extent of

5,000 H.P. by the Swiss Aluminium Company. Owing to the rapid flow navigation above Basle was hitherto impossible. A hydro-electric power plant of a capacity of 18,000 H.P. was erected at Rheinfelden some 17 years ago, the greater part of the power being used for electro-metallurgical and electro-chemical purposes, a further plant with 35,000 H.P. at Augst-Wyhlen, a few miles above Basle, was started about two years ago, a third plant with a capacity of 50,000 H.P. will be started in a few months, and further generating stations are contemplated at Niederschwoerstadt with 44,000 H.P., at Waldshut with 28,000 H.P., and at Eglisau and Rheinau, each with about 18,000 H.P. In all, it is reckoned that about 270,000 H.P. can be obtained between the Lake of Constance and Basle. At the same time the river will be made serviceable as a waterway for vessels capable of carrying about 1,000 tons.

Another and still larger scheme in contemplation is to make the River Rhone navigable in a similar way from the Mediterranean to the Lake of Geneva. It is anticipated that power stations created in this manner and combined with cheap means of transport will become large industrial centres, and it is most probable that the electro-metallurgical industry will be attracted in the first instance.

A pet idea of some people is to obtain useful power from the rise and fall of the tides. No doubt power can be obtained from this source and, technically, there is no difficulty in the way of carrying out such schemes at places where the tides rise to a considerable height, but apart from the fact that the power cannot be constant, the cost of such installations would put them beyond practical possibility from the financial point of view.

It will be seen from the foregoing that water-power may be obtained under widely different conditions. As regards the United Kingdom, the greater part of the water power available is situated in Scotland, Wales and Ireland, mountainous districts with a considerable annual rainfall, which conditions make it possible to develop the power at a quite reasonable capital outlay and under absolutely favourable conditions, by which is meant the possibility of obtaining a fairly constant power during the whole year. This is easily achieved with high falls, when a relatively small volume of water is required per unit of power, which can easily be stored by damming, but it is not possible with low falls, and as these are seldom constant it would appear that they are valueless for the purpose of generating power. There are, indeed, many turbine installations in this country, utilizing low and varying falls, which are exceedingly unsatisfactory, and are possibly one of the causes of prejudice against the utilisation of water power.

These failures have, however, been brought about entirely by want of knowledge and experience on the part of those responsible for these installations. A closer examination of the nature of low and varying falls will show that in almost every case the reduction of the fall is due to an increased volume of water, so that *the available theoretical power is constant within certain limits*, and it is only a question of selecting a suitable type of motor and of adapting it to the varying conditions.

This brings us to the consideration of the different classes and types of water motors. In contra-distinction to steam, or gas power, for which we can arrange the conditions as we desire them, we have to take them in the case of water power as we find them ; we cannot alter them, and they are different in almost every case. To meet all the different conditions and requirements we have a great variety of water motors to select from. They are constructed on various principles : either the water is applied to act by its dead weight, as in overshot, high-breast, and Sagebien water wheels (Fig. 1.), or by pressure, as in pressure engines, or by kinetic energy, as in undershot water-wheels and turbines.

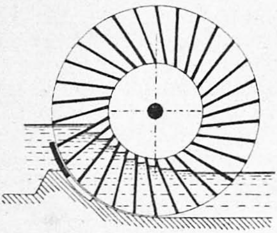


FIG 1.—SAGEBIEN WATER WHEEL.

All motors in which the water acts by its dead weight are highly efficient, yielding, if properly constructed, up to 80 per cent. of the theoretical power, which is the efficiency that may be expected from a very good turbine. It would be misleading to say that more power could be obtained by substituting a turbine for a dead-weight water-motor ; the only advantage would be that power would not be lost in the gearing required by a waterwheel on account of its slow speed. For a new installation, however, a turbine would be preferable on account of greater simplicity and, probably also of cost. Pressure, or piston-engines are very efficient also but their applicability is limited by the necessity of the water being free from sand. Before the advent of the distribution of power by electricity such engines were extensively used in connection with the high-pressure service in towns, for small industries, also for operating cranes, dock-gates, etc.

Water motors which make use of the kinetic energy of water, and in which the water must have attained a certain velocity before it reaches the motor, are the most commonly used. These include all turbines and the undershot waterwheel. Here

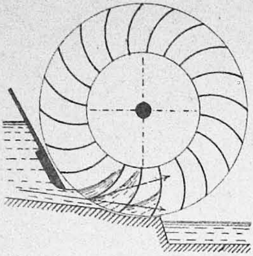


FIG. 2.—PONCELET WATER WHEEL.

the gain in power owing to greater efficiency is most apparent, for while the efficiency of the ordinary undershot wheel is at most 35 per cent., that of a well designed turbine is at least 75 per cent. and under favourable conditions may be 80 per cent. or even more. The power at a given place may therefore be more than doubled by substituting a good turbine for an undershot wheel. There is, however, one particular type of undershot wheel, the Poncelet wheel (Fig. 2), which, as regards efficiency comes very near the turbines. The essential difference between the Poncelet wheel and the ordinary undershot wheel is that in the latter the kinetic energy is transmitted to the floats of the wheel by "shock," which is avoided in the Poncelet wheel by gradually deviating the water from its course as in a turbine; in fact the Poncelet wheel is an impulse turbine pure and simple. It does excellent work under falls up to about 5 or 6 ft. where there is no backwater, if a high speed is not required and if only a small capital is available. (Fig. 2.)

Classification of turbines.—Turbines are usually classified into impulse-turbines and pressure turbines, and it is sometimes held that impulse turbines are suitable only for high heads and

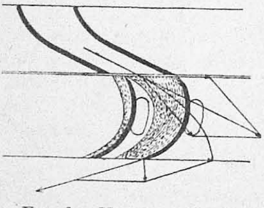


FIG. 3.—VANES OF IMPULSE TURBINE.

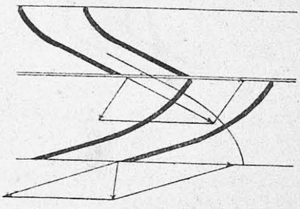


FIG. 4.—VANES OF PRESSURE TURBINE.

pressure turbines only for small heads, but this is not correct; in fact, impulse turbines have been used for heads as low as 3ft. with very good results, and pressure turbines are now frequently adopted for heads of 500ft. and more. The scientific definition of the two classes is that the water enters the vanes of an impulse turbine with the velocity corresponding to the full head, whereas in the case of pressure turbines only a part of the head is applied to generate velocity, while the other part is used to produce pressure within the wheel itself. It is clear from this definition that the selection of a turbine from one class or the other does not depend on the head alone but also on other factors which will be referred to later on. The difference between the two classes is shown in Figs. 3 and 4, the former showing a section through the vanes of a impulse-turbine and the latter a section through the vanes of a pressure turbine. In both diagrams the absolute path of the water through the vanes is shown as well as the relative values of the velocity of entrance, velocity of rotation, and velocity of discharge. The absolute velocity of discharge represents unutilized energy and must therefore be made as small as possible. This is achieved by making the angle at the discharge end small. The passages of the pressure turbines must be entirely filled by the water as otherwise no pressure could be produced.

The advantage of the impulse turbine is that its hydraulic efficiency is constant, *i.e.*, it is independent of the volume of water admitted to the wheel and it matters not whether the water impinges on the whole or only on a part of the periphery of the wheel, and the water does not generally fill the buckets during its passage. This type is, therefore, eminently suitable for a varying water supply. The wheel must, however, run clear of the tail-water, a condition which can seldom be fulfilled in the case of low falls where the tail-water is liable to rise with an excess of water, but if the vanes are designed as shown in Fig. 5 so that the passages are entirely filled with water, the efficiency is not affected by submersion. The efficiency of impulse turbines is, however, considerably influenced by the speed, and if they are running at a speed different from that due to the head, their efficiency falls off. Wheels provided with buckets as shown in Fig. 5, may be considered as the connecting link between impulse and pressure-turbines.

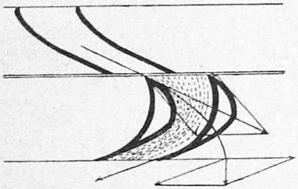


FIG. 5.—VANES OF INTERMEDIATE TYPE TURBINE.

The latter class, sometimes also called reaction-turbines, lend themselves admirably to the utilization of low falls. On account of the necessity of the buckets being entirely filled with water, their diameter may be taken smaller than that of impulse turbines for the same fall and power; their speed is therefore higher, which is a great advantage. Another advantage is that, while impulse turbines must be placed as near to the tail-water as possible, pressure turbines may be placed in any position between head-water level and tail-water level, provided the height of suction does not exceed from 20 to 25ft., and provided there is a sufficient body of water above the turbine to prevent air from being drawn into it. The turbine must in that case be connected to the tail-race by means of an airtight draft tube, either of iron or concrete. The part of the total head below the turbine acts then by suction.

Turbines of either class may be designed as parallel-flow turbines, or as radial inward-flow or radial outward-flow turbines. From the point of view of efficiency alone, the first two are about equal, but the loss by unutilized energy is much greater in radial outward-flow turbines.

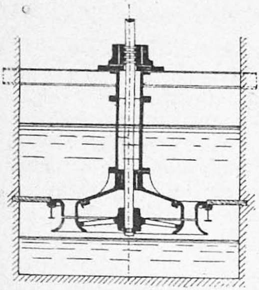


FIG. 6.—GERARD TURBINE WITH VERTICAL SHAFT.

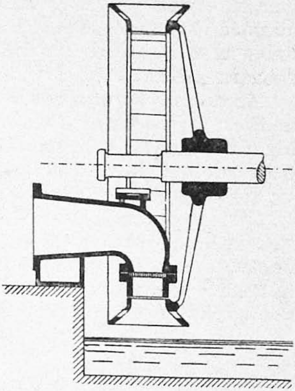


FIG. 7.—GIRARD TURBINE WITH HORIZONTAL SHAFT.

Types of impulse turbines are shown in Figs. 6, 7, 8 and 9. Fig. 6 represents the ordinary Girard turbine with vertical shaft, as used for low falls; Fig. 7, a Girard turbine with horizontal shaft, suitable for high heads with a fairly large water supply; Fig. 8, the well-known Pelton wheel as now commonly used for high heads and a relatively small volume of water. The tangential wheel shown in Fig. 9 is a radial inward-flow turbine most suitable for medium and high heads with a large water supply.

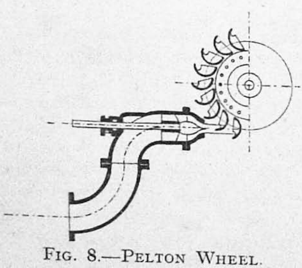


FIG. 8.—PELTON WHEEL.

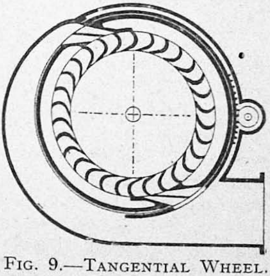


FIG. 9.—TANGENTIAL WHEEL.

Pressure turbines.—Pressure turbines of the radial outward flow type are the invention of Fourneyron, but are better known in this country as McAdam turbines. Such a wheel for a low fall is shown in Fig. 10. Curiously enough, this type was adopted for the 5,000 H.P. units first installed at the Niagara Falls.

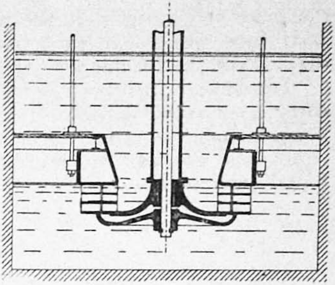


FIG. 10.—FOURNEYRON TURBINE.

Admirably adapted to low and varying heads with a varying water supply is the parallel flow or Jonval turbine, which has been adopted in a large number of cases to drive flour mills in this country, invariably with highly satisfactory results. In order to obtain a good efficiency under the varying conditions the wheel is subdivided into two or three concentric rows of buckets, each row practically representing a complete turbine in itself. The outer row is of such dimensions that it will pass the minimum quantity of water, which generally corresponds with the maximum head, while the inner row or rows of buckets will be capable of passing an increased volume when the head is reduced, whereby the power is kept constant. It will be observed that, when the outer row of buckets alone is used with the maximum head, the diameter on which the water acts is larger than when the water is also admitted to the inner row under a reduced head, when the velocity of the water is obviously smaller. In this way the speed of the turbine is also kept constant. (Fig. 11.)

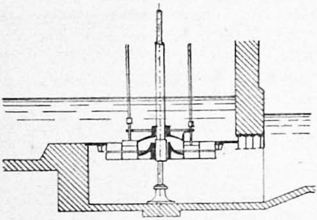


FIG. 11.—JONVAL TURBINE.

A good instance of an installation of a Jonval turbine under varying conditions is that at Strencham Mills near Worcester, giving 40 H.P. under a minimum fall of 2ft., which is probably the smallest fall ever utilized by a turbine. The maximum head with the normal summer supply is 4ft. 3in., but after a heavy rainfall, and during the winter months it is frequently reduced for long periods to 2ft. and even less. The question was to make the best possible use of these varying conditions. The wheel consists of two concentric rows of buckets, the outer one being capable of passing 6,700 cu. ft. of water per min. with a head of

4ft. 5in., and developing 40 H.P. When the fall is reduced to 2ft., 14,000 cu. ft. are required for 40 H.P., but the outer row will then pass only 4,500 cu. ft. per min., the inner row must, therefore, be capable of passing 9,500 cu. ft. per min. The outside diameter of this wheel is 14ft. and its constant speed is 14 r.p.m. With a light load this turbine drove the mill even when the fall was reduced to 18in.

Considered from the point of view of efficiency alone, the Jonval turbine is eminently suitable for the conditions described, but its great drawback is that it does not lend itself easily to automatic regulation such as is required in installations intended for the generation of electricity. For this reason it has been superseded by the Francis turbine, the prototype of the radial inward-flow turbine.

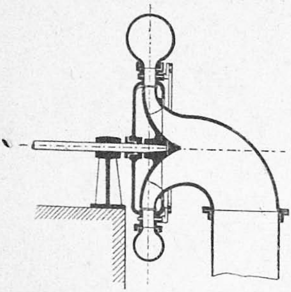


Fig. 12.—Inward Flow Turbine.

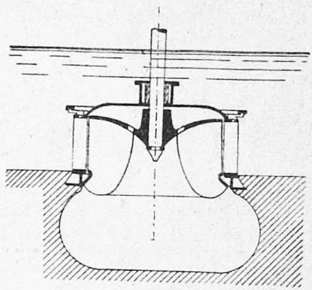


Fig. 13.—Mixed Flow Turbine.

There are a great variety of designs of the latter type, differing principally in the proportions of the diameter and width, and in the construction of the regulating device. Originally, it was an inward-flow turbine pure and simple, the water entering and being discharged in a radial direction. This required a relatively large diameter and the speed was consequently small. Partly with the object of producing cheap turbines, and partly to satisfy the demands of electrical engineers for a high speed, the diameter of the wheels was gradually reduced, the width increased and the vanes extended in an axial direction and provided with scoop-shaped ends, the water leaving them in a more or less axial direction. In this way the mixed-flow turbine was evolved from the pure inward-flow turbine. Fig. 12 shows a pure inward-flow turbine for medium or high heads, and Fig. 13 a mixed-flow turbine for a low head. A few first-class makers have succeeded in obtaining, under specially favourable conditions, an efficiency of 84 to 85 per cent., but it would be absurd to deduce from this that such results would be obtained in all cases. It is important to point out that a high speed relative to the fall can only be obtained at the expense of efficiency, more particularly at part gate, *i.e.*, with a reduced volume of water. High speed turbines are, therefore, uneconomical where the water supply is sometimes reduced for a considerable time. If the loss of power on account of inferior efficiency, whether at full gate or at part gate, were considered more often in the light of £ s. d., and capitalised, many of the turbines largely advertised under high sounding names as the most economical, would soon disappear from the market.

The efficiency, generally, of a turbine depends on the proper dimensions and the correct and scientific design, but at part gate it is further influenced by the system of regulation of which there are three :—the cylinder gate, the register-gate, and the movable guide blades. The cylinder gate (Fig. 14) consists of a

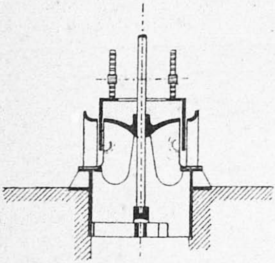


FIG. 14.—CYLINDER GATE.

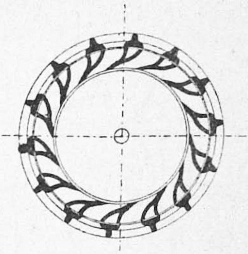


FIG. 15.—OUTSIDE REGISTER GATE.

cylinder placed between the guide wheel and the runner which is moved parallel to the axis by means of racks and pinions, whereby the width of the opening through which water is admitted to the wheel is altered. It is clear from the illustration that eddies must be produced when the gate is partly open, which are detrimental to the efficiency of the turbine. In the Hercules turbine transverse partitions are provided to prevent the formation of eddies at the entrance but they are hardly effective.

The register gate is also cylindrical, but it is made to turn on its axis. It may be placed either on the outside (Fig. 15), or on the inside (Fig. 16), of the guide wheel. The latter is preferable, but it has often been a source of great trouble where the water contains sand or other solids.

The best method of regulation of radial and mixed-flow turbines is undoubtedly that by means of movable guide blades. As shown in section in Fig. 17, the guide-blades are hinged on pins which pass through the walls of the guide wheel and carry cranks or eccentrics which are connected to a ring by means of which all the guide blades are moved simultaneously. In some turbines the attachment for moving the guide blades is inside and seriously obstructs the passage of the water.

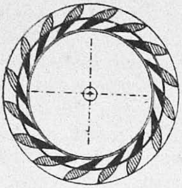


FIG. 16.—INSIDE REGISTER GATE.

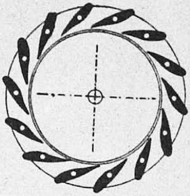


FIG. 17.—MOVABLE GUIDE BLADES.

Although this mode of regulation of pressure turbines is not theoretically correct, in so far as the relation between the areas of the guide passages and of the runner, by which the degree of re-action is fixed, is disturbed, quite satisfactory part gate results are obtained from carefully designed turbines. Generally, the greater the head applied for producing velocity, or the smaller the head applied for producing pressure, the better the efficiency of the turbine when working at part gate.

Fig. 18 shows the curves of efficiency at different gate openings of a Pelton wheel, a Francis turbine designed for a high efficiency under varying conditions, and a modern "high speed" Francis turbine. It will be seen that, while the efficiency of the Pelton wheel is practically constant for a very wide range of gate openings, that of the high-efficiency Francis turbine is also high down to half gate, and still quite satisfactory at $\frac{1}{3}$ gate, while the efficiency of the high-speed turbine decreases rapidly with the reduced gate opening. The space marked on hatched lines represents the loss of power resulting from the disregard of varying conditions when choosing a turbine. A purchaser will do well to consider what effect this loss would have on his revenue.

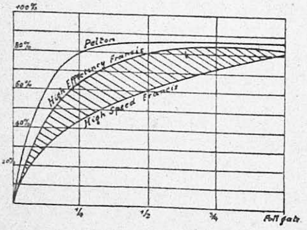


FIG. 18.—EFFICIENCY CURVES OF PELTON WHEEL AND FRANCIS TURBINES.

Application of Turbines to various conditions.—After having considered the conditions under which water power may be obtained, and the different classes and types of water motors, the application of the latter is perhaps best explained by describing some typical modern turbine installations, beginning with low heads.

Turbines utilizing heads up to 6 or 7ft. are invariably fixed on a vertical shaft. The whole weight of the parts fixed on the turbine shaft revolves on a footstep which may be placed either below or above the turbine. In the first case its lubrication is mostly left to the water. Apart from the fact that water is a very bad lubricant, the inaccessibility of the most delicate part of the turbine is very objectionable. Moreover, the lignum vitæ bearing is generally carried by a bridge or cross piece fixed in the draft tube and thus forms a serious obstruction to the free discharge of water. In modern practice the footstep is placed above the turbine and submerged in oil. Fig. 19 gives an idea of an overhead footstep very commonly used for turbines of moderate power.

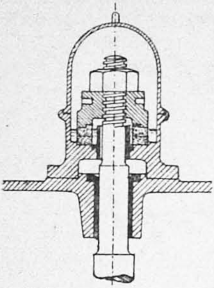


FIG. 19.—STEP BEARING.

Ball thrust bearings have so far not been extensively used in connection with turbines, although they have proved highly satisfactory in vertical high-lift turbine pumps. The conditions here are, however, different. Turbine-pumps run at a very high speed and the thrust to be taken up is not very great, while in the case of water-turbines the speed is relatively small, but the weight of the revolving masses is very great. Ball thrust bearings were used for three turbines at the Portland Cement works at Aarau, in Switzerland, each turbine giving 740 B.H.P.* under a head of 6ft. 5in. The turbine wheel (shown on the screen) has a diameter of 12ft. 6in., and is 5ft. 6in. wide and runs at 28½ r.p.m. The wheels are cast in one piece and each weighs 10 tons. The total load on the ball thrust bearing, consisting of the turbine wheel, the shaft, the large bevel wheel on top and the water pressure, is 50 tons. The thrust bearings have proved to be very satisfactory in this case.

It is quite an exception that so large a power is produced by one single wheel under such a low head, and is accounted for by the fact that a slow speed was admissible in this case. Where a high speed, or large units of power, are required with a low head, as in the case of power installations utilizing large rivers, two or more wheels are fixed on a common shaft, either vertical or horizontal.

On the screen is shown one of 11 units with wheels fixed on a vertical shaft, installed at the power station at Beznau, on the River Aare. The fall varies from 10 to 19ft.; each unit is designed to give from 1,000 to 1,200 b.h.p.,† and the speed is 66.6 r.p.m. In order to utilize the available power as economically as possible under such varying conditions, six units have

* See Fig. 22A (facing p. 14). † See Fig. 22B (facing p. 14).

been designed to give the best efficiency with the maximum head and the minimum water supply, and five units with the minimum head during floods. The upper and the middle wheel discharge the water into a common draft tube, formed in concrete, whereby the water pressure from these two wheels is balanced. The total load transmitted on to the footstep is 45 tons. This load is reduced by balancing, by 12·7 tons when the head is 11ft., and by 23·7 tons when the fall is 19ft. The step bearings, of 22in. diameter, are situated in a gallery below the generators. The footstep proper is contained in a casing filled with oil, kept cool by a coil through which water is circulated. The oil is forced into the step bearing with a pressure of 360 lb. per sq. in. The whole weight thus revolves practically on a film of oil and the loss of power by friction is trifling. In large installations like this a special pumping plant is provided for producing the pressure necessary for the hydraulic governors and for the forced lubrication of the footsteps of the turbines and generators.

A horizontal arrangement of multiple turbines is illustrated in Fig. 20 and has been adopted for the power installations at Augst-Wyhlen, near Basle, already referred to in connection with the navigation scheme of the Rhine. The fall, created by the erection of a sluice weir across the river, varies from 18 to 27½ft., and each unit is capable of producing from 2,200 to 3,000 B.H.P. To obtain a speed of 107 r.p.m., the volume of water required for that capacity, maximum 115,000 cu. ft. per min., is divided between four wheels on one shaft, the wheel pits being placed in the river and separated from the engine house by a thick wall. The guide wheel nearest the wall is mounted on a large cast iron wall-plate which hermetically closes the opening of the shaft. Access to the bearings of the turbine shaft is obtained through galleries in the foundations.

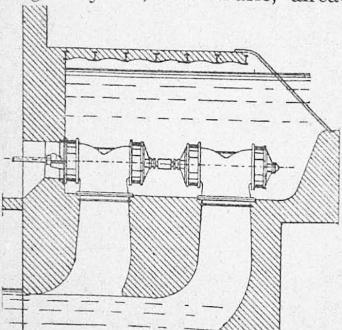


FIG. 20.—QUADRUPLE HORIZONTAL TURBINE.

Opinions differ as to the superiority of the vertical over the horizontal arrangement. The first requires a smaller area for the foundations and power house, and allows an almost complete balancing of the load on the footstep, thus eliminating friction, but a saving in area is not necessarily identical with saving of cost. Special local conditions, such as the nature of the ground, will, in most cases, be the determining factor for the adoption of the vertical or the horizontal arrangement.

Figs. 21 to 25 show various arrangements of Francis turbines, with vertical and horizontal shafts, single and double, in open water-chambers. In some of them the draft tubes are of con-

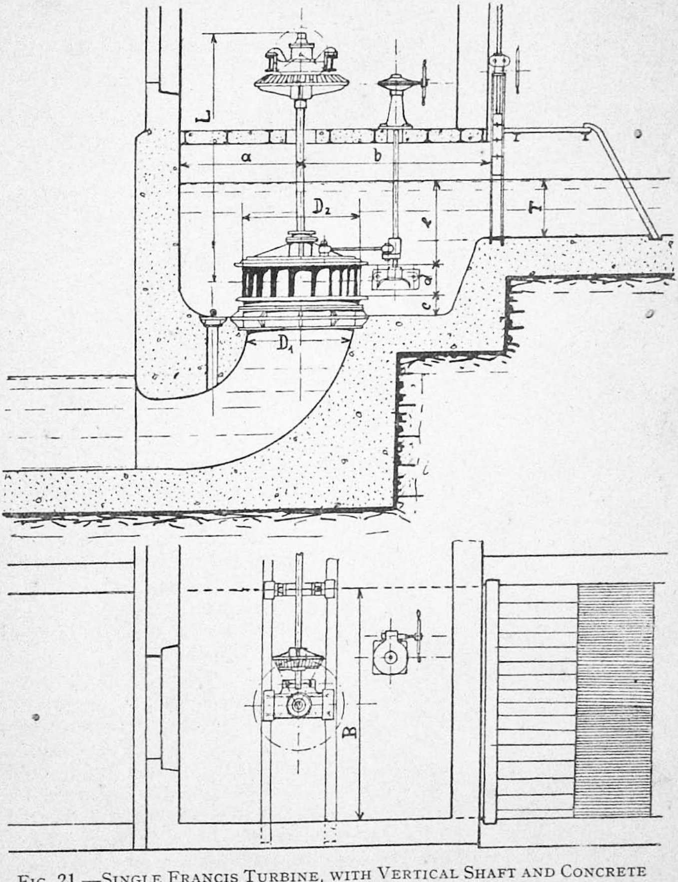


FIG. 21.—SINGLE FRANCIS TURBINE, WITH VERTICAL SHAFT AND CONCRETE SUCTION TUBE.

crete, which is generally preferred because the direction of flow is changed gradually from the vertical to the horizontal. The area of the draft tubes should gradually increase towards the lower end so as to reduce the velocity of discharge, which represents a gain in efficiency of the installation.

With heads above 30ft., open turbine pits are seldom used. The turbines are enclosed in casings to which the water is admitted through pipes. The turbine may be a single one (Figs. 26 and 26a), or double, discharging through two draft tubes (Fig. 27), or two wheels may be fixed on a common shaft, discharging the water into a common draft tube between them (Fig. 28). The latter arrangement is preferable because the wheels can be placed nearer the bearings, and will, therefore, run steadier and the stuffing boxes on the suction side (which are always liable to let in air and destroy the vacuum in the draft tube) are not required. The casing for a single wheel is generally of a spiral shape, and for two wheels cylindrical. The spiral casing gives a better emission of water to the guide wheel and tends to increase the efficiency.

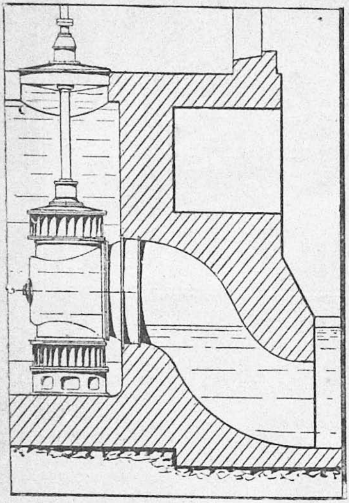
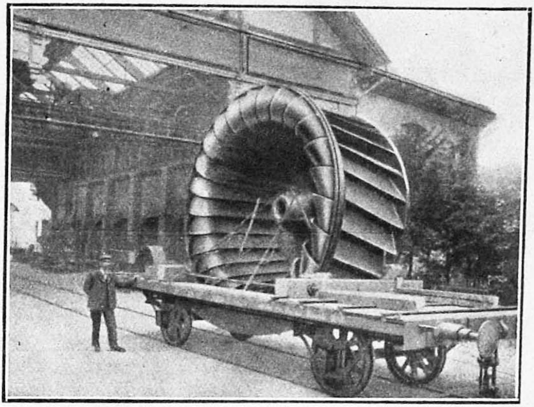


Fig. 22.—Double Turbine, Vertical Shaft with Concrete Draft-Tube.

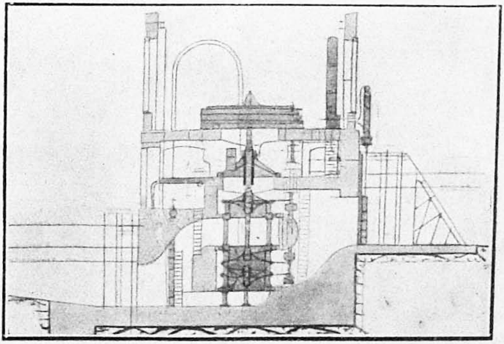
A double spiral turbine is shown on the screen. It is one of five turbines installed at Vigeland, Norway, for the Anglo-Norwegian Aluminium Company. The output is 3,000 b.h.p.,* with a net fall of 55ft. and the speed is 220 r.p.m.

It has been mentioned that pressure turbines may be, and are, used for very high heads, but there is a limit. As the volume of water required, even for a relatively large power, is obviously small, the diameter of the turbine, the passages of which must be entirely filled, will be small, and, consequently, the speed very high. The question whether a high fall is to be utilized by a pressure turbine or by an impulse turbine is therefore, determined by the power required from a unit and by its speed. To illustrate this, we will assume that the Victoria Falls are to be utilized. The height of these Falls is 420ft.

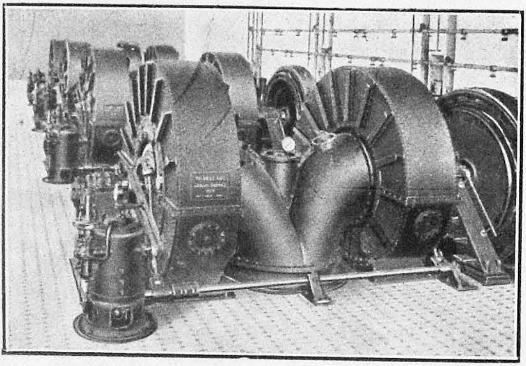
* See Fig. 23A (facing p. 15).



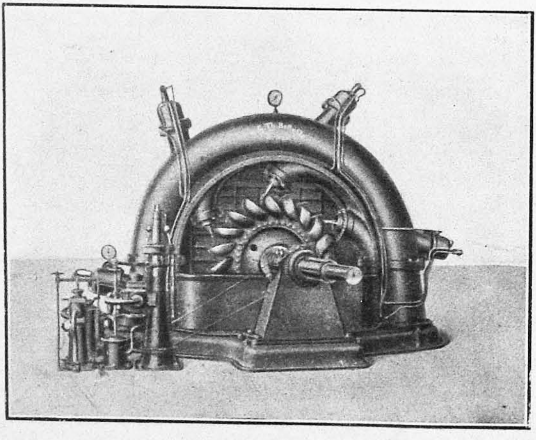
TURBINE WHEEL FOR 740 B.H.P. FALL 6 ft. 5 in.
FIG. 22A (*see p.* 13).



TRIPLE FRANCIS TURBINE AT BEZNAU. 1,200 H.P.
FIG. 22B (*see p.* 13).



DOUBLE SPIRAL TURBINE. 3,000 H.P.
FIG. 23A (*see p.* 16).



PELTON WHEEL WITH 6 NOZZLES.
FIG. 23B (*see p.* 24).]

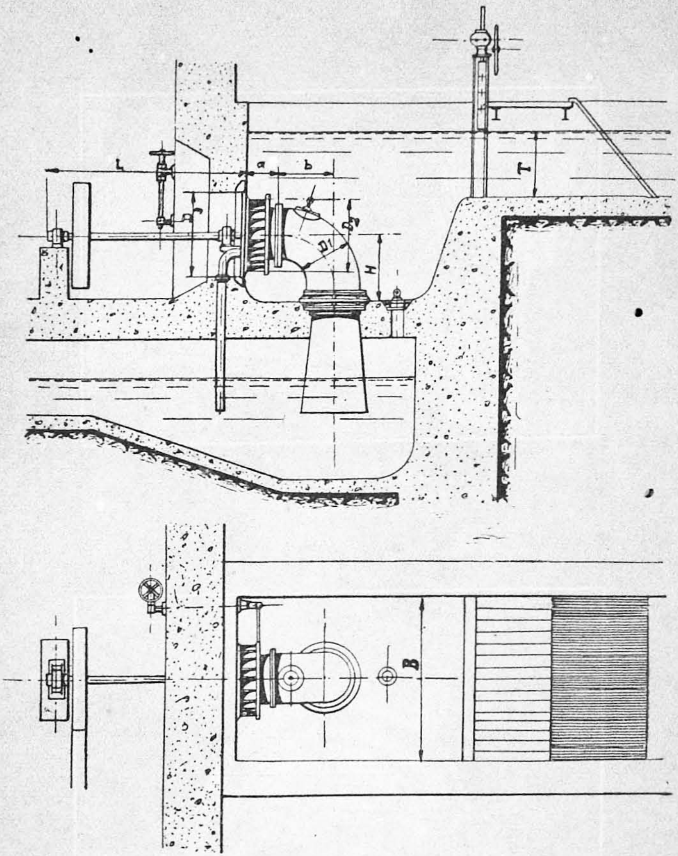


FIG. 23.—SINGLE FRANCIS TURBINE, WITH HORIZONTAL SHAFT AND IRON SUCTION TUBE.

If units of say 3,000 b.h.p. were adopted, the smallest speed at which a satisfactory efficiency could be obtained from a Francis turbine of that power would be about 550 r.p.m. If this speed were considered excessive for units of 3,000 b.h.p., then an impulse turbine would have to be chosen or, alternatively, the power of the units would have to be increased. As the total power available at Victoria Falls is several hundred thousand h.p., units of the largest practicable capacity, say from 20,000 to 30,000 b.h.p., would be adopted for which a speed of 300 r.p.m. would probably be admissible.

Impulse Turbines.—We are not bound by such limits in choosing the speed if we adopt impulse turbines for high heads. In these, each jet acts independently and there is, in the strict sense of the word, no relation between the quantity of water and the diameter of an impulse turbine.

The turbine of this class, now almost universally used, is known as the Pelton wheel. It consists of a number of single

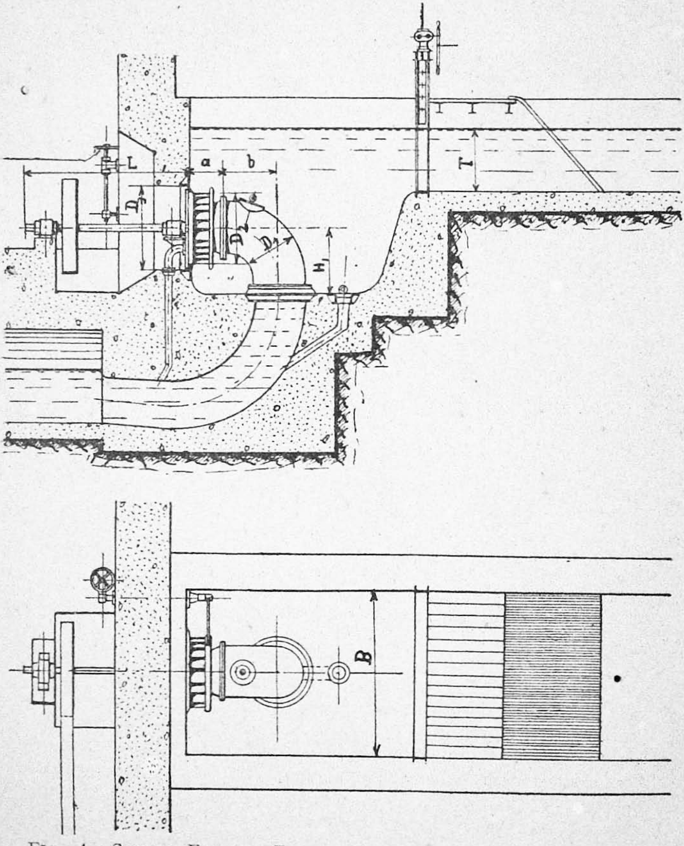


Fig. 4.—Single Francis Turbine with Horizontal Shaft and Concrete Suction Tube.

or double spoon-shaped buckets, bolted on to a disc fixed on the shaft and rotating in a watertight casing. The buckets are made either of cast iron, cast steel, or bronze. They are often ground or highly polished on the concave surface to minimize the friction and thus increase the efficiency. There are a large number of different designs of buckets, according to the ideas

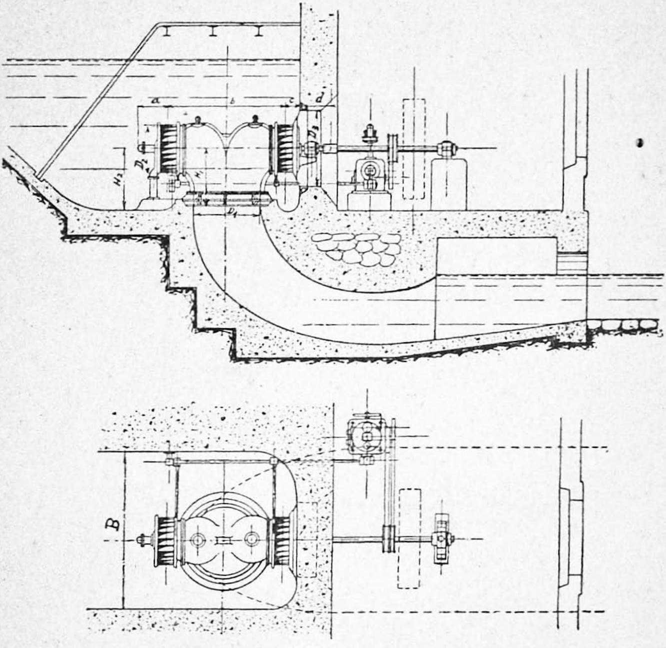


FIG. 25.—DOUBLE FRANCIS TURBINE WITH HORIZONTAL SHAFT AND CONCRETE SUCTION TUBE.

of the makers. The Pelton bucket is characterised by its more or less rectangular shape, with a sharp-edged flat lip in front and an edge across which divides the jet in halves. The rather abrupt corners found in some such buckets are a great drawback in so far as they must produce shock and eddies which, as has recently been discovered, cause a dissociation of oxygen from the water, thus corroding the metal very quickly. The rapid destruction of the buckets in some cases was at first thought to be due to sand but was subsequently traced to the above cause.

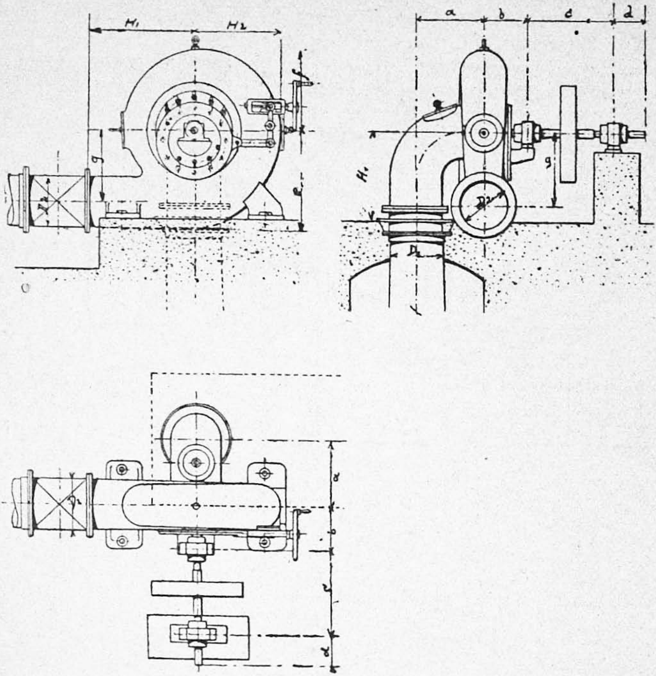


FIG. 26.—SINGLE SPIRAL TURBINE, WITHOUT STUFFING BOX ON SUCTION BEND.

Doble buckets are of elliptical shape, with a recess in front and also an edge which divides the jet. No eddies can be formed in these buckets, nor shock produced; they are, therefore, more durable and also more efficient than the Pelton buckets. The "Hug" bucket is little known, but is of excellent design. It is shown in Fig. 31. Tests made with a wheel of Hug's design have proved it to be as efficient as wheels with Doble buckets. The shape of the buckets has little influence on the efficiency as long as the water can impinge without shock, is gently deflected from its original course and discharged from the wheel without impediment and as nearly as possible in a lateral direction. It is curious to note that some makers seem to hold the opinion that the water should be discharged as nearly as possible in a direction opposite to that of the jet. This has misled them into making the housing too narrow, with the result that the water, after having been discharged, rebounds on to the wheel and, thus reduces the efficiency.

The most important part next to the buckets is the nozzle. It is either rectangular or circular in section, the latter shape being now generally preferred on account of its simplicity of regulation. This is accomplished by pushing a spear or needle,

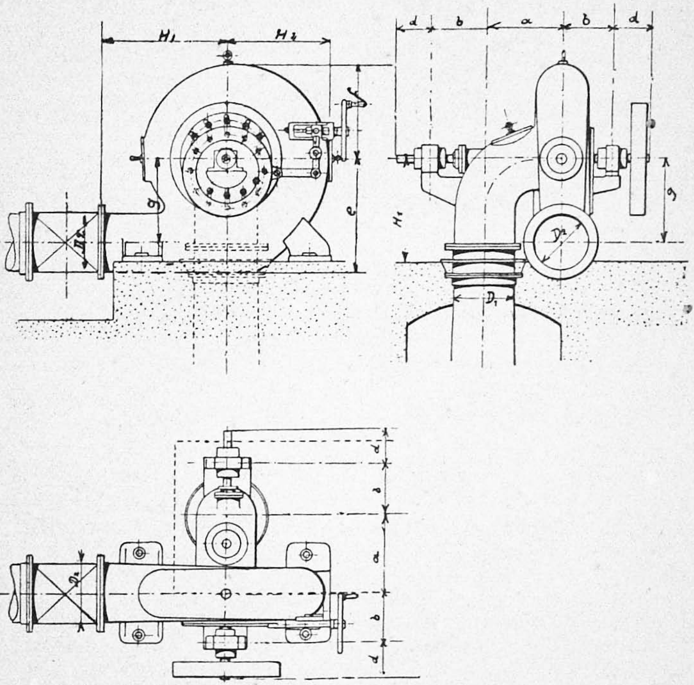


FIG. 26A.—SINGLE SPIRAL TURBINE, *with* STUFFING-BOX ON SUCTION BEND.

provided with a cone-shaped plug into the mouthpiece of the nozzle (Fig. 8). The rectangular nozzle is regulated by a hinged tongue or gate as shown in Fig. 32 and 33. Sometimes Pelton wheels are found without any means of reducing the area of the nozzle, the regulation being effected either by a sluice valve, or by the deflection of the nozzle from its normal position. Both methods are objectionable, the first because it produces

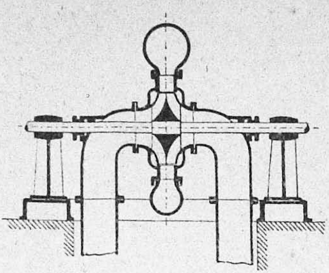


FIG. 27.—DOUBLE SPIRAL TURBINE WITH TWO DRAFT TUBES.

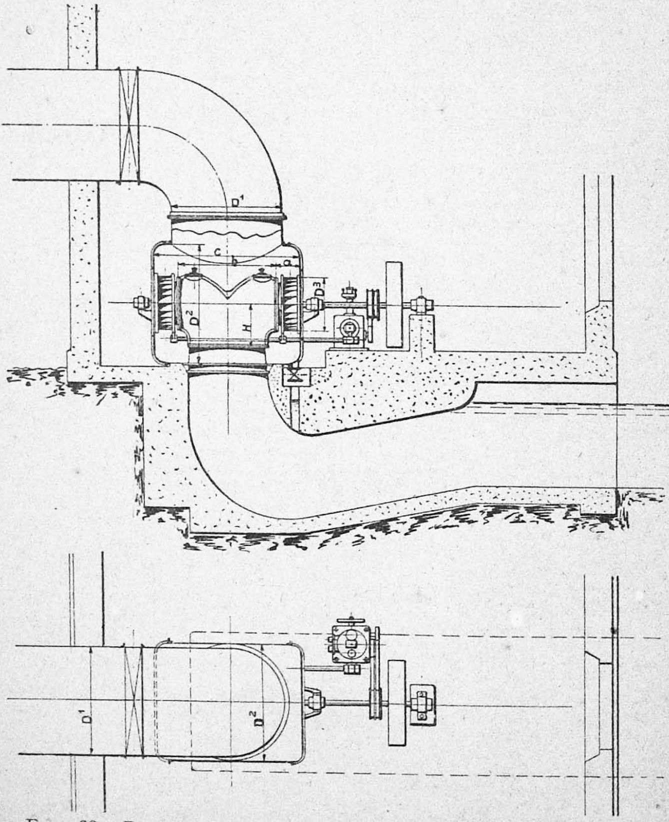


FIG. 28.—DOUBLE FRANCIS TURBINE, HORIZONTAL SHAFT AND CYLINDRICAL CASING.

a loss of head, and the second because it causes the jet to impinge at an improper angle, producing shock and more rapid wear of the buckets; moreover, the movable joint is liable to become leaky and, in addition, it is wasteful.

The nozzle of a Pelton wheel may be large if the diameter of the wheel is large. The Pelton wheel of 16,000 B.H.P., erected at the Loentch Electricity Works for a head of 1,150ft., is provided with two nozzles of 8in. diameter each. The diameter of the wheel is 7ft., giving a speed of 300 r.p.m. Incidentally, it may be mentioned that this wheel, like the 6,500 H.P. wheels at the same place, is fixed direct on to the free shaft end of the generator.

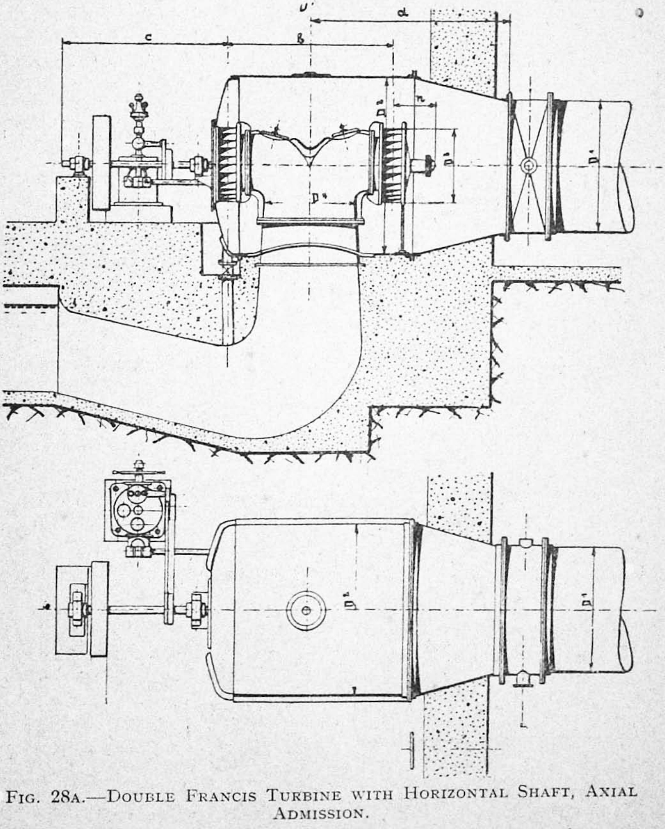


Fig. 28a.—Double Francis Turbine with Horizontal Shaft, Axial Admission.

If it be necessary to divide the water between several nozzles, these may be directed on to one wheel, or to two wheels fixed on a common shaft. The single wheel is preferable from every point of view cost, saving of space, and lastly of efficiency.

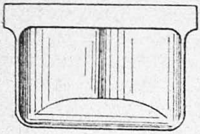


FIG. 29.—PELTON BUCKET.

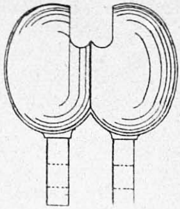


FIG. 30.—DOBLE BUCKET.

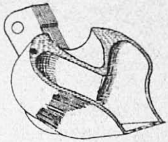


FIG. 31.—HUG BUCKET.

A Pelton wheel with six nozzles is shown on the screen.* This was supplied by the author for the temporary installation at Kinlochleven, for the British Aluminium Company. It was calculated to give 3,000 b.h.p. with a head of 380ft., and to run at 300 r.p.m. The six nozzles are placed at equal distances in the spiral casing which surrounds the wheel and through which the water is admitted to the latter. In order to prevent obstruction of the jets by the water discharged from other jets, deflectors or baffle plates are fixed in the spherical side walls of the housing which guide the water into the pit leading to the tail race.

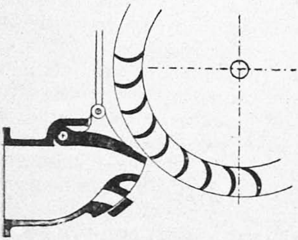


FIG. 32.—SQUARE NOZZLE WITH HINGED TONGUE.

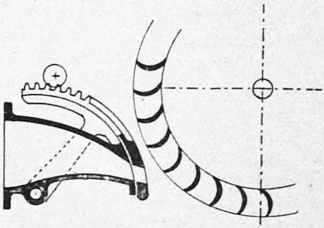


FIG. 33.—SQUARE NOZZLE WITTH HINGED GATE.

The arrangement of two Pelton wheels on one common shaft would seem unavoidable where the nozzle area becomes large, but where a Francis turbine would run at too high a speed, a single Girard turbine, or a tangential wheel, fixed on either a horizontal or a vertical shaft would, in the author's opinion, be better and cheaper. Pelton wheels have become the fashion

* See Fig. 23b (facing p. 15).

for high heads, but there is no reason whatever why another type should not be employed if, in a given case, it offers greater advantages.

Under the heading "Pressure turbines" a fall of two feet has been mentioned as the lowest fall which it is practicable for a turbine to utilize. For impulse turbines the question is, which is the highest fall which can be utilized by one wheel? It is, indeed, interesting to observe the progress made in recent years. Two decades ago the most experienced maker of Pelton wheels would have declared it impossible or, at least very risky, to utilize a fall of 2,000ft. in one stage; at present there are several well-known instances of installations where such heads are used with complete success, both in America and in Europe, and heads of even 3,000ft. are now unhesitatingly used. One of these is the installation at Arniberg, on the Gothard Railway, of several units of 3,000 b.h.p., under a head of 2,800ft. One of these units is shown in Fig. 34, and will be described later on in connection with the hydraulic governor. An installation with a still higher fall, namely 5,000 ft., is now in course of construction and the author's opinion has recently been asked as to the possibility of utilizing a fall of 6,000ft. The chief difficulties to overcome in utilizing such high falls consist in finding a material which will withstand with absolute safety the strain to which a wheel rotating at a peripheral velocity of about 260ft. per second is exposed, to produce pipes of adequate strength and to govern such wheels with perfect accuracy. Thanks mainly to electro-metallurgy, material of the highest quality is now available, and hydraulic governors have been brought to such a state of perfection that that part of the problem may also be considered as successfully solved.

Governing.—The method of automatically regulating the speed of turbines has undergone a complete change. Excellent as many of the old mechanical governors were, their action was much too slow for modern requirements. Thus the hydraulic governor has been called into being, viz., a governor in which hydraulic pressure is used to move the regulating mechanism of the turbine. The hydraulic pressure may be obtained direct from the water if the head is high, otherwise pumps are used and the liquid put under pressure is oil. Water taken from the penstock must pass through a filter before it is admitted to the regulating valve. In modern practice the oil pressure-governor is preferred even in connection with Pelton wheels utilizing very high heads. Such a governor is shown in Fig. 35. It consists mainly of a centrifugal pendulum, a regulating valve, a hydraulic cylinder with piston, called the servomotor, the relay mechanism and a rotary oil pump. The action is as follows: Any slight change in position of the pendulum, following a change of load, is

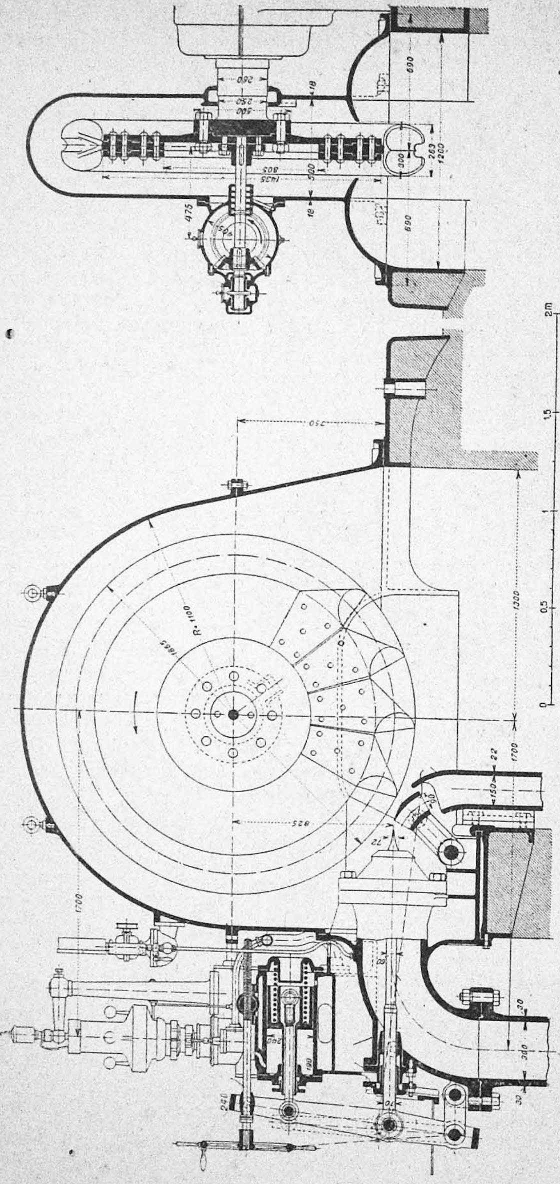


Fig. 34.—Cross Section of 3,000 h.p. Pelton Wheel at Arniberg.

immediately transmitted to the regulating valve V., by means of the lever H. By raising or lowering the regulating valve a connection is established between the pump and the pressure cylinder, when the liquid under pressure moves the piston in the desired direction and closes or opens the nozzle or guide passages. Attached to the piston rod is the relay-mechanism G. Immediately the piston begins to move, the further end of the lever H is also moved. and thereby the regulating valve returned to its normal position.

The prompt action of hydraulic governors renders special provisions necessary where the water is taken to the turbines through pipes. The sudden checking of the motion of a large mass of water, usually at a great velocity, produces a pressure far in excess of the normal, which exposes the pipes to the danger of bursting, while at the same time, tending to increase, instead of decreasing the speed of the turbine. Various means are used to prevent this : a by-pass of the same area as the nozzle may be made to open as the latter is closed, the nozzle may be deflected from its normal position to direct the jet away from the wheel, or a shield may be inserted into the jet to deflect the latter from its normal direction. The drawbacks of the deflecting nozzle have already been pointed out. The automatic by-pass and the automatic deflector are generally fitted with a device by means of which their return motion is so slow that the pressure in the pipe line cannot rise enough to endanger it.

The automatic deflector is the most recent device and, combined with the ordinary regulation of nozzles is the most perfect means of keeping the speed constant under difficult conditions. This combination as adopted at Arniberg for a fall of 2,800ft., and also for the 16,000 Pelton wheel at the Loentsch, is shown in Fig. 34, and its action illustrated diagrammatically in Fig. 36. The deflector is a curved shield with a knife edge which in its normal position is tangential to the jet. The governor is connected to the regulating valve (for the nozzle) and the regulating valve 11 (for the deflector), by means of levers ; the lever for the nozzle is provided with an oilbrake to prevent it from moving quickly, while the lever for the deflector is free. If the load on the wheel is changed gradually, the governor will move both the needle and the deflector at the same time, and as the jet becomes reduced in diameter the deflector will remain tangential to it, but as soon as any sudden or great change of load takes place, the deflector will at once cut into the jet and cut off part of the water, while the spear of the nozzle cannot close quickly owing to the oilbrake and a spring connected with the servomotor. The accuracy with which this device acts both on the speed of the Pelton-wheel and on the pressure in the pipe line may be seen from the diagrams, Fig. 37, which

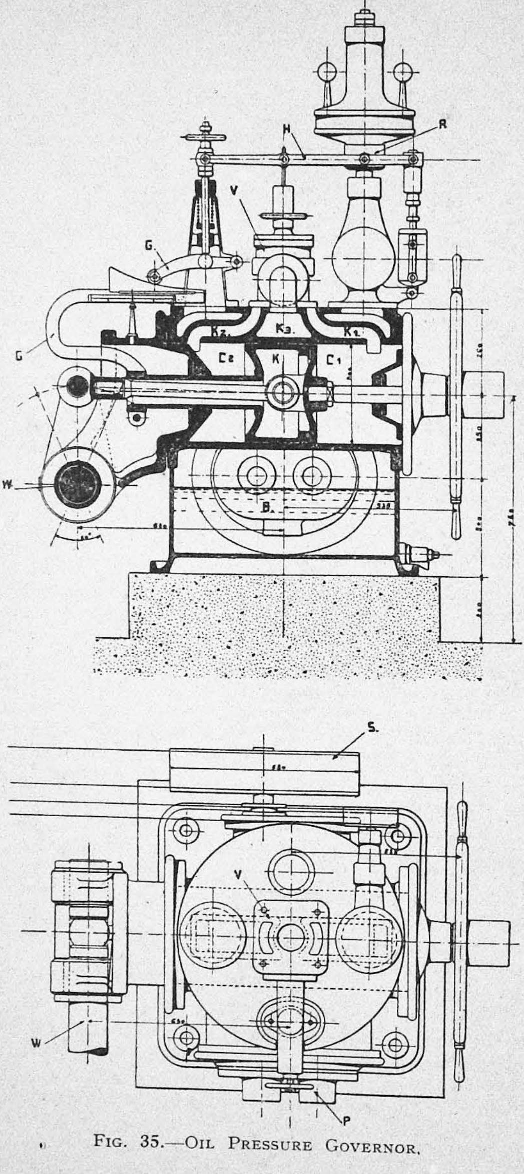


FIG. 35.—OIL PRESSURE GOVERNOR.

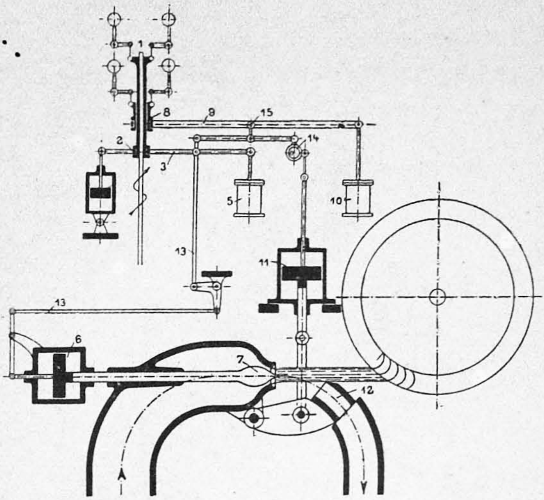


FIG. 36.—DIAGRAM OF AUTOMATIC REGULATOR.

were taken at the official tests at Arniberg. It will be noticed that the increase of pressure in the pipe line remains well within 5 per cent. of the normal when the whole 3,000 b.h.p. are suddenly thrown off.

The automatic regulation of water turbines has thus reached a state of perfection and refinement which can hardly be surpassed. The safety of the running parts as well as that of the pipe line is well assured. Yet, in view of the consequences which would follow the bursting of a pipeline under high pressure, a further safety device has been invented and successfully applied. This is an automatic valve, which is fixed to the upper end of a pipeline. Its construction may be seen from Fig. 38. The valve is held in balance by means of a counter-weight fixed on a lever, so that the increase of pressure, produced by the increased velocity which would result from a burst of the pipe, will throw over the counterweight and shut the valve. A standpipe must, of course, be provided of sufficient area to allow air to enter and to keep the pipeline from collapsing if the automatic valve should be suddenly closed.

The Pipeline.—The pipeline is very often by far the largest item in the total capital cost of a power plant using a high fall. To keep the cost low, the diameter of the pipes is taken small and the velocity of the water increased; it must thereby be considered that the loss of head by friction increases practically

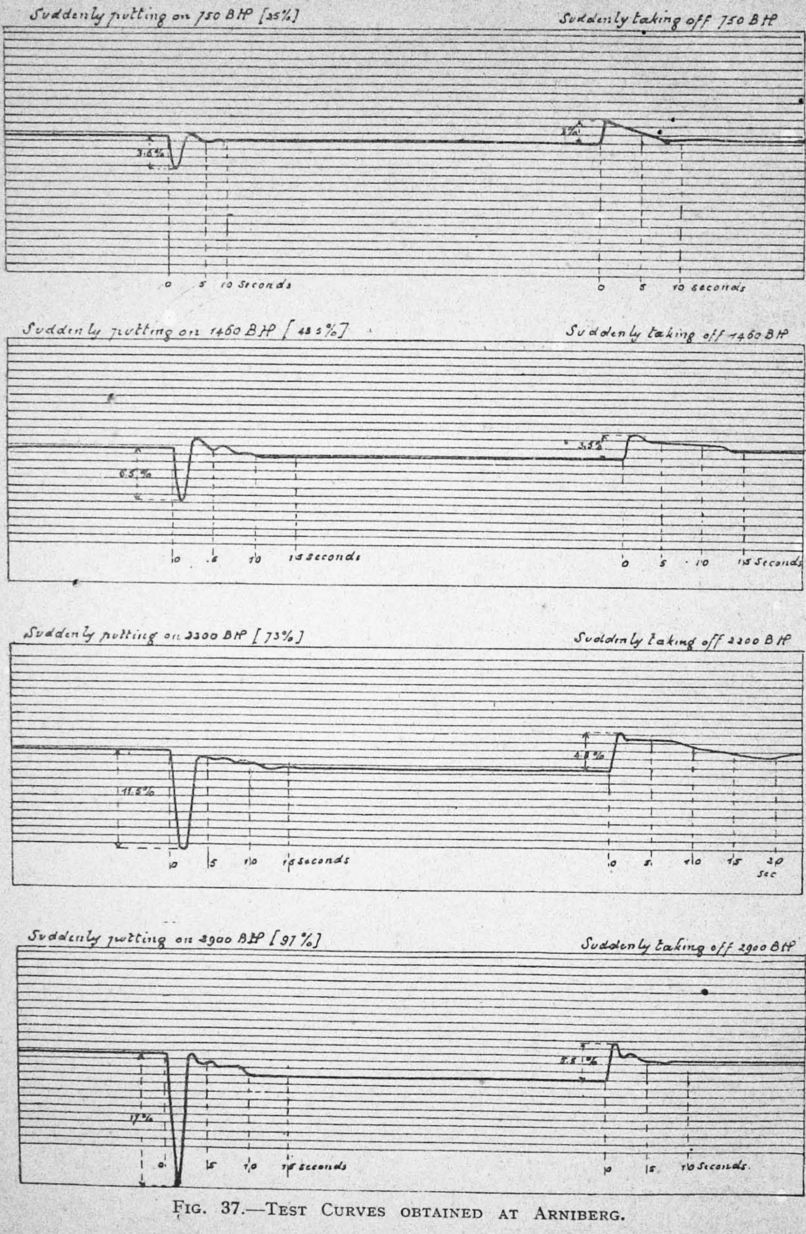


FIG. 37.—TEST CURVES OBTAINED AT ARNIBERG.

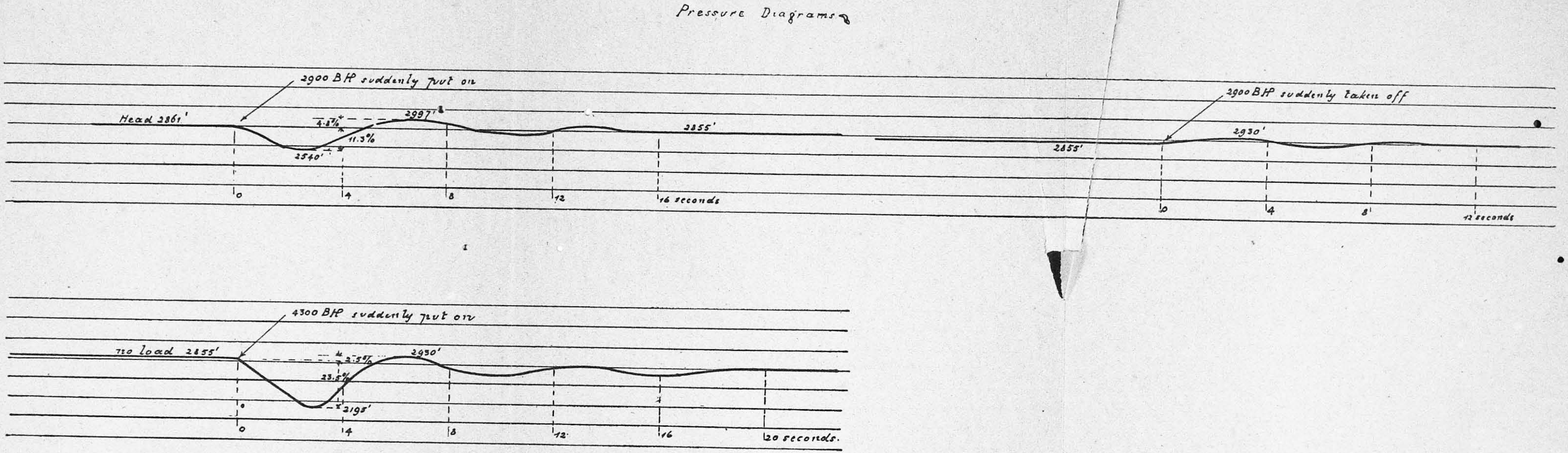


FIG. 37A.—CURVES OF TURBINE TESTS AT ARNIBERG.

as the square of the velocity. The power corresponding to the head lost by friction in the pipeline in many cases represents a considerable capital value, which must be carefully weighed against the extra capital outlay involved in pipes of larger diameter. Generally, the diameter of the pipes is chosen so that the total loss by friction does not exceed 5 per cent. of the total static head. Whereas formerly a velocity of from 3 to 5ft. per second was considered the admissible maximum, we find in modern power installations velocities up to 15ft. in the lower part of the pipelines, where it is desirable to keep the diameter small on account of the thickness of the plates required under high pressure.

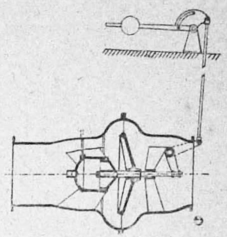


FIG. 38.—SELF CLOSING VALVE FOR PIPE LINE.

The most suitable material for pipes is soft mild steel in riveted or welded plates. The pipes are mostly made in lengths at the factory and provided with flanges, but to save cost in transport, the plates are sometimes bent and drilled at the works, and riveted on the site in considerable lengths without flanges. Allowance must, however, be made for expansion and contraction through changes of temperature if the pipes are laid on the surface. For this purpose expansion joints are inserted at suitable distances, or at the bends, and the pipes are laid on saddles to allow movement without deterioration.

In America, where wood of suitable quality is plentiful and cheap, pipe-lines of large diameter and great length have been made of wooden staves tied by hoops, apparently with good results. In recent years pipes of reinforced concrete have also been used for pressures up to 100ft. and proved to be entirely satisfactory. In all probability there will be a further development in this direction.

The Cost of Power.—So far the subject under consideration has been treated from the purely technical point of view, but it must also be considered from the commercial side. In every case where power is required, the question of cost will be considered in the first instance. In comparing water power with other sources of power from this point of view, not the capital outlay alone, but also the annual cost of the power must be taken into account. If the capital cost alone were considered, waterpower would be at a considerable disadvantage as it is often greater than that of other sources of power. It should be the deciding factor only if the available capital is limited or if the amount to be allowed for interest, depreciation and sinking fund is of considerable influence on the annual expense.

If, on the other hand, the annual cost of the power is carefully calculated, it will be found that these are smaller for water-power than those of any other sources of power, even if the capital outlay for the hydraulic power is twice and three times that of say a steam plant. The annual cost of power from various sources are variously given by different authors, but the following figures, taken from the *Electrical Review*, may be considered as fairly correct :

	£	s.	d.
Electrical H.P. per annum from water in Switzerland	1	19	0
Steam in England	4	11	8
Blast furnace gas in Germany	4	1	7
Producer gas in England	5	0	0

The amount given for electrical power from water in Switzerland, viz. : £1 19s. corresponds at 7 per cent. to a capital outlay per H.P. of £27 17s., at which figure water power could certainly be developed in the parts in Great Britain already mentioned.

In water-power plants from ½ to ¾ of the total capital is absorbed by permanent structures like dams, canals, pipelines and building work, for the annual maintenance of which 1 per cent. of the capital is quite sufficient. An additional 1 per cent. per annum will cover the depreciation of turbines, labour, maintenance and repairs. Adding 5 per cent. for interest, the total annual cost of water power is 7 per cent. of the capital cost.

In the case of a power generating plant using steam, or gas, or oil, a much greater allowance for depreciation must be made as the machinery is much more liable to deteriorate, and it forms the greater part of the total capital cost ; 5 or 6 per cent. for depreciation on the cost ot the machinery will, therefore, not be too high a figure. Adding to this 5 per cent. for interest and 1½ per cent. for labour involved in handling fuel, ashes and attending to the machinery, the annual cost may amount to 12½ per cent. without the fuel. The cost of fuel varies according to locality and the quality of the installation. Expressed in per cent. of the capital cost, au allowance of 7½ per cent. for fuel is probably a moderate assumption, which makes the total annual expense 20 per cent., or nearly three times that for water power. The capital cost of a water power plant may be about three times that of a steam plant for the same annual cost of power.

The capital cost of hydraulic power installations depends on local conditions and requirements, the size of the plant and the size of the units, but not necessarily on the height of the fall utilized, as is sometimes assumed. There are power plants with high falls involving a larger capital outlay than that of plants using smaller falls. Figures of the capital cost of a number of existing hydraulic power plants in various countries, published from time to time, show that it varies from £5 to £50 per b.h.p.; in exceptional cases the last figure has even been exceeded, but it is seldom more than £25 or £30 per b.h.p. for fairly large plants. Probably, in the majority of cases it is not more than that of an up-to-date steam plant.

The cost of the turbine proper may be an infinitesimal part or it may be 50 per cent. of the total capital cost, and a calculation of the cost of a turbine installation which is based on the price of the turbine alone will, therefore be absolutely misleading. It is, however, correct to say that the lower the fall the higher the price of the turbine per B.H.P., and, the larger the power of a unit under a given fall, the smaller the cost.

The capital outlay for a hydraulic power plant may be very large and appear prohibitive, yet prove to be a perfectly sound investment. The annual cost per B.H.P. would probably be smaller than that of a steam plant.

Whether a large capital outlay is justified will depend on the load factor. It would certainly not be justified for instance for a plant intended exclusively for the supply of electric light which is only required a few hours each day, but if the power can be applied also for other purposes, for power in factories, for traction, etc., a greater capital outlay is justified. The most favourable conditions are, of course, those where the power is required continuously as in many factories, mines and especially in electro-metallurgical works. These latter practically owe their existence to water power.

The objection is frequently raised against water power that it is irregular and unreliable, requiring a standby, or supplementary plant, at an additional capital outlay, to supply the deficiency during short water time. It has, however, been proved that, provided the load factor is above a certain minimum, the cost per kilowatt hour is not increased and may even be lower. This is borne out by the fact that numerous hydro-electric power stations in Switzerland and elsewhere, have added steamplant to the hydraulic plant with quite satisfactory financial results.

Power plants in industrial centres have mostly a heavy day load, while the night load is very light, or nil. These, if they are situated in a hilly country, can increase the power for the day load by using the power available during the night, otherwise wasted, for raising water to a reservoir at a high level to be used during the day by means of a separate turbine.

An interesting example of such an accumulator plant is that at Schaffhausen, in Switzerland. This is a town with a population of about 20,000 inhabitants and a large industry, possessing two engineering works, flour mills, rope works, and jute spinning mills, besides some minor industries. It obtains from the River Rhine 3,800 b.h.p. at two separate generating stations, with a fall at each of 15ft. In order to increase this output to satisfy the increased demand, it was decided a few years ago, to put down a high-pressure plant with four units of 1,000 b.h.p. each, of which two are already installed. The surplus power from the low fall plants is transmitted to two electric motors with an output of about 1,000 Kva each. To each of these motors is coupled on one side a high lift centrifugal pump and on the other side a double Francis turbine of 1,000 b.h.p. Each pump is capable of delivering 55·4 cu. ft. per minute to a height of 528ft., running at a speed of 1,450 r.p.m.

The water is delivered into a reservoir 515ft. above the centre of the pumpshaft, capable of holding 2,650,000 cu. ft. through a pipe line 7,100ft. long, with a diameter increasing from 3ft. to 3ft. 4in. This delivery pipe is connected to the pumps as well as to the turbine of each unit. During the night, and on Sundays, the pipe line is used for delivering water into the reservoir and during the day it supplies the turbines, and the electric motors act as generators. This accumulator plant adds 980 b.h.p. during ten hours to the power obtained from the low fall installations. Apparently, the high load factor has in this case justified the expense for the accumulator plant which, owing to the long pipeline, must have been very considerable.

Concessions.—In view of the rapid development of, and the ever increasing demand for water power, since the introduction of the electrical transmission of power, it has become necessary to protect the sometimes conflicting interests involved in flowing water, so much so, that it has been suggested in some countries to make the use of such waters a State monopoly. Whether there is wisdom in such a suggestion the author is not prepared to say, but it might be pointed out that those who intend to utilize water power have as much right to protection as those who make use of rivers for other purposes. It may otherwise happen that schemes which would benefit the population of a district are opposed by riparian owners for no other reason than short-sightedness or prejudice. The application of the laws of expropriation, if extended to water power, would in such cases be a wholesome remedy.

Fishery interests, for instance, are often put forward as a ground for opposing water power schemes and excessive compensation is claimed for alleged damage to the fishery industry. In reality, fishery is not affected at all by the installation of turbines, as long as fish-ladders of proper construction, and suitable gratings in front of the power house, are provided.

These afford ample protection against large fish getting into the turbines, while small fish will pass through them absolutely unhurt.

Guarantees.—Orders for turbines are often placed very carelessly and then result in disputes or lawsuits between the purchaser and the turbine maker. Few purchasers realise the practical meaning and value of "efficiency." They are quite satisfied if they obtain the power which they require, regardless of the efficiency. It is quite easy to satisfy such a customer, for a very inferior turbine will give more power than the water-wheel which it is to replace, or a turbine may be supplied which consumes a larger volume of water than the required power warrants. A buyer is apt to take the cheapest turbine offered and seldom considers that the cost of the turbine is only a small item in the total outlay. To make certain that he gets value for his money, he should ask for the statement of a guaranteed "efficiency"—not power—and, where the fall or the water supply, or both, are varying, for definite and legally binding figures for the efficiency at full as well as at part gate.

Unfortunately, the testing of turbines on the site is somewhat troublesome and costly, yet only tests made on site are of real value to the purchaser. A perfectly good turbine may give very poor results if the installation has been badly planned.

It is useful to embody in every contract a clause providing that in case of any doubt as to whether the efficiency guarantee is fulfilled, tests shall be made *in situ*, whereby each party is represented by an engineer experienced in making such tests, the costs to be borne by the losing party. Such a clause is an effective protection against extravagant guarantees of efficiency which are sometimes given to secure a contract but seldom fulfilled. If tests are foreseen in this manner, then it is also necessary to fix on the method to be adopted for measuring the volume of water. If it is to be measured by means of a weir or a sluice gate, the formula to be used and the coefficient for contraction also is to be agreed upon. A difference in the formula or the coefficient for contraction will easily account for a difference in efficiency of

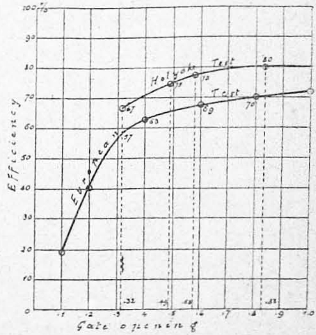


FIG. 39.—BRAKE TEST CURVES OBTAINED ON SAME TURBINE IN U.S.A. AND EUROPE

10 or even 15 per cent. In proof of this, a diagram is given (Fig. 39) showing the results obtained by two experts making separate tests on the same turbine. The variation in the results is entirely due to the different formulæ used in the two sets of tests.

No turbine maker of reputation will refuse to accept conditions such as stated above. Should a small deficiency be established by the tests, then it will be a fair arrangement to stipulate a certain sum to be paid by the contractor to the purchaser for each per cent. deficiency by way of indemnity, the same amount to be paid by the purchaser to the contractor for each per cent. above the guarantee. Such a condition would be quite reasonable up to a difference in the efficiency of say 5 per cent.; if the efficiency is found to be more than 5 per cent. below the guarantee then the purchaser should be entitled to reject the turbine with the liberty to place his order for another turbine elsewhere. An agreement containing such or similar provisions will save much expense in the Law Courts and assure a smooth and mutually satisfactary execution of the contract.

Testing of Turbines.—This includes the following operations:—

1. The measurement of the fall.
2. The measurement of the volume of water passed through the turbine, and
3. The actual testing by means of a dynamometer, generally a Prony brake, or in hydro-electric installations, by a water resistance or water brake.

Where the water is taken to the turbine through pipes, the pressure head is measured by a pressure-gauge fixed at the height of the centre of a pressure-turbine or at the nozzle of a Pelton wheel some distance from the mouthpiece where the velocity of the water is not very great. This will show whether the calculation of the loss by friction was correct. The height from the nozzle to the tail-water level must, of course, be deducted from the gross fall. The suction head of pressure turbines is best measured by means of a vacuum gauge which would show whether the vacuum is complete or whether there is any leakage of air. In installations with open turbine-chambers the fall is measured by levelling, but it is of advantage to provide indicators permitting the actual head to be read at any time in the engine house where the testing takes place. These indicators consist of floats, surrounded by perforated tubes to assure steadiness. The floats are suspended on cords passing over pulleys, provided at the other end with a counterweight and a pointer which runs along a measured rod divided into inches.

The second operation, the measurement of the water, is the most important, and in most cases also the most difficult operation. For an accurate measurement—and, of course, only these are of any value—the common method by a floating body is obviously out of question. The methods which give the best guarantee for reliability are the weir measurements for small quantities of water and the Woltmann propeller or current meter for large volumes. Both methods are reliable and accurate if applied with proper care. Of course, all instruments, for whatever purpose they may be required, must be properly tested and their accuracy certified before they are used for testing turbines.

The weir measurement is very delicate, and in order to assure its reliability it is necessary to erect the weir at a place where the water flows to it at a very low velocity so that its surface is perfectly smooth, and that its height above the edge of the weir can be measured with absolute accuracy, for a slight error in that measurement will make an appreciable percentage error in the efficiency. The coefficient of contraction varies with the proportion of the width of the weir to that of the millrace, the height of the edge above the bottom of the race and the height above that edge, measured not less than 7ft. behind the weir. The coefficient is not theoretical but can be found only by experiment. The results obtained by various hydraulicians differ according to the scale on which the experiments have been made, proving the necessity of the utmost care in choosing it. It is desirable, therefore, to erect the weir as near as possible to the dimensions of those for which the coefficient has already been established. The edges where contraction takes place must be sharp and the stream of water as it falls over, must be surrounded by air on all sides. If it adhered to the board of the weir, the volume of water might be as much as 29 per cent. more than that obtained by the formula. It is further of importance to see that all leakage of water at the bottom or on the sides of the weir is absolutely prevented. Much water is sometimes lost through such leakage, which of course has passed through the turbine without being measured, with the result that the efficiency found by the test is higher than the actual efficiency.

For the measurement of the water by a current meter a place must be chosen where the millrace is straight and as far as possible rectangular. The area is divided into a number of sections, the more the better, and the instrument placed in each section for say half a minute. This will, of course, require a considerable length of time in a millrace of large area and it is necessary to see that during the whole time the turbine is run with the same gate opening and at a uniform speed. As the velocity of the water may vary at the same spot from various causes, a repetition of the measurement is desirable. If the measurement by current meter were taken at a bend of the mill-race, it might happen that the velocity of the water is so small on the concave side that the instrument would not indicate, or the water might even flow backwards and form a whirl, which obviously would make the whole measurement illusory.

The mechanical device by which the power of a motor is measured, is generally known as the "Prony Brake." By this brake the power produced by the motor is absorbed by friction between a pulley and some wooden blocks which are pressed against it. The formula by which the output is found, is :—

$$p = \frac{L\pi}{30 \times 550} \cdot nW$$

in which "L" denotes the length of the lever in feet, "n" the number of revolutions per minute, and, "W" the weight in lb. acting at the end of the lever to keep it in balance. As the length of the lever will be the same for a series of tests, the factor $\frac{L\pi}{30 \times 550}$ will be constant for this series and we have only to note the weight and speed for each test.

Simple as the operation appears to be at first sight, there are many difficulties to overcome if the tests are to be reliable. The turbines are often placed so awkwardly that the placing of the brake is by no means easy. Then it is of the greatest importance to keep the brake steady while a test is proceeding. To prevent the brake from catching fire, a very frequent occurrence, a jet of water, or better of a soap solution, is directed on to the brake and this jet must be very even to assure a nice balancing of the lever. It is best, where possible, to use a specially constructed brake pulley which can be kept cool by a separate jet of water applied to the inner surface of the rim, while the outer face, where the friction takes place, is lubricated independently by means of oil. Of course, the feed of the lubricant must be very regular.

According to the disposition of the turbine and the turbine house, the brake may be fixed direct on the turbine shaft, whether it is vertical or horizontal, and the weight necessary to balance the power may be measured direct by letting the end of the lever press on the table of a weighing machine, or the weight may be suspended on a cord passing over one or more sheaves. In the latter case, the stiffness of the cord, and the friction on the bearings which carry the pulleys form a factor of uncertainty, and experts will have to determine what allowance should fairly be made for such losses.

The same also applies where the brake must be fixed on a countershaft, driven by intermediate gearing. It is in such cases extremely difficult to arrive at a safe and convincing conclusion of the efficiency of the motor proper. A well arranged set of wheel gear will absorb very little power in itself and the power absorbed by it may be very much exaggerated; on the other hand, a badly proportioned set of gear will absorb an amount of power, which it is impossible to ascertain with accuracy. It will be seen from this that the preparations for the testing of a turbine, as well as the testing itself, require a good deal of time and there may be a tendency to get them over as quickly as possible, giving superficiality an opportunity to creep in and, eventually, to destroy the whole object and value of the tests. A complete test should consist of a series of records, taken every few minutes at the same speed and the same load on the brake while the latter is absolutely steady, with the same gate opening. Records should also to be taken for the same gate opening at different speeds, and repeated for different gate-openings. These records are then tabulated, or recorded on a diagram. The latter method has the advantage that it will at once show errors in any of the measurements, of which there is always a possibility, and which can then be eliminated by a repetition of the test.

The paper, though somewhat lengthy, has left many points untouched which, the author hopes, will induce discussion and thus add to its value as a contribution to the literature on the subject of water power.

Discussion.

The President said that he was sure that those present had all listened with extreme pleasure to the paper, and had viewed with interest the slides which the author had shewn on the screen. He knew that it was their wish that he should propose to the author a hearty vote of thanks for the contribution which he had made.

The vote of thanks was carried by acclamation.

Mr. Holroyd Smith said that the paper gave a large amount of very useful information without causing the members to rack their heads with formulæ which nobody understood. It was a good many years since he had any real active practice in reference to water power, but he had a pleasant recollection that the work which he then did was very successful. The case with which he was concerned was that of some large paper mills in Yorkshire where there was a high fall and three water wheels in succession. Those water wheels had to be taken out and a turbine substituted. He was afraid that the turbine used then would be rather amusing to the author. Anyhow it was most effective in its work. It earned quite a good reputation in the district, and he had to attend to all the mills further down the stream to improve their water power.

There was a little point which the author had not mentioned, which, in his opinion, was of great importance in dealing with the utilisation of water, and that was the prevention of air being carried down with the supply of the water to the turbine. That was a point which he found was often overlooked by those who were putting turbines down the stream to which he had just referred. He attributed a large part of the success of the installation which he had undertaken to the fact that he provided very large flumes at the intake of the water, so that any air that tended to come in had plenty of time to bubble up before the water entered and was carried down the main pipe. He was also liberal in regard to the diameter of the pipes down to the turbine. That was a point of such importance that he was taking the opportunity of stating what his practice was so that other people might profit by it. He would say, " Do not neglect the area of the intake of water to the water turbine."

There was another point which he felt was a practical one which had not been mentioned in the paper. That was with reference to taking sufficient care to prevent debris and leaves of trees getting down into the pipe. He found in figures 20, 21, 23, 24 and 25 an error which he had had to protest against over and over again, namely, the slope of the screens shown was the usual 45 degrees. He had found it advisable to make the angle of the screen with the bottom of the channel about 25 degrees, so that the leaves and the stuff that came could be easily scraped up over the top and carried away. This was only a little detail, but such little details counted.

On page 38 the author spoke of testing by means of the Prony brake. If by Prony brake Mr. Steiger meant the primitive contrivance that usually went by that name, then if there was one thing connected with the question of testing power that he (the speaker) detested and abominated more than another it was the Prony brake. He thought it the most risky and unsatisfactory means of testing the power that could well be conceived. He had a vivid recollection of the last occasion when he used the Prony brake for testing water power in Cornwall. When they got it into operation everybody fled except himself, and he had to find a change of clothes very soon afterwards. He would suggest that instead of using the Prony brake, or even the better sort of absorption dynamometer, they should use a transmission dynamometer. He wondered why so experienced a gentleman as the reader of the paper had not given attention to a transmission dynamometer for the purpose. He should be very pleased to have a little conversation with him afterwards, when he thought he could suggest a transmission dynamometer which would save him a lot of the trouble caused by the uncertainty and unreliability of the Prony brake.

He would like to ask a question in order to get as much information as possible and clear his brain of any error or hallucination that might have been hovering there for years. Ten or fifteen years ago Professor Walker showed to several people an idea sent to this country from Canada for the utilisation of water power which was so different from anything else that he would like to know what Mr. Steiger thought of it. The water was caused to go down a number of pipes with trumpet-shaped mouths, carrying the air with it. The air was sucked in in the same way as when one pulled the plug of a bath. They all knew the noise that was then made. The air in the case he referred to was drawn down the pipes until it reached a large tank at the bottom of a deep pit, and there it was liberated into a big chamber, obtaining the pressure due to the fall of the water. The water came up from the bottom of the tank, and flowed out again at the lower surface level, and the air was taken from the top of the chamber and used for driving air engines in a factory. Probably Mr. Steiger knew the place in Canada where that was actually done. He would like to know what the real fallacy in the operation was, because, as far as he knew, it had never been adopted in this country. If it was a good idea why had it not been put into effect? The opportunity of transmission through a lot of little engines planted round works made it a very useful thing. The idea was highly spoken of at the time, and some of those present might remember it.

Mr. W. B. Esson said that whenever he heard Mr. Steiger read a paper he learned a good deal from it, and the present paper was no exception. He should like to make a few observations on brake tests. Mr. Steiger talked about hydraulic brakes, but were such brakes constructed to test turbines of 10,000 horse-power? He had never heard of them. It seemed to him a very difficult thing to test turbines at all with a dynamometer, and it was very unsatisfactory, as Mr. Holroyd Smith had pointed out. On pp. 35-6 of the paper the author referred to a turbine tested by an expert in Europe and another expert in America, and it appeared that the difference at full load was as much as 8 per cent., while the difference at 80 per cent. of full load was 10 per cent. This showed that it was a very difficult operation. He thought the only way of dealing with turbines was to test them electrically. If they had a turbine driving an electric generator the testing operation became perfectly simple so far as the power yielded was concerned. Speaking for himself, he would never split a contract for a turbine and generator between the makers of each, but would make the contract either with the turbine maker or with the generator maker so that there would be no divided responsibility. The efficiency that the contractor would have to guarantee would be the electric power produced for a given fall and quantity of water. They could not measure the water except in the way that Mr. Steiger had described, and here again there was great difficulty. The result was a matter of much uncertainty, and, as had been shown, the efficiency came out differently according to the formulæ used.

He would like to mention that often it was far less expensive to put in a Pelton wheel than to put in a turbine, not so much on account of the first cost as on account of the wearing out of the buckets. He remembered that the buckets of the Pelton wheels that were installed at the Burma Ruby Mines some years ago wore out in a very short time owing to the water being loaded with ruby earth; under the circumstances turbines would have been useless, as their buckets are dear while Pelton buckets are cheap.

With reference to the efficiency of turbine wheels it was unimportant, generally speaking, unless there was a shortage of water, to have a high efficiency at half gate or partial gate. They wanted to get the maximum power out of the water as a rule, but for any intermediate power, unless they were short of water, it did not matter very much. The thing was to get the highest efficiency at the highest power.

Mr. C. T. A. Hanssen said that the substitution of turbines for water wheels in this country seemed to be somewhat difficult because the compensation generally demanded by the owners of the water power was so great that it swallowed the whole of the profit due to the saving of coal. He had had a little to do with some compensation cases in Wales, where there were some falls developing about 12 H.P., and by diverting some of the water about 4 H.P. was taken away. The idea of compensation was that a petrol engine of 12 H.P. should be put down and then a money payment equivalent to the capitalised value of the petrol used should be allowed. Instead of being content with 4 H.P. additional, the owners wanted the whole of the 12 H.P., because they said that the remainder was no good for driving their factory. They did not get the compensation which they asked for. They were offered simply a money payment down, and they had to accept it. If they could have done it they would have driven a very hard bargain indeed. Speaking generally, he thought that all water power suffered a great deal from agricultural drainage. As soon as agricultural drains were put in in a district the greater part of the water flowed away during a short period of maximum rainfall, and during the rest of the year there was very little flow left to supply the water power or drive the turbine. He was afraid that that difficulty could never be obviated except in mountainous districts where there was no cultivation of the land. As the author said, afforestation in mountainous districts was a very important thing, and he hoped that the Government would take notice of that, and fulfil their promises to plant forests on the mountains and in unfertile districts, which were natural collecting grounds for all water power that might be available in this country. There was a very large quantity of water in some of the Welsh mountains, but the great point seemed to be that the compensation demanded was excessive and that it was not as a rule uniformly distributed over the whole year. It came with a rush in spring and autumn, but during the summer months there was hardly any, and that fact made a water wheel almost as expensive as a steam engine. The great thing was to have the water all the year round and either to use it day and night or to be able to store it in large reservoirs during the night. If that could be done they could get water power at a very low price. Mr. Steiger spoke of £1 19s. per H.P. year, but he supposed that the figure referred to power used for part of the time only. It had been found possible, in countries where compensation for water power was small, to get it as low as £1 per H.P. year. That meant working continuously day and night all the year round. If it could be got at that price a great deal could be done in the way of chemical engineering, but if it was more expensive than that it did not seem remunerative to use it for making nitrates and other such products from the atmosphere, which had to be produced in large quantities at a comparatively low cost. Mr. Steiger did not say how he arrived at the figure of £1 19s. Patentees for nitrogen and so on stipulated that the cost of power must not be higher than £1 per H.P. year. There were several large installations in Norway, and he thought in other places too, where the cost per H.P. year had actually been below £1 when working all the year round, day and night.

Mr. Humphrey M. Morgans said that the way in which the harnessing of water power had developed was very fascinating. The plant units grew larger and larger. In electrical and steam plant the same tendency was to be noted. Efforts were constantly being made to get the most horse-power out of every pound of material put into a machine, and new and stronger materials had to be developed.

For governing Pelton wheels the designer needed to know the profile and the proposed size of the pipe line, so that he would know what inertia there was in the moving water in the pipeline. The inertia of the rotating parts made a difference on the speed changes when changes of load occurred. He wanted to know whether it was the practice, with a good oil pressure governor in use, to put an automatic relief valve at the bottom of the pipe line or to rely absolutely on the oil pressure governor to keep the pressure rise in the pipe line within permissible limits. It was a marvellous thing that they should be able to knock off the whole of a big load and get a permanent speed change of only 9 per cent. and an increase in pressure in the pipe line of not more than 5 per cent.

As regards pipe lines Mr. Steiger said that speeds up to 15ft. per second were allowed in high pressure pipe lines, chiefly on account of the difficulty of getting strong enough pipes for a lower velocity. It would be difficult to keep the friction loss within 5 per cent. at such high speeds unless big pipes were used.

He would suggest that it might be a useful addition to the paper to put in one or more reliable formulæ for obtaining the frictional loss in the pipe line. In the *Engineering and Mining Journal* of the 7th December, 1912, there were half a dozen formulæ given, also a set of curves giving the frictional loss in pipes up to 12 ins. bore based on the average of the formulæ.

The speed of an ungoverned Pelton wheel might run up to 80 per cent. in excess of normal speed on the load falling right off, so that a generator on the same shaft as the Pelton wheel ought to be capable of an excess speed of 80 per cent., and that needed particularly to be made known to the generator maker when the order was placed.

On the question of water brakes, mention had not been made of what was really the standard water brake nowadays, namely, that made by Messrs. Heenan & Froude, of Worcester. He believed that Messrs. Sulzer Brothers, in Switzerland, have a brake of this make capable of absorbing 4,000 horse power continuously.

Mr. Esson said that he would like the author to tell them in his reply whether the buckets which he had shown on the screen, which were so worn out, were steel or cast iron buckets.

The Author : Cast iron.

Mr. A. R. Tattersall said that he thought that the main point was that every water power scheme appeared to require to be considered as to its variable water quantity and the fall, and that a certain turbine was not suitable for every position. One must study the life-history, so to speak, the particular location and the varying quantities of water at different times of the year and the height of the tailwater, to get the best type of turbine to put in. He remembered meeting Mr. Steiger about twenty years ago on a water power problem in the eastern counties. The board of directors had received nine turbine estimates, and they asked him (the speaker) if he knew anything about turbines. He said that he did not know very much but he knew a man who did. That gentleman was called in and he threw over the whole of the nine estimates and specifications and said that they were all wrong and that, having regard to the varying quantity of water and the varying height, he thought there should be a turbine which would have two concentric rows of buckets, so that when the water varied in quantity and there was a maximum height and a minimum quantity of water, it would give as good results as when there was a maximum quantity of water and very little fall. When the board of directors put in the particular type of turbine which the author recommended, they found that they could drive their mill with only 18 inches of water fall, which they had never expected to be able to do, and had never done before.

When the author left the technical side of the paper and went to the commercial side he was rather at fault. He had taken the *Electrical Review* as his authority for the cost of £1 19s. 0d. per H.P. year as against £5 for producer gas. He thought that there were producer gas makers who would tell them that they could get 10 horse power hours for a penny, and running for 140 hours a week and fifty weeks a year it only cost £2 18s. per annum, reckoning coal at 30s. a ton.

He was very much obliged indeed to Mr. Steiger for the information that he had given. He would like to ask him at what height he would stop using other types of turbine and put in a Pelton wheel. He once put in a Pelton wheel in Spain of which he had a very unpleasant recollection. It did not turn out good enough and it had to be replaced by another type. He thought that there must be some limit to the fall at which a Pelton wheel should be introduced. There should be a certain height for it ; it would not do at low falls. He would like to know whether there was any rule on the subject.

Mr. Harry Geen said that he had had an opportunity of testing some low pressure Pelton wheels some years ago. He did not know what Mr. Steiger's opinion might be, but he found 35 ft. the limit of head at which it was possible to get good results, and that at anything less than 35 ft. it was very inefficient. If his memory was right, at 35 ft. there was an efficiency of only about 62 per cent. He would like to ask Mr. Steiger when it became desirable to have a Pelton wheel instead of a turbine. After various investigations he had come to the conclusion that for variable flows and low variable flows a Pelton wheel above the 35 ft. limit was a better motor than a turbine, because they might have three or four nozzles, as had been shown that evening, and when they had a small flow of water they might use one or two nozzles and get full efficiency out of them, whereas one did not get full efficiency out of half gate or third gate in the case of a turbine.

He thought that Mr. Steiger knew the installation at the electrical works at Lynton in North Devon. The result there was that by changing the old turbine wheel of ·62 per cent. efficiency and putting in a turbine wheel under Mr. Steiger's advice, the efficiency then (and he believed now) measured electrically and not measured in any haphazard way, was 84 per cent. Mr. Steiger recommended pumping during the day. Seeing that electrical current was required more in the evening and at night, the plan which had been adopted with very good results at Lynton had been to pump during the day to a height of 800 ft. above the electrical station into a small circular reservoir, using the stored water at night with the Pelton wheels to help the turbine. That was an installation which, he thought, had not been copied anywhere else in England.

He was afraid that part of the difficulty, as previous speakers had said, was the question of payment to riparian owners and to people who owned water rights. As regarded the figure of £1 19s. per H.P. year, his small experience of Switzerland was that there were no long water courses, or very few, to pay for. One found there a vertical fall of water with only a straight line of pipe from the top flume down to the water generator. That state of things was not very often found in England. To give a simple illustration, some years ago he was interested in an electrical installation in a small town where the owners of the water asked for £100 per annum for its use, and the right to cut through some ordinary moorland for a water course to take the water for the turbine. It meant cutting a water course about a mile and a half long. The capital cost of it, with the payment of £100 per annum, was a first charge on the use of the water. That and the cost of the installation killed the whole scheme. He was convinced that many installations would be put in in England but for excessive greediness on the part of landowners, and excessive cost in compensation.

Mr. Alfred S. E. Ackermann said with regard to transmission dynamometers he knew that Mr. Holroyd Smith was the inventor of one, but he had forgotten the details as it was many years since it was described to him. The trouble with transmission dynamometers was that they could not be calibrated very easily whereas the Prony brake could be. If he were called in to test a plant with a transmission dynamometer, it would probably take him the best part of two or three days before he could determine what the constant of the brake was, whereas in the case of a Prony brake that could be ascertained in half an hour. When it came to water turbines of 20,000 horse power, it was probable there was no other way than to take the over-all efficiency of the turbine and dynamo, and if they wanted to know the turbine efficiency separately, it would be necessary to predetermine the efficiency of the dynamo, or rather of two sister dynamos, by applying the Hopkinson test to them.

Mr. Holroyd Smith said the speaker was assuming that hydraulic power was used only in combination with electric power, but it was sometimes used without.

Mr. Ackermann said that that was so, for most of the big hydraulic power stations were hydro-electric.

Mr. Holroyd Smith had mentioned the compression of air by falling water; that was known as the Taylor air-compressor. A large Taylor air-compressor was installed at Magog near Montreal, Canada, and had been reported on favourably by his former chief, Prof. Unwin, F.R.S., M.I.C.E., and by Mr. W. G. Walker, A.M.I.C.E., in 1897. It developed about 150 H.P. and compressed to 52 lb. per sq. in. by gauge. Mr. W. G. Walker had a large working model near by in Westminster some years ago and it might be there still. It was curious that the air so compressed was dry.

Mr. Norman Scorgie said that Mr. Geen's remarks about riparian owners might to some extent indicate the reason why there were not more water power installations in this country. One thing which struck him when he was journeying about two years ago in the Austrian Tyrol, was that nearly every little village of only 400 or 500 inhabitants had its own water power electric light installation, no doubt from the mountainous torrents which were everywhere apparent. On the Dolomites the little villages dotted here and there always had electric light. He was away from railway districts because he was motoring at the time. Noticing the state of things he made enquiries, and one and all told him that they had a little water power installation. He was afraid that as regards Scotland, Ireland, and Wales (he could speak more particularly for Scotland) there were very few streams that Mr. Steiger would find available for water power installation. He remembered many years ago finding an installation in Fort William in Inverness-shire, from Glen Nevis. Water power installation for electric light purposes was a great surprise to the inhabitants, and it was one of the curiosities of the place. People from the hills around used to come to see it. An old lady from the hills went to a grocer's and found nice little electric lamps glowing there. She asked what it was that gave such a beautiful light and the grocer told her "current." She said, "I will have a pound of those, and if I cannot make a light I can make the old man a pudding."

REPLY.

The author said in reply to Mr. Holroyd Smith that air must in all circumstances be prevented from getting into the turbine. The mouth of a pipe line or the turbine itself must be placed so far below the surface of the water that no whirl could form and no air be drawn in. The entrance of air into a turbine produced irregular motion and a reduction of efficiency, which was especially great in pressure turbines. In the case of low-fall turbine installations there was a tendency, in order to save excavation, to place the turbine too near the surface of the water to provide sufficient area for the discharge of the water from the turbine. The result was that a whirl formed above the wheel, and air passed to it, reducing the efficiency at once by 15 to 20%.

Mr. Holroyd Smith was quite right in what he said about the angle of the screen in the figures, which must not be taken as showing exactly what would be required in every case. Where one could be sure that the water was fairly free from weeds, etc., an angle of 45° might be adopted with perfect safety, but he had very often seen almost vertical screens in this country. That was bad practice, because weeds, pieces of wood, and so on stuck in the screen and at once reduced the fall by a few inches. Wherever it was possible to take a flatter angle, say 40° or 30° with the horizontal it was certainly preferable, and was simply a matter of expense. With a flat angle the weeds were carried to the top of the grating, leaving the spaces between the bars of the grating entirely free. He was reminded of a visit to some paper mills in Scotland where a turbine had given a lot of trouble, the alleged cause being that " the turbine gets choked." In each case the turbine was a Macadam turbine. These wheels were generally subdivided into a number of stages with orifices of small area, which were bound to get choked unless a proper grating were placed in front of it. Generally the space between the bars of a grating should not be more than three-quarters of the narrowest dimensions of an orifice. In one case a turbine of 120 H.P. had been removed owing to the trouble it gave on this account. At that time they paid 4s. for a ton of coal, now the price will be quite 10s., and they would have effected a considerable saving by having installed a new and more suitable turbine.

He should be very glad to know more of Mr. Holroyd Smith's transmission dynamometer. So far he had always used a Prony brake, but where the power was used for driving a dynamo, the efficiency of which is generally tested at the maker's works before delivery, the power actually developed was preferably determined by the reading of the ammeter and voltmeter.

Mr. Esson had asked how a 10,000 H.P. turbine could be tested. The efficiency of the generator being known, it would simply be a question of measuring the fall and volume of water.

In the measurement of large volumes of water by the most accurate methods, either by a current meter or by a weir, there may always be a difference of from 2 to 5% between the result of the measurement and the actual volume. It therefore seemed absurd, in view of the friction and other losses, to claim efficiencies of 90 per cent. and upwards.

Mr. Esson had mentioned a Pelton wheel, the buckets of which showed excessive wear and had to be renewed every few weeks. With high falls, such as are mostly utilised by Pelton wheels, it was important to provide for pure water and to allow sand or grit to settle before the water reached the wheel. In Cornwall he had heard complaints of the buckets or vanes wearing out very quickly, but this was no doubt due to the presence of sand in the water, or to the unsuitable design or material of the buckets. Bronze was the best material for buckets exposed to the action of sand.

Mr. Esson had said that a turbine should give its best efficiency at full gate, and that it mattered little if the efficiency were low at part gate. That was correct if it were a question of reducing the gate opening to suit a varying load for short periods, but if, as in most cases the water supply was diminished during long periods, it was actually of the greatest importance that the efficiency should also be high at part gate, otherwise the loss of revenue from the plant might be very considerable.

Mr. Geen had referred to the difficulty which sometimes arose when water was taken away from a water course which supplied a water power plant. That was sometimes a serious matter because if the efficiency of the motor was inferior at part gate, the power would not only be reduced in proportion to the water abstracted, but would be further diminished on account of the inferior efficiency. He had once to make an investigation and give evidence in a case where a waterwheel was used to drive some light machinery in a flour mill. A neighbour asked and received permission from the miller to lay one or two pipes to take water from the head-race to some tanks for trout-rearing, but actually ten pipes had been laid, and so much water abstracted that the wheel was no longer capable of driving the machinery, and had become useless. The lawsuit ended in favour of the miller.

The cost of an electrical H.P. from water power in Switzerland had been given as £1 19s. He believed this figure was based on a 12 hours day and 300 working days per annum, but such figures have only a relative value, as the annual cost of power obviously varied in every case.

In reply to Mr. H. Morgans, pressure regulators were necessary, particularly in connection with long pipe lines. If, in consequence of suddenly taking off load, the gate of a turbine were rapidly closed, the pipe line would be exposed to the danger of bursting, unless means were adopted to prevent the water hammer which follows a sudden check in the motion of a large column of water, and this could be accomplished either by a pressure regulator or by an automatic or safety valve, but not by both. To secure a good regulation, an extra fly-wheel was required if sufficient momentum could not be obtained from the rotor of the generator.

Mr. Tattersall had stated that the cost of power from producer gas given in the paper was too high. It was quite possible that in some cases such power might be produced at £2 10s., and did not know where the figures given in the *Electrical Review* came from, but thought they might be considered accurate. If power could be produced more cheaply, all the better, but the allowance for maintenance and depreciation should not be understated.

He had been asked what was the lowest fall which could be utilised by a Pelton wheel. The question was somewhat vague; it depended on the power which was required. A Pelton wheel can be used for a fall of 15 ft. if not more than ½ or 1 H.P. was to be developed, but it was seldom that a Pelton wheel was used for heads of less than 30 ft. If the power required, or the volume of water were too large for a single Pelton wheel and too small for a Francis turbine, then a Girard or a tangential turbine would be better than putting two or more Peltons on one shaft, as had occasionally been suggested. For this reason he had pointed out in the paper, that it was unfortunate that the Francis turbine and the Pelton wheel had become the fashion, to the exclusion of other good types. There would always be cases where none of the now fashionable types would answer all requirements satisfactorily. A case in point was the temporary installation at Kinlochleven. There the problem was to supply a motor capable of developing 3,000 h.p. under a fall of 380 ft., and to run it at a speed of 300 r.p.m. Tenders were received for a Francis turbine, a double Pelton-wheel and a single Pelton wheel with six nozzles. The latter was the best solution of all; the Francis turbine certainly could not have been efficient, and the double Pelton wheel would have been very costly. Another solution, which would have been preferable to either the Francis or the double Pelton wheel, would have been a Girard turbine or a tangential wheel with horizontal shaft.

He wished to thank the Society for having given him the opportunity to read his paper, which was intended to give useful information to all who had to do with water power, and he also wished to thank Messrs. Theodore Bell & Co., of Kriens, Switzerland, for the diagrams illustrating some of their turbine installations described in the paper.