Experimental study on hydraulic performance Optimization of pump house with ultra-short forebay

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Abstract: The intake channel of circulating water pump house is an important part of water supply system in thermal power plant. The good hydraulic performance of intake channel is very important for operation efficiency of water pump and ensuring the safety of power plant. A hydraulic model of scale 1:12 is used to study the hydraulic characteristics of circulating pump house with an ultra-short forebay in this paper, the reasons for the formation of undesirable flow patterns, such as flow bias at the inlet, rotating filter outlet of the flow channel and backflow the circulation of the pipe at the bottom of the flapper, and the appearance of the suction vortex in the suction chamber, are analyzed, a rectifying facility consisting of "column + beam" is proposed to be installed in the forebay, a curved bias pier is added at the outlet of the traveling network, and a breast wall is suggested to be set in the suction chamber. With undesirable flow patterns in the original scheme are eliminated, the uniformity of the flow velocity distribution in the flow channel is improved, the flow pattern is relatively stable and smooth, and the ideal inflow condition of the suction mouth is guaranteed. The research results can provide a reference for the design and hydraulic performance optimization of the pump house of similar thermal power plant.

1. Introduction

The hydraulic performance design of the inlet channel of the circulating water pump house in thermal power plant involves the safety and economic problems of the circulating water pump operation. Good flow channel design is not only beneficial to the safety of the pump, but also can make the pump house layout compact and reasonable, and reduce the overall investment. Intake forebay is an important part of the circulating water pump house. The circulating water reference flow of large fire nuclear power plants is large. The forebay often needs a large space if designed according to the conventional diffusion angle. In practical engineering, limited by the site, construction cost and other aspects, sometimes we have to adopt a shorter design scheme of the forebay, and the research corresponding auxiliary rectifier facilities has become the focus of pump house design.

The auxiliary rectification facilities of the circulating water pump house, which needs to be determined according to the characteristics of the circulating water pump house, have no specific mode,. Fu et al. [1] proposed the hydraulic performance optimization measures by setting a semi-circular diffusion pier and a suspended partition plate through the model test. Wang et al. [2] proposed to set beams and bias walls with the same width as the forebay on the front of the outlet of the bias tunnel through model tests to improve the uniformity and smoothness of the water body. Luo et al. [3] proposed to optimize the hydraulic layout, the diffusion angle of the forebay and the length of the forebay in the pumping station by optimizing the diffusion angle, setting the bottom ridge and column. Bai et al. [4] [5] proposed...
through the model test and numerical simulation of the pump house, proposed a “multi-character” structure composed of inclined and straight bias piers to reduce the scope and strength of the reflux area. Xia et al. [5] used RNG k-ε model to numerically simulate the flow pattern of the pumping station’s forebay with a single row of square columns. The arrangement of columns can significantly improve the flow pattern. Gao et al. [6] used the Reynolds time-averaged N-S equation combined with the standard k-ε turbulence model to numerically simulate the flow pattern of the forebay and the intake pool. After the combination of three rectification measures, namely, the discontinuous bottom ridge, the discontinuous bucket and the water pressure plate, the flow pattern of the whole forebay and the intake pool was improved.

The circulating water pump room of a coastal thermal power plant is taken as the research object in this paper. In view of the hydraulic problems such as the flow pattern at the inlet of the flow channel caused by the ultra-short forebay body shape, the amplification effect of the bias flow caused by the outlet of the filter network body shape, and the vortex on the surface of the suction chamber, the rectification measures are put forward, such as the combination of ‘column + beam’ in the forebay, the arc bias pier at the outlet of the filter network, and the breast wall in the suction chamber. These measures ensure the smooth and uniform flow along the intake channel, and maintain the pump running near the efficient working point. The test results can provide a scientific basis for the optimization design of approximate engineering.

2. Model Details

A new 2 × 1000MW supercritical coal-fired power plant is under construction. Seawater direct current circulation supply System is adopt. Seawater is introduced into the forebay of the pump house, supplying water for 6 circulating pumps, and the width of the inlet channel is 6m. The pump house is arranged in turn along the flow direction with gate holes, trash racks, side inlet rotary filter, seawater intake pump, circulating pump and other equipment. The transverse length of the forebay is 43.2m, and the longitudinal length is 10m. The plane layout of a single unit is shown in Figure 1.

Figure 1 Layout plan of circulating water pump room
2.1 Model scale
The physical model of circulating water pump house focuses on the overall flow velocity distribution and the generation and disappearance of vortices. Therefore, the model is designed according to the Fr similarity criterion (gravity similarity criterion) to meet the similarity of the overall flow field, and the flow velocity field distribution is measured on this basis. At the same time, because the generation of flow vortex is related to the characteristics of water viscosity and surface tension, according to the HI standard of the United States and the standard of the Japanese Mechanical Association, the Reynolds number of the suction mouth of the model $Re > 6 \times 10^4$, and the Weber number $Wb > 240$, which can minimize the influence of the water viscous force on the formation of vortex in the model and achieve similar vortex in the model.

The model scale is chosen as $\lambda_L=12$, it is calculated that $Re=1.1 \times 10^5$ and $Wb=773$, which can meet the requirement of vortex similarity.

2.2 Model making and measurement
The simulation range includes a part of the intake pipe, the inlet forebay to the circulating pump suction chamber and the suction mouth. The main part of the model is made of organic glass, so as to observe the flow pattern, including the occurrence and development of vortex.

Water level is controlled using 1/50mm Vernier stylus and flat water tank. The flow velocity was measured by OA-type rotary slurry optical fiber sensor developed by Nanjing Institute of Water Resources, ADV three-dimensional ultrasonic flow velocity meter (mainly for the flow velocity distribution in the inlet channel) and the Pitot tube (mainly for the flow velocity distribution around the suction mouth and throat) connected with a special acquisition system. The flow rate is measured and controlled by a standard rectangular water measuring weir. The silk thread method and coloration method are used to observe the flow pattern, and the horizontal projection angle of the left and right swing direction of the silk thread should not greater than 10°.

![Figure 2 Model photos](image-url)

3. Analysis of hydraulic characteristics of pump house
The 97% low tide level and two units operating conditions (6 pumps fully open) were selected for the experiments on the flow velocity distribution under the typical cross section. Due to the short forebay, the inflow diffuses insufficiently in the forebay and forms reflux on both sides of the bias pipe. The inlet of 3# and 4# flow channel directly opposite to the inlet pipe was obviously biased, with violent
turbulence and high surface yon. The maximum average flow velocity deviation of inlets on both sides of the rotary filter reaches 57 %. On the 1.5D section at the front of the suction mouth, the flow is obviously concentrated to one side, and backflow occurs on the other side. The flow formed around the suction pipe, surface vortex was found occasionally in the suction chamber, 8 points at the bottom of the bell wire swing violently. Suction chamber water flow conditions are poor.

Figure 3 Schematic diagram of the original plan flow pattern

4. Experimental Study on Optimization Scheme

In the preliminary test results, it can be found that under different operating conditions, there are adverse flow patterns in the circulating water pump house, such as inlet bias flow, water surface oscillation, suction chamber reflux, external circulation and surface vortex, which are not conducive to the safe and stable operation of the circulating water pump. It is necessary to adjust the overall flow pattern of the circulating water pump through optimization measures. The objective of the scheme optimization: the flow condition of the forebay is good and the inlet flow of each channel is uniform. The flow between the filter is uniform and smooth, and there is no surface vortex in the suction chamber. The flow around the suction bell is uniform and smooth.

4.1 Forebay optimization scheme

The flow pattern of the circulating pump house was observed during the test. It was found that the insufficient diffusion of the flow in the forebay was the main reason for the bias flow at the inlet of the channel and the water level fluctuation in the channel. The rectification measures in the forebay should be able to meet: (1) Promote the diffusion of water in limited space. (2) Weaken the influence of bias pipe flow on the inlet. For this purpose, two rows of columns were arranged at the inlet of the forebay. The baffle was set at the bottom of the first row of columns, and a cross beam was set behind the second row of columns. The rectification optimization scheme was adopted, and six pumps were selected as typical working conditions.
Figure 4 Schematic diagram of the forebay optimization scheme

Under this scheme, the bias flow of 1 #, 2 # and 3 # channels has been greatly improved (shown in figure 5). The maximum average flow velocity deviation of the chest wall section at the inlet of 3 # channel decreases from 57 % to 16 %, and the average flow velocity deviation is basically less than ±10 %. The uniformity of lateral flow velocity and vertical flow velocity has been significantly improved compared with the original scheme. The average velocity of the right section of the filter inlet is 0.45 m/s, and the left section’s average velocity is 0.42 m/s. The velocity distribution of the left and right inlets is close, and the flow distribution is uniform (shown in figure 5( c ) ). From the vertical distribution of flow velocity, the mainstream is inclined to the bottom, and the flow in the inlet is relatively stable and smooth.

4.2 Optimization scheme of suction chamber

During the experiment, it was found that there were two cases of bias formation at the outlet of the filter: (1) When the inlet flow of one side of the filter was significantly larger than the other side, the flow formed a stable bias towards the side of the smaller flow rate (in figure 6). (2) When the inlet flow on both sides of the filter is roughly equivalent, the flow initially flows along the center line and spreads along the path, accompanied by an unstable oscillation from side to side, so that the shear movement occurs between the water bodies with different flow rates. The two sides gradually form reflux, and the reflux area further compresses the flow. The amplitude of flow swing increases, and a partial flow is formed after a certain swing (in figure 7).
In view of the phenomenon of transverse flow deviation, the bias piers on both sides are changed into elliptical arc sections, and the ratio of long side to short side is 1 : 3, which can eliminate the reflux space on both sides, and achieve the function of stabilizing water flow and slow gradual diffusion. The experimental results show that under the effect of the curved guide pier scheme, the lateral deviation and reflux of the flow in the suction chamber disappear, and the lateral flow velocity distribution is uniform.

As shown in Figure 9, the flow velocity inside the suction chamber presents a distribution form of large at the top and small at the bottom in the vertical direction. Through the coloring liquid method of observing the flow state of the suction chamber. When the flow passes through the outlet of the filter, the flow is affected by the bottom of the hill, and the main flow is sharply deflected upward. When it is close to the suction pipe, the water is absorbed by the flapper and the water is rapidly submerged, thus forming a surface depression, and there is a certain probability of forming a surface vortex in the prototype. In order to prevent the formation of surface vortex, a breast wall is set at the end of the curved pier (in Figure 10), and the bottom of the breast wall is lower than the lowest water level of the suction chamber by 0.9 m.
The outlet flow of the filter passes through the diversion and adjustment of the arc bias pier, and due to the setting of the breast wall, the mainstream submerges at the front of the chest wall. The surface water flow moves slowly after the chest wall, and the flow in the suction chamber is relatively calm. Using the wire method to observe the flow pattern around the flapper. The filament swings stably at 8 points in the front of the suction flapper, and the maximum deviation of the average velocity is 15%. The horizontal projection angle of the wire swing is less than 5°.

![Figure 9 1.5D section velocity distribution diagram of suction chamber (without breast wall)](image)

![Figure 10 1.5D section velocity distribution diagram of suction chamber (with breast wall)](image)

5. Conclusion
In this paper, a physical model test is carried out for the inlet duct of circulating water pump house in a thermal power plant. According to the results of the original scheme, the optimization of the program was carried out, and the following conclusions are drawn:

(1) In the original scheme, due to the short distance of the forebay, the water flow can not fully diffuse in the forebay, resulting in serious flow bias at each inlet of the flow channel. There are adverse flow patterns such as asymmetric flow on both sides of the filter inlet, partial flow in the suction chamber, circulation flow outside the bottom of the suction mouth, and intermittent observation of suction vortex, which would cause vibration and cavitation damage of the pump.

(2) The scheme of “column + cross beam” in the forebay aggravates the collision, mixing, momentum and energy exchange between water flow particles, and promotes the full turbulent diffusion in horizontal and vertical directions. The flow in each inlet of the channel is relatively stable and smooth, and the flow in the filter inlet is symmetrical, The flow distribution is uniform and the velocity distribution is reasonable.

(3) The diffusion section of the filter outlet is equipped with an arc-shaped guide pier, which can eliminate the backflow space on both sides and make the flow stable and gradually diffuse. The velocity distribution of homogenized suction chamber after the breast wall is set up in the suction chamber, the surface water flow behind the breast wall moves slowly, and the water flow in the suction chamber is
relatively calm, which effectively prevents the circulation outside the tube at the bottom of the suction mouth and the generation of surface vortex.

The overall hydraulic performance of the pump house flow channel is optimized, and the research results can provide a reference for the hydraulic performance optimization of the pump house forebay with similar structure.

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