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Experimental Research on the Efficiency of Impulse Turbine Based on Ultrasonic Flow Measurement Method

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Abstract. In this paper, we studied the impulse turbine of a power station based on the ultrasonic flow measurement method. Efficiency tests were carried out on the nozzle head, nozzle needle and deflector disc spring of the unit before and after the transformation. The results showed that the absolute efficiency of the unit before and after the transformation was basically the same. The efficiency value and economic performance have been improved to a certain extent, and the results obtained by using the ultrasonic method to carry out the unit efficiency test are correct and credible.

1 Introduction

As one of the basic test tasks of the Hydropower unit, the efficiency test of the turbine is an effective method to directly understand the running state of the turbine and master the basic power characteristics of the unit. Through the efficiency test of the unit, it is possible to evaluate the efficiency performance and output characteristics of the unit, which can provide technical data for the overhaul and transformation of the power station, and provide technical guarantee for the stable and economic operation of the power station. The ultrasonic flow measurement method can be used when measuring the flow in the efficiency test, which has the advantages of strong anti-interference ability and continuous tube installation by using the characteristics of ultrasonic[1,2].

In this study, an impulse hydropower unit was used as an example to compare and analyze the efficiency test before and after the modification of the nozzle head, the nozzle needle and the deflector disc spring of the unit using the ultrasonic flow measurement method.

2 Test principle

2.1 Flow measurement principle

The flow measurement of the efficiency test is carried out by the ultrasonic flowmeter installed on the site of the power station. The ultrasonic flowmeter measures the flow rate by receiving the feedback of the fluid flow on the ultrasonic beam [3,4]. The average flow velocity of the fluid can be measured according to the propagation time difference between the sound waves emitted by the transmitters installed upstream and downstream in different flow directions, and then the volume flow rate of the fluid can be obtained according to the cross-sectional area of the pipeline. Based on the wave recorder to collect the flow simulation signal, carry out statistical analysis, and use the computer group's passing machine flow. The flow calculation formula is as follows:

$$V=(T_1-T_2)/(T_1+T_2)L/(2\cos\Phi) \quad (1)$$

In the formula, V is the average flow velocity along the direction of the sound wave; T1 is the counter current propagation time between the transducers; T2 is the downstream propagation time between the transducers; L is the distance between the transducers.

2.2 Working head measurement

The working head of the turbine is calculated by the following formula:

$$F=\frac{p_1^{'}}{\bar{\rho}}+\bar{g}\cdot\left(z_{1'}-z_2\right)+\frac{v_1^2}{2}=\frac{p_1^{'}}{\bar{\rho}}+\bar{g}\cdot Z+\frac{v_1^2}{2} \quad (2)$$

In the formula, p_1 is the pressure of the water distribution loop, which can be measured by a pressure sensor with an accuracy of 0.2%; ρ is the weight of water, 9810 (N/m^3); v_1 is the average water velocity of the water distribution loop section (m/s); g is the local gravity acceleration value, which is taken as m/s^2 according to the altitude and latitude of the power station;

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Z is the water distribution loop elevation z_1' and the nozzle axis and the bucket jet The difference between the average elevation z_2 of all intersection points of the pitch circle diameter.

2.3 Head conversion

In the hydraulic turbine efficiency test, due to the changes in the upstream and downstream water levels and the different flow rates at each operating point, the head loss of the diversion pipe is different, and the actual water head at each test operating point will be different. In order to calculate and sort out the characteristic curve of the unit, it is necessary to select one of the calculated heads, and then convert the actual measured values of the efficiency and flow rate of each operating point to the selected calculated head (or designated head). In order to compare the results of the two tests, the average value of the water head at each working condition of the two tests is taken as the calculated water head, which is calculated as 506.79m.

3 Test results and analysis

3.1 Basic parameters of power station

The basic parameters of turbine and generator are shown in Table 1 and Table 2.

Table 1. Main parameters of the turbine.

Water turbine	
Model number	CJ520-L-295/6X25.6
Rated output	123MW
Rated head	482m
Maximum head	513.8m
Minimum head	482m
Rated speed	300r/min
Runaway speed	555r/min

Table 2. Main parameters of the generator.

Generator	
Model number	SF120-20/6500
Rated power	120MW
Rated voltage	13.8kV
Rated current	5578.3A
Power Factor	0.9（Hysteresis ）

3.2 Test conditions and measuring point layout

3.2.1 Test conditions

The efficiency test is carried out under variable load conditions, setting 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95% and 100% rated load conditions, adopt one-way load adjustment, after each load adjustment is completed, keep for a period of time until the relevant pressure is stable before data collection. The next operating point test is performed after the data collection is completed.

3.2.2 Measuring point layout

The test equipment adopts HY-80 hydraulic machinery comprehensive tester, the pressure transmitter used is PTX630, with the accuracy reaches 0.5% and the accuracy of power transmitter reaches 0.2%. The flow measurement adopts Shenrui Electric GER9000 ultrasonic flow measurement system, with measurement accuracy for pressure pipes can reach ±0.5%. The test points are as follows:

1)Unit passing flow rate;
2) Pressure of water distribution loop;
3)Unit active power;
4)Needle opening;
5)Upstream water level, downstream water level (monitored and read by the central control room).

3.3 Test data analysis

3.3.1 Absolute value calculation of efficiency

Based on the efficiency test, the turbine efficiency characteristics of the nozzle head, nozzle and deflector disc spring of a power station No. 2 unit were studied before and after the transformation, and the absolute value calculation data of the turbine efficiency (Table 3 and Table 4) were summarized. The machine efficiency is taken from the generator efficiency curve. To calculate the water head, take the average value (506.79m) of the water head at each working condition of the two tests. Then compared the results of the two tests.

Table 3. Calculation of absolute value of hydraulic turbine before modification.

Generator		Pressure of water distribution ring	Flow	Working head	Water turbine		Converted to an average head of 506.79m			
Power	Effectiveness				Output	Absolute efficiency	Output	Flow	Effectiveness	Water consumption rate
MW	%	MPa	m^3/s	m	MW	%	MW	m^3/s	%	m^3/kWh
6.36	95.5	4.99	1.68	507.09	6.66	80.05	6.36	1.68	76.63	0.948

12.09	95.5	4.97	3.13	505.34	12.66	81.77	12.15	3.13	78.28	0.933
18.21	95.5	4.96	4.58	504.86	19.07	84.33	18.32	4.58	80.73	0.906
24.25	95.5	4.95	5.97	503.96	25.39	86.17	24.45	5.99	82.49	0.889
29.95	95.5	4.96	7.26	505.33	31.36	87.30	30.08	7.27	83.57	0.874
35.58	96.1	4.96	8.58	505.56	37.02	87.19	35.71	8.59	84.00	0.869
41.38	96.6	4.95	9.84	504.77	42.84	88.13	41.63	9.86	85.34	0.857
47.43	97.0	4.95	11.17	505.40	48.90	88.45	47.63	11.19	86.01	0.849
53.74	97.3	4.94	12.62	504.58	55.23	88.58	54.09	12.65	86.40	0.847
59.13	97.5	4.94	13.80	505.26	60.65	88.83	59.40	13.82	86.82	0.842
65.29	97.7	4.94	15.20	505.09	66.82	88.91	65.62	15.22	87.08	0.840
72.53	97.8	4.94	16.83	506.86	74.15	88.78	72.51	16.83	87.06	0.835
78.21	97.9	4.93	18.11	505.95	79.84	88.98	78.40	18.13	87.38	0.834
82.57	98.0	4.91	19.11	505.02	84.22	89.15	83.01	19.14	87.62	0.835
89.65	98.1	4.92	20.64	506.41	91.39	89.31	89.75	20.65	87.83	0.829
95.40	98.2	4.92	21.90	507.11	97.14	89.34	95.30	21.89	87.95	0.826
101.39	98.2	4.93	23.17	508.78	103.21	89.43	100.80	23.13	88.07	0.821
108.05	98.3	4.91	24.70	508.81	109.92	89.36	107.41	24.65	88.05	0.821
114.01	98.4	4.90	26.12	508.80	115.89	89.06	113.33	26.07	87.83	0.823
119.29	98.4	4.90	27.43	509.73	121.23	88.56	118.25	27.35	87.36	0.825

Table 4. Calculation of absolute value of hydraulic turbine after modification.

Generator		Pressure of water distributio n ring	Flow	Working head	Water turbine		Converted to an average head of 506.79m			
Power	Effectiveness				Output	Absolute efficiency	Output	Flow	Effectivene ss	Water consumption rate
MW	%	MPa	m3/s	m	MW	%	MW	m3/s	%	m3/kWh
5.83	95.5	4.97	1.54	505.31	6.10	80.36	5.85	1.54	76.74	0.952
12.18	95.5	4.97	3.14	505.69	12.75	82.27	12.22	3.14	78.57	0.929
18.14	95.5	4.97	4.53	505.52	19.00	84.91	18.21	4.54	81.09	0.900
24.17	95.5	4.98	5.89	506.36	25.31	86.91	24.20	5.89	83.00	0.877
29.58	95.5	4.98	7.09	506.94	30.97	88.25	29.56	7.09	84.27	0.863
35.23	96.1	4.97	8.40	506.50	36.66	88.18	35.26	8.41	84.74	0.859
41.72	96.6	4.98	9.80	507.28	43.19	88.93	41.66	9.80	85.91	0.845
47.43	97.0	4.97	11.08	506.84	48.90	89.17	47.43	11.08	86.49	0.841
53.24	97.3	4.98	12.34	508.25	54.72	89.37	53.01	12.32	86.95	0.833
59.89	97.5	4.97	13.80	508.54	61.42	89.61	59.58	13.78	87.36	0.828
64.81	97.7	4.96	14.93	507.34	66.33	89.66	64.70	14.92	87.60	0.829
72.23	97.8	4.96	16.61	508.59	73.84	89.51	71.85	16.58	87.56	0.826
77.33	97.9	4.95	17.73	507.40	78.94	89.86	77.19	17.72	88.03	0.825
82.83	98.0	4.93	18.98	507.02	84.49	89.92	82.77	18.97	88.16	0.825
88.37	98.1	4.93	20.18	507.66	90.08	90.03	88.14	20.16	88.32	0.821
94.54	98.2	4.92	21.56	507.54	96.27	90.10	94.33	21.54	88.48	0.820
101.57	98.2	4.93	23.05	509.05	103.39	90.22	100.90	23.00	88.64	0.815
106.47	98.3	4.90	24.25	507.34	108.31	90.14	106.30	24.24	88.61	0.820
112.57	98.4	4.90	25.65	508.35	114.43	89.85	112.06	25.61	88.39	0.819
118.51	98.4	4.90	27.12	509.38	120.44	89.29	117.61	27.05	87.86	0.822

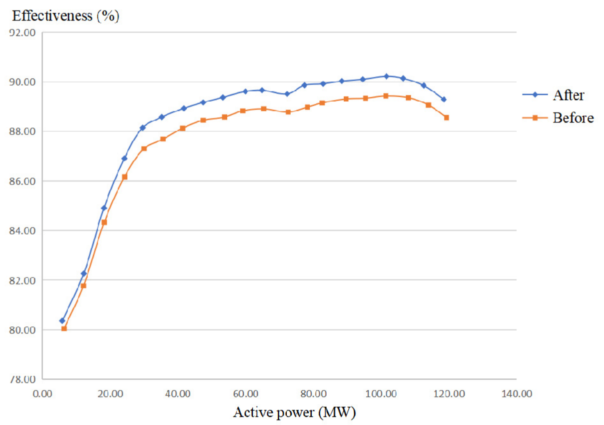

Fig. 1. Comparison diagram of turbine efficiency characteristic curve.

A comparison chart of the efficiency characteristic curve of the turbine before and after the transformation was drawn, as shown in Figure 1. It can be seen that the absolute efficiency change trend before and after the transformation is basically the same, and the efficiency value after the transformation has a certain degree of improvement. The absolute efficiency curve before and after the transformation was fitted:

The absolute efficiency curve fitting equation before transformation is:

$y=-0.0000003x^4+0.00008x^3-0.0098x^2+0.5903x+73.265.$

The absolute efficiency curve fitting equation after transformation is:

$y=-0.0000002x^4+0.00007x^3-0.0089x^2+0.552x+73.207.$

3.3.2 Economic Evaluation

In the actual operation of the power station, in order to give full play to the potential of the unit, improve the efficiency of water energy utilization, and obtain greater benefits with less resource efficiency, it is necessary to evaluate the operating economy of the power station. Water consumption rate is often used as the basis for economic evaluation. It is defined as the amount of water consumed per unit of power generation, in m^3/kWh. Based on the efficiency test data, the water consumption rate is converted to the average head to compare the results of the two tests. The calculated water consumption rate is shown in Table 5, and the water consumption rate curve comparison chart is drawn as shown in Figure 2.

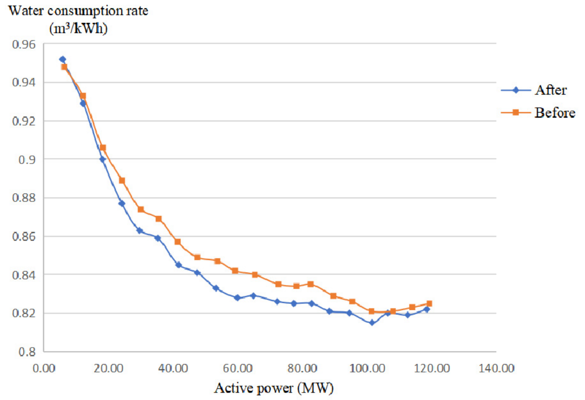

Fig. 2. Comparison chart of water consumption rate curve.

Table 5. Comparison of water consumption rate before and after modification.

Before transformation		After transformation	
Power (MW)	Water consumption rate (m^3/kWh)	Power (MW)	Water consumption rate (m^3/kWh)
6.36	0.948	5.83	0.952
12.09	0.933	12.18	0.929
18.21	0.906	18.14	0.900
24.25	0.889	24.17	0.877
29.95	0.874	29.58	0.863
35.58	0.869	35.23	0.859
41.38	0.857	41.72	0.845
47.43	0.849	47.43	0.841
53.74	0.847	53.24	0.833
59.13	0.842	59.89	0.828
65.29	0.840	64.81	0.829
72.53	0.835	72.23	0.826
78.21	0.834	77.33	0.825
82.57	0.835	82.83	0.825
89.65	0.829	88.37	0.821
95.40	0.826	94.54	0.820
101.39	0.821	101.57	0.815
108.05	0.821	106.47	0.820
114.01	0.823	112.57	0.819
119.29	0.825	118.51	0.822

For hydropower units, the main factors affecting water consumption rate are turbine efficiency and working head. Under the same conditions, the higher the efficiency of the unit, the lower the water consumption rate. It can be seen from Figure 2 that the change trend of the water consumption rate before and after the renovation is basically the same, and the water consumption rate after the renovation has been reduced to a certain extent, indicating that the economic performance of the unit has improved after the renovation. From the perspective of unit economy, the optimal economic operation area of the unit is 60MW~120MW.

3.3.3 Error Analysis

1) In the efficiency test, the detection error of the pressure sensor of the water distribution loop is 0.5%, and the calculation error including the flow head is 1%. After square root synthesis, the calculated head error is: ±1.118%.

2) The efficiency test measurement of active power uses a power transmitter with an accuracy level of 0.2. According to the procedures of IEC60041 and GB/T20043, the system error of electric power measurement is 0.78% when the confidence level is 95% in high-precision measurement occasions.

3) The efficiency test uses an ultrasonic flowmeter to measure flow, and its accuracy depends on the calibration accuracy and flow measurement accuracy of the ultrasonic flowmeter. According to the information provided by the flowmeter manufacturer and combined with the on-site situation, the error is ±0.5%.

From the above, it can be concluded that the system error of the efficiency test is ±1.45%. According to the estimated value of efficiency standard deviation, the random error of efficiency test is ±0.75%.

Finally, the comprehensive error of the efficiency test is: fn=± √(fns2+ fnr2)=±1.63%.

4 Conclusion

1) Based on the ultrasonic flow measurement method, an efficiency test was carried out before and after the transformation of a power plant unit. The results showed that the absolute efficiency change trend before and after the transformation was basically the same, and the efficiency value was improved to a certain extent after the transformation. According to the test data, the absolute efficiency curve equation before and after the transformation is fitted to guide the operation of the power station.

2) Based on the efficiency test data, the economic performance of the unit was analyzed, and the results showed that the change trend of the water consumption rate before and after the transformation was basically the same. From the perspective of unit economy, the optimal economic operation area of the unit is divided into 60MW～120MW.

3) Judging from the results of the efficiency test, the results obtained by the unit efficiency test using the ultrasonic method are correct and credible. The total error of the efficiency test is 1.63%, which meets the requirements of ±1.5% to ±2.5% specified in the IEC regulations.

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