Analysis of Specific Operation of Circulating Water System in a Power Station

WAN Zhong-hai¹ ²*, CHEN Wen¹, LU Jin¹ ², LIU Zhuan¹, CAI Wen¹, YAN Tao¹

¹State Grid JiangXi Electric Power Research Institute, Nanchang 330096, Jiangxi Province, China
²Nanchang Kechen Power Test Research Co., Ltd., Nanchang 330096, Jiangxi Province, China
*Corresponding author’s e-mail: wzhjjch@163.com

Abstract. Affected by the continuous decline of the water level and the reform of the condenser, the actual operating conditions of a company’s circulating water pump seriously deviated from the design conditions. Especially in the double pump condition, only one pump can be maintained in normal operation, the other’s current is obviously low and the pump body vibrates greatly, and the double pump cannot be maintained in parallel operation. After several field tests and analysis, it was found that when the running head was between the two pump-inflation points of the parallel running, due to the difference in performance between the pump bodies, one of the circulating water pumps runs normally, while the other pump has a sudden current drop and an increase in pump vibration; at the same time, the two pumps have been running for more than ten years, the performance of the equipment is aging, and the head is insufficient, which is one of the main reasons.

1. Introduction

The circulating water system of a power station adopts the direct discharge cooling method. Each unit is equipped with two circulating water pumps, and the cooling water source is taken from the Ganjiang River. The circulating water pump is a 72LKS-26A vertical single-suction single-stage rotor component extractable oblique flow pump produced by Changsha Pump Factory. The motor is YKSL2000-16/1730-1 motor produced by Xiangtan Motor Factory.

The average water level of Ganjiang River has been 20.68m for many years, and the dry water level is 18.07m. However, in recent years, the dry water level has dropped to 14.0m. Affected by the continuous decline of the water level and the reformation of the condenser, the inlet pressure head of the circulating water pump is reduced, and the outlet pipe resistance is increased (the condenser water resistance is increased by about 32 kPa), which makes the circulating water pump seriously deviate from the design working condition. Especially in the case of double pump operation, only one pump can be maintained in normal operation, and the current of the other pump is obviously low (only about 200A, while the normal running current of the pump is about 240A) and the pump body vibrates greatly. It is not possible to maintain the parallel operation of the dual pumps [1-2].
2. Field test results
Commissioned by the company, in September 2017, the #4 circulating water pump was tested in the field. In July 2018, the pump was again tested on the specific operating conditions of the circulating water system.

2.1. Test results in July 2018
In #4 pump single pump working condition, #4 pump operating condition is Q=21422m³/h, H=25.66m, η=82.92%, I=232.7A; outlet flow measurement position is in #2 mother pipe straight pipe section.

In #3, #4 pump double pump working condition, #4 pump operating condition is Q=13143m³/h, H=26.19m, η=64.28%, I=206.2A (#3 pump current 240A); The flow rate is taken as one-half of the measured value of the circulating water flow of the #2 mother pipe of 26286 t/h.

| Item                                               | single pump condition | double pump condition |
|----------------------------------------------------|-----------------------|-----------------------|
| Atmospheric pressure (kPa)                         | 100.1                 | 100.1                 |
| Circulating pump inlet diameter (mm)               | 2000                  | 2000                  |
| Circulation pump outlet pipe inner diameter (mm)   | 1780                  | 1780                  |
| Pump outlet flow (m³/h⁻¹)                          | 21422                 | 13143                 |
| Imported water level elevation difference (m)      | -6.05                 | -6.15                 |
| Pump inlet static pressure (MPa)                   | 0.041                 | 0.040                 |
| Pump outlet pressure gauge reading (MPa)           | 0.198                 | 0.204                 |
| Pressure gauge elevation difference (m)            | -0.900                | -0.900                |
| Pump outlet pressure corrected by elevation (MPa)  | 0.289                 | 0.295                 |
| Pump outlet flow rate (ms⁻¹)                       | 2.39                  | 1.47                  |
| Pump motor current (A)                             | 232.7                 | 206.2                 |
| Motor Power (kW)                                   | 1902.41               | 1536.78               |
| Motor efficiency (%)                               | 94.80                 | 94.80                 |
| Motor output shaft work (kW)                       | 1803.48               | 1456.87               |
| Pump inlet density (kgm⁻³)                         | 998.29                | 998.29                |
| Pump outlet density (kgm⁻³)                        | 998.36                | 998.36                |
| Pump outlet speed head (m)                         | 0.291                 | 0.110                 |
| Pump head (m)                                      | 25.66                 | 26.19                 |
| Pump output shaft work (kW)                        | 1496                  | 937                   |
| Pump efficiency (%)                                | 82.92                 | 64.28                 |
| Pump set efficiency (including motor) (%)          | 78.61                 | 60.94                 |

After consulting the relevant design materials, the average water level of Ganjiang Design in 1996 was 20.68m, and the dry water level was 18.07m. According to the data collected in 2016, the average water level dropped to 15-17m, and the dry water level reached 14m. The geometric head of the piping unit has been increased by 3-4 m.

In the past few years, the power station has successively upgraded the capacity of four steam turbine units, and the condenser has also undergone capacity expansion. Under the condition that the condenser casing is not changed, the cooling area is increased by 15%. For this reason, the copper tube
technology of the original Φ28 is changed to the stainless steel tube of Φ22, which undoubtedly increases the water resistance of the water side of the condenser. After field testing, the water resistance increased by 32 kPa.

In view of the above two reasons, the circulating water pump needs a higher head when it is running, and the operating condition is naturally biased toward the small flow area. But this does not explain why not maintain the parallel operation of the dual pumps.

2.2. In-depth analysis

Preliminary observation of the above test data, #4 circulating water pump operating data under dual pump conditions seems to be contrary to the theoretical view that the head, flow and motor current are basically the same under the two-pump parallel working condition. In order to identify the specific situation, the following three parts can be analyzed in depth:

2.2.1. It can be seen from Fig. 1 that the operating characteristic curve of the circulating water pump of this type is non-linear, and at the same time, when the flow rate is lowered, the flow rate is not always increased, but there is a partially saddle shape. In this area, the same head, such as point G and point C, has different flow rates. The operating state of the circulating water pump is thus very unstable, with a slight disturbance, it oscillates between point G and point C [3].

![Head and flow relationship curve](image)

Figure 1. Head and flow relationship curve.

In the case of the parallel operation of the dual pumps, the current dip of the #4 circulating water pump motor is due to the fact that the running head of the #4 circulating pump falls into the unstable operating area and is suddenly switched from point C to point G.

Analysis of pipeline characteristics: As the water level of the Ganjiang River continues to decrease, and the condenser pipe resistance increases slightly after the technical transformation, the static lift between the suction end and the discharge end of the #4 circulating water pump is continuously increased, and the pipe of the #4 circulating water pump is continuously increased [4-5]. The road characteristic curve is moved from the curve H-I in the figure to the curve E-F.

Analysis of Pump operating point: During the test, the operating point of the #4 circulating water pump under single pump condition is E, the working point under double pump working condition is G, and the characteristic curve of #4 circulating water pump pipeline is E-F. Point F is equal to the head of point G, but its flow doubles, as shown in Figure 2.
Analysis of the flow-head characteristics of the parallel operation: In Fig. 2, the A-B line segment is part of the #4 pump characteristic curve, and the A-F line segment is the characteristic curve of the #4 pump under the parallel operation condition [6].

The “saddle” performance curve of the diagonal flow pump: According to the principle of the pump and the fan, the maximum head point C in the figure is the inflection point (demarcation point) of the stable operation area and the unstable operation area of the centrifugal pump, and the BC section is the unstable operation area, the CD section is a stable operating area;

The oblique flow pump has a saddle-shaped characteristic due to the backflow and vortex appearing at the rim of the impeller outlet under small flow conditions. The saddle curve consists of the head sag B-C and the subsequent ascending section A-B. In this flow range, the oblique flow pump is prone to abnormal phenomena such as vibration and noise due to unstable flow.

2.2.2. Under the parallel operation condition, there is no sudden drop in the #3 pump motor current, because there is an individual difference between the pump and the pump. Although the #3 pump has a similar flow-head characteristic as the #4 pump, the inflection point of the #3 pump (the head corresponding to point C in Fig. 2) is higher than the inflection point of the #4 pump according to the actual situation. Therefore, under the parallel operation condition, the operating condition of the #3 pump still falls within its stable operating range [7].

2.2.3. It should be noted that since the ultrasonic flowmeter measurement accuracy has a relatively high requirement on the length of the straight pipe section, the measurement position of the #4 pump outlet flow rate is selected on the pump outlet mother pipe instead of the #4 pump outlet position. Therefore, the #4 pump outlet flow rate under the double pump condition is based on the parallel operation theory of the conventional centrifugal pump, and the flow value measured at the mother tube is equally divided. In fact, under the parallel operating conditions, due to the difference in performance between the #3 pump and the #4 pump, one is in a stable operating area and the other is in an unstable operating area, their respective outlet flows should be different, And the outlet flow of #3 pump will be greater than the outlet flow of #4 pump (the heads of #3 and #4 pumps are similar), so the current of #3 pump motor is also larger than #4 pump motor.

Figure 2. Schematic diagram of #4 pump operating conditions.
3. Conclusion
According to the specific operating conditions of the circulating water system and the field test data, the #3 and #4 circulating pumps have large differences in the currents of the parallel operating conditions, and the reasons for the insufficient increase in the outlet flow are:

As the pipeline resistance increases and the water level of the Ganjiang River decreases, the pump operating lift increases. When the water level of the Ganjiang River is as low as 15m, the running head is higher than the inflection point of the two pumps. The two circulating water pumps running in parallel will enter the small flow unsteady operation area.

When the running head is between the inflection points of the two circulating water pumps, due to the difference in performance between the pump bodies, the #3 pump inflection point lift is higher, and the #4 pump inflection point lift is lower, so the #3 pump is operating normally; its current is stable, and the #4 pump is operating abnormally; its current dips and its pump body vibration increase. Since the two pumps have been in operation for more than ten years, the performance of the equipment is aging, and the headroom margin is insufficient, which is one of the main reasons.

References
[1] Gota A. Suppression of mixed-flow pump instability and surge by the active alteration of impeller secondary flows [J]. ASME Journal of Turbomachinery, 1994, 116(4): 621～628.
[2] Pan Zhongyong, Li Junjie, Li Hong, et al. Overview for research on rotating stall of pump [J]. Fluid Machinery, 2011, 39(2): 35～39. (in Chinese)
[3] Sinha M, Pinarbashi A, Katz J. The flow structure during onset and developed states of rotating stall within a vaned diffuser of a centrifugal pump [J]. ASME Journal of Fluids Engineering, 2001, 123(3): 490～499.
[4] Pedersen N, Larsen P S, Jacobsen C B. Flow in a centrifugal pump impeller at design and off-design conditions-part I:particle image velocimetry (PIV) and laser Doppler velocimetry (LDV) measurements [J]. ASME Journal of Fluids Engineering, 2003, 125(1): 61～72.
[5] Hong Wang, Tsuyakamoto H. Experimental and numerical study of unsteady flow in a diffuser pump at off-design conditions [J]. ASME Journal of Fluid Engineering, 2003, 125(5): 767～778.
[6] Brenen C E. Hydrodynamics of pumps [M]. Oxford: Oxford University Press, 1994: 226～228.
[7] Shi Weidong, Zou Pingping, Zhang Desheng, et al. Performance prediction and circulation distribution analysis at impeller inlet and outlet of mixed-flow pump [J]. Transactions of the Chinese Society for Agricultural Machinery, 2011, 42(9): 94～97. (in Chinese)