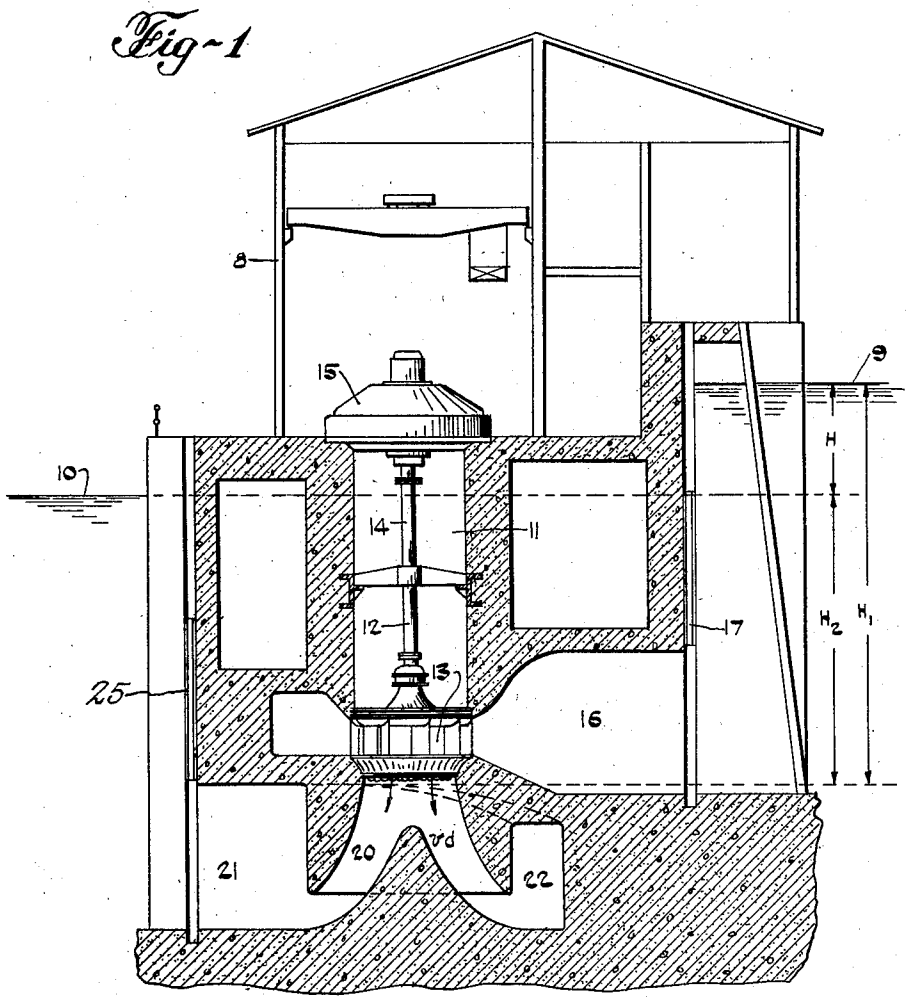
March 25, 1930. H. B. TAYLOR 1,751,667

HYDRAULIC APPARATUS

Original Filed Dec. 4, 1919 4 Sheets-Sheet 1

Fig-1



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HYDRAULIC APPARATUS

Original Filed Dec. 4, 1919 4 Sheets-Sheet 2

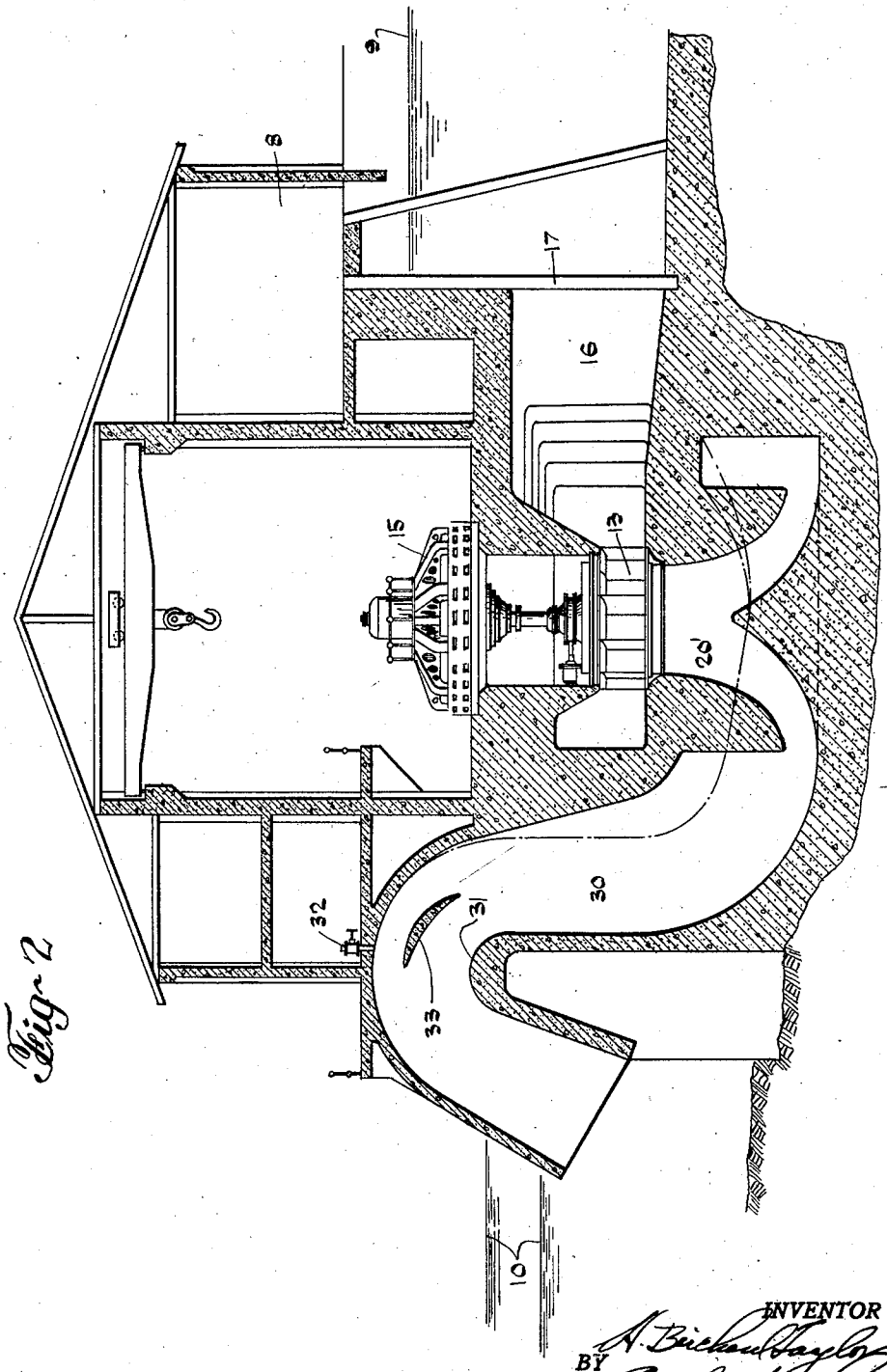


Fig. 2

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HYDRAULIC APPARATUS

Original Filed Dec. 4, 1919 4 Sheets-Sheet 3

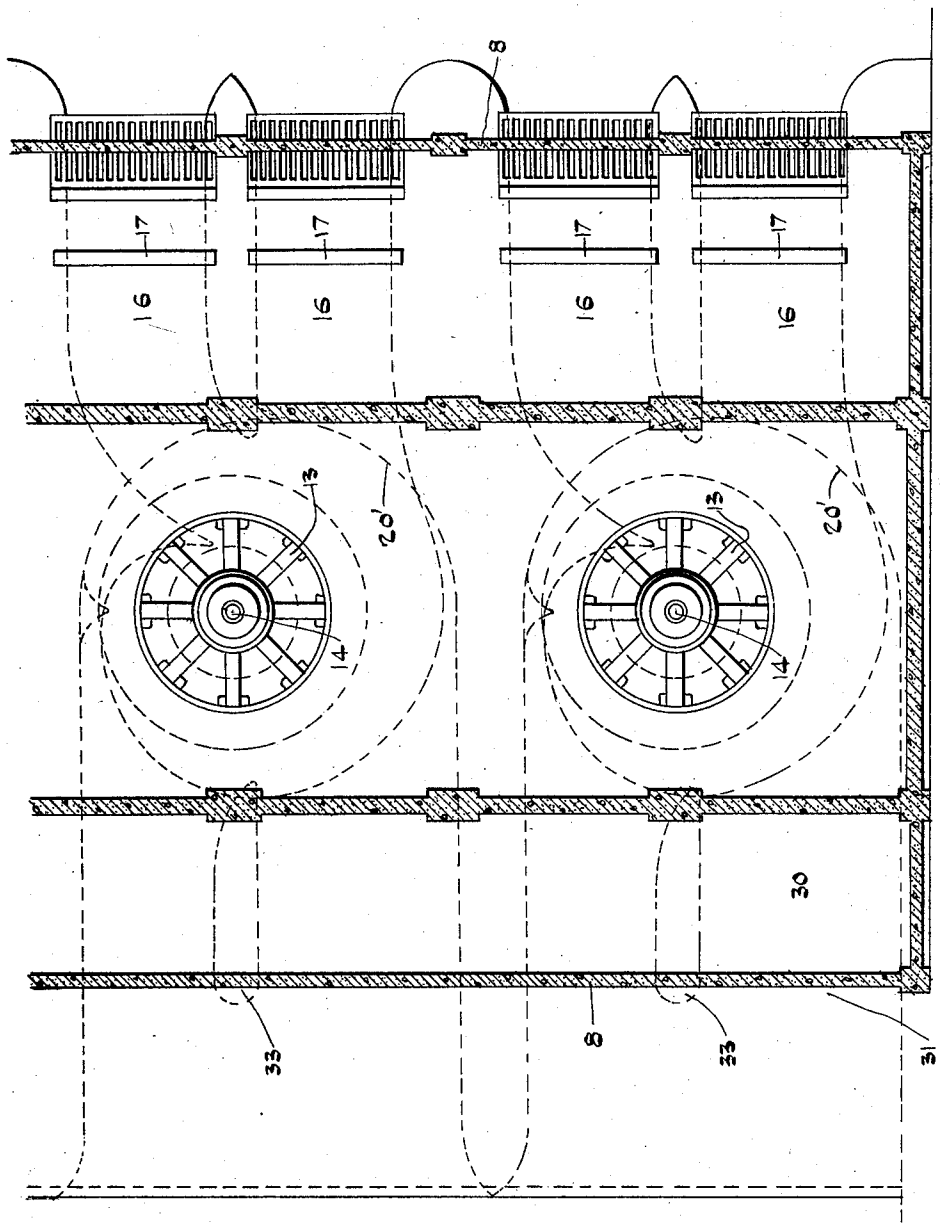


Fig. 3

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HYDRAULIC APPARATUS

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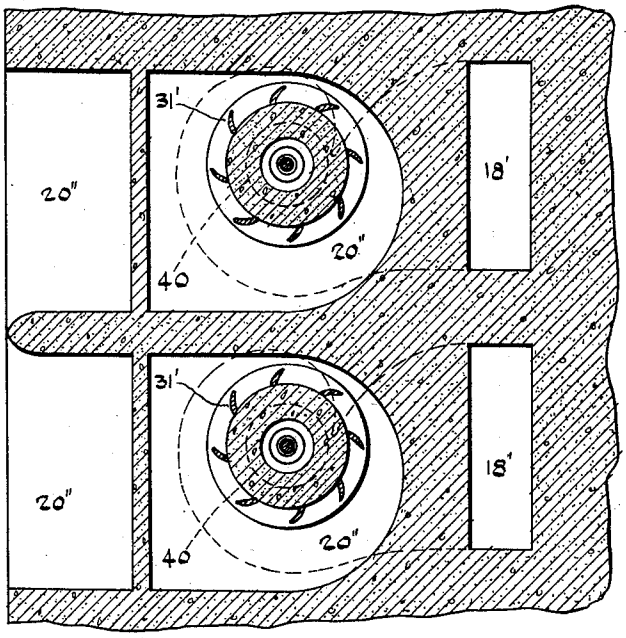


Fig-4

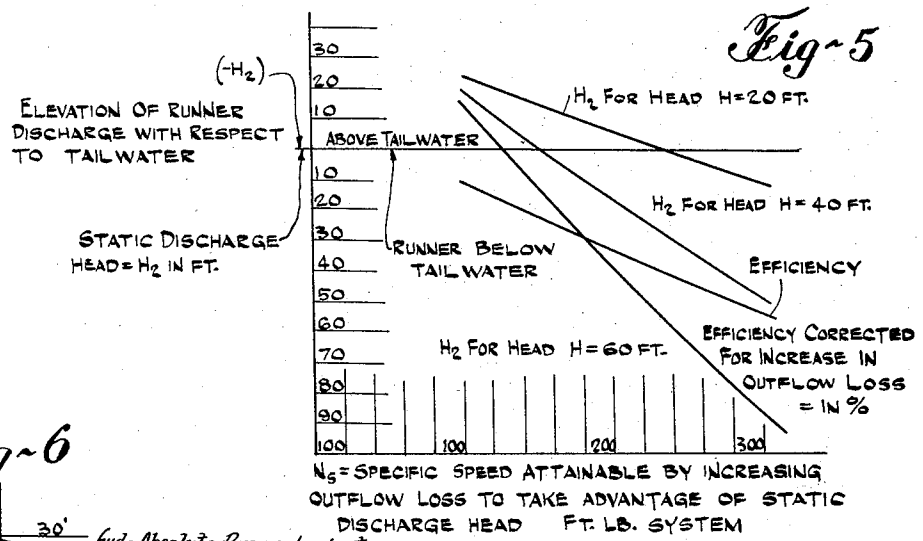
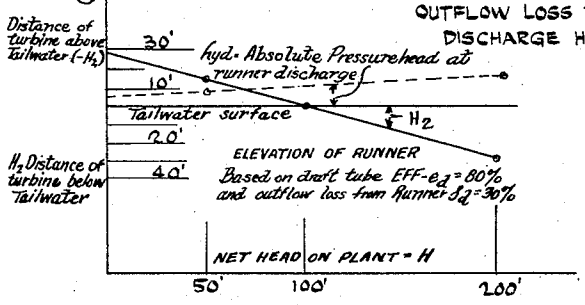


Fig-5

Fig-6



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UNITED STATES PATENT OFFICE

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HYDRAULIC APPARATUS

Original application filed December 4, 1919, Serial No. 342,383. Divided and this application filed February 1, 1928. Serial No. 251,156.

This invention relates to hydraulic power plants and particularly to such plants where the available water supply is under small and moderate heads. In such plants it is necessary to use a large flow of water to develop power in commercial quantity. In order to keep the turbines and power house required to handle these great quantities of water from being prohibitively large and expensive it is desirable to increase the velocity of the water as much as possible particularly where it passes through the turbines and at discharge from the runners; and in order to keep the electrical generators from being unduly large, it is desirable to obtain the highest possible rotary speed for the turbines. This high speed is also advantageous in making it possible to use standard electric machinery in many installations where otherwise large special machines would be necessary. When the velocity in the water passages is increased beyond a certain amount, however, the corresponding drop in pressure, according to hydraulic principles hereinafter explained, permits the pressure to approach the point at which the water will vaporize and if carried too far allows the continuity of the water column to be broken causing loss of head and danger of surges and other disturbances. Even before actual break in the water column there will be danger of rapid corrosion of exposed metal surfaces so that a margin of safety must be allowed above the point of vaporization.

This is particularly the case at the turbine runners, where velocities are usually highest, and with turbines located as heretofore at a considerable elevation above the tail water there has been a limitation on the permissible velocity in the water passages which has so increased the size of the turbines for the power developed as to make the first cost of turbines and power house prohibitive.

The object of this invention is to provide a hydraulic power system for such low and moderate head conditions which will not require such large and expensive apparatus and in which high velocities of flow may be safely used without danger of interrupting the continuity of the water column. In the system of this invention reduction in pressure due to high velocity of flow is counteracted by a correspondingly high applied pressure head on the water particularly at the points of maximum velocity and, therefore, any velocity may be used within the limits of the opposing pressure head. To supply this opposing pressure head the turbines or other parts of maximum velocity are in the system of this invention placed at an elevation with respect to the level of the tail water corresponding to the desired velocity and the pressure head necessary to counterbalance the reduction in pressure resulting therefrom, departing from the customary practice of limiting the runner to positions above the tail water level.

In the accompanying drawings illustrating specific applications of the principle of the invention—

Fig. 1 is a vertical sectional view of a power plant showing one embodiment of the invention; Fig. 2 is a vertical sectional view of a modification; Fig. 3 is a plan view of the same; Fig. 4 is a partial plan view of the same, and Figs. 5 and 6 are diagrams illustrating the principles hereinafter explained.

In the embodiment of the invention illustrated in Fig. 1 a power house 8 has the head water 9 in the usual forebay or liquid basin on one side and tail water 10 in the usual forebay or liquid basin on the other. A vertical pit 11, is provided for the vertical shaft turbine 12 having a runner 13 below and shaft 14 driving generator 15 in the power house above. The inflow to the turbine runner is provided by passage 16 from head water 9 and controlled by gate 17 and at the runner this intake 16 has the form of a spiral or volute of progressively decreasing section delivering the water to the runner blades with a combined radial and circumferential flow. The turbine 13 is of the high speed type and is positioned below the level even of the tail race 10 and the supply head H_1 between the runner and the surface of the head water 9 is greater than the net head difference H between this head water and the tail race surface so that the water at the turbine is under relatively great static head; the absolute

values of the hydraulic pressures being however determined by the conditions of flow and the effect of the relatively high velocities desired at these points. With the turbine runner under a certain initial head H_1 above the runner discharge, and having an absolute pressure h_{Pd} at the runner discharge then the head H_t on the turbine proper, between intake and discharge, will be expressed by the following formula:—

$$H_t = H_1 + h_{at} - h_{Pd}; \text{------}(a)$$

where h_{at} is the head corresponding to atmospheric pressure.

It is proposed according to this invention to place the runner at such an elevation (here assumed below tail water) that the turbine proper can operate under a head H_t considerably greater than the head on the system H. To accomplish this, the velocity head at the runner discharge must be so related to the atmospheric pressure and the height of tailwater above the section that h_{Pd}, the static pressure head at the runner discharge, has a value safely in excess of that at which the water will tend to vaporize and the continuity of the water column in the draft tube will be in danger of being broken. The relation is as follows:—

$$h_{Pd} = H_2 + h_{at} - \frac{vd^2}{2g} + L_2 + \frac{v_f^2}{2g} = H_2 + h_{at} - (1-\zeta)\frac{v_d^2}{2g}$$

or

$$h_{Pd} = H_2 + h_{at} - e_d \frac{v_d^2}{2g}; \text{--------}(b)$$

Here H_2 denotes the height of tailwater above the runner discharge; v_d denotes absolute velocity of discharge from the runner; L_2 the loss of head in the draft tube; v_f the velocity of final discharge from the draft tube; ζ, the percentage of velocity head lost in, and at final discharge from, the draft tube; and e_d the efficiency of the draft tube.

$$\frac{v_d^2}{2g} = \frac{H_2 + h_{at} - h_{Pd}}{e_d} \text{----------}(c)$$

In well designed draft tubes e_d can be assumed to be in the neighborhood of 75% in the case of large units. If H_2 and (consequently) H_1 are made large in comparison with H, and $\frac{v_d^2}{2g}$ increased in accordance with the above formula (keeping h_{Pd} within a range of say from 5 to 10 ft. as a proper margin, to allow for variations in velocity, etc.) then a value of H_t can be secured considerably in excess of H.

If N_s is the specific speed of a runner computed in the usual manner from the formula,

$$N_s = N\frac{\sqrt{HP}}{H^{\frac{5}{4}}},$$

in which HP is horsepower and if H_t is the head on the turbine proper corresponding to the H upon which this value of N_s is based, let N_{s_t} be the N_s for the turbine proper, based on H_t; that is:

$$H_t = H_1 + h_{at} - h_{Pd} = H_1 + h_{at} - H_2 - h_{at} + e_d\frac{v_d^2}{2g}$$

from (a) and (b)

or:

$$H_t = H + e_d\frac{v_d^2}{2g}; \text{----------}(d),$$

and

$$N_{s_t} = N\frac{\sqrt{HP}}{H_t^{\frac{5}{4}}} = N\frac{\sqrt{HP}}{\left(H + e_d\frac{v_d^2}{2g}\right)^{\frac{5}{4}}} = N\frac{\sqrt{HP}}{H^{\frac{5}{4}}\left(1 + e_d\frac{v_d^2}{2gH}\right)^{\frac{5}{4}}}$$

or

$$N_{s_t} = \frac{N_s}{\left(1 + e_d\frac{v_d^2}{2gH}\right)^{\frac{5}{4}}} \text{---}(e)$$

In other words, in a turbine having a discharge velocity head from the runner of $\frac{v_d^2}{2gH}$ (sometimes called the "outflow loss", which we may denote by ζ_d) expressed as a percentage of the head H ($\div 100$), and a draft tube efficiency of e_d, the specific speed of the turbine proper can be found from the specific speed of the complete turbine by dividing the latter by $(1+e_d\zeta_d)^{5/4}$. For example, in a turbine of 100 specific speed, having an outflow loss of 25%, and draft tube efficiency of 80%, the specific speed of the turbine proper would be:

$$N_{s_t} = \frac{N_s}{(1+e_d\zeta_d)^{\frac{5}{4}}} = \frac{100}{(1+.80\times.25)^{\frac{5}{4}}} = \frac{100}{(1.20)^{\frac{5}{4}}} = 80$$

Suppose now, that without altering H, the turbine is set at a low elevation compared to head and tailwater surfaces, under a head on the turbine proper $= H_{t_1}$, and the runner altered to give an increased discharge velocity in accordance with Formula (c); the specific speed of the turbine proper. N_{s_t}, will remain the same, but the effective specific speed of the complete turbine will be

$$N_{s_1} = N_{s_t}(1+e_d\zeta_{d_1})^{\frac{5}{4}},$$

in which ζ_{d_1} is the new value of the outflow loss.

Continuing the above example, if the turbine of 80 N_{s_t} is placed 7 ft. below the surface of tailwater and is altered so as to increase its outflow loss to take advantage of this location, its outflow velocity head will be

increased to $\frac{v_{d_1}^2}{2_g}=\frac{H_2+h_{at}-h_{Pd}}{e_d}=\frac{7+34-6}{80}=$ 44 ft., a value of h_{Pd}. of 6 ft. being provided.

If the actual net head H on the system is 20 ft. the outflow loss will be

$$\zeta_{d_1}=\frac{v_{d_1}^2}{2_g H}=\frac{44}{20}=2.20\ (220\%)$$

The specific speed of the complete turbine will then be:

$$N_{s_1}=N_{s_t}(1+e_d\zeta_{d_1})^{\frac{5}{4}}=80(1+.80\times 2.20)^{\frac{5}{4}}=80(2.76)^{\frac{5}{4}}=285.$$

The change in the location of the turbine, accompanied by the increase in the outflow loss which is thus permitted, has therefore made possible an increase in the specific speed from 100 to 285, which would give a corresponding increase in the actual speed of the unit.

It should be understood that the increase in specific speeds made possible by this method involves a certain sacrifice, which in this problem takes the form of a possible loss in efficiency. If a turbine having an original outflow loss of ζ_d and efficiency of e is altered so as to increase its outflow loss to ζd_1, the additional direct loss caused by this change will be $\zeta(\zeta_{d_1}-\zeta_d)$H. The new efficiency due to this will be:

$$e_1=\frac{eH-\zeta(\zeta_{d_1}-\zeta_d)H}{H}=e-\zeta(\zeta_{d_1}-\zeta_d)\text{.....}(f)$$

It is probable that there will also as a rule be an accompanying increase in the other losses in the turbine, although this will not be as great. If all the losses increased in the same ratio as the outflow loss we should have:

$$(1-e_1)=(1-e)\frac{\zeta_{d_1}}{\zeta_d}\text{ or }e_1=1-(1-e)\frac{\zeta_{d_1}}{\zeta_d}.$$

The probable efficiency will lie between these limits, and it is believed will be close to the first value. It should be considered that with draft tubes of types recently introduced it is possible to regain the whirl components of velocity as well as the meridian components; this makes it possible to reduce the relative velocities at the runner discharge and to minimize the losses within the runner by giving the absolute discharge velocity a considerable whirl component. Moreover high speed turbines are continually being improved and higher efficiencies secured.

In the example just considered, the effect upon the efficiency of the great increase in speed which we have found to be possible will be as follows:—Assuming the original efficiency of the 100 N_s turbine to be 90%, and the efficiency of the draft tube to be 80% as already used, the increase in outflow loss from 25% to 220% will reduce the efficiency, due to draft tube losses alone, to

$$e_1=e-\zeta(\zeta_{d_1}-\zeta_d)=.90-.20(2.20-.25)=.90-.39=.51;\text{ or }51\%.$$

This result is largely dependent on the draft tube efficiency which it may be possible to realize. In the structure shown in Fig. 1 the turbine 13 discharges downward with axial and whirling motion and the draft tube 20 is designed to have the greatest possible efficiency in converting the velocity head at the runner discharge into pressure head at the outflow 21 into the tail race. Draft tube 20 is of the spreading conical type suited to runners of high specific speed since it regains efficiently the velocity head of both the axial and the whirl components. From draft tube 20 the water is collected by volute outlet 22 progressively increasing in cross section and further converting velocity head into pressure head at the outflow 21. With such a draft tube the expected efficiency of conversion may be as high as 90%. If this value is applied in the above example the efficiency resulting from an increase in outflow loss from 25% to 220% would be:

$$e_1=.90-.10(2.20-.25)=.90-.195=.705\text{ or }70.5\%.$$

It may be pointed out that in the example discussed above a head on the plant of only 20 ft. was considered. The increase of head on the turbine proper consisted in this example largely of the atmospheric pressure, the distance at which the turbine was assumed to be placed below tailwater being only 7 ft. or just about sufficient to supply the absolute pressure head which has been provided at the point of discharge from the runner. If a case had been considered in which the net head on the plant had been higher it would have been found necessary to locate the turbine at an increased distance below the tailwater surface in order to realize any such increase in specific speed as was found possible in the example considered.

The relations expressed by the preceding formulæ may be more readily grasped if presented graphically. Figure 5 is therefore given for the purpose of showing the effect of the variations of some of the factors upon each other. This diagram is based on the same data as was assumed in the example given above, namely:

The specific speed of turbine proper, $N_{s_1}=80$

Turbine efficiency, $e=.90$

Draft tube efficiency, $e_d=.80$

$\zeta=1-e_d=.20$

$\zeta_d=.25$

$h_{Pd}=6$ ft.

$h_{at}=34$ ft.

The curves plotted in the diagram show the manner of variation of the efficiency in

relation to the specific speed when the specific speed is increased by increasing the outflow loss from the runner. The elevation at which the turbine must be placed with respect to tailwater in order to obtain the increased values of specific speed are shown for three different values of the net head H on the plant, namely, for 20, 40 and 60 ft. It will be noted, for example, that in order to obtain a specific speed of 167 when the net head on the plant is 60 ft. it will be necessary to depress the turbine 20 ft. below tailwater, and this increase in specific speed will reduce the efficiency to 75%.

With the turbine of this invention, the velocity of discharge from the turbine runner can be increased to the point where the pressure head against which the turbine is discharging is reduced to within a small margin of absolute zero, and the turbine will then operate under an effective head represented by the entire gross head on the intake side, including the atmospheric pressure acting on the head water surface. This head in low head plants may be several times the net head measured from head water to tail water so that the turbine can be operated at a speed corresponding to the gross intake head, and will be correspondingly reduced in dimensions and cost and the electrical generator or other driven machine also reduced in size and cost.

In the system shown in Fig. 1 a discharge gate 25 may be closed to exclude the tail race water 10 and with the inflow gate 17 also closed the turbine passages may be pumped out to give clear access to the turbine parts. In the modification of the invention shown in Fig. 2 the draft tube 20′ is continued from the core surface immediately below the axial portion of the tube leading from the runner, in a vertical passage 30 which curves in a vertical plane to pass over a crest 31 which is placed at an elevation slightly higher than the maximum tailwater elevation. The tube then passes downward, to provide a curtain wall, and is completely enclosed to a depth slightly below the lowest tailwater elevation to which the plant would be subjected. The passage thus formed will act as a siphon enabling the turbine discharge to take place below the tailwater surface while at the same time providing a protecting wall or crest to protect the turbine from submergence by tailwater whenever the siphon and draft tube passages are unwatered. This unwatering would be effected by shutting down the turbine, closing the head gates 17, admitting air to the top of the siphon through the air valve 32, and pumping out the water in the draft tube to a point sufficiently beneath the turbine to provide convenient access. The air valve 32 at the top of the siphon can also be used for the attachment of a hydraulic ejector or pump to draw out any air which may collect at that point during operation. It is, however, proposed in general to provide sufficient velocities in the draft tube to sweep out any air which might have a tendency to collect. A curved baffle plate 33 is shown which may be used if necessary to increase the local velocities at the top of the tube at the point where air is most likely to collect.

Not only does the method of this invention provide a means for greatly increasing the specific speeds of turbine for any given head, but it also enables turbines of given specific speeds to be operated at much higher heads than are used in present practice. Present practice is based on the erroneous assumption that the degree of specific speed which can be used depends upon the net head on the plant. This is only true when the practice is adhered to of placing the runner at an arbitrary height above tailwater. The method now in use by hydraulic engineers for determining the leading factors in a power plant design is to plot a curve, based on accepted practice, between specific speed and net head on the plant, and as soon as the available net head is known for any new development, to select from such a curve the specific speed to be used. Such a curve as described, however, does not represent any true relation, since it is plotted between two variables which are not necessarily functions of each other. The permissible specific speed does not depend on the net head on a plant, but upon the pressure-head h_{Pd} beneath the runner. As long as this pressure-head is not allowed to fall to within an unduly small margin of absolute zero, the runner may be as safely used under higher heads as under low. As much margin in pressure (h_{Pd}) may be provided in any case as may be considered desirable by placing the runner at a sufficiently low elevation with respect to tailwater, the distance required being computed by solving Formula (b) for H_2.

To illustrate this point, let us consider the use of a runner of $N_s=82$ having 30% outflow loss, when applied to various heads. Present practice would confine the use of such a runner to heads lower than about 50 ft. The possibilities opened up by this invention in the case of such a turbine are shown in the diagram (Fig. 6) which gives the elevation H_2 of the runner discharge with respect to tailwater which would enable the same turbine to be used under a wide range of heads. This curve is plotted from Formula (b) transposed:

$$H_2=e_d\zeta_d H-h_{at}+h_{Pd}\text{--------}(g)$$

The assumed values are as follows:—

$$e_d=0.80;\ \zeta_d=0.30;\ h_{at}=34\text{ ft.}$$

h_{Pd} has been increased so as to allow greater margin for higher heads, 10 ft. being provided at 100 ft. and 15 ft. at 200 ft. This has

been done to take care of greater variations in pressure when the velocities are higher, and to give additional insurance against corrosion of the metal of the turbine under the higher heads. The formulæ from which the curves have been plotted are:

$$h_{Pd}=5+.05H$$

and

$$H_2=0.8\times 0.3H-34+5+.05H=.29H-29$$

or

$$H_2=29\left(\frac{H}{100}-1\right).$$

To compare the possibilities indicated by these curves with present practice, consider the turbine represented as applied to a head of 200 ft. By placing the runner 29 ft. below the tailwater surface a specific speed of 82 can be realized. For a head of 200 ft. present practice dictates specific speeds not higher than 40, so that the specific speed and correspondingly the actual speed of a turbine can be more than doubled by this method. For example, if a turbine similar to that here considered is built in such a size as to deliver 40,000 H. P. under 200 ft. head, the speed in accordance with present practice would be limited to 150 revolutions per minute, but by the method here outlined can be raised to 300 R. P. M. or higher. This will very greatly reduce the cost of both the turbine and electrical generator and will effect economies in carrying out a power development. The increase in speed just outlined need not involve any sacrifice in efficiency.

Referring to Formula (*c*), it will be noted that the velocity with which the runner discharges into the draft tube is properly a function of H_2, and is not a function of H, the net head. The velocity which can be employed at the discharge from the runner is therefore independent of the net head on the turbine, and for a given atmospheric pressure and a given allowance for the absolute pressure in the draft tube, this velocity is dependent only on the location of the runner with respect to tailwater. It should also be noted that the actual location of the turbine runner should be fixed by measuring H_2 called for by Formula (*g*) from the elevation of low tailwater in a plant in which the tailwater level is subject to variation at different stages of the river and under different conditions of operation of the plant. It will therefore be necessary in some cases to place the runner at a somewhat greater depth below normal tailwater than the value called for by the formula. Whenever a siphon draft tube is used it will also be necessary in plants subject to variations in tailwater level to place the lower wall of the siphon at its crest at an elevation equal to or slightly higher than the highest tailwater expected for the plant, and the discharge end of the siphon must be carried a sufficient distance below the low tailwater level to insure the siphon remaining sealed under all conditions of operation.

In some cases and particularly with the inverted form of turbine the draft tube may have a straight tapered portion interposed between the runner discharge and the spread portion to axially elongate the tube and accommodate a deeper setting of the runner. By the system of this invention a wide range of speeds is available for the turbine and by the adoption of increased speeds, the entire installation may be reduced in size and cost. In many low-head developments this first cost is the really determinative consideration; the problem is not to develop the greatest amount of power possible from the full flow of the river, but is to develop some power as economically as possible. In many such cases, it will pay to allow some water to go to waste, if the rest can be utilized economically. In many cases, efficiency will not be a ruling consideration if rotary speeds for the turbines and generators can be increased to values which will enable cheaper machines to be used. In such cases the system of this invention affords a direct and practicable solution of the problem and makes available power hitherto altogether lost.

In this specification, "tailwater" means the elevation of the surface of the tailrace. "Static discharge head" means the difference in height of tailwater and point of discharge of runner (H_2) plus the head corresponding to the pressure of the atmosphere. "Discharge pressure" and "discharge pressure head" means the absolute pressure and pressure head at the point of discharge of the runner with reference to absolute vacuum as zero. By "continuity of the water column" is meant that the intake, turbine and draft tube passages during operation remain filled with water forming a continuous column through these passages from head water to tailwater without interruption at any section.

I claim:—

1. The combination with a turbine of a downward flow draft tube and a water sealed vacuum chamber into which the draft tube discharges.

2. The combination with a turbine having a downward flow draft tube of a chamber larger in area than the draft tube, said chamber having a curtain wall below the level of the water in the tail race.

3. The combination with a turbine having a downward flow draft tube of a vacuum chamber into which said tube extends, the discharge area of said chamber increasing upwardly for a portion of its height.

4. The combination with a turbine having a downwardly extending draft tube of a vacuum chamber, and means to exhaust the air from said chamber whenever necessary.

5. The combination with a turbine having

a downwardly extending draft tube increasing in diameter downwardly, of a vacuum chamber having a curtain wall extending below the level of the water in the tail race into which the draft tube extends, and means to exhaust the air from the vacuum chamber whenever necessary.

6. The combination with a turbine having a downwardly extending draft tube of a vacuum chamber extending above the level of the bottom of the draft tube, the discharge area of said chamber being greater at an intermediate point than at the bottom.

7. The combination with a turbine and a downwardly extending draft tube of a vacuum chamber, said chamber extending upwardly from the bottom of the draft tube and being of increasing cross-sectional area from its lower portion to an intermediate portion thereof, and means to exhaust the air from said chamber when necessary.

8. The combination in a hydraulic turbine comprising a downward-flow draft tube having a portion leading axially from the turbine, means forming a surface immediately below said axial portion, a conduit leading from said draft tube and having a curved portion therein, and a horizontal baffle member disposed in said conduit and also being spaced and separate from the axial portion of said draft tube and said surface immediately below said axial portion.

9. The combination in a hydraulic turbine comprising a draft tube having a portion leading axially from the turbine and means forming a surface immediately below said axial portion, a conduit leading therefrom, and a transverse baffle disposed in said conduit and spaced from the opposite walls thereof and also being spaced and separate from said draft tube and surface.

10. The combination in a hydraulic draft tube comprising a downward-flow spreading draft tube, and a water-sealed vacuum chamber into which the draft tube discharges.

11. The combination in a hydraulic turbine comprising a downward-flow draft tube which flares at its lower end, a cone extending upwardly into said draft tube for cooperation with the flaring portion thereof, and a water-sealed vacuum passage into which the draft tube discharges.

12. The combination in a hydraulic turbine comprising a downward-flow draft tube, and a water-sealed vacuum passage into which the draft tube discharges, said passage extending upwardly above the uppermost portion of said draft tube.

13. The combination in a hydraulic turbine comprising a downward-flow draft tube, and a water-sealed vacuum passage into which the draft tube discharges, said passage extending upwardly above the uppermost portion of said draft tube, and then extending downwardly to discharge into a liquid basin.

14. The combination in a hydraulic turbine comprising a downward-flow draft tube, a passage leading upwardly therefrom and to one side thereof, and then turning downwardly to a liquid basin to form a liquid-sealed passage.

15. The combination in a hydraulic turbine comprising a downward-flow draft tube and a water-sealed passage into which the draft tube discharges, said passage having upwardly and downwardly extending portions which are connected by a relatively smooth curving upper surface.

16. The combination in a hydraulic turbine comprising a downward-flow draft tube and a water-sealed passage into which the draft tube discharges, said passage having upwardly and downwardly extending portions which are connected by a relatively smooth curving upper surface of large radius.

17. The combination in a hydraulic turbine comprising a downward-flow draft tube, and a water-sealed passage extending upwardly and then downwardly and into which said draft tube discharges, the downwardly-extending portion of said draft tube being flared in the direction of flow therethrough.

18. The combination in a hydraulic turbine comprising a downward-flow draft tube, and a water-sealed passage extending upwardly and downwardly and into which the draft tube discharges, the upwardly-extending portion of said passage having walls contracting in the direction of flow through said passage.

19. The combination in a hydraulic turbine comprising a downward-flow draft tube, and a water-sealed passage extending upwardly and then downwardly and into which said draft tube discharges, the upwardly-extending portion of said passage having walls which contract in the direction of flow, while the downwardly-extending portion of said passage has walls diverging in the direction of flow.

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