Innovative design of exhaust enthalpy algorithm for small turbine

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Abstract. This paper presents a method to determine the exhaust enthalpy of small steam turbine. Starting from the feed water pump group, the feed water pump and small steam turbine are studied as a whole. Based on the thermodynamic method, the efficiency of the feed water pump is obtained separately, and then the efficiency and exhaust enthalpy of the small steam turbine are deduced. This method only needs to measure the inlet and outlet pressure, temperature, feed water flow of feed water pump, inlet steam pressure, temperature and flow of small turbine. It has the advantages of less measurement parameters, low measurement cost and small measurement error. It provides a reliable basis for a comprehensive understanding of the performance of small steam turbine and guiding its economic and safe operation.

1. Introduction

At present, the feed water pumps of 300MW and above units in China are mostly driven by small steam turbines, because compared with the traditional electric feed water pumps, they have obvious advantages in saving auxiliary power and economy [1]. With the increase of unit capacity, the power consumption of feed pump accounts for about 2% - 4% of the main engine power. Therefore, it is of great significance to study the operation characteristics of small turbine for guiding the economic and safe operation of power plant. The last stage blade of small steam turbine works in the wet steam area. Steam humidity will not only reduce the efficiency of steam turbine, but also cause blade water erosion, which seriously threatens the safe operation of steam turbine. It is difficult to measure the steam humidity directly. The steam humidity can be obtained from the exhaust enthalpy of small steam turbine. However, because the exhaust steam of the small turbine is located in the wet steam area, only by measuring the exhaust steam pressure and temperature of the small turbine, the exhaust enthalpy of the small turbine can not be accurately obtained, so the steam humidity can not be obtained.

There are many models and methods to calculate the exhaust enthalpy of large turbine, but the method of calculating exhaust enthalpy of small turbine is almost blank. As an important auxiliary of power plant, small turbine plays an important role in the economic and safe operation of power plant [2]. Traditionally, the method of calculating exhaust enthalpy of large turbine can also be used for exhaust enthalpy of small turbine strictly. However, due to the particularity of small turbine, it is difficult to add measuring points. If the heat balance method is used to calculate the exhaust enthalpy of small turbine, it is necessary to measure multi-stage steam parameters, which is complicated and difficult to
operate. In order to solve the above technical deficiencies, a simple and easy operation method is proposed to determine the exhaust enthalpy of small turbine.

2. Common calculation models of steam turbine exhaust enthalpy
The exhaust enthalpy of condensing steam turbine in power station is an important economic index in the operation of steam turbine unit. Because the exhaust steam of steam turbine is in the wet steam area, it is impossible to measure its enthalpy directly with instruments. Therefore, the calculation method of exhaust enthalpy of steam turbine has become the focus of research. Typical calculation methods are: freuger formula method, equivalent enthalpy drop method, relative internal efficiency method and neural network method, etc [3, 4].

Freuger's formula is widely used in off design calculation of steam turbine. The steam temperature and pressure of each stage are determined by combining with the variation formula of internal efficiency. However, freuger's formula is only an empirical formula. Practice has proved that the error of this formula is small when there are many stages, and it must meet the following conditions in application: under the same working condition, the flow through each stage of the stage group is the same, and the flow area and reaction degree of each stage in the lower group under different working conditions remain unchanged [5]. In essence, the calculation of exhaust enthalpy of steam turbine is obtained by subtracting the power generated by previous groups from the total power of known units, and the equivalent enthalpy drop method is used to calculate the power of previous groups. When using the equivalent enthalpy drop method to calculate the heat balance, it is based on the known steam state line of the unit, which is not suitable for the condition with large load change [3]. Due to the large difference between the actual relative internal efficiency and the indicative internal efficiency of the low pressure cylinder, the calculation error of steam turbine exhaust volume is large [6]. Neural network method to calculate exhaust enthalpy is to establish exhaust enthalpy model based on deep mining of a large number of known input and corresponding output arrays of power plants. This method can comprehensively consider a variety of influencing factors, without considering the mapping relationship between input and output. With the rise of machine learning, it is gradually popular, but it is not universal.

3. The present situation of the heat supply reform of Shandong power grid thermal power unit
The partial structure diagram of small steam turbine is shown in Figure 1, including 1 small steam turbine, 2 feed pump, 3 transfer shaft and 4 orifice flowmeter. The method for calculating the exhaust enthalpy of a small steam turbine includes the following four steps.

![Figure 1. Structure diagram of small steam turbine](image)

(1) The flow rate of the fluid at the inlet and outlet of the feed water pump and the pressure and temperature of the steam inlet of the small turbine were measured respectively. The enthalpy values h1 and h2 of the fluid at the inlet and outlet of the feed water pump, the isentropic enthalpy value h2s at the outlet pressure and the steam inlet enthalpy value hjq of the small turbine were calculated by using IFC-97 industrial water and steam thermodynamic property model.
(2) The differential pressure of feed water flow at the outlet of feed water pump and the differential pressure of steam flow at the inlet of small turbine are measured by orifice flowmeter, and then the feed water mass flow $G_{gs}$ and the steam inlet mass flow $G_{jq}$ of small turbine are calculated according to the calculation model of orifice flowmeter.

(3) First, the pressure $P_1$, $P_2$ of the fluid and temperature at the inlet and outlet of the feed water pump are measured. Combined with the enthalpy calculated in step (1), the efficiency of the feed water pump was obtained by thermodynamic method; Then, the effective power of the feed water pump is calculated by using the feed water mass flow $G_{gs}$ obtained in step (2), and then the effective power output of the small turbine is obtained.

The calculation formula of the efficiency of feed pump by thermodynamic method is as follows:

$$
\eta_g = \frac{h_{2g} - h_1 + \frac{\alpha_2 u_2^2 - \alpha_1 u_1^2}{2} + g(Z_2 - Z_1)}{h_z - h_1 + \frac{\alpha_2 u_2^2 - \alpha_1 u_1^2}{2} + g(Z_2 - Z_1) + \Delta E_m + E_x} \quad (1)
$$

Where: $\eta_g$ -efficiency of feed pump; $h_2$ -enthalpy of feed water outlet; $h_1$ -enthalpy of feed water inlet; $h_2$ -isentropic enthalpy at outlet pressure; $\alpha_2$ -outlet velocity coefficient; $\alpha_1$ -inlet velocity coefficient; $u_2$ -outlet velocity; $u_1$ -inlet velocity; $g$ -acceleration of gravity; $Z_2$ -distance between measured section and datum plane of feed water pump outlet; $Z_1$ -distance between measured section and datum plane of feed water pump inlet; $\Delta E_m$ -leakage flow loss and heat loss of pump body of balancing device and shaft sealing device; $E_x$ -fluid mechanical loss.

The calculation formula of effective power of water pump is as follows:

$$
P_{sg} = G_{gs} g H \quad (2)
$$

Where: $P_{sg}$ -effective power of feed water pump; $G_{gs}$ -feed water mass flow; $H$ -lift.

The calculation formula of head is as follows:

$$
H = \frac{p_2 - p_1}{\rho g} \quad (3)
$$

Where: $p_2$ -outlet pressure of feed water pump; $p_1$ -inlet pressure of feed water pump; $\rho$ -average density of inlet and outlet of feed water pump.

The calculation formula of effective power output of small steam turbine is as follows:

$$
ps = \frac{p_s}{\eta_2 \eta_3} \quad (4)
$$

Where: $p_s$ -effective work of small steam turbine; $\eta_2$ -the transfer efficiency of the transfer shaft, the design value.

(4) According to the calculation results in step (3), the exhaust enthalpy of the small turbine is calculated as follows:

$$
h_{jq} = h_{jq} - \frac{P_s}{G_{jq}} \quad (5)
$$

Where: $h_{jq}$ -exhaust enthalpy of small turbine; $h_{jq}$ -Inlet enthalpy of small steam turbine; $G_{jq}$ -inlet steam flow of small steam turbine.
In the calculation formula for calculating the efficiency of the feed water pump by the thermodynamic method in step (3). The inlet and outlet velocity coefficient $\alpha_1$ and $\alpha_2$, inlet and outlet velocity $u_1$ and $u_2$ and the distance $Z_1$ and $Z_2$ from the measured section of feed pump inlet and outlet to the datum plane are equal. $\Delta E_m + E_s$ is factory coefficients, which is 1% - 2% of the enthalpy rise of feed water pump. The formula is simplified as follows:

$$\eta_s = \frac{h_{z_2} - h_1}{(1+1\% \sim 2\%)(h_{z_2} - h_1)}$$ (6)

4. Improvement of operation management of thermal power unit

The calculation of exhaust enthalpy of small steam turbine can use the model of exhaust enthalpy of large steam turbine. In view of the shortcomings of the above methods to calculate exhaust enthalpy of small steam turbine, considering the particularity of small steam turbine, for example, it is difficult to install measuring points. If the heat balance method is used to calculate exhaust enthalpy of small steam turbine, multi-stage steam parameters need to be measured, which is complicated and difficult to operate. The method of calculating exhaust enthalpy of small steam turbine proposed in this paper only needs to measure the inlet and outlet pressure, temperature, feed water flow of feed water pump, and inlet steam pressure, temperature and flow of small steam turbine. The measurement error has little influence on the results, and has been effectively applied in practice. It provides reliable data support for the economic and safe operation of small steam turbine.

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