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Hutarew

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[54] PUMPED STORAGE POWER PLANT

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[52] **U.S. Cl.** .... **290/52 X;** 290/43 R; 417/374
[51] **Int. Cl.** **F03b 3/10**
[58] **Field of Search** 417/374, 351; 290/52, 1, 290/44, 53

[56] **References Cited**

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[57] **ABSTRACT**

Pumped-storage plant including a pump turbine, an electric motor-generator coupled with the pump turbine, an additional pump also coupled with the motor-generator, and means for admitting operating medium separately to the pump turbine and the additional pump, the additional pump having a construction for pumping only in an upper delivery head subrange ranging upwardly to maximum delivery head, and the pump turbine having a construction so that, when operating as a pump, it pumps only in a lower delivery head subrange ranging downwardly to minimum delivery head, both of the subranges being at least mutually adjacent, the pump turbine being further constructed so that, when operating as a turbine, it operates within the entire fall head range.

7 Claims, 3 Drawing Figures

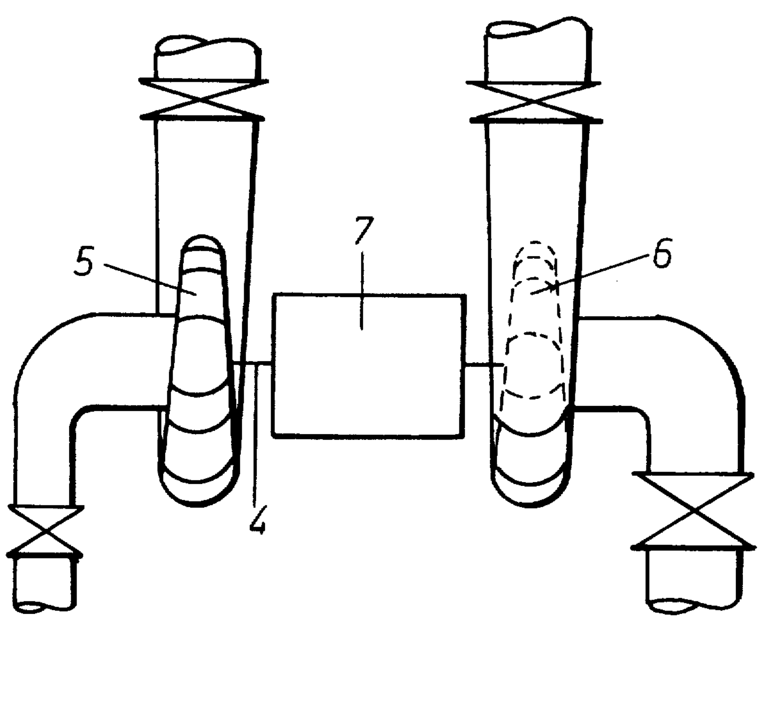
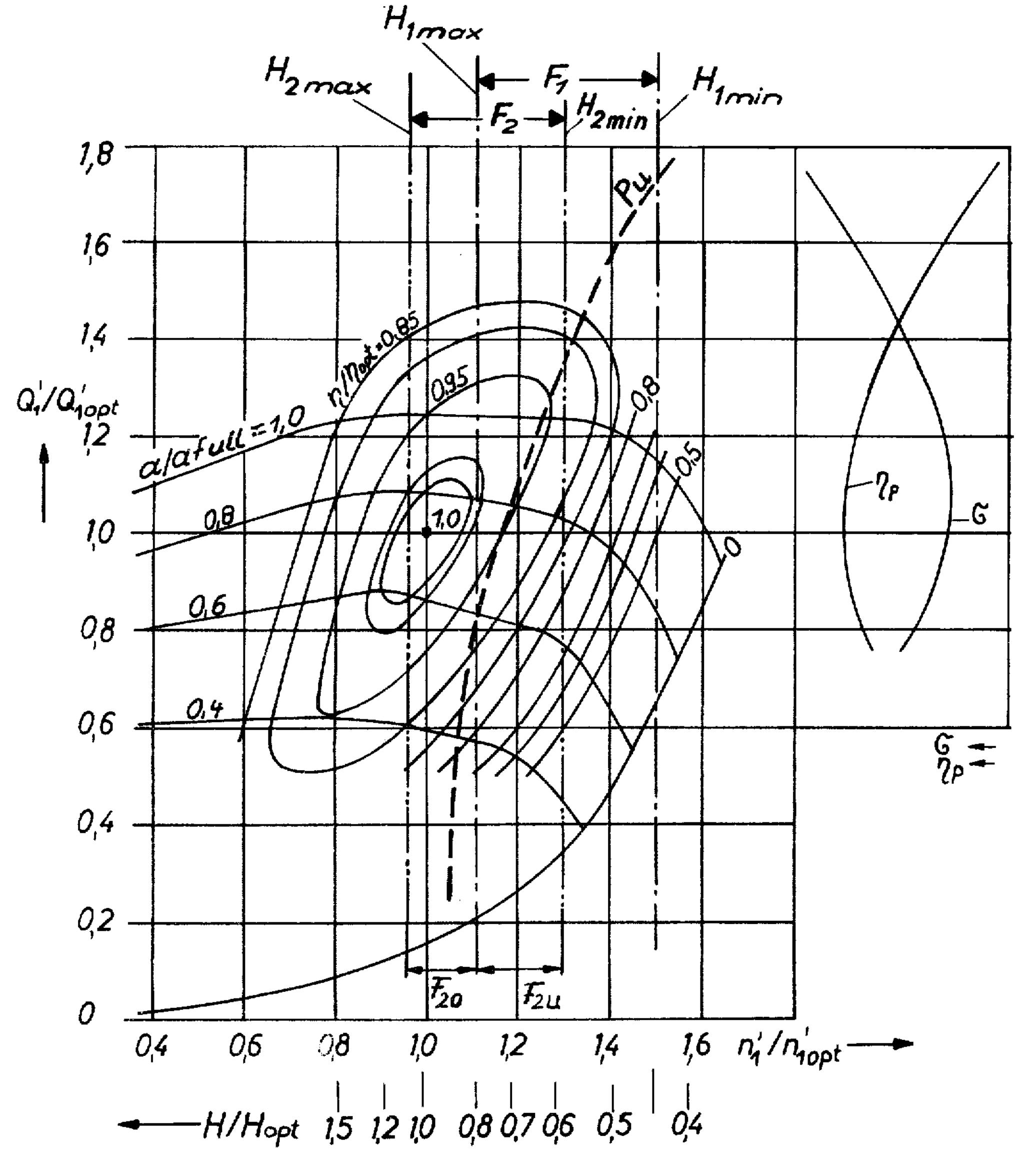


Fig.1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H2max
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F2
H2min
H1min
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ηP
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F2o
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n'1/n'1opt
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Fig.2

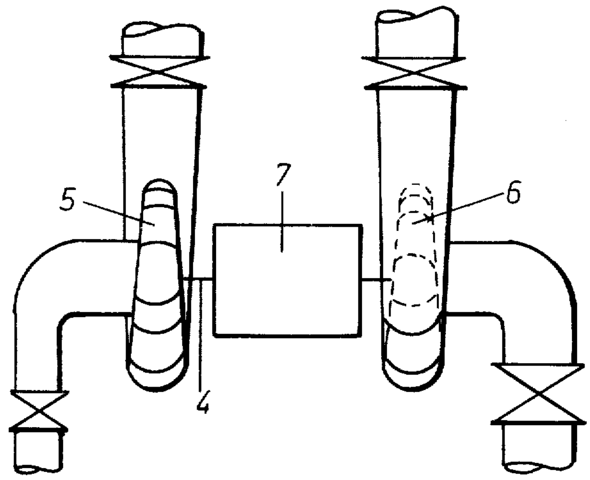
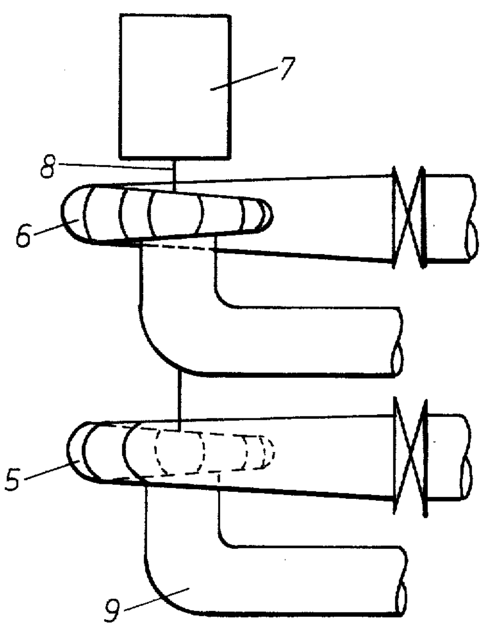


Fig.3



PUMPED STORAGE POWER PLANT

The invention relates to a pumped-storage power plant, particularly, to a pumped-storage power plant for a wide range of fall heads and delivery heads, having a pump turbine provided with adjustable guide vanes and coupled with an electric motor-generator.

As is well known, for physical reasons the optimum for turbine and pump operation, both of which are at the same speed of rotation, occur at differernt fall and delivery heads for the two modes of operation. In pumped-storage plants having a relatively wide operating range between the maximum and minimum fall heads and between the maximum and minimum delivery heads respectively, the following aggravating conditions occur. In both modes of operation, regions of the operating range have relatively low effeciency must be taken into account; a condition which is normally in the lower part of the fall and delivery head ranges. This is usually accompanied by an increase in the running instability or roughness. During turbine operation, the region characterized by pressure fluctuations in the suction pipe and detrimental secondary phenomena related thereto becomes more pronounced and larger. But also during pumping operation, increasing pressure fluctuations at the entrance to the guide vanes as well as to the rotor can be expected with increasing distance from the optimum operating point because of flow separation. But the most serious point is that during pumping operation, the cavitation behavior becomes more and more unfavorable with increasing distance from the optimum operating point.

It is known that in order to avoid undesirable cavitation effects with respect to possible destruction of material as well as with respect to a detrimental effect upon the characteristic curves, considerably lower levels for installation of the machine must be selected with increasing delivery head range than with a smaller delivery head range in the vicinity of the optimum operating point. Primarily, however, the pressure-side cavitation at the rotor, which becomes more pronounced with decreasing delivery head or increasing output flow, would require economically unfeasible extremely large feed heights or levels, in order to avoid the attendant drop in efficiency and a shift on the characteristic curve toward the steep decline in the delivery head, which occurs beginning with a given region.

These phenomena, caused by physical process, generally apply to so-called conventional sets of machines formed of a pump and a turbine, as well as to machine sets with reversible pump turbines. In the latter case, the following special conditions apply. Due to the relative position of the pump characteristic outside of or beyond the optimum of the performance diagram of the turbine, the aforedescribed unfavorable conditions of turbine operation are encountered even at a much smaller fall head range with decreasing fall head.

It is true that in a pump turbine with adjustable guide vanes, the possibility exists to a certain degree, for the pumping operation, to limit pump flow for decreasing delivery head by reducing the guide vane aperture so that the installation depth basically required, i.e, without adjustable guide vanes, can be reduced. However, the pump characteristic is then shifted into a region of unfavorable efficiency. The detrimental effect during turbine operation, as compared with a machine set having a separate turbine, can in some cases be compensated for by selecting a lower speed for turbine operation than for pumping operation. This, however, results again in a large expenditure for the electrical part of the plant and is unable to be realized advantageously in all rotary speed ranges.

It is an object of the invention to provide a pumped-storage power plant with a pump turbine which affords coverage of a wide range of heads in both modes of operation, but, however, have the power plant operate outside unfavorable regions of the performance diagram with respect to cavitation behavior or efficiency, and avoid low, economically unjustifiable installation levels as well as the need for an electric machine having two operating speeds.

With the foregoing and other objects in view, there is provided in accordance with the invention a pumped storage power plant comprising a pump turbine, an electric motor-generator coupled with the pump turbine, and an additional pump also coupled with the motor-generator, means for admitting operating medium separately to the pump turbine and the pump, the additional pump being constructed for pumping only in an upper delivery head subrange ranging upwardly to maximum delivery head, and the pump turbine is so constructed that, when operating as a pump, it pumps only in a lower delivery head subrange ranging downwardly to minimum delivery head, both of the subranges being at least mutually adjacent, the pump turbine being further so constructed that as a turbine, it operated within the entire fall head range. The pump turbine is thus constructed advantageously so that maximum delivery head is located in the region of the optimum of the turbine performance diagram, and preferably somewhat below the optimum normalized speed.

In this manner, there is obtained a pumped-storage plant with a wide fall and delivery head range which operates economically druing turbine operation as well as during pumping operation thereof with good efficiency and, particularly during pumping operation thereof, largely avoiding regions wherein there is danger of cavitation.

A pumped-storage plant having a pump turbine and an additional pump for controlling large fall and delivery heads has, in fact, become known heretofore, wherein both machines are used simultaneously in series for pumping operation (note the article in "Hydraulische Maschinen für Pumpspeicheranlagen..." by E. H. Muehlemann in Escher-Wyss-Mitteilugen 1972/1. p. 3 to 11, particulary FIG. 6, p.6). Each machine of this heretofore known assembly takes over part of the total delivery head. Such an installation, however, is not suited for controlling a large delivery head range, because the same detrimental operational conditions described hereinabove would occur therein. This known assembly furthermore requires a separate starting turbine whereas, in an installation according to the invention of the instant application, a separate starting turbine can be dispensed with if, in accordance with a preferred embodiment of the invention, during operation as a turbine, the additional pump is operated with the same direction of rotation as the pump turbine. Then, the pump can be accelerated with the pump turbine which operates as a turbine, and the pump can be used as a start-up turbine for the pump turbine in the direction of rotation of the pump. Although the latter procedure is used only in the lower fall head range, wherein the pump functioning as a turbine operates in a relatively unfavorable operating range, this will in most cases be possible down to the minimum fall head because, on the one hand, the nominal pump output of the pump turbine is lower than that of the pump and, on the other hand, when starting up, maximally only about 25% of the nominal power is required against the closed guide vanes when the norminal rotary speed has been reached.

Other features considered as characteristic for the invention are set forth in the appended claims.

Although the invention is illustrated and described herein as embodied in a pumped-storage power plant, it is nevertheless not intended to be limited to the details shown, since various modifications and structural changes may be made therein without departing from the spirit of the invention and within the scope and range of equivalents of the claims.

The construction and method of operation of the invention, however, together with additional objects and advantages thereof will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings, in which:

FIG. 1 is a performance graph or diagram of the machines of a pumped-storage power plant constructed in accordance with the invention of the instant application; and

FIGS. 2 and 3 are diagrammatic views of two different embodiments of the pumped-storage power plant of the invention showing varying assemblies of the machines thereof.

Referring now to the drawing and first, particularly, to the diagram or graph of FIG. 1, normalized speeds n_1'/n_{1opt}' referred to the respective optimal value, are plotted along the abscissa increasing from the left to the right-hand side of the figure, and values H/H_{opt} of the fall or delivery head, also referred to the respective optimum value, are plotted along the abscissa increasing from the right to the left-hand side of the figure along the ordinate at the left-hand side of FIG. 1, normalized water flow Q_1'/Q_{1opt}', again referred to the optimal value is plotted. In the diagram of FIG. 1 there is also plotted for turbine operation the efficiency curves η/η_{opt}, or so-called "shell curves," and the curves of different guide vane aperture a/a_{full} as well as the pump characteristic curve Pu for pump operation of the pump turbine. For better understanding, the curves of the cavitation coefficients σ and the efficiencies σ_P for pump operation of the pump turbine, as a function of Q_1'/Q_{1opt}', are added at the right-hand side of FIG. 1.

The operational behavior of a heretofore known pumped-storage plant with only a pump turbine will be explained first with the aid of the diagram or graph of FIG. 1. For this purpose, the maximum and minimum fall or delivery head H_{1max} and H_{1min} shown by the dot-dash lines in the diagram of FIG. 1, are given for the relatively large operating range F_1; in order to simplify the presentation, the pipeline losses have not been taken into consideration. It is known that during turbine operation, this range F_1 is outside the optimal point $\eta/\eta_{opt} = 1$; it is still relatively close to this point for the maximum fall head H_{1max}, but even with the guide vanes fully open, $a/a_{full} = 1$, it is below $\eta/\eta_{opt} = 0.7$ for the minimum fall head H_{1min}. For the pumping operation, it will be seen from the diagram of FIG. 1 that unfavorable cavitation coefficients σ and efficiencies η_P are obtained in the lower delivery head subrange, as previously explained hereinabove. In the diagram example of FIG. 1, these unfavorable values are above about $Q_1'/Q_{1opt}' = 1.4$.

The situation is completely different, however, when the pumped-storage plant is constructed in accordance with the invention of the instant application. The fall and delivery head range F_2 for this case is represented by respective dash-dot-dot-dash lines in the diagram of FIG. 1 for H_{2min} and H_{2max}. It will be readily seen that the optimal point $\eta/\eta_{opt} = 1$ is fully encompassed with the range F_2 for turbine operation and is near H_{2max}. Rather favorable values for the efficiency are also yet obtained for H_{2min}.

For pump operation, the range of delivery heads F_2 is divided into two subranges F_{2u} and F_{2o}. The pump turbine can be used for pump operation, of course, only in the lower fall head range F_{2u} down to H_{2min}. The upper limit of this range is located at about the value H_{1max} of the first example of a plant with only a pump turbine. The η_P and σ values obtained the range F_{2u} at the level of the intersection of H_{2min} with the pump characteristic curve Pu are considerably more favorable than in the first case discussed hereinabove. The adjacent upper subrange F_{2o} is taken over by the additional pump alone of the invention of this application, which can be constructed specifically for this delivery head subrange. The two pump subranges should be divided so that a certain amount of overlap is obtained and so that overall, optimum efficiency and the least possible installation levels can be achieved.

In FIG. 2, one embodiment of an installation according to the invention having a horizontal shaft **4** is shown. The motor-generator **7** is located between the pump turbine **5** and the additional pump **6**. Whichever machine **5** or **6** is not in use is vented. The pump-turbine **5** is provided with conventional adjustable guide vanes.

In the embodiment of a set of machines having a vertical shaft **8** according to FIG. 3, that hydraulic machine which requires the greater feed height should be in the lower position, if possible. In the embodiment of FIG. 3, the pump turbine **5** is constructed for a greater feed head, because it is advantageous that the suction pipe **9** of the pump turbine **5** be not penetrated by the shaft **8** and, in consideration of the turbine operation, a sufficient axial extension of the suction elbow should be realized. In the embodiment of FIG. 3, the pump **6** is disposed immediately above the pump turbine **5**. However, it is also possible to locate the pump **6** above the motor-generator **7** with the suction elbow extending upwardly.

I claim:

1. Pumped-storage plant comprising a pump turbine, an electric motor-generator coupled with said pump turbine, an additional pump also coupled with said motor-generator, and means for admitting operating medium separately to said pump turbine and said additional pump, said additional pump having a construction for pumping only in an upper delivery head subrange ranging upwardly to maximum delivery head, and said pump turbine having a construction so that, when operating as a pump, it pumps only in a lower delivery head subrange ranging downwardly to minimum delivery head, both of said subranges being at least mutually adjacent, said pump turbine being further constructed so that, when operating as a turbine, it operates within the entire fall head range.

2. Pumped-storage plant according to claim 1 wherein said pump turbine is constructed so that said maximum fall head is located in a region of optimal performance in a performance diagram of the turbine made of said pump turbine.

3. Pumped-storage plant according to claim 2 wherein said maximum fall head is located below optimum normalized speed.

4. Pumped-storage plant according to claim 1 wherein said additional pump has a direction of rotation which is the same as that of said pump turbine in the turbine mode of operation thereof.

5. Pumped-storage plant according to claim 1 wherein said additional pump is actuable as a starting turbine for starting up said pump turbine in the pumping mode of operation thereof.

6. Pumped-storage plant according to claim 1 wherein said pump turbine has adjustable guide vanes.

7. Pumped-storage plant according to claim 5 wherein said pump has guide vanes which are adjustable to form a wider aperture therebetween than required for normal pump operation.

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