

Study on Characteristics of Special Turbine in Hydrodynamic Cooling Tower

Li Yanpin, Zhang Lanjin and Chen Dexin

School of Electric Power, North China Institute of Water Conservancy and Electric Power,
Zheng zhou Henan 450011, China

Abstract: Today a special type of hydraulic turbine is used to replace electromotor to drive the fan in hydrodynamic cooling tower. This is a brand new turbine application. At present, systematic researching about the special turbine has still not been seen. The energy consumption of the electromotor is saved entirely because the power source comes from the surplus energy of circulating water system. But the special turbine works in a series of pressure flow system, its flow characteristic, working characteristics and regulative characteristics different from conventional power turbine. This study introduces the theory analysis and experimental study on these characteristics. The research shows that special turbine has more complex flow characteristics and the turbine-fan unit has good self-adaptive characteristics and regulative characteristics. When the turbine is not in its optimal condition we can regulate it to a proper condition by adjusting the guide glade and the angle of the fan's vane or replacing the diameter of fan. These are never been found.

Keywords: Flow characteristic, hydraulic turbine, hydrodynamic cooling tower, regulate characteristic, working characteristic

INTRODUCTION

Commonly used cooling tower generally need fan to accelerate cooling process and fan is driven by a reducer, which is driven by a motor (Zhou *et al.*, 2010; Yang *et al.*, 2009; Chen, 2009). Due to higher motor speed and the reducer so they run noisy, easily broken and need regular maintenance. The motor consumes large amounts of energy at the same time. The supply and water distribution systems usually left some margin pressure in the cooling tower and the residual energy is often wasted. In recent years, a dedicated turbine is to replace the motor to drive the cooling tower fan to reuse this residual energy (Zhou *et al.*, 2010; Yang *et al.*, 2009). This turbine works entirely to use system residual pressure, therefore, it has a good energy saving effect. At the same time, as it can be connected with the fan directly, saving the reducer and reduce the noise and vibration, improving the environment. Compared with the motor, the turbine need not consider dust and explosion problems, so that the security of system operation is improved (Duan and chuan, 2008; Zhang *et al.*, 2004; Zhang, 2010). In addition because the structure of turbine is simple it is not easy to fail and the maintain workload and operating costs can be greatly reduced also (Chen, 2009). Because of these advantages, the mechanical ventilation cooling tower,

which turbine works as the driving force, has been widely used gradually.

Currently, it is very little study in depth on dedicated turbine in industrial cooling tower (Chen, 2009; Wang *et al.*, 2009; Liu, 2003). The theory of hydrodynamic cooling tower is proposed by Zhang Fei-kuang, but his most modification works have failed (Zhou *et al.*, 2010). The literature has researched on the design of special turbine in cooling tower systematically and proposed firstly a kind ultra-low specific speed dedicated Francis turbine for cooling tower. It is of great significance to study special turbine for hydrodynamic cooling tower. The literature has proved by model test that the ultra-low specific speed Francis turbine can meet the requirements of stable and reliable operation of cooling tower. According to the low specific speed ($n_s = 55 \text{ m.kw}$), the literature has proposed a kind of cross-flow turbine, but the fact proves that this kind of turbine is very inefficient, not suitable for cooling tower. But at present all the literatures which can be checked have never done deeply systematic research on the characteristics of special turbine for hydrodynamic cooling tower. In this study, the author analyzes theoretically and studies experimentally on the characteristics of special turbine in hydrodynamic cooling tower.

THE FLOW CHARACTERISTIC OF TURBINE IN HYDRODYNAMIC COOLING TOWER

As the working environment of the turbine in cooling tower is different from that of the turbine in hydropower station, its flow characteristics have been changed significantly. The turbine flow characteristics in hydropower station relate only with its working head and guide blade. However, the flow characteristics of the turbine, working in cooling tower, are more complicated. In the water system of cooling tower, the turbine is only one of the resistances, which also include the heat exchanger and the water distributor and they working in a pressure water system in series. The turbine flow is the system's flow. The turbine flow is limited by the flowing capacity of the system and the turbine flow also limits the system flowing capacity at the same time. The size of the turbine discharge is determined by the resistance of all the resistance elements. In addition, the characteristics of the turbine-fan unit have a direct impact on the flow capacity of the turbine. This is particularly important to the ultra-low specific speed Francis turbine. To ensure the plenty cycle water of the cooling tower, it is not only need to consider the system resistance characteristics of the cooling tower but also need to consider comprehensively the influence of the variety factors, which include the characteristics of the turbine itself and the turbine-fan unit's. Figure 1 shows the flow system and working system of turbine in cooling tower.

In cooling tower water system, the pressure head in the water pump export was consumed by the heat exchanger, turbine and nozzle together. If the head of heat exchange for H_C , head of the turbine for H_T , head of the water distributor for H_S and the difference between the turbine inlet centerline and pump export elevation for Z , while excluding the loss of pipeline, the system's energy balance formula:

$$H_p = Z + H_C + H_T + H_S \quad (1)$$

The turbine is only one of energy components in this series pressure system. The size of head consumed by each component is determined by its resistance characteristic and this is similar to the voltage consumed by the resistance components in the series circuit.

Assume that the resistance coefficient of heat exchanger for ξ_C , the resistance coefficient of turbine for ξ_T , the resistance coefficient of the nozzle for ξ_S ,

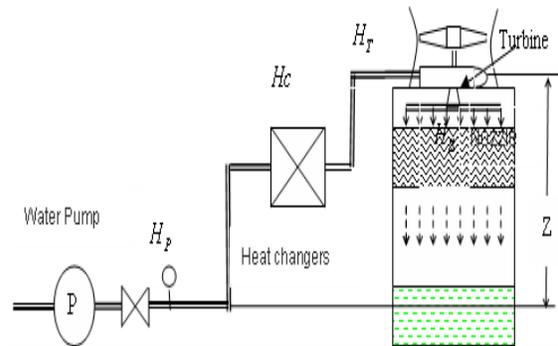


Fig. 1: The flow system and working system of turbine in cooling tower

when the system flow is for Q , the system's energy balance formula is as follow:

$$H_p = Z + \xi_C Q^2 + \xi_T Q^2 + \xi_S Q^2 \quad (2)$$

The flow was obtained from the above:

$$Q = \sqrt{\frac{H_p - Z}{\xi_C + \xi_T + \xi_S}} \quad (3)$$

When the pump head H_p and the resistance coefficients of the flow system components are determined, we can use formulation (3) to determine the system flow. The system flow is namely the turbine over-flow.

WORKING CHARACTERISTICS OF TURBINE CHARACTERISTICS OF TURBINE-FAN UNIT

Speed-flow characteristics of turbine-fan unit: The turbine, which drives the fan in cooling tower, can be connected with fan through reduction gear. But the simplest connection way is connected with the fan directly to form a turbine-fan unit. So the fan speed is namely the turbine speed. The speed of the turbine-fan unit is determined by the turbine output P_T and the shaft power P_a which is needed to drive the fan.

As the similarity law of fan shows that the shaft power of fan is proportional to the three times of the fan speed:

$$n \propto P^{\frac{1}{3}} \quad (4)$$

By the similarity law of turbine, the turbine output is directly proportional to the three times of the turbine's discharge:

$$P \propto Q^3 \tag{5}$$

From the (4) and (5), it is available that the speed of turbine-fan unit is proportional to the turbine's discharge:

$$n \propto Q \tag{6}$$

It is an important characteristic of turbine-fan unit that its speed is proportional to its discharge. This characteristic can be called the self-adaptive characteristic or self-regulation characteristic. And this characteristic has never been found. The speed of the turbine-fan unit can increase or decrease in proportion automatically with the increase or decrease of the cooling water so that the output of the wind of the fan can be increased or decreased automatically and the cooling effect is maintained in the required range. This is also one of the main advantages of fan which is droved by turbine.

Table 1 shows the relationship of the fan speed n and the turbine discharge Q in 1000 m³/h cooling tower. Turbine is for HL50-LJ-60 and fan is for LF60.

The speed-discharge relationship of turbine itself:

As the special turbine must conform the flow condition of industrial cooling tower, the turbine used in cooling tower must be ultra-low specific speed Francis turbine. Statistics show that the turbine specific speed is in the range of 40~70 m.kW. There is a clear feature of this kind of Francis turbine that is the over flow of turbine will decrease with the turbine speed rises when the guide vane opening is constant. I designed an ultra-low specific speed Francis turbine HL50-LJ-60, through experimental test testing, the speed-flow characteristics of itself shown in Fig. 2, when use the discharge Q and speed n .

Determination of the poerating point of turbine-fan unit:

The turbine in cooling tower acts like a pump to automatically stable at a certain operating point. The operating point is determined by the characteristics of the turbine itself and the characteristics of the unit. The operating point is the intersection of relationship of turbine-fan unit shown in Table 1 and the $Q \sim n$ characteristic curve shown in Fig. 2 when the two curves are drawn in the same coordinate system, shown as in Fig. 3. The parameters at the operating point, the turbine discharge 1010 m³/h and the speed of turbine-fan unit 160 r/min, agree with the field test data. When

Table 1: The speed-discharge relationship of turbine-fan unit

Measuring point	1	2	3	4	5	6	7
Discharge/T/h	790	850	880	920	980	1011	1042
Fan speed	125	135	140	145	155	160	165

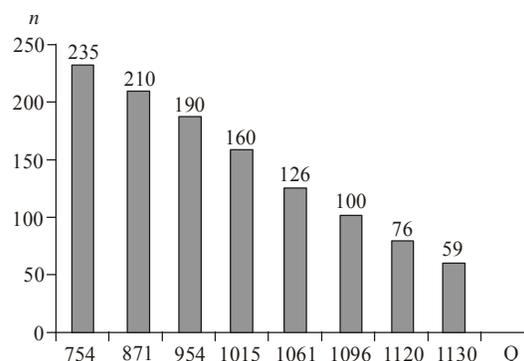


Fig. 2: The $Q \sim n$ characteristic of special turbine

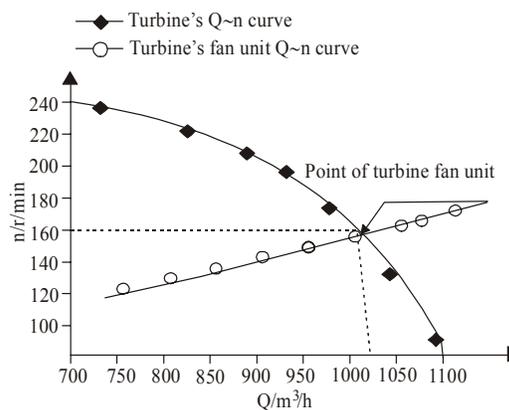


Fig. 3: The operating point of turbine-fan unit

the system flow and the turbine-fan unit parameter are set values, the turbine-fan unit will be automatically stable in the corresponding operating point.

THE REGULATONG CHARACTERISTIC OF THE SPECIAL TURBINE

The operating point regulation of the turbine in cooling tower water system is much more complex than the power generation turbine. The main reason is the power turbine's speed is fixed and its operating point will not be affected by speed. However, as the driven power of the fan the turbine works in cooling tower and connects directly with the fan, forming a turbine-fan unit so that the $Q \sim n$ characteristic of the unit directly affects the turbine operating point. Rather, should use

the "working point" concept described in the turbine operating point.

When the working head is certain the discharge of the turbine, working in the hydropower (for fixed blade turbines), is determined only by the intake value of the guide glade so that it is easy to adjust the turbine's operating point. But as a special turbine in turbine-fan unit, the speed of the unit will affect the flow characteristic of it, coupled with the special turbine must be a low specific speed so the speed will affect the flow characteristic of the turbine significantly. Therefore, to adjust the operating point of the special turbine, you must consider the effect of the intake value of the guide glade and the effect of the speed of turbine-fan unit on the turbine's discharge at the same time. The operating point is determined by the over flow characteristic curve of the turbine itself and the speed-flow curve of the turbine-fan unit jointly.

We can see from the above studies, hydrodynamic cooling tower has good self-regulation characteristics. But when poor choice of turbine parameters of the system or system changes lead to the turbine can not work in the optimal range of operating condition and the turbine efficiency of the cooling will decrease, which affects its cooling effect, we need adjust the turbine's operating conditions appropriately. Although in this case it is difficult to adjust the fan's air flow and air pressure in a wide range, but according to the dynamic properties of the turbine-fan unit, we still can regulate the operating parameters within a certain range effectively. The regulations of turbine operating conditions can be as follows:

- **Set the adjustable guide vanes:** When the system flow or pressure changes, by adjusting the turbine guide vane to change operating conditions and so the flow of the turbine can match the requirements of the fan power.
- **Adjusting the angle of fan blades:** By adjusting the angle of fan blades to change the amount of fan drive power and the air flow, air pressure and so we can indirectly regulate the turbine's operating conditions.
- **Replacing different diameter fan:** When the guide vane is not set, this method can be used to change the fan drive power. Using the characteristics of turbine-fan unit we can regulate the turbine's working conditions indirectly to achieve a better cooling effect.

The former two adjustments are introduced as the followings:

Table 2: The operating condition changes with the guide vane opening changes

Measure point	1	2	3	4
Q/T/h	352/344	401/395	445/425	502/482
Fan speed	138/179	155/207	177/232	201/251
H/m	2.8/3.8	3.5/5.0	4.25/5.6	5.5/7.0
n_{11} /r/min	34.6/38.6	34.8/38.9	36.0/41.2	36.0/39.8
Q_{11} /L/s	329/278	338/278	340/283	337/287

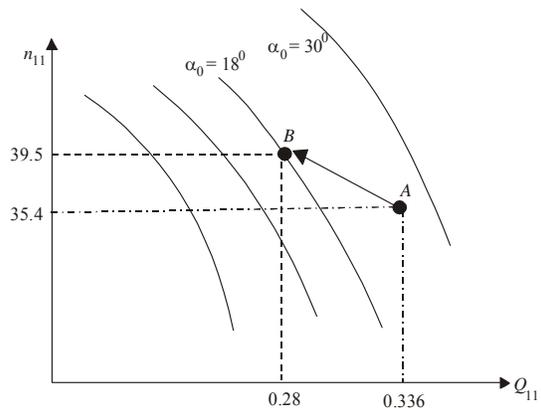


Fig. 4: The operating condition changes with the guide vane opening changes

Set the adjustable guide vanes: When setting an adjustable guide vane and the fan blade angle φ is constant, we can adjust the unit operating point by regulating the turbine guide vane opening degree. However, the special turbine works in the series system, which is different from the power generation and so the working head H is not only a function of traffic, but also a function of guide vane opening. So when the guide vane opening changes, the working conditions change is more complex than that of the power generation. The unit discharge is in proportion to the guide vane opening basically. But the guide vane opening reduces, the turbine utilized head increases. The qualitative basic law is that the guide vane opening increases, the turbine unit flow rate increases, unit speed decreases and vice versa.

The tests on HL90-LJ-42 with LF38 fan turbine, which formed turbine-fan unit, proved the basic law which the working conditions of the special turbine changes with the guide vane opening. Data from Table 2 shows, when the guide vane exit angle decreases from 30° to 18° , the turbine's average unit discharge reduced from 0.336 to 0.28 m^3/s and the average unit speed increased to 39.5 from 35.4 r/min. Shown in Fig. 4, the operating point changes under

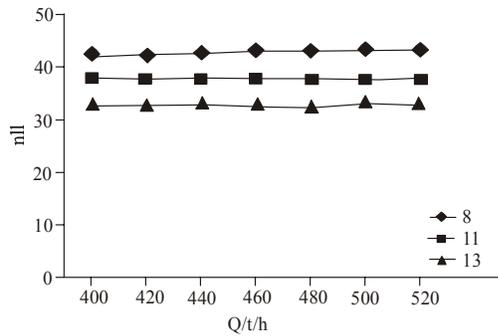


Fig. 5: $n_{11} \sim \varphi$ curve

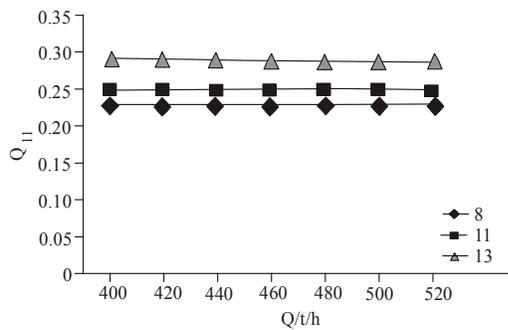


Fig. 6: $Q_{11} \sim \varphi$ curve

the direction to the right when the guide vane opening increases, to adjust the turbine operating condition from A to B and vice versa.

Note: Before and after "/" are the corresponding parameters which the guide vane outlet angles are 30° and 18°.

Adjusting the angle of fan blades: For turbine-fan unit with fixed guide vane, to adjust the turbine

operating conditions only can achieve by adjusting the angle of the fan blades. The basic principle of regulation is when we can ensure essentially the fan flow conditions, changing the torque of the fan by adjusting its blade angle, the speed of turbine-fan unit changing with the torque and so that the turbine operating conditions can be adjusted to a better location. According to the characteristics of fans, in the same shaft power, the blade angle decreases, the speed of turbine-fan unit increases and the turbine unit speed increases. The unit discharge will reduce because of the ultra-low specific speed characteristic of the special turbine in cooling tower, and vice versa. Jointly using the flow characteristic curve of turbine and the fan characteristic curve, the change of operating condition can be determined when the fan blades' angle changes. Figure 5 shows $n_{11} \sim \varphi$ curve. Figure 6 shows $Q_{11} \sim \varphi$ curve.

Tests on HL50-LJ-50 turbine with LF42 fan, which formed a turbine-fan unit, were divided into three groups, corresponding to the fan angle φ : 8°, 11° and 13° (Table 3 and 4). in the fixed blade angle, change the turbine flow in sequence, at the same time test the fan speed and the turbine operating parameters to calculate the unit speed and unit discharge, the results shown in Table 5, 6 and Fig. 7 and 8.

CONCLUSION

The main contribution in this study is the deep and systematic analysis, combined the experimental data, of the flow characteristics of special turbine, the working characteristics and the regulating characteristic of turbine-fan unit in hydrodynamic cooling tower. These are no one has ever done. These characteristics can provide theoretical support for the hydrodynamic reconstruction from industrial cooling tower and can be

Table 3: The parameters of turbine working condition: LF42 fan, $\varphi = 13^\circ$

Operate point	1	2	3	4	5	6
Q/T/h	420.000	440.000	460.000	480.000	500.000	520.000
Actual Q/m ³ /s	0.117	0.122	0.128	0.133	0.139	0.144
Fan speed	141.000	148.000	155.000	162.000	170.000	177.000
H/ m	3.450	3.800	4.200	4.600	5.000	5.500
N_{11} /r/min	38.000	37.960	37.800	37.800	38.000	37.700
Q_{11} /L/s	0.252	0.251	0.250	0.250	0.249	0.246

Table 4: The parameters of turbine working condition: LF42 fan, $\varphi = 8^\circ$

Operate point	1	2	3	4	5	6
Q/T/h	420.000	440.000	460.000	480.000	500.000	520.000
Actual Q/m ³ /s	0.117	0.122	0.128	0.133	0.139	0.144
Fan speed	141.000	148.000	155.000	162.000	170.000	177.000
H/m	3.450	3.800	4.200	4.600	5.000	5.500
n_{11} /r/min	38.000	37.960	37.800	37.800	38.000	37.700
Q_{11} /L/s	0.252	0.251	0.250	0.250	0.249	0.246

Table 5: The parameters of turbine working condition: LF42 fan, $\phi = 11^\circ$

Operate point	1	2	3	4	5	6
Q/T/h	420.000	440.000	460.000	480.000	500.000	520.000
Actual Q/m ³ /s	0.117	0.122	0.128	0.133	0.139	0.144
H/m	4.400	4.650	5.000	5.500	6.000	6.500
N/r/min	177.000	185.000	193.000	204.000	213.000	222.000
N ₁₁ /r/min	42.200	42.900	43.200	43.500	43.500	43.500
Q ₁₁ /m ³ /s	0.222	0.227	0.229	0.227	0.227	0.227

Table 6: The working conditions of the special turbine change with the fan blade angle changes

$\phi/^\circ$	8.00	11.00	13.00
Q ₁₁ /m ³ /s	0.23	0.25	0.29
n ₁₁ /r/min	43.00	38.00	33.00

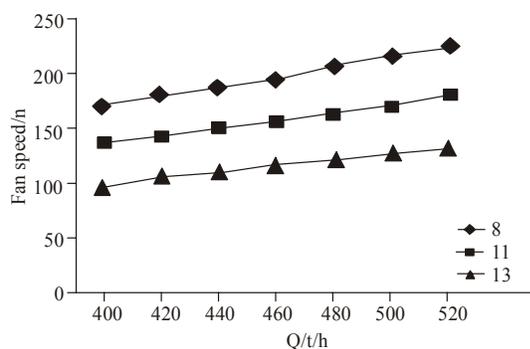


Fig. 7: The speed-flow characteristics of turbine-fan unit when fan blade angle change

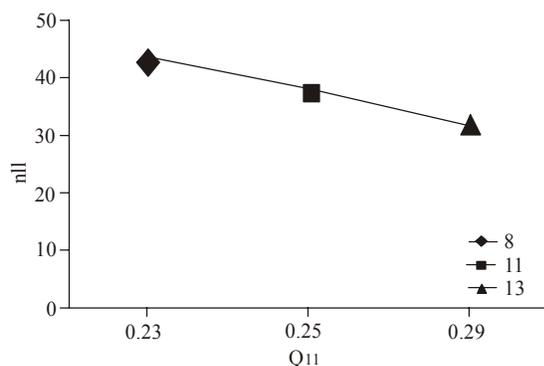


Fig. 8: The turbine working condition changes with the ϕ

used as the theory foundation of the research on the special turbine-fan unit in hydrodynamic cooling tower. The study in this article can provide the directions and

ideas for the more deep studies in the future. At the same time, these characteristics theory has been used successfully in the hydrodynamic reconstruction from industrial cooling tower and those successful examples prove these theories are correct in turn.

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