Study on an efficiency algorithm for the opening middle tap of steam feed pump

Lingkai Zhu *, Qian Wang, Song Gao, Yue Han, Ziwei Zhong, Wei Zheng, Panfeng Shang, Junshan Guo
State Grid Shandong Electric Power Research Institute, Jinan, China
*Corresponding author e-mail: zhulingkai@woyoxin.com

Abstract. This paper presents a method for calculating the efficiency of steam feed pump, which fills the literature gap in calculating the efficiency of steam feed pump when the middle tap of feed pump is opened. This method has the advantages of convenient measurement and few measurement parameters. Combined with IFCIFC-97 industrial water and steam thermodynamic property model, the efficiency of feed pump can be calculated.

1. Introduction
The operation economy of steam turbine generator unit depends not only on the efficiency of main steam turbine, but also on the configuration and operation performance of each auxiliary machine in thermal system [1]. Steam feed pump unit is an important auxiliary equipment of thermal system in thermal power plant. It is mainly used to increase feed water pressure, convert condensate into boiler feed water and provide desuperheating water to superheater and reheater [2]. With the increase of unit capacity, the power consumption of feed pump accounts for about 2% - 4% of the main engine power. Measuring the efficiency of steam driven feed pump is very important to guide the safe and economic operation of power plant. The traditional methods for measuring the efficiency of steam driven feed pump include hydraulic method and thermodynamic method, but no matter what method is adopted for testing, the middle tap of feed pump needs to be closed. However, in the actual operation of power plant, a certain amount of reheat desuperheating water must be put into the boiler side in case of overtemperature, and the reheat desuperheating water needs to be extracted from the middle tap of feed pump. Therefore, after closing the middle tap of the feed pump, the reheat desuperheating water cannot be put into operation, which will cause overtemperature at the boiler side.

If the middle tap of the feed pump is opened, the effective power obtained by the tap must be considered when calculating the pump efficiency, that is, the heat taken away by the reheat desuperheating water. In the existing literature, there is no clear method to calculate the efficiency of the feed pump when the middle tap of the feed pump is opened. In order to solve the above technical problems, this paper proposes a method to calculate the efficiency of steam driven feed pump when the middle tap of feed pump is opened. This method has the advantages of convenient measurement and less measurement parameters. The efficiency of feed pump can be calculated in combination with IFCIFC-97 industrial water and steam thermodynamic property model.
2. Calculation method of efficiency of steam driven feed pump

With the increase of single unit power of thermal power units, more and more units begin to use small steam turbine to drive feed water pump to reduce auxiliary power consumption rate [3]. At present, the feasible performance monitoring method of small steam turbine is to monitor the efficiency of boiler feed pump, and the relative internal efficiency of small steam turbine is indirectly obtained through the power transmission of steam feed pump unit. Therefore, the calculation and monitoring of steam feed pump unit efficiency is of great significance to improve the operation economy of thermal power unit.

DL/T 839-2003 proposes a thermodynamic method to measure the efficiency of feed pump. This method determines the efficiency of feed pump based on the enthalpy difference at the inlet and outlet of feed pump. The inlet and outlet temperature of feed pump is a direct factor affecting the enthalpy difference [4]. This method is simple and efficient, but because the temperature difference at the inlet and outlet of the feed pump is very small, the accuracy of the temperature sensor is very high, and the accuracy required in different test occasions is also different. GB/T 3216-2016 puts forward the measurement method of hydraulic performance acceptance test of rotary power pump, but this method has strict requirements on measurement parameters and is suitable for pump acceptance test in laboratory or test bench of pump manufacturer [5]. The researchers of Shanghai Jiaotong University realized the on-line calculation of turbine shaft power in combined cycle power plant with the help of photoelectric torque sensor, but the small distance between small turbine and feed pump brought great difficulties to the installation of photoelectric torque sensor photosensitive film [6]. Northeast Electric Power University proposes to use the three thermal system method to monitor the efficiency of feed water pump unit on line. The three thermal systems refer to steam turbine unit, low pressure cylinder low pressure regenerative system and steam driven feed water pump unit. Firstly, according to the heat balance equation of steam turbine unit and low-pressure cylinder low-pressure regenerative system, the energy converted from the shaft power of feed pump to feed water enthalpy rise in steam feed pump unit is calculated, and the shaft power of feed pump and the output power of small turbine are determined. Then, the input power and output power of steam feed pump unit are analyzed and determined, and then the efficiency and Efficiency of feed pump and relative internal efficiency of small turbine [7].

3. Calculation method of efficiency when the middle tap of feed pump is opened

The structural diagram of steam feed pump system is shown in Figure 1. The parameters to be measured are calibrated in the figure. T represents temperature, P represents pressure and G represents flow. In order to calculate the efficiency of the steam feed pump, it is necessary to measure the fluid pressure and temperature at the inlet and outlet of the feed pump, the pressure and temperature of the re desuperheating water, the outlet flow of the feed pump and the re desuperheating water flow respectively. The position of each measuring point is shown in TP in Figure 1.

![Figure 1. Structural diagram of steam feed pump system](image-url)
The method for calculating the exhaust enthalpy of small steam turbine given in this paper includes the following five steps:

1. Measure the pressure and temperature of the inlet and outlet fluid of the feed pump and the reheat desuperheating water respectively, and calculate the enthalpy of the inlet and outlet fluid and the reheat desuperheating water by using the IFC-97 industrial water and steam thermodynamic property model loaded in Excel. According to the pressure and temperature of the inlet fluid, the inlet entropy of the feed pump is calculated, and the isentropic enthalpy under the outlet pressure of the feed pump and the isentropic enthalpy under the re reduced water pressure are obtained respectively by using the inlet entropy, the outlet pressure and the re reduced water pressure.

2. The differential pressure of feed water flow is measured through the flow orifice installed in the outlet pipe of feed water pump, and then the mass flow of feed water is calculated according to the orifice flow calculation model. Similarly, the flow differential pressure of reheat desuperheating water is measured through the orifice installed on the reheat desuperheating water header, and then the mass flow of reheat desuperheating water is obtained.

The method for calculating the mass flow of feedwater is as follows:

\[ G_{gs} = \frac{C}{\sqrt{1-\beta^4}} \varepsilon \frac{\pi}{4} d^2 \sqrt{2\Delta p \rho_i} \]  

Where:  
- \( G_{gs} \) - feedwater mass flow;  
- \( C \) - orifice outflow coefficient;  
- \( \beta \) - ratio of throttle diameter to pipe inner diameter at operating temperature;  
- \( \varepsilon \) - coefficient of fluid expansion, liquid is 1;  
- \( \alpha \) - outlet velocity coefficient;  
- \( d \) - diameter of throttling element at operating temperature;  
- \( \Delta p \) - measure feedwater flow differential pressure;  
- \( \rho_i \) - fluid density at operating temperature.

The method for calculating the mass flow of reheat desuperheating water according to the differential pressure of reheat desuperheating water flow is as follows:

\[ G_{zj} = \frac{C}{\sqrt{1-\beta^4}} \varepsilon \frac{\pi}{4} d^2 \sqrt{2\Delta p \rho_i} \]  

Where:  
- \( G_{zj} \) - mass flow of reheat desuperheating water.

3. According to the definition of pump efficiency, pump efficiency = energy absorbed by isentropic flow / (energy supplied to the pump by actual flow + various losses). In this algorithm, the water flow at the inlet of the feed pump is divided into two paths. Driven by the rotation of the impeller of the pump, one path flows to the middle tap of the feed pump and is pumped out, that is, the flow of reheat desuperheating water; The other fluid normally flows to the outlet of the feed pump, which is the outlet flow of the feed pump. The energy absorbed by two flow isentropic flows and the energy supplied by the actual flow to the pump are calculated by thermodynamic method. The specific formula is as follows:

Energy absorbed by isentropic flow of re reduced water:

\[ Q_{zjs} = G_{zj} (h_{zjs} - h_i) \]  

Energy absorbed by isentropic flow of feed pump outlet flow:

\[ Q_{gs} = G_{gs} (h_{gs} - h_i) \]  

Energy transmitted to the pump by the actual flow of re reducedwater:

\[ Q_{zj} = G_{zj} (h_z - h_i) \]  

Energy transmitted to the pump by the outlet actual flow of feed pump:
\[ Q_{gs} = G_{gs}(h_2 - h_1) \] (6)

Where: \( Q_{gs} \) - energy absorbed by isentropic flow of re reduced water; \( G_{gs} \) - re reduced water mass flow; \( h_{gs} \) - isentropic enthalpy at re reduced water pressure; \( h_1 \) - inlet flow enthalpy of feed pump; \( Q_{gs} \) - energy absorbed by isentropic flow of feed pump outlet flow; \( G_{gs} \) - feed water flow at outlet of feed pump; \( h_{gs} \) - isentropic enthalpy under outlet pressure of feed pump; \( Q_{zj} \) - energy transmitted to the pump by the actual flow of re reduced water; \( h_{zj} \) - re desuperheating enthalpy; \( Q_{gs} \) - energy transmitted to the pump by the outlet actual flow of feed pump; \( h_2 \) - outlet flow enthalpy of feed pump.

(4) Deal with all kinds of lost energy. The energy loss item includes the energy loss caused by the leakage flow of the balancing device and shaft sealing device, the heat loss caused by the heat dissipation of the pump body, and the mechanical loss of fluid, which is mainly caused by the bearing friction loss of the feed water pump. In practical engineering applications, since these loss terms account for only 1% - 2% of the total energy transmitted to the fluid, the energy loss term is calculated by the following formula:

\[ \Delta Q = (1\% ~ 2\%)(Q_{zj} + Q_{gs}) \] (7)

Where: \( \Delta Q \) - various energy loss items; \( Q_{zj} \) - energy transmitted to the pump by the actual flow of re reduced water; \( Q_{gs} \) - energy transmitted to the pump by the outlet actual flow of feed pump.

(5) In the According to the treatment methods in step 1, step 2, step 3 and step 4, the calculation formula of feed pump efficiency when the middle tap of feed pump is opened can be deduced. The specific formula is as follows:

\[ \eta_f = \frac{G_{zj}(h_{zj} - h_1) + G_{gs}(h_{gs} - h_1)}{(1+1\% ~ 2\%)(G_{zj}(h_{zj} - h_1) + G_{gs}(h_{gs} - h_1))} \] (8)

Where: \( G_{zj} \) - re reduced water mass flow; \( h_{zj} \) - isentropic enthalpy at re reduced water pressure; \( h_1 \) - inlet flow enthalpy of feed pump; \( h_{gs} \) - outlet flow enthalpy of feed pump; \( G_{gs} \) - feed water flow at outlet of feed pump; \( h_{gs} \) - isentropic enthalpy under outlet pressure of feed pump; \( h_{zj} \) - re desuperheating enthalpy.

4. Conclusion

This paper presents a method for calculating the efficiency of steam driven feed pump when the middle tap of feed pump is opened, including: calculating the enthalpy of inlet and outlet fluid and reheat desuperheating water, inlet entropy of feed pump, isentropic enthalpy under pump outlet pressure and isentropic enthalpy under re desuperheating pressure respectively; Calculate the mass flow of feedwater and reheat desuperheating water; Calculate the energy absorbed by the reheat desuperheating water flow and the feed pump outlet flow under isentropic flow and the energy supplied to the pump during actual flow respectively; Calculate the lost energy; The efficiency of the feed pump when the middle tap of the feed pump is opened is calculated according to the energy absorbed by the reheat desuperheating water flow and the outlet flow of the feed pump under isentropic flow, as well as the energy and loss of the feed pump during actual flow. This method has the advantages of convenient measurement, few measurement parameters and little influence of measurement error on the results. It has been effectively applied in practice, and fills the literature gap of calculating the pump efficiency when the middle tap of the steam feed pump is opened.
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