APPLICATION OF INTELLIGENT TECHNOLOGY IN FLOOD DISCHARGE FACILITIES OF XILUODU HYDROPOWER PLANT

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ABSTRACT

Flood discharge facilities guarantee the security of Xiluodu hydropower plant, which consist of 7 spillway surface holes and 8 flood discharge deep orifices in the dam, and 4 long tail flood discharge tunnels arranged on each side of the dam. The floods from the surface holes and deep orifices are designed to overflow stratified and collide in the air, the energy of the flood will be dissipated in the plunge pool. The maximum discharge capacity of the surface holes and deep orifices is 32,278 m^3/s. The 4 flood discharge tunnels are all consisted of pressurized section and an unpressurized section. Their maximum discharge capacity is 16,648 m^3/s. These flood discharge facilities have been successfully used for nearly 500 times. The hydraulic hoist, the pressure-filled water-seal, the status monitoring and the fault diagnosis system and the image monitoring system cooperate each time, while large quantity of data has been acquired at the same time. Based on calculating and analysis of these data, Xiluodu hydropower plant has gradually improved the reliability of the whole system by technological remolding and upgrading, also constantly improved the integration of the system, striving to achieve unattended self-operating of the hydropower station.

1. BACKGROUND

1.1 Flood discharge facilities

Xiluodu Hydropower Plant is located on the lower reaches of Jinsha River, which is also the border of Leibo County in Sichuan Province and Yongshan County in Yunnan Province. This mega pivotal project is designed to generate electricity, also to control flood, block sand and improve the navigation condition of the reservoir area. The installed capacity of the Xiluodu Hydropower Plant is 13860 Mw, which is the third largest on earth, also the critical point of the implementation of the West power supply to the East in China.

The flood discharge facilities of the plant are consisted of 7 spillway surface holes and 8 flood discharge deep orifices in the dam, and 4 long tail flood discharge tunnels arranged on each side of the dam, with the maximum total discharge capacity of 48926 m^3/s.

1.2 Spillway surface hole

The spillway surface holes are symmetrically arranged on both sides of the overflow centerline of the arch dam, and the centerline of the holes coincides with the overflow centerline. Steel radial gates are set up to block water, and the adjacent openings are separated by gate piers.

The WES overflow curve is adopted on the weir; the upstream surface of the top of the weir is an elliptic curve. The nose ridge with large dip angle and continuous nose ridge plus shunt tooth ridge is adopted at the end of the surface hole to dissipate energy of flood.

1.3 Flood discharge deep orifice

The 8 deep orifices are arranged in the arch dam and their center line is arranged in the middle of the corresponding section of the dam. The entrance grooves are located on the gate pier of the orifice, which is arranged in a circle, and the center of the circle coincides with the circle center of the plane trajectory line of the spillway surface hole control point. which is convenient for the effective collision between the water tongues of the surface hole and the deep orifice.

The pressure turning structure is adopted in the graphic design of the body of the deep orifice, and the axis of the body is arranged radially in front of the control point and properly deflected to both sides after the control point, so as to avoid the adverse influence of the radial concentration of the discharge flow of the arch dam, and reduce the overlap phenomenon of the water tongue in the falling area. The dynamic water impact pressure in the plunge pool can also be controlled in the range of initial design.

Orifices with outlets at an angle of elevation are designed to raise, the others with outlets at an angle of depression are designed to bow. The entrance section is equipped with accident maintenance groove, the outlet is equipped with radial gate, and the whole flow channel is protected by the composite steel plate.

The maximum discharge capacity of the holes and orifices is 32278m^3/s, accounting for about 66% of the total discharge capacity of the Xiluodu hydropower plant.

1.4 Long tail flood discharge tunnel

The 4 tunnels are all composed of intake sluice, pressurized tunnel section, underground working gate chamber, non-pressurized tunnel section, dragon's fallen tail section, exit open channel and bucket section. The pressurized section is used to make a plane turn in all 4 tunnels. The inlets of the tunnels are placed between the dam and the inlets of the plant, the outlets are located on the lower reaches of the tailrace tunnel outlet of the plant, which are basically symmetrically arranged.

About 70% of the waterhead is concentrated on the tail, which accounts for 25% of the length of the whole cave. The inlet velocity from the non-pressure upper flat section to the "Dragon's fallen tail" section is 25 m/s, the velocity of the end of the anti-arc section is 50 m/s. This arrangement could reduce the range of the high velocity and the difficulty of aeration to reduce erosion, also is conducive to the centralized treatment of high-speed flow problems. The maximum discharge capacity of the 4 tunnels is 16648 m3/s, accounting for about 34% of the total discharge capacity of the Xiluodu hydropower plant.

1.5 Operation

The reservoirs of Xiluodu and Xiangjiaba are naturally cascade connected. The lowest water level of Xiluodu tail water is normally 369.25m. The Xiangjiaba hydropower plant operates between the dead water level of 370.00m and the normal storage water level of 380.00m, which coincides with the waterhead of Xiluodu. The two reservoirs influence with each other, which are also unified operated.

The controlling water area of Xiluodu and Xiangjiaba dam are 454,400 km^2 and 458,800 km^2, accounting for nearly 97% of the Jinsha River and 50% of the section of the Yangtze River above Yichang city. The flood control capacity of the two reservoirs is 5,553,000,000 m^3, which is adjacent to the upper reaches of the Yangtze River. The two reservoirs are the most important engineering measure to solve the flood controlling problem of the upper reaches of the Yangtze River, which can improve the flood control capacity of Yibin and other cities along the river combined with other measures.

Meanwhile, the flood storage of the Jinsha River by the two reservoirs in the flood season reduces the flood directly into the Yangtze River, also can improve the flood control capacity of the middle and lower reaches of the Yangtze River combined with the help of the Three Gorges reservoir, which is part of the flood control system of the Yangtze River.

2. OPERATING SYSTEM OF STEEL RADIAL GATE OF THE DEEP ORIFICE

2.1 Brief

The flood discharge deep orifices are the most important flood discharge facilities of the Xiluodu pivotal project, with their high waterhead, large discharge flood capacity and power, the reliability of their operating system is the key to ensure the safety of the Xiluodu hydropower plant in flood season. The operating system of the radial gate at the outlet is composed of an executive system and an auxiliary system. The executive system includes a steel radial gate, a hydraulic hoist and a pressure-filled water-seal. And the auxiliary system includes the online state monitoring for radial gate, the status monitoring & the fault diagnosis system and the image monitoring system.

2.2 Steel radial gate

The model of orifice is a short tube with pressure. Its discharge capacity is calculated according to the equation,

$$Q = \mu A_k \sqrt{(2gH_0)}$$

where Q = quantity of flow (m^3/s), A_k = exit area (m^2), H_0 = waterhead above the central line of the outlet of the orifice (m), μ = flux coefficient (0.88), g = acceleration of gravity (m^2/s).

The maximum discharge capacity of a single hole is 1629 m^3/s. Each single deep orifice is equipped with an inlet accidental groove, a steel radial gate and an outlet working groove. The sectional dimension of the orifices is 6.0m·6.7m. The typical profile of the flood discharge deep orifice is shown in Figure 1.

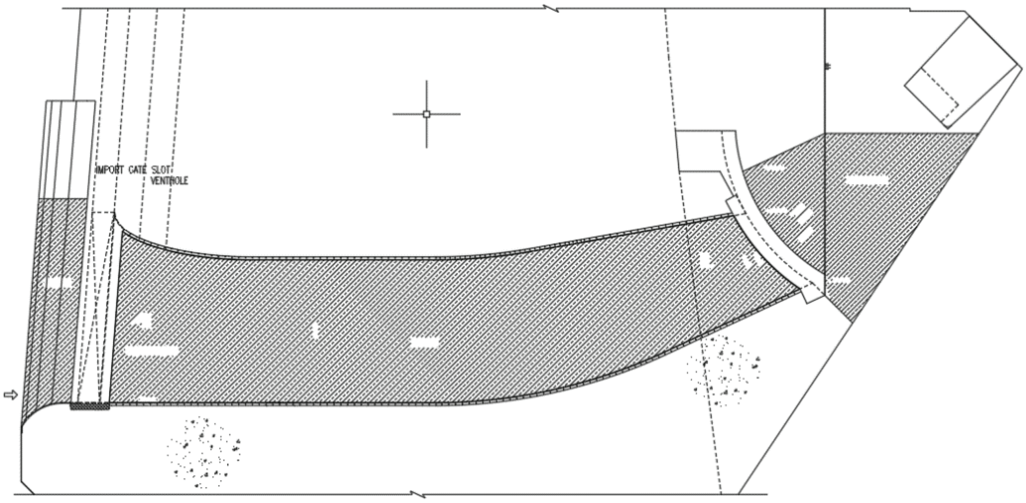

Figure 1 : The typical profile of the flood discharge deep orifice.

2.3 Hydraulic hoist

Each radial gate is opened and closed by a central swing double-acting hydraulic hoist. The main technical characteristics and performance assurance parameters of the hoist are as shown in Table 1.

Table 1 : The technical characteristics and performance assurance parameters of the hoist.

Characteristic	Parameter
Rated load while opening	4000kN
Rated load while closing	1000kN
Maximum stroke	11.5m
Working Pressure while opening	18.8Mpa
Working Pressure while closing	3.2Mpa
Requirement	Entirely closing or opening in dynamic water
Type of the hoist	Middle swing double-acting hydraulic hoist

2.4 Pressure-filled water-seal system

The designed waterhead of the orifice is far beyond 80m, as the pressure-filled seal system is being used. Each radial gate is sealed with an expansion water seal, the 8 seals share a public water supply, drain and vacuum system. The main water seal pressure water is drawn from the fire water supply. A pressure stabilizing water tank is set at the corresponding elevation of the dam, which passes water through the electric ball valve and water filter to the main pipe. The water inlet at the top of the water seal of each gate is supplied by the branch pipe which is supplied by the main pipe. After the normal impoundment of the reservoir, the average actual pressure inside the telescopic water seal is about 1.48 MPa, which can fully meet the requirement of water seal. The schematic diagram of the pressure-filled water-seal system is shown in Figure 2.

2.5 The status monitoring & the fault diagnosis system

The status monitoring and fault diagnosis system is a set of data storage, management and analysis system, which takes the large-scale database as the background and integrates the functions of data monitoring, data mining, data statistics and analysis and processing. The on-line monitoring and fault analysis of the main equipment of Xiluodu hydropower plant are realized. As a network-oriented distributed opening system, it is composed of several servers. The open ethernet connection data is transmitted through the local area network after reliable physical isolation to the outside. Constantly monitoring and security analysis of the status of the equipment of the plant are carried out where the network is within reach.

The arch dam is equipped with local control unit, important signals in the local control cabinet of the hydraulic hoist and pressure-filled seal system connected with the corresponding remote RIO through hard wire with IO type. Meanwhile, each local PLC forms an on-site DP Bus through optical fiber to communicate with the local cabinet of the arch dam local control unit to realize data exchange, monitor its opening and closing process in real time, and find out any hidden dangers or symptoms in time, which is equivalent to the "black box" of power system production safety monitoring and recording.

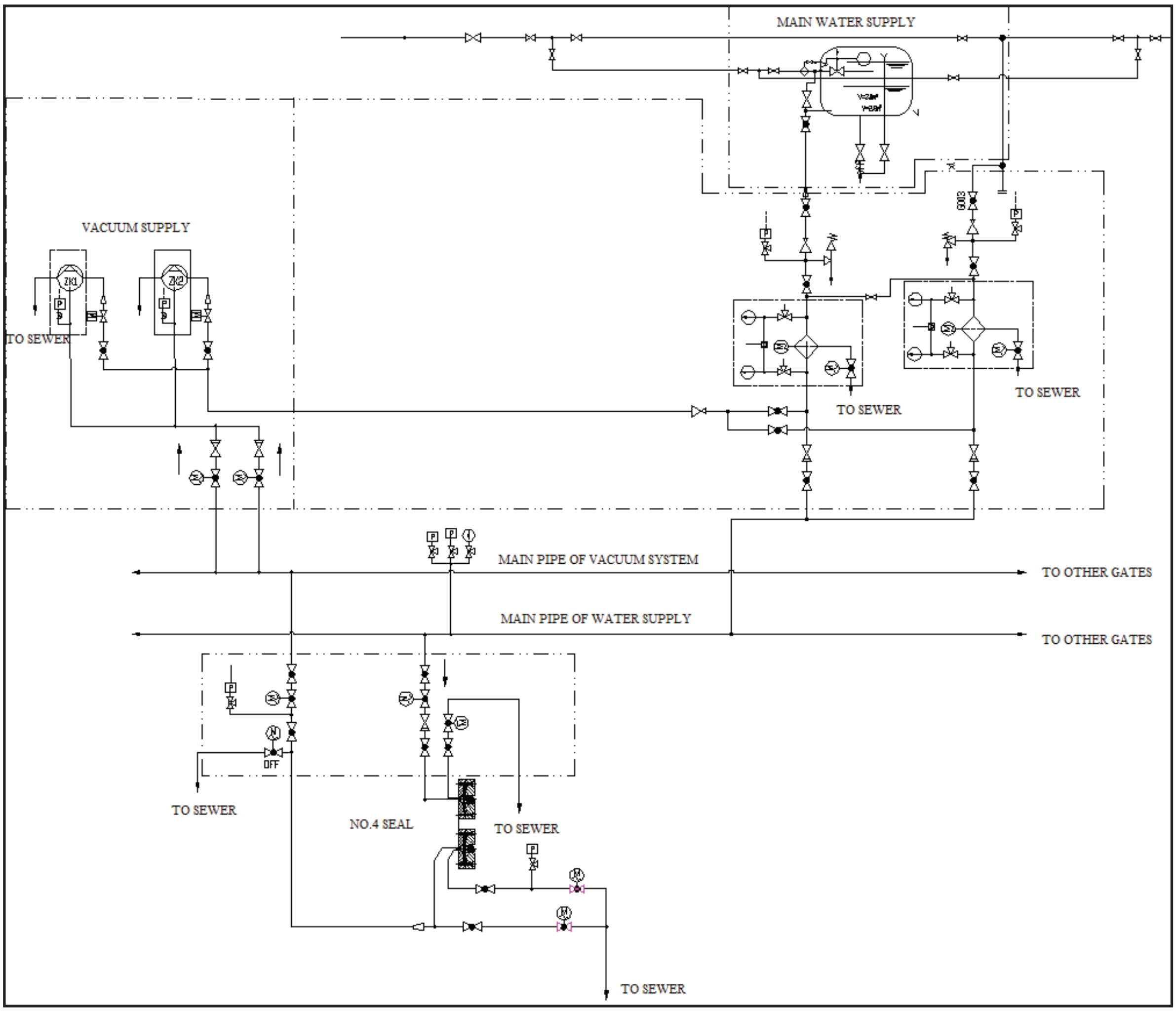

Figure 2 : The typical profile of the flood discharge deep orifice.

2.6 The image monitoring system

The image monitoring system adopts a hierarchical structure, and each partition is divided into control level and local level. According to the actual situation of camera distribution, ordinary super five types of network lines are used for camera points no more than 100m, and optical fiber is used for camera points more than 100m away. The execution system of the radial gate of the deep orifice is within the monitoring range of the image monitoring system, which can realize the unattended operation.

3. AUTOMATICALLY CONTROLLING SYSTEM OF RADIAL GATE OF THE DEEP ORIFICE

3.1 System flow

The malfunction and operation signal could be remotely collected and processed by the central control layer of the status monitoring and fault diagnosis system.

In the non-flood season, all the operation of the deep orifices could be executed by the local centralized control layer or the local distributed layer, while all the status is being monitored constantly by the upper computer. In the flood season, each deep orifice will be remote-centralized and operated by the central layer, which could coordinate the execution of all the flood discharge facilities, including the electric generator.

For example, the procedures for opening of the radial gate of deep orifice for example are as follows,

(I) The main computer of the central control layer will choose the corresponding flood discharge deep orifice and calculate the lasting time by the protocol of dispatching regulation when the upland water reached the flood discharge threshold.

(II) The plant will initiate the alarming broadcast, and the affected area of flood discharge will be confirmed to be absolute clear by the image monitoring system.

(III) Distant opening orders are given from the central computer to the local cabinets of the hydraulic hoist and pressure-filled water seal system.

(IV) The pressure-filled water seal system will open the two electric ball valves of draining at the bottom of the seal, the electric ball valve of draining at the top of the seal, electric ball valve of venting at the bottom of the seal. The water filled in the seal will outflow thoroughly with enough time.

(V) The pressure-filled water seal system will close the two electric ball valves of draining at the bottom of the seal, the electric ball valve of draining at the top of the seal, electric ball valve of venting at the bottom of the seal.

(VI) The pressure-filled water seal system will start the vacuum pump and open the electric vacuum pump. The expansion seal will shrink completely after the vacuuming and will not expand again.

(VII) The pressure-filled water seal system will close the electric vacuum pump and the vacuum pump and open the two electric ball valves of draining at the bottom of the seal, the electric ball valve of draining at the top of the seal, electric ball valve of venting at the bottom of the seal.

(VIII) A signal will be transmitted to the cabinet of hydraulic hoist system that the gate opening condition is satisfied by the cabinet of the pressure-filled water seal system.

(IX) The hydraulic hoist will be accomplished the opening procedures and send a signal to tell the pressure-filled water seal system that the gate is fully open.

(X) The status monitoring and fault diagnosis system will monitor the main signals of the hydraulic hoist system and the pressure-filled water seal system constantly, while the image monitoring system confirms that the equipment in the hoist room is in normal condition.

3.2 Practical application

As the main flood discharge facility of Xiluodu pivotal project, the flood discharge deep orifices have been operated by Xiluodu hydropower plant since 2015. The total discharge of all the deep orifices was 34,270,000,000 m^3, and the operation details of the deep orifices are shown in Table 2.

Table 2 : Statistic data of the operation of the deep orifice of 2015-2018.

Orifice No.	Total times of opening and closing (time)	Total time of discharging (hour)
1	4	89.88
2	76	3066.55
3	100	3796.94
4	62	1680.55
5	70	1359.94
6	82	2525.15
7	74	2409.38
8	4	55.32
Total	432	14983.71

In the flood season of 2015, the first-time success rate of automatic opening and closing of the steel radial gate of the flood discharge deep orifices is quite low. By collecting and analyzing the operation data with the status monitoring and fault diagnosis system, the Xiluodu hydropower plant has taken a lot of measures to improve, such as:

(I) Replacing the unstable equipment pertinently, such as recoil water filter, water ring vacuum pump and electric ball valve.

(II) Large number of simulations and practical experiments were carried out to optimize the linkage process of the pressure-filled water seal and the hydraulic hoist system.

(III) The on-line monitoring system of the gate was added to monitor and collect the data of vibration, noise and elastic deformation in the process of opening and closing of the steel radial gate in constantly.

(IV) Vibration monitoring in the hydraulic hoist was added while opening and closing. Various means were adopted to After the equipment upgrading and optimization of the opening and closing procedures are completed, the reliability of the equipment has been improved every year. The first success rate of automatic opening and closing over the years is shown in Figure 3.

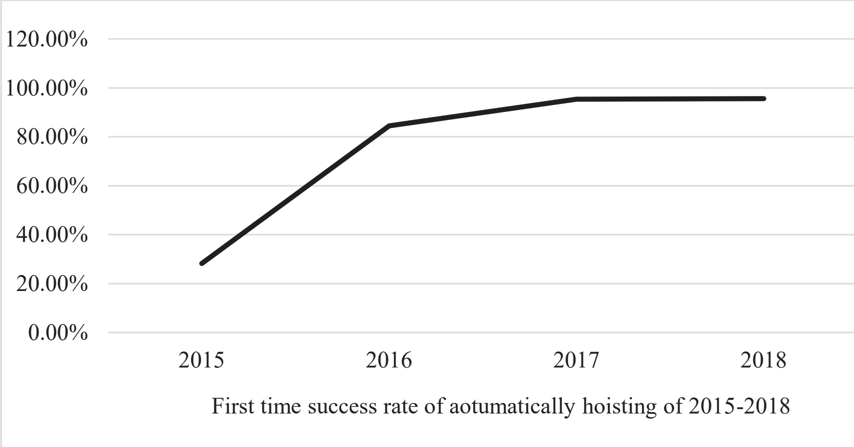

Figure 3 : First time success rate of aotumatically hoisting of 2015-2018.

4. CONCLUSION

The rainy season in the Jinsha River basin begins in June every year. Since the flood discharge deep orifices were put into automatic operation in 2015, the maximum upland water inflow is 16300m^3, and all the 8 holes have participated in flood discharge. In accordance with the instructions of the Yangtze River General Prevention and Control Center on reservoir operation, Xiluodu hydropower plant strictly implementes the operation process and standard requirements of flood discharge facilities, and gradually improves the stability of the equipment by various means. As a result, the reliability of the automatic operating system of the flood discharge deep orifice is stabilized around 95%, ensuring the safely and reliable operation of flood discharge facilities, also accumulating valuable technical experience.

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