Model test of pumping operation of Sanhekou hydro-junction project

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Abstract. Aiming at the pumping operation of Sanhekou Hydropower Station’s pump-turbines, based on model tests, data measurements were performed on the rated speed and variable speed pumping operations. In addition, the efficiency test and hump margin test were implemented, and the corresponding performance curves were obtained. The results meet the engineering design requirements and can provide technical guidance for the speed control of the power station.

1. Introduction
With the increasingly severe environment and energy situation, the country has begun to vigorously promote energy conservation and environmental protection. By adopting speed control of water pumps, significant energy saving effects can be achieved[1], and the head of variable frequency pumps is the same when running in parallel with rated frequency pumps, only the highest head in the performance curve is different[2]. At present, the average efficiency of systems equipped with fans or pumps in China is only 35%, while that of developed countries is as high as 70%[3]. There are two main reasons for such a large gap. One is that our country's fans and pumps are lagging behind. The other is that power frequency operation is used in our country, which means water pumps running at the highest speed and a large amount of power is consumed in the throttling of various regulating valves[4]. In addition to high-efficiency water pumps and motors, variable frequency motors are widely used in foreign countries.

William[5] used energy consumption and economic feasibility as indicators, and compared the different conditions of the pump at constant flow and variable flow based on model tests. It was found that the energy consumption of the pump was lower when running at variable flow rates. The energy-saving principle and energy-saving effect analysis of frequency control under different parallel pumping operation schemes were discussed by Zuo[6], and the optimal speed control range of the water pump was finally determined. At present, the frequency control of water pumps is widely used in various heating systems, especially in multi-pump systems such as multi-heat source network systems[7]. However, there are few related studies on the frequency control of reversible pump-turbine. In this paper, a model test of the reversible unit of Sanhekou Power Station was carried out. Data is measured for the rated speed and variable speed pumping operating conditions to obtain the corresponding performance curve, which will provide technical guidance for the frequency control of the power station.

2. Test plant and model pump-turbine
2.1. Overview of Sanhekou Water Control Project
The Sanhekou Water Control Project is the storage hub for the project of the water diversion from Han River to the Wei River. The total storage capacity of the Sanhekou Reservoir is 710 million cubic meters and the adjusted storage capacity is 660 million cubic meters [8]. There are two operation modes of water supply and supplementary water. Therefore, the water supply station behind the dam was constructed, which is equipped with two turbines with a capacity of 20 MW and two pump-turbines with a capacity of 10 MW, with a total installed capacity of 60 MW. The designed maximum generating flow during the water supply period of the reservoir is 72.71 m³/s, and the turbines will generate according to the downstream flow. When the water diversion volume of the Huangjinxia Hydropower Project is greater than that of Guanzhong, and the Sanhekou Reservoir needs to be recharged for water storage, the reversible pump-turbines will be put into operation under the pumping condition. The designed pumping flow is 18.00 m³/s, and the total installed pumping power is 24 MW.

2.2. Test plant and pump turbine
TP1 was used in this test, a general test bench for hydraulic machinery models of the China Institute of Water Resources and Hydropower Research. The system is a closed cycle system, which includes reservoir, circulating water pump, electromagnetic flowmeter, pressure tank, model unit, tail water tank, stainless steel pipeline system and weighing barrel. According to the needs of model tests and flow calibration, the circulation system can be closed or open. The elevation view of TP1 test rig is shown in Figure 1. The partial enlarged display area is the model pump turbine. The model of the pump turbine is similar to the prototype, with a similar ratio of 4.25: 1.

![Figure 1. Elevation view of TP1 test bench circulation system.](image)

3. Pumping operation model test
3.1. Pumping at rated speed
When the Sanhekou Reservoir is in the replenishment period and the head is above 85 meters, the unit will pump at a rated speed of 500 r/min. According to IEC60193, the flow, input and efficiency when converted to the prototype are shown in the table below. Figure 2 shows the flow-head-efficiency
relationship curves when the rated speed is 500r/min. The relationship between the flow and the input of the pump at the rated speed is shown in Figure 3.

| parameter | head (m) | 99  | 94  | 89  | 84  | 79  | 74  |
|-----------|---------|-----|-----|-----|-----|-----|-----|
| efficiency (%) |       | 90.54 | 91.69 | 91.78 | 91.46 | 91.19 | 90.12 |
| input (MW) |       | 9.14 | 9.61 | 9.93 | 10.10 | 10.20 | 10.26 |
| flow (m³/s) |       | 8.53 | 9.55 | 10.42 | 11.21 | 12.02 | 12.71 |

Figure 2. Flow-Head-Efficiency Curve at rated speed of 500r/min.

Figure 3. Flow-Input Curve at rated speed of 500r/min.

Combined with the above figure, and taking into account factors such as the hump margin of the pump at the maximum head, the maximum input power of the minimum head, cavitation characteristics, and pressure pulsation characteristics, 96.44-78.4m (net head 94-74m) is recommended as the head range for pumping operation at a rated speed of 500r/min, and the corresponding flow range is 9.04-12.14m³/s. During this period, the pump turbine is driven by the motor to rotate in a counterclockwise direction (top view). The motor absorbs power from the grid and drives the pump turbine to pump water. The inverter is not put into operation.
Figure 4. Partially enlarged view of the high-head hump area when operating at the rated speed of 500 r/min

As can be seen from the above figure, when the pump is operating at a head of more than 92 m, in order to avoid the hump area and leave a certain safety margin, there should be a limit on the opening, that is, the guide vane opening at a certain head should not be greater than a certain limit. For example, in the figure, there is a pipeline characteristic curve of two pumps with a maximum net head of 94 m, and the guide vane openings at the lowest points of the corresponding hump curves are 102.0 mm, 93.5 mm, 85.0 mm, 76.5 mm, etc. Among these openings, the maximum opening that can meet the hump margin is 85.0 mm, so the 85.0 mm is selected to be the maximum guide blade opening of 94 m net head.

3.2. Pumping at reduced speed
When the Sanhekou Reservoir is in the replenishment period and the head is below 78.4 m, the pump-turbine needs to run at a reduced speed. As shown in Figure 5, the pump-turbine’s motor is controlled by the inverter and pumps at a speed lower than the rated speed. The frequency reduced by the inverter is determined according to the head.

Figure 5. Relation curve between flow and head when the pumping at variable speed
It can be seen from the figure that the revolving speed varies within the range of 500 r/min to 300 r/min, the change of the flow is 5.4-12.14 m³/s, while the head 96.44-28.22 m. When the speed is reduced to 300 r/min, the minimum head is 28.22 m and the flow rate is 7.28 m³/s. According to the pipe hydropower loss when one machine is running, the minimum net head is 26.71 m, which can meet the planned minimum 29.8 m net head. Therefore, if the speed is changed between 500 r/min and 300 r/min, the pump turbine can meet the requirements.

4. Conclusion
(1) When pumping at rated speed, taking into account factors such as the hump margin of the pump at the maximum head, the maximum input power of the minimum head, cavitation characteristics, and pressure pulsation characteristics, 96.44-78.4 m (net head 94-74 m) is recommended as the head range for pumping operation at a rated speed of 500 r/min, and the corresponding flow range is 9.04-12.14 m³/s.

(2) Significant energy-saving effect can be achieved when the unit adopts frequency conversion in the pumping condition of reduced speed. The frequency reduced by the inverter is determined according to the head, and if the speed is changed between 500 r/min and 300 r/min, the pump turbine can meet the requirements.

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References
[1] Qi Cao, Analysis of the performance of covert water pump, J. The World of Invertors. 2005(4):181-184.
[2] Ziqiang Wu, The Graphic Analysis Method of Pump Speed Variable Running, J. The World of Invertors. 2005(7):130-134.
[3] Kawabata, Yoshitaka. a New Variable-speed, Constant-frequency, Stand-alone Power Generating Stem. Electrical Engineering in Japan. 2004, 146(2):75-85.
[4] Keld Ferwick. the Power of Variable Speed Pumps Benefits. World Pumps. 2000,(11):36-38.
[5] William P. Bahnfleth, Eric Peyer. Energy use and economic comparison of chilled-water pumping systems alternatives[J]. ASHRAE Transaction, 2006, 112(2):198-208.
[6] Xingtao Zuo, Characteristic Analysis of Speed Control Performance of Parallel Pump and Its Application in Piping System Research, D. Harbin Institute of Technology.
[7] Zhaoyu Shi, Several technical problems of water pump in speed control application, J. District Heating. 2014(3):1-8
[8] Bo Yuan, Analysis on Construction and Management of the Project of the water diversion from Han River to Wei River in Shaanxi Province, J. China Water Resources. 2013(20):24-25.