Study on hydraulic transient process of K hydropower station with low head, large flow and complex long tail water system

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Abstract. K hydropower station is a hydraulic engineering with the main task of power generation, which is also a typical hydropower station with low head, large discharge and long tail water conveyance system. The hydraulic characteristics of these-type hydropower stations are of high water inertia, large amplitude of surge chamber water level fluctuation and poor stability of units. Therefore, due to the control requirements of the stability, the area of the horizontal section of the surge chamber is usually large, which leads to the long period of water level fluctuation of the surge chamber and the relatively long time of unit output oscillation in the transition process, and the regulating quality of the unit is often difficult to meet the control requirements due to the large inertia time constant of the water flow in the water conveyance system and the unique characteristic curve of unit. It is important to design appropriately to ensure the safe and stable operation of the hydropower station. In this paper, it is shown the process of hydraulic design of these-type stations. According to the design of K hydropower station, the simple surge chamber and restricted orifice surge chamber are compared in terms of hydraulic characteristics including the head loss of steady operation, the water level fluctuation of transition process and the stability of operation. Based on the optimized restricted orifice surge chamber, the overall calculation and analysis of the hydraulic transition process and the stability analysis of K hydropower station are carried out, it is concluded that the unit stability quality of the K power station is fine and the maximum pressure of pipe is in control, which provide strong support for the safe and stable operation of K station. The comprehensive and thorough analysis in this paper can provide reference for the design of the similar projects.

1. Project Introduction
The K Hydropower station is installed with 600MW units totally, the single unit capacity is 100MW, and the rated head is 60.0m. The whole power station is composed of the header barrage dam, water delivery system and underground power house system. The maximum dam height of the barrage dam is about 14m and the length is about 314.43m. The water conveyance system consists of the intake, the headrace tunnel, the tailrace branch tunnel, the tailrace surge tank, the long tailrace tunnel and the tail outlet. The headrace tunnel is arranged in a single hole and single machine, and the diameter of the tunnel is 7.7m. The section size of the six tailrace branch tunnels is the same as that of the headrace tunnel. The tailrace surge chambers is connected to the tailrace branch tunnels. The three units share a tailrace water surge chamber and one tailrace tunnel with a length of about 8.6km. downstream the surge chamber. The layout of one hydraulic unit water conveyance system is shown in Figure 1.
2. Optimization of surge chamber type

According to the design experience, the simple surge chamber and the restricted orifice surge chamber are suitable for the hydropower station with low head, large discharge and long tunnel. The shape of the simple surge chamber is unchanged, the structure is uncomplicated, and the effect of reflecting water hammer wave is good. However, the water level fluctuation amplitude is large and the attenuation is slow, so the volume of surge chamber is large. The hydraulic loss at the junction of tunnel with the surge chamber is relatively large when units operate normally. The restricted orifice surge chamber is arranged with a small orifice at the bottom, and the water flows into and out of the chamber to consume a part of energy, which can effectively reduce the amplitude of the water level fluctuation and accelerate the attenuation speed, so that the volume required of the surge chamber is small. Besides the head loss is small during normal operation. For K Hydropower Station, the two types of surge chambers have the possibility of being arranged. It is necessary to select a surge tank type with fast attenuation, small fluctuations in output, low head loss, and low engineering cost.

2.1. Comparative analysis of steady flow state

When stable operation, the head loss at the bottom of the surge tank in the water system is closely related to the flow state. The flow state at the bottom of the two surge chambers is simulated by three-dimensional numerical simulation software, and the head loss is calculated as a comparison basis. The calculation condition is that all three units are running stably. In this condition, the discharge of the water conveyance system is the largest to simulate distribution of the flow at the bottom surge chamber is uniform or not. The flow velocity distribution at the bottom of the surge tank is shown in Figure 2~3.
It can be seen from the flow velocity distribution diagrams in Figure 4~5, in stable operation, although the restricted orifice surge chamber has the existence of impedance holes, it has minimal influence on the flow velocity distribution. While, due to the area of the simple surge tank is relatively large compared to the tunnel section at the bottom, some of the water in surge tank is not affected by the outlet flow of the branch tunnels and the inlet flow of tailrace tunnel. The flow velocity remains at 0 and distribution is uneven.

Using the Bernoulli energy equation, the head loss of the two types of surge chambers can be calculated for stable operation. The calculation results are shown in Table 1.

| Parameters                  | restricted orifice surge chamber | simple surge chamber |
|-----------------------------|----------------------------------|----------------------|
| Head loss (m)               | 0.752                            | 1.840                |

The calculation results show that the head loss of the restricted orifice surge chamber is 1.088m, which is smaller than that of the simple surge chamber. Because of the energy exchange between the water at the bottom of the simple surge tank and the water in the tunnel, the flow state is disordered, so the water head loss of the simple surge tank is larger. Therefore, from the perspective of the flow state, the impedance type is better than the simple surge chamber during stable operation.

2.2. Comparative analysis of extreme values of hydraulic transition process

According to the layout of the K hydropower station, in the transient process conditions, the main difference between the restricted orifice surge chamber and the simple surge chamber on the water conveyance system is the minimum pressure of the draft tube inlet and the water level of the tailrace surge chamber. Therefore, the extreme value control conditions are selected for comparative analysis. The conditions are as follows:

Condition 1: The highest water level in the upstream, the lowest average tail water level in the downstream 30-year runoff series, the three units reject load suddenly when running normally at rated output. In this condition, the lowest water level of surge chamber and the minimum pressure on the draft tube inlet appear.

Condition 2: The highest generating water level in the upstream, the 10000-years-flood water level in the downstream, and the three units reject load suddenly when running normally at highest output. In this condition, the highest water level appears in the tail surge chamber.

The comparison of calculation results is shown in Table 2 and Figure 4 to 5.

| Parameters                  | Restricted orifice surge chamber | Simple surge chamber |
|-----------------------------|----------------------------------|----------------------|
| Minimum pressure of draft tube inlet | 6.73                            | 2.07                 |
| Water level of surge chamber | Maximum                          | 977.80               | 983.89               |
|                             | Minimum                          | 943.24               | 938.58               |
It can be seen from the calculation results that, when arranging the restricted orifice surge chamber, the minimum pressure of the draft tube inlet is larger than that of the simple surge chamber, so the safety margin is larger. And it can effectively reduce the fluctuation range of the water level in restricted orifice surge chamber. The maximum water level reduction is up to 6.09m, which can greatly reduce the amount of excavation of the surge chamber and save investment.

2.3. Comparison and analysis of units regulation stability
According to the theory of unit regulation stability, the analysis of units stability without considering the load characteristics of the grid is conservative and safe. It is known that the lower the working head of the turbine, the worse the stability of unit regulation. The calculation condition is selected as follows: the upstream is normal water level, the downstream is full output water level, the three units of the same hydraulic unit suddenly drop 2% of the rated load when running at rated output. The calculation results are shown in Figure. 6–7.
It can be seen from the calculation results that the quality of unit regulation of restricted orifice surge chamber is similar to that of the simple surge chamber, but the water level fluctuation of the restricted orifice surge chamber is obviously faster, which is more favorable to the stability of power grid.

2.4. Summary

From the results of the flow state analysis, hydraulic transition process analysis, and the comparative analysis of the units regulation stability, it can be seen that the restricted orifice surge chamber is superior to the simple surge chamber. So the K hydropower station is equipped with a restricted orifice tailrace surge tank.

3. Analysis of hydraulic transition process

According to the design experience of conventional hydropower stations, the conditions of large initial head and large flow may become the control conditions of the extreme value of the water conveyance system in transition. So the following operating conditions are selected as the calculation conditions.

Condition D1: The highest generating water level in the upstream, the full output water level in the downstream, and the three units of the same hydraulic unit reject load suddenly when running normally at exceed output. The discharge of this condition is large, which may become the control condition of the maximum unit speed.

Condition D2: the highest generating water level in the upstream, the normal generating water level in the downstream, and the three units of the same hydraulic unit reject load suddenly when running normally at rated output. The initial head of this condition is large and the discharge is also large, which may become the control condition of the maximum pressure of pipe and the unit speed.

Condition D3: The highest generating water level in the upstream, one unit rejects load suddenly when running normally at 50% rated output. In this condition, the initial head of the unit is large, but the discharge does not reach the maximum.

The initial parameters of the units in the three conditions are calculated in Table 3.

| Table 3 Comparison of initial parameters of the units |
|------------------------------------------------------|
| Parameters | Conditions      | Condition D1 | Condition D2 | Condition D3 |
| Initial head (m) | 58.4 | 70.7 | 68.3 |
| Initial opening of guide vane | 99% | 99% | 80% |

The calculation results of the transition process are shown in Table 4 and Figure 8~13.
### Table 4 Calculation results comparison of transition process

| Parameters                             | Condition D1 | Condition D2 | Condition D3 |
|----------------------------------------|--------------|--------------|--------------|
| The maximum pressure of pipe (m)       | 105.1        | 105.2        | 106.7        |
| Maximum increased speed of unit        | 48.7         | 49.7%        | 39.3%        |

It can be seen from the calculation results that the maximum rise rate of unit speed in the condition D2 is the largest, and the maximum pressure of the pipe in the condition D3 is the largest. Although the initial discharge is not the maximum in the condition D3, the dQ/dY value is maximized within this opening degree, and the initial head of the unit is higher than the other conditions, so it is more likely to become the control condition of the maximum pressure. Therefore, for such a power station with low conditions.

![Figure 8 Process of unit speed in condition D1](image)

![Figure 9 Process of pressure in condition D1](image)

![Figure 10 Process of unit speed in condition D2](image)

![Figure 11 Process of pressure in condition D2](image)

![Figure 12 Process of unit speed in condition D3](image)

![Figure 13 Process of pressure in condition D3](image)
head and large-discharge, the maximum pressure of the single-unit-reject-load condition may be the highest.

4. Conclusion

Taking K hydropower station as an example, this paper analyzed the optimal method of surge chamber for hydropower stations with low head, large discharge and long tailrace tunnel, and calculated the hydraulic transition process. The main conclusions are as follows:

(1) It is determined that the restricted orifice chamber is superior in terms of small head loss of stable running, small amplitude of water fluctuation and fast attenuation in transition process.

(2) Due to the low head of the power station, in order to meet the requirements of the Toma section, the horizontal section of the surge tank is often large and needs to be rationally designed. According to the calculation results, the unit quality of the K power station is fine.

(3) For low-head, large-discharge conventional hydropower stations, the control conditions of water hammer pressure are not necessarily the conditions of the units in the same hydraulic unit reject load simultaneously. The condition of single unit rejects load may become the control condition of water hammer pressure.

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