Water Hammer Analysis of Hydropower Station with Multi-level Water Intake

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Abstract. It's special and complicated of water hammer analysis of hydropower station with multi-level water intake.In this paper, water hammer analysis is carried out for a hydropower station with stratified intake.The results show that the project layout and power generation water level meet the operation requirements.In addition, the ventilation hole and the upper pipe are considered as surge chamber to carry out the sensitivity analysis of the surge chamber impedance coefficient. The results show that due to the small area of the vent hole, the calculation results are almost unchanged when it is considered as a surge chamber. However, when the lower intake water to generate electricity, the upper pipeline can be considered as a surge chamber, which has a inhibitory effect on the water hammer.

Keywords: water hammer; hydropower station; multi-level water intakes.

1 Introduction

The dam of a hydropower station is designed as an gravity dam. A bottom outlet and environmental flow release equipment have been integrated into the dam body.

The environmental flow turbine is located at the downstream of the culvert. The intake structure adopts the method of multi-level water intakes, and there are 4 water intakes in total. Each pipe is composed of the inlet section, the horizontal buried pipe section and a vertical section in the dam. After leaving the dam, a bifurcation pipe is arranged to divide into the environmental flow turbine section and environmental flow outlet section.The main purpose of this article is to check the water hammer protection[1~3].

2 Calculation basis

Water Hammer Calculation adopts hysim software of "Simulation calculation software for transition process of complex hydraulic system" independently developed by East China Institute for calculation and analysis, and the calculation model diagram is shown in Figure 1.

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After trial calculation, the opening and closing rules of guide vanes are calculated according to the hydraulic transition process of hydropower station during power generation as follows:

The guide vane of the unit is closed by a straight line of 6s.

The guide vane of the unit is opened in a straight line for a period of 40s.

After trial calculation, when discharging, the discharge gate is closed and opened in a straight line of 120s.

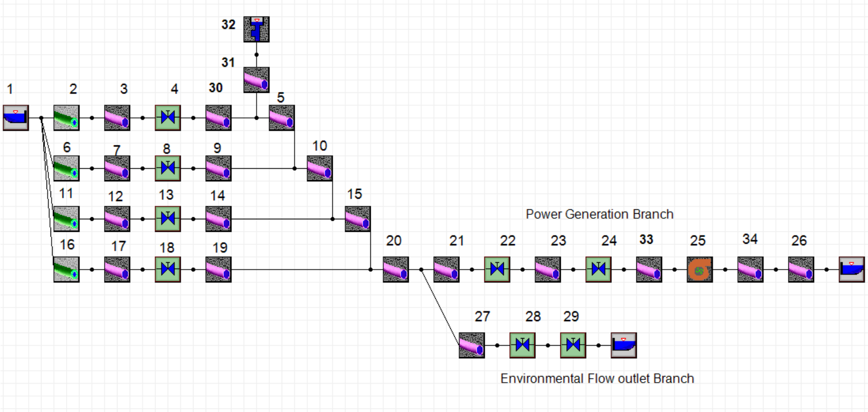

Fig. 1. Calculation Model Diagram

3 Calculation of working condition and results

The calculation conditions [4~5] for respective intakes are shown in table 1.

Table 1. Working Conditions of Calculation

Working condition	Upstream Water Level (m)	Downstream Water Level (m)	Load change	Notes
D1/D5/D9/D13	135	65	1→0	The upstream normal pool level, the tail water level of one downstream unit at full capacity, rated output operation, sudden load rejection. the intake at 129.5m/119.6m/110m/77m
D2/D6/D10/D14	135	65	0→1	At the normal pool level in the upstream and the tail water level of one downstream unit, increase the load to the rated output for operation. the intake at 129.5m/119.6m/110m/77m
D3/D7/D11/D15	132.5/122.6/113.0/100	65	1→0	The lowest water level of upstream power generation, the tail water level of one downstream unit at full capacity, the maximum output operation, and sudden load rejection. the intake at 129.5m/119.6m/110m/77m
D4/D8/D12/D16	132.5/122.6/113.0/100	65	0→1	At the normal pool level in the upstream and the tail water level of one downstream unit, increase the load to the maximum output for operation. the intake at 129.5m/119.6m/110m/77m

D17/D21/D25/D29	135	71.8	Gate start	At the full supply water level in the upstream, the unit gate is closed without power generation, and the downstream EFO valve is gradually opened from closing to the design water level. The intake at 129.5m/119.6m/110m/77m
D18/D22/D26/D30	135	71.8	Gate closed	At the full supply water level in the upstream, the unit gate is closed without power generation, and the downstream EFO valve is gradually closed from opening. The intake at 129.5m/119.6m/110m/77m
D19/D23/D27/D31	132.5/122.6/113.0/100	71.8	Gate start	The lowest water level for intake at 129.5m/119.6m/110m/77m, the unit gate is closed without power generation, and the downstream EFO valve is gradually opened from closing to the design water level.
D20/D24/D28/D32	132.5/122.6/113.0/100	71.8	Gate closed	The lowest water level for intake at 129.5m/119.6m/110m/77m, the unit gate is closed without power generation, and the downstream EFO valve is gradually closed from opening.
D33	135	65	1→0	The upstream normal pool level, the tail water level of one downstream unit at full capacity, max.power at max. net head operation, sudden load rejection. the intake at 129.5m
D34	135	65	0→1	At the normal pool level in the upstream and the tail water level of one downstream unit, increase the load to the max.power at max. net head for operation. the intake at 129.5m
D35	83	71.8	Gate start	The lowest water level for intake at 77m to keep 2m pressure, the unit gate is closed without power generation, and the downstream EFO valve is gradually opened from closing to the design water level.
D36	83	71.8	Gate closed	The lowest water level for intake at 77m to keep 2m pressure, the unit gate is closed without power generation, and the downstream EFO valve is gradually closed from opening.
D37	135	65	0→1→0	At the normal water level in the upstream and the tail water level of one downstream unit, increase the load to the rated output for operation, and sudden load rejection, the intake at 129.5m
D38	135	65	Gate closed	The upstream normal water level, the tailwater level of one downstream unit at full capacity, the maximum output operation sudden the valve before turbine is closed from opening.

Calculate the proposed working conditions, and the calculation results are shown in Table 2.

The large fluctuation of the project is mainly analyzed for the Maximum pressure of spiral case, the Maximum rise rate of unit speed, and the Minimum pressure of the draft tube.

Table 2. Extreme Value Calculation Table of Working Conditions in Power Generation

Parameter	Working condition	Limit value	Control value
Maximum spiral case terminal pressure (m)	D33	93.88	≤99.64
Maximum rise rate of unit speed (%)	D33	54.3	≤60.00
Minimum inlet pressure of the draft tube (m)	D33	-4.81	≥-7.92
Minimum pressure along the waterway system (m)	D8	2.45	≥2.00

When the closing time of guide vane is 6s, the maximum pressure of unit volute is 93.88.m, corresponding to working condition D33; The maximum speed rise rate is 54.3%, corresponding to working condition D33; The minimum pressure at tailrace inlet is -4.81m, corresponding to working condition D33; The minimum pressure along the waterway pipeline is 2.45m, corresponding to working condition D8, which meets the control requirements and has a certain safety margin.

4 Sensitivity analysis of the head loss coefficient

The sensitivity analysis of the head loss coefficient law mainly focuses on the maximum pressure of spiral case[6~7], the minimum pressure of the draft tube, and the maximum rise rate of speed during large fluctuations. Select D1 and D7 working conditions as representatives, the calculation results are shown in Table 3~4.

Table 3. Results of effect of local head loss coefficient for working condition D1

Local head loss coefficient of flowing in and flowing out	8.88/5.2 (+20%)	9.99/5.85 (+10%)	11/6.5	12.21/7.15 (-10%)	13.32/7.8 (-20%)	No surge shaft
Minimum pressure along the waterway system (m)	5.01	5.01	5.01	5.01	5.01	5.01
Maximum pressure along the pipeline (m)	93.21	93.21	93.21	93.21	93.21	93.22
Maximum spiral case terminal pressure (m)	92.55	92.55	92.55	92.55	92.55	92.56
Maximum rise rate of unit speed (%)	51.4	51.4	51.4	51.4	51.4	51.4
Minimum inlet pressure of the draft tube	-4.75	-4.75	-4.75	-4.75	-4.75	-4.75
Min water level in surge shaft (m)	134.46	134.46	134.46	134.46	134.46	/
Max water level in surge shaft (m)	135	135	135	135	135	/

From the calculation, it can be seen that as the local head loss of the outflow and outflow from the surge chamber increases, there is almost no change in various parameters. When there is no surge chamber in the 129.5 m inlet pipeline, there is almost no change. So when the ventilation pipe is used as a pressure regulating chamber, it does not have a pressure regulating effect.

Table 4. Results of effect of local head loss coefficient for working condition D7

Local head loss coefficient of low-ing in and flowing out	1.01/0.96 (-20%)	1.17/1.08 (-10%)	1.3/1.2	1.43/1.32 (+10%)	1.56/1.44 (+20%)
Minimum pressure along the water-way system (m)	2.43	2.45	2.47	2.49	2.51
Maximum pressure along the pipe-line (m)	75.09	75.1	75.11	75.12	75.13
Maximum spiral case terminal pres-sure (m)	76.13	76.13	76.14	76.14	76.15
Maximum rise rate of unit speed (%)	44.7	44.7	44.7	44.7	44.7
Minimum inlet pressure of the draft tube	-4.7	-4.7	-4.7	-.4.7	-4.7
Min water level in surge shaft (m)	119.93	119.98	120.01	120.04	120.08
Max water level in surge shaft (m)	125.95	125.93	125.91	125.89	125.87

The calculation shows that as the local head loss of the surge chamber outflow and outflow increases, the minimum pressure of the pipeline, maximum pressure along the pipeline, maximum spiral case terminal pressure and Maximum spiral case terminal pressure gradually increases, Max water level in surge shaft gradually decrease, while the minimum surge increases and the maximum surge decreases. But the parameter change is very small and meets the requirements.

5 Conclusion

Under the power generation condition of the turbine, according to the layout of the water diversion system of the hydropower station, the guide vane of the unit is closed by a straight line of 6s. The guide vane of the unit is opened in a straight line for a period of 40s. The calculation results of hydraulic transient process meet requirements.

For other intakes, because the upper intake pipe works as surge shaft thus the diameter is relatively larger, so there are small oscillation inside the pipe. But in all calculated conditions, the maximum water level in the surge shaft is 136.71m.

In order to prevent water from the upstream reservoir from flowing to the dam surface from the surge shaft, the top elevation of the surge shaft pipe is equal to the top elevation of the parapet wall, which is 141.30m.

When working, the water inlet should have sufficient submerged depth to prevent negative pressure in the pipeline and cause damage.

According to the calculation results shown above, the pressure bearing of steel pipe meets the requirements under the maximum pressure. Therefor there is no need to take additional water hammer protection measures.

References

1. Gaohui L, Shaojia Y, Weijie C, et al. Study on Influence of Flow Inertia of Pressure Pipe on Critical Stable Sectional Area of Surge Tank[J]. Journal of Physics: Conference Series,2023,2565(1).
2. Shaojia Y, Yu L. With a Long Connecting Pipe Surge Hydraulic Characteristics Research[J]. Journal of Physics: Conference Series,2023,2418(1).
3. Mohammad M, Mohammad N. Effects of Surge Tank Geometry on the Water Hammer Phenomenon: Numerical Investigation[J]. Sustainability,2023,15(3).
4. Zhongyuan S, Dongfang L, Huaxiang Y, et al. The water hammer in the long-distance steam supply pipeline: a computational fluid dynamics simulation[J]. Cogent Engineering,2022,9(1).
5. Kamil U, Anton B, Michał S, et al. Water Hammer Simulation Using Simplified Convolution-Based Unsteady Friction Model[J]. Water,2022,14(19).
6. Gaohui L, Shaojia Y. Flow inertia effect on critical stable sectional area of surge tank[P]. Powerchina Huadong Engineering Corporation Limited (China),2022.
7. Shaojia Y, Yu L. Connecting pipe of pumped storage power station surge flow characteristic analysis[P]. PowerChina Huadong Engineering Corporation Ltd. (China),2023.