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Original Paper

Analysis on Hydraulic Design of Runner Blades of Francis Turbine

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Abstract

Francis turbine is the most widely used model in hydropower station, and the hydraulic design of runner blades affects the efficiency of the unit. This paper discusses how to complete the hydraulic design of Francis turbine runner blades according to the given parameters. In hydraulic design of Francis turbine runner, firstly, the structural scheme is determined according to the given parameters. On the basis of referring to excellent hydraulic model, a Francis turbine runner blade is designed according to the given head. By analyzing and calculating the data, the geometric parameters and axial projection of the Francis turbine runner flow channel are determined, and the axial flow network is drawn and checked, so as to complete the calculation of axial vortex line and blade drawing. Finally, the airfoil is thickened by a certain thickening principle.

Keywords

Francis turbine, Hydraulic design, Rotating wheel, Blade drawing

1. Introduction

Hydraulic turbine is a kind of vane-type fluid machinery. Among the components of hydraulic turbine, runner is the core component and the most important flow component of hydraulic turbine. Its performance will directly affect the quality of the whole unit, so the design of turbine runner has a direct impact on the power generation of hydropower station.

2. Overview

Runner is the key component of hydraulic turbine, which directly converts water energy into mechanical energy. The design of runner directly affects the flow capacity, hydraulic efficiency, cavitation performance, working stability and adaptability of hydraulic turbine to off-design conditions. At present, in the hydraulic design of Francis turbine runner, it is assumed that:

(1) Water flow is an ideal fluid;

(2) The relative motion in the runner is steady motion;

(3) The number of blades is infinite, and the thickness of blades is infinitely thin;

(4) The water flow in the runner is axisymmetric.

Under the above assumptions, different assumptions are made on the axial flow, which leads to different hydraulic design methods. The binary theory design method adopted in this design assumes that the axial flow in the runner area is potential flow and axisymmetric flow, and the runner blades are infinitely thin, and the vm is distributed according to the potential flow law along the water-crossing section, and its vm size is related to the two coordinates of the section. The curvature of the runner of Francis turbine with medium and high specific speed is small, and most or all of the blades are located in the turning area of the runner. The turning of water flow has a great influence on the runner speed, that is, the runner speed increases from the top crown to the bottom ring along the water crossing section, which is close to the distribution law of the assumed potential flow on the runner surface in binary theory, so the method of binary theory is mostly used to design the Francis turbine with medium and high specific speed. This method is stricter in theory than monistic theory, and the actual effect of the designed runner is also good, so it is widely used.

3. Determine the Calculation Conditions of the Mixed Flow Turbine Runner

Based on the design head and referring to the model water turbine model, selecting a suitable model can determine the optimal unit speed, optimal operating efficiency, maximum unit flow rate, and relative height of the guide vanes of the model water turbine. Based on the design head in China, the specific speed can be determined. It can be seen that the increase of can be achieved by separately increasing or simultaneously increasing. When the design head H is greater than 125m, the main method is to increase and the auxiliary method is to increase; When the design head H is less than 125m, the main method is to increase and the auxiliary method is to increase. Preliminary selection of relevant data for designing the impeller.

3.1 Determine Model Speed and Model Flow Rate

For the convenience of drawing calculations, usually the hydraulic calculation and design of the runner are carried out by taking the model head and the model runner diameter. Calculate the rotational speed and flow rate of the model runner separately under the determined runner calculation conditions.

3.2 Determine the Relative Height of the Guide Vanes

The relative height of the guide vanes directly determines the cross-sectional area of the inlet of the runner flow channel. Increasing, while keeping the diameter of the impeller constant, will increase the inlet flow area of the impeller, increase the flow rate, and increase the output of the unit. At the same time, increasing the height of the guide vanes will limit the strength of the guide vanes, and prolonging the height of the flow channel will cause the inlet edge of the impeller blades to lengthen, affecting the strength and stiffness of the blades themselves. Therefore, the selection must also be appropriate, so that the relative opening of the guide vanes is maintained within 30%~70% during the calculation of operating conditions. At this time, the outlet angle of the guide vanes is between, which can minimize the hydraulic loss inside the water guide mechanism.

3.3 Determine the Crown and Lower Ring of the Impeller

The shape of the crown on the impeller has a significant impact on efficiency and maximum flow rate, and there are two types of shapes: linear and upward curved. The linear upper crown has good manufacturing and processing technology, but it will reduce efficiency and Q11 at high flow rates, so it is rarely used now. The upward curved crown, although slightly more troublesome in manufacturing and processing, greatly increases the flow area near the impeller outlet, which is conducive to improving the unit flow rate Q11 and hydraulic efficiency. The upward curve should not be too close to the horizontal position, as there may be secondary reflux in the upper crown area within a small flow range. Therefore, the angle between the tangent line of the upward crown shape and the centerline of the water turbine should be controlled on the left and right. At the same time, ensure that there is no detachment or impact at the junction between the lower part of the crown and the drainage cone, and the angle between the drainage cone and the center of the main shaft should be controlled within.

The function of the lower ring of the impeller is to increase the strength and stiffness of the impeller and form a flow passage with the upper crown. The shape of the lower ring of the impeller and the cross-sectional area near the impeller outlet have a significant impact on the impeller's water passing capacity, efficiency, and cavitation performance. The shape and cone angle of the lower ring are related to the specific speed of the water turbine. For high head (H>230m) low ns water turbines, the lower ring shape is curved, which can make the water flow turn smoothly with a larger curvature radius, otherwise it is prone to flow separation. At this point, the diameter of the impeller outlet D2/D1 æ 1; For water turbines with low head (H ＜ 150m) and high ns, the shape of the lower ring is conical or cylindrical, which means that the lower ring has a certain cone angle, which helps to increase the cross-sectional area of the outlet of the runner. At this time, D2/D1 ＞ 1, it is beneficial for increasing the flow rate, reducing the water flow velocity at the outlet of the runner, and improving the cavitation and cavitation performance, but the cone angle of the lower ring should not be too large.

3.4 Determine the Number of Blades

The number of turbine blades affects the energy and cavitation performance of the water turbine, and also has a significant impact on the structural strength. The number of blades for a mixed flow turbine is generally 13-19. The lower the ns, the more leaves there are. As the number of blades decreases, the squeezing effect of the blades on water flow weakens, the flow rate increases, and the friction loss decreases. However, the force per unit area of the blades increases, the cavitation performance decreases, and the strength is affected; As the number of blades increases, the friction loss increases, the water flow squeezing effect strengthens, the flow rate decreases, and the hydraulic efficiency decreases. At the same time, the selection of blades should also consider the processing method and the issue of matching with the number of guide vanes to avoid entanglement of the unit vibration due to mismatch between the two.

3.5 Draw an Axial Flow Network

On the axial flow channel diagram, select 5 flow lines, including the upper crown flow line and the lower ring flow line, and make the flow rate in the unit flow channel equal between adjacent flow surfaces. Furthermore, binary theory assumes that axial flow is a potential flow. Therefore, in the axial plane, the streamline and potential line are orthogonal, and an accurate flow network can be obtained according to the above conditions.

The drawing of the first approximate flow network: Assuming that the axial flow velocity is uniformly distributed at a sufficient point before and after the turning of the flow channel, it is designated as the starting inlet section and the outlet section of the flow channel, and the inlet and outlet sections are divided using axial flow lines according to the principle of equal flow rate in each unit flow channel. Four axial flow lines are taken, and the inlet section is divided into four equal parts, with each section length of; The outlet section is evenly distributed and divided into four equally sized circular rings, and the radii of each channel are calculated. Then, based on this, complete the first approximate flow network by orthogonalizing the streamline and equipotential lines. According to the condition that the flow rate of each unit flow channel is equal, accuracy check and calculation can be carried out. During the process, successive approximation can be used to adjust until the error meets the design requirements.

3.6 Blade Airfoil Thickening and Forming

In order to ensure sufficient strength of the blades, it is necessary to thicken them. The thickened airfoil should be streamlined to ensure that the liquid flow through the blades does not cause vortices and detachment. Therefore, the thickness variation along the length direction of the airfoil should follow certain rules. The maximum stress on the blades of a mixed flow turbine occurs at the upper crown flow surface. Therefore, the maximum thickness of the blades at this location should be determined by the requirements of blade strength and stiffness. In actual design, it is also possible to refer to the blade thickness of similar runners and consider specific working conditions, blade shape, and materials for comprehensive analysis and comparison, ultimately determining a reasonable maximum thickness value. The thickness variation along the airfoil bone line can refer to the aerodynamic airfoil thickness law with good performance, which can obtain a good velocity and pressure distribution along the airfoil surface, ensuring that the runner has good energy and cavitation characteristics.

Expand and thicken the approximate conical or cylindrical surface using geometric projection, and thicken the back of the airfoil with the airfoil bone line as the working face. Approximating the computational flow surface of a trumpet shaped spatial surface with a conical surface, then converting the blade profile lines on the flow surface to the approximate conical surface, thickening the blade profile on the conical unfolding surface, and finally transferring the thickened blade profile on the conical unfolding surface to the projection map of the impeller shaft surface.

4. Conclusion

The mixed flow impeller is widely used in industrial fluid treatment and plays an extremely important role in urban power supply systems. It is an indispensable role in modern society, widely used and involves various sectors of the national economy, and plays a crucial role. The impeller is the core part of the pump, and the performance, efficiency, anti cavitation ability, and shape of the characteristic curve of the pump are closely related to the hydraulic design of the impeller. Therefore, continuous analysis and optimization of the hydraulic design of the turbine blades are of great significance for the development of the turbine.

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