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Research on the Flow-Head Characteristics of the Turbine Driving Fan in Cooling tower

Li Yanpin, Ren Yan, Zhang Lanjin and Chen Dexin
School of Electric Power, North China Institute of Water Conservancy and Electric Power, Zheng zhou Henan 450011, China

Abstract: The flow-head characteristics of the special turbine in cooling tower are very different from the general power turbines'. This study has analyzed the former theoretically and proposed the theoretical formula of the head-flow. At the same time, the paper has studied the characteristics of the flow-head using the CFD method. The tests results have proved the principle of the flow-head of the turbine in cooling tower.

Keywords: Cooling tower turbine, head-flow characteristics, hydraulic machinery

INTRODUCTION

The specific work environment and work conditions of cooling tower turbine determine its special work characteristics and also decide its different flow-head characteristics from the hydropower station turbines (Li *et al*., 2011; Li, 2011).

The cooling tower turbine connects with the fan directly, forming turbine-fan unit. The unit is the combination of power machine and driven machine, which is similar to turbine-pump unit and turbo-pump unit. They are all turbo-machinery (vane hydraulic machinery). The unit has three characteristics:

- One is the turbine speed is equal to the fan's
- Second is the output power of turbine is the fan power
- Thirdly, the power machine and the working machine are all hydraulic machineries and they have the same similitude.

Li *et al*. (2011) study the approximate calculation of the flow capacity of special turbine in cooling tower. Guo *et al*. (1996) have a research of the hydraulic losses model of the diversion components of hydraulic turbine. Launder and Spalding (1974) analyzes the numerical computation of turbulent flows. computer methods in applied mechanics and engineering. Menter (1994) studies the two equation eddy-viscosity turbulence models for engineering applications. Li *et al.* (2011) studies on regulation characteristics of special turbine-fan unit in cooling tower.

In this study, we get the results that the head that the cooling tower turbine, working in a turbine-fan unit, can use is not equal to the head that the system provide to it. It is determined by the characteristics of the turbine-fan unit. The available head of the turbine is proportional to its flow square. The theory analysis, the CFD calculation and the test results all proved the conclusion. This theory can be used to design and operate the special turbine-fan unit.

METHODOLOGY

The theory expression of head-flow characteristic: In turbine-fan unit, the speed of the fan is determined by the output power of the turbine, when it is a certain fan. The output power of the turbine is determined by the flow Q and water head H, which is can be used by the turbine. H and Q are all the functions of the speed of the turbine-fan unit. Thus it formed the special relationship among the water head, the flow and the speed.

It determines the flow-head characteristic of cooling tower turbine, which works in a series pressure system. Based on the basic equations, which descript the dynamic behaviors of the turbine and the fan, with their power balance and speed equal for coupling conditions, we can derived the flow-head equation of the turbine.

In turbine-fan unit, the turbine's speed and power are same as the fans'. According to fan's similitude, there is:

$$\left(\frac{n_P}{n_M}\right)^{\frac{1}{3}} = \left(\frac{N_P}{N_M}\right) \quad (1)$$

There, N is the shaft power of the fan.

Corresponding Author: LI Yanpin, School of Electric Power, North China Institute of Water Conservancy and Electric Power, Zheng zhou Henan 450011, China

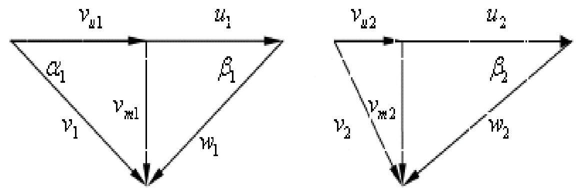


Fig.1: The inlet and outlet velocity triangle of turbine

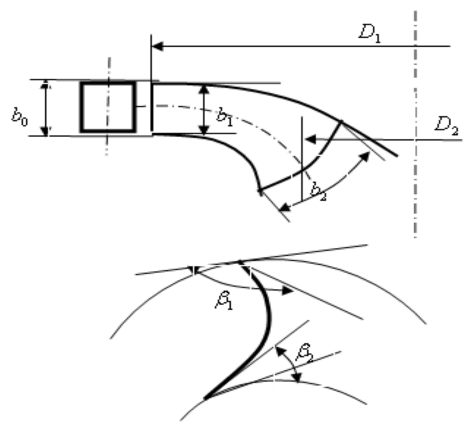


Fig. 2: The parameters of the runner flow

Because the turbine and the fan couple directly and N is the output shaft power of the turbine, it is:

$$N = \gamma QH \tag{2}$$

D_1 : The diameter of blade inlet
D_2 : The diameter of blade outlet
b_0 : The high of guide vane
b_1 : The high of blade inlet
b_2 : The high of blade outlet
β_1 : The flow angle of blade inlet
β_2 : The flow angle of blade outlet

There, γ is the specific gravity of water; Q is the turbine flow and H is the work head of the turbine. Know therefore: in fan, there is $n \propto N^{\frac{1}{3}} = (\gamma QH)^{\frac{1}{3}}$, because $\gamma = const$, there is:

$$n \propto (QH_e)^{\frac{1}{3}} \tag{3}$$

According to the basic equation of turbine, the effective water head is for:

$$H_e = H\eta_h = \frac{1}{g}(u_1 v_{u1} - u_2 v_{u2}) \tag{4}$$

where,
H_e : The effective water head of turbine
η_h : The hydraulic efficiency of turbine
u_1 : The circumferential velocity of the turbine inlet
V_{u1} : The circumferential velocity component of the turbine inlet
U_2 : The circumferential velocity of the turbine outlet
V_{u2} : The circumferential velocity component of the turbine outlet

The inlet and outlet velocity triangle of turbine are shown as Fig. 1. The parameters of the runner flow are shown as Fig. 2.
The parameters of the turbine are as the following:

$$v_{u1} = v_{m1}.c\tan\alpha_1;\ v_{u2} = u_2 - v_{m1}.c\tan\beta_2$$

$$u_1 = \frac{\pi D_1 n}{60} = k_1 n,\ k_1 = \frac{\pi D_1}{60} = const$$

Also available:

$$u_2 = k_2 n\ ,\quad k_2 = \frac{\pi D_2}{60} = const$$

$$v_{m1} = \frac{Q}{\pi D_1 b_1}\ ,\quad v_{u1} = \frac{Q}{\pi D_1 b_1} c\tan\alpha_1 = k_3 Q$$

there: $k_3 = \dfrac{c\tan\alpha_1}{\pi D_1 b_1} = const$

Also available:

$$v_{m2} = \frac{Q}{\pi D_2 b_2}$$

$v_{u2} = u_2 - v_{m2} c\tan\beta_2 = k_2 n - k_4 Q$, there:

$$k_4 = \frac{c\tan\beta_2}{\pi D_2 b_2} = const$$

The known turbine basic equation is:

$$H_e = \frac{1}{g}(u_1 v_{u1} - u_2 v_{u2})$$

Will the above u_1, v_{u1}, u_2, v_{u2} into the turbine basic equation may have:

$$H_e = \frac{1}{g}[k_1 n.k_3 Q - k_2 n(k_2 n - k_4 Q)]$$

$$= \frac{1}{g}[(k_1 k_3 + k_2 k_4) nQ - k_2^2 n^2]$$

As can be seen (3):

$$n = k_5 (QH_e)^{\frac{1}{3}}$$

Will the above equation into the turbine basic equation may have:

$$H_e = \frac{1}{g}[(k_1 k_3 + k_2 k_4) k_5.(QH_e)^{\frac{1}{3}} Q - k_2^2 k_5^2 (QH_e)^{\frac{2}{3}}]$$

Let $(k_1 k_3 + k_2 k_4) k_5 \frac{1}{g} = K_a$, $\quad k_2^2 k_5^2 \frac{1}{g} = K_b$

where, K_a and K_b are constants.

Thus, the basic equation can be turned into:

$$H_e = K_a Q^{\frac{4}{3}} H_e^{\frac{1}{3}} - K_b Q^{\frac{2}{3}} H_e^{\frac{2}{3}}$$

Finishing, we can get:

$$H_e^{\frac{2}{3}} + K_b Q^{\frac{2}{3}} H_e^{\frac{1}{3}} - K_a Q^{\frac{4}{3}} = 0 \quad (5)$$

Let $X = H_e^{\frac{1}{3}}$, $A = Q^{\frac{2}{3}}$, Then the equation can be written as a quadratic equation of x:

$$X^2 + K_b A.X - K_a A^2 = 0$$

X is the unknown solution of the equation to get:

$$X = \frac{-K_b A \pm \sqrt{(K_b A)^2 + 4K_a A^2)}}{2} = KA$$

where, K is a constant.

Use $X = H_e^{\frac{1}{3}}$ and $A = Q^{\frac{2}{3}}$ restore the parameters H and Q, are:

$$H_e = K^3 Q^2$$

Abbreviated as:

$$H_e = K_H Q^2 \quad (6)$$

That is $H \propto Q^2$, or $Q \propto \sqrt{H_e}$

Type (6) is the head-flow equation of cooling tower turbine. The equation shows that in a certain cooling tower turbine-fan unit, the effective water head of the turbine is proportional to the square of its flow. When known the geometry parameter of the turbine and its flow, we can calculate the effective head of the turbine by (8). If known hydraulic turbine efficiency, then we can calculate the effective head H of the turbine. The head-flow characteristic of the cooling tower turbine is quite different from the conventional power turbine's. The water head of the latter is determined by the upstream level and downstream water level, so its flow has little effect on its head.

Therefore, the both head-flow characteristics are essentially different.

The CFD analysis of the head-flow characteristic of cooling tower turbine:

Calculation model parameters: Turbine parameters type: HLX-LJ- B; the runner parameters for: D_1 = 0.42 m, D_2 = 0.21 m, b_0/D_1 = 0.1; the blade inlet angle: β_{1b} = 145°; the blade outlet angle: β_{2b} = 26°; the guide vane inlet angle: α_0 = 16°; the guide vane outlet angle: α_1 = 13°. The volute is round section, inlet section velocity: v = 5m/s; design head: H = 7.5 m; design flow: Q = 500 T/h; rated revolution: n = 240 r/min.

Fan parameters type: LF38; Fan diameter: D = 0.38 m; blade installation angle: 15°; The rated revolution: n = 240 r/min.

Simulation model: The simulation model of the turbine is a standard κ-ε turbulent model based on the N-S Eq. (5) and (6). The geometric model of the whole channel is a three-dimensional model, including metal volute, stay ring, runner and draft tube etc., the calculation meshes are unstructured grids, for a total of 1.1 million.

RESULTS ANALYSIS

Use $Q \propto \sqrt{H}$, the turbine-fan unit also has $n \propto N^{\frac{1}{3}} \propto (QH)^{\frac{1}{3}} \propto (Q.Q^2)^{\frac{1}{3}} \propto Q$, that is the flow-head relationship of the turbine-fan unit:

$$n \propto Q \quad (7)$$

Type (7) shows that the rotate speed of the turbine-fan unit is proportional to the turbine flow. Therefore,

Table 1: The hydraulic losses of turbine flow

n/r/min	182.4	202	221	240	260
Q/m^3/h	380	420	460	500	540
H1/m	4.689	5.685	6.823	8.035	9.358
H2/m	4.518	5.482	6.589	7.768	9.055
H3/m	4.008	4.871	5.858	6.911	8.063
H4/m	0.619	0.750	0.903	1.066	1.241
H5/m	0.594	0.720	0.867	1.0236	1.191

H1: Volute inlet pressure; H2: Volute outlet pressure; H3: guide vane outlet pressuse; H4: Runner outlet pressure; H5: draft tube outlet head

Table 2: The head-flow characteristic of the special super-low specific speed Francis turbine in cooling tower

Working points	Q/m^3/h	Q/m^3/s	H/m	H/Q^2
1	380	0.106	4.17	371.13
2	420	0.117	5.06	368.91
3	460	0.128	6.07	367.61
4	500	0.139	7.15	370.06
5	540	0.150	8.32	369.80

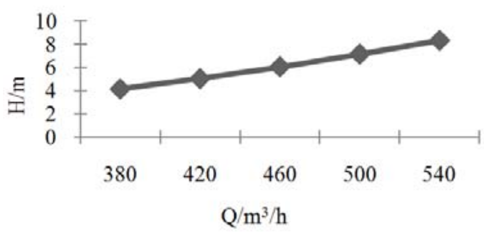
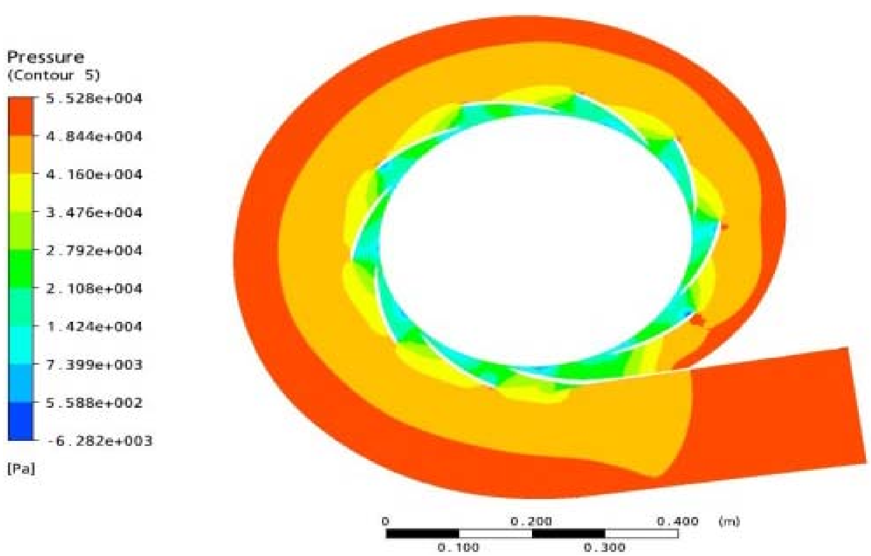


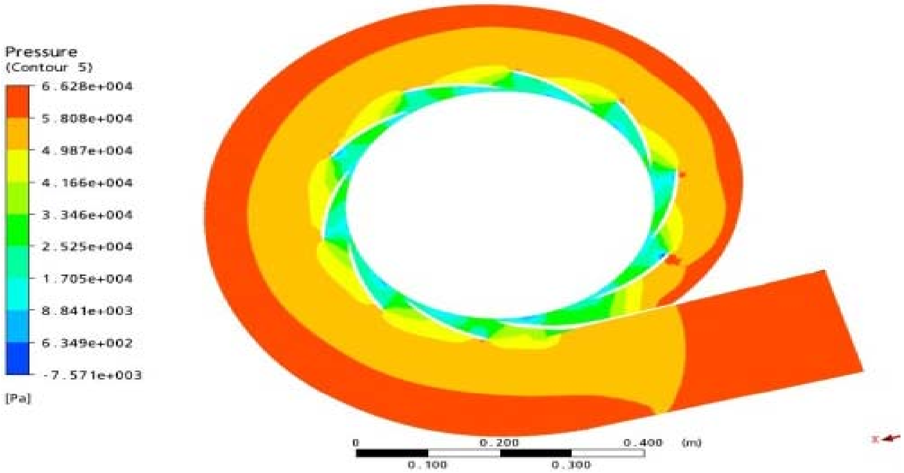
Fig. 3: Flow-head relationship

the speed n and the flow Q should be given according to the law of $n \propto Q$, when we calculate the flow-head relationship through CFD analysis. Through CFD analysis, we can calculate the velocity field and further work out the water head H, so that we can get the flow-head relationship $H = f(Q)$. The CFD calculation results of pressure distribution are shown in Table 1. The flow-head relationship is shown as Table 2 and Fig. 3. It can be seen from the data that the turbine head and the pressure difference between inlet and outlet of flow components increase when the speed n and flow increase.

Pressure distribution of flow field: The pressure distribution of flow field decides how much water head can be used by the special turbine. From the pressure of the volute inlet and the runner inlet and outlet, it can be seen that the pressure difference between the inlet and outlet of the flow components increase with the increase of flow and rotating speed increases. It means that the water head of turbine increase. Corresponding to the data in Table 1, the pressure distribution in runner and volute are shown in Fig. 4. Li *et al.* (2011) study the performance and type selection of special hydraulic turbine in cooling tower, yet they have not discuss the flow-head characteristics of the turbine driving fan in cooling tower. Li *et al.* (2011) also have a research of the regulation characteristics of special turbine-fan unit in cooling tower, however,



(a)



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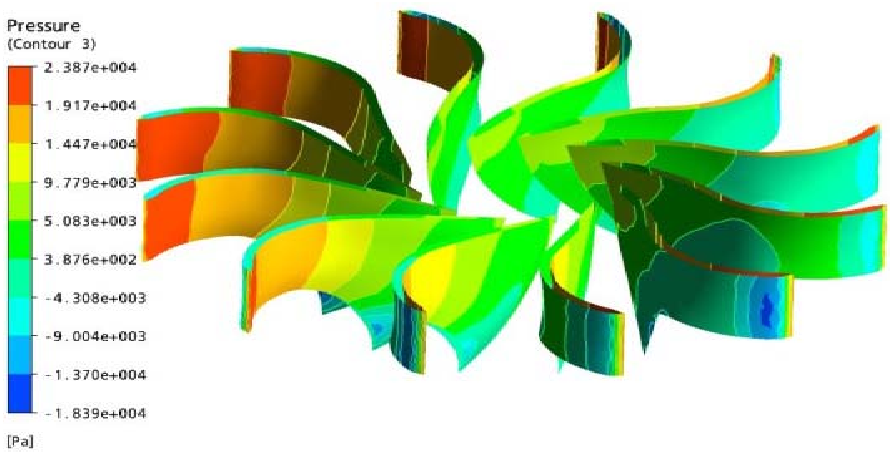

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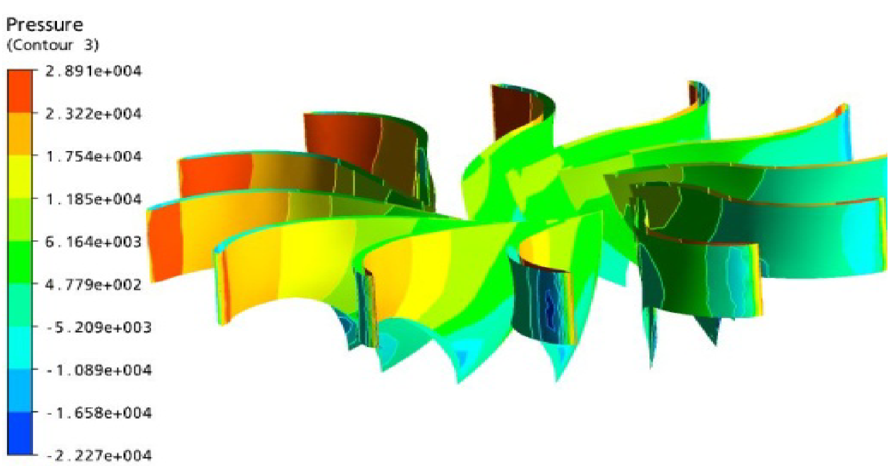

(d)

Fig. 4: The pressure distribution of flow components

Table 3: HLX-LJ- B turbine test results

Test points	$Q/m^3/h$	H/m	n/r/min	H/Q^2
1	364	4.0	179	412
2	395	4.7	193	405
3	423	5.3	205	406
4	435	5.7	215	410
5	453	6.0	219	409
6	480	6.7	232	407
7	510	7.4	243	400

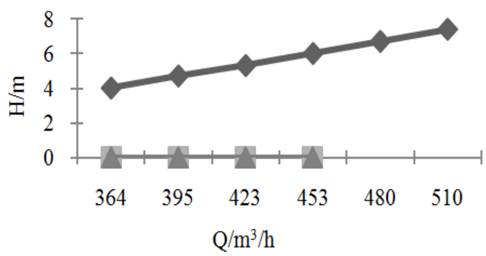

Fig. 5: Flow-head characteristic curve of the special turbine

their method do not consider the flow-head characteristics of the turbine driving fan in cooling tower. In this way, our method and research scope seem to be extensive and intensively, which is superior to the existing work.

HEAD-FLOW CHARACTERISTIC TEST OF COOLING TOWER TURBINE

Model parameters: The parameters are same as the CFD simulation model. Model turbine and fan are all made according the CFD simulation models.

Method test: The prototype turbine-fan tests have been done in a closed cooling tower experimental facility. Using the import valve of the turbine, adjust the flow to the given value in Table 3 and at the same time measure the fan speed n and the turbine head H.

Test results and relative analysis: Test results are shown as Table 3 and Fig. 5. The experimental data of Table 3 and Fig. 5 shows that the 500 T/h cooling tower turbine has a typical head-flow characteristics, the test data, the theoretical analysis results and the CFD simulation results are in good agreement. So that the results can verify the head-flow characteristic of the special turbine in cooling tower.

CONCLUSION

The head that the cooling tower turbine, working in a turbine-fan unit, can use is not equal to the head that the system provide to it. It is determined by the characteristics of the turbine-fan unit. The available head of the turbine is proportional to its flow square. The theory analysis, the CFD calculation and the test results all proved the conclusion. This theory can be used to design and operate the special turbine-fan unit.

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