ENERGY LOSS AND CONSUMPTION DEVIATION ANALYSIS OF 1000MW ULTRA SUPER CRITICAL STEAM TURBINE UNIT ON OFF-DESIGN CONDITION

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ABSTRACT In this paper, the operating economy of the 1000MW USC (Ultra Super Critical) steam turbine unit is studied by the energy loss and heat consumption deviation analysis. The heat economy calculation model is built by using the conventional heat balance method and the equivalent enthalpy drop method, and the key parameters on off-design condition are determined, which ensure the accuracy of the results of the energy loss and heat consumption deviation analysis. For some special conditions which are not suitable for the equivalent enthalpy drop method, the off-design condition calculation of the steam turbine and its thermal system is adopted.

Keywords: Steam turbine unit, Energy losses analysis, Off-design condition, Target value, Coefficients of heat consumption deviation

1. INTRODUCTION

Energy loss and heat consumption deviation analysis of the thermal system of the steam turbine is the base of designing and developing a performance detection system for steam turbine units, which can detect the operating condition of the steam turbine-units on-line and help the power plants know clearly their real-time operating costs. So, energy loss and heat consumption deviation analysis has been considered to be an effective approach to improve the economical efficiency of the steam turbine units. Normally, in the power network, large capacity steam turbine units operated at basic load, and the efforts were focused on their operational economics on rated conditions. Along with the rapid growth of the power network capacity, more and more large capacity steam turbine units are required to participate in the regulation of the power network. Accordingly, it is necessary to carry forward the research on their operational economics on off-design condition.

This paper tries to study the operating economy of the 1000 MW USC (Ultra Super Critical) steam turbine unit by energy loss and heat consumption deviation analysis. Firstly, use the conventional heat balance method and the equivalent enthalpy drop method to build the heat economy calculation model of the 1000MW USC steam turbine unit. Then, on the base of the model and its calculation results, determine the key parameters (the target values and the coefficients of heat consumption deviation) of the unit on off-design condition. Consequently, the results of the energy loss and heat consumption deviation analysis are accurate enough to satisfy the need of the unit to operate economically at both full and partial load. In addition, for some special conditions such as the failure of the auxiliary equipments, perform the off-design condition calculation of the steam turbine and its thermal system.

2. BUILDING OF THE HEAT ECONOMY CALCULATION

The building of the heat economy calculation model of the 1000 MW USC steam turbine unit is based on the conventional heat balance method and the equivalent enthalpy drop method.

2.1 The Initial Condition

The initial condition of the energy loss and heat consumption deviation analysis includes the basic operating parameters of the unit on four typical loads (100%, 75%, 50%, 30%THA). Generally, they are the pressure and temperature of the steam and water in the thermal systems of the steam turbine, which are the input values of the conventional heat balance calculation.

2.2 Results of the Conventional Heat Balance Calculation

By the conventional heat balance method, the main heat economic indicators (the internal efficiency of the steam turbine unit η_i and the coal consumption rate b_b) on the four typical loads can be obtained, as shown in table 1.

Table 1 The main heat economic indicators

Load	100%	75%	50%	30%
η_i (%)	50.032	49.323	47.815	45.176
b_b (g/kW×h)	275.41	279.37	288.18	305.02

2.3 Results of the Equivalent Enthalpy Drop Calculation

By the equivalent enthalpy drop method, we can get the equivalent enthalpy drop of the live steam H , and the equivalent enthalpy drops H_j and efficiencies η_j of the extraction steams of the steam turbine.

With the varying of one of the operating parameters, the equivalent enthalpy drop of the live steam and the heat absorption of the cycle change, and the changed values are

expressed as $H' = H + \Delta H$ and $Q' = Q + \Delta Q$ respectively. The changed internal efficiency of the steam turbine unit is defined as

$$\eta'_i = \frac{H'}{Q'} \quad (1)$$

and the relative change of it can be worked out:

$$\delta\eta_i = \frac{\eta'_i - \eta_i}{\eta_i} = \frac{\frac{H'}{Q'} - \frac{H}{Q}}{\frac{H}{Q}} = \frac{\Delta H - \Delta Q \eta_i}{H + \Delta H} \quad (2)$$

Consequently, the increase of the coal consumption rate can be figured out:

$$\Delta b_b = b_b \delta\eta_i \quad (3)$$

where b_b : the initial coal consumption rate.

2.4 Examples of the Heat Consumption Deviation Analysis

According to the principle, calculate and analyze the energy losses causing by the influencing factors. Here are two examples: the curves in Fig. 1 show the relationship between the increase of the pressure losses of the No.1~4 extraction steam and the increase of the coal consumption rate, and the curves in Fig. 2 show the relationship between the increase of the terminal temperature differences of the No.1~3 high pressure heater and the increase of the coal consumption rate.

Figure 1 The energy loss causing by the pressure losses of the No.1~4 extraction steam

3. DETERMINATION OF THE KEY PARAMETERS ON OFF-DESIGN CONDITION

The principle of energy loss and heat consumption deviation analysis of the thermal system of the steam turbine is based on the fact that the operational economics of steam turbine-units depend on the approach degree

between real-time operating parameters and the target values. Accordingly, the accuracy of the coefficients of heat consumption deviation and the target values determines the accuracy and reliability of the results of energy loss and accuracy and reliability of the results of energy loss and heat consumption deviation analysis. Presently, large capacity steam turbine units are frequently required to regulate their loads, and the target values under the part loads are different from that under the rated load and vary with the running load.

Figure 2 The energy loss causing by the terminal temperature differences of the No.1~3 heaters

3.1 The Target Values

The calculation of the target values on the off-design condition of turbine is based on the steam and water parameters on four loads (100%, 75%, 50% and 30%THA) from the steam turbine heat balance diagrams. The calculating method is fitting the relationship curve between the target value and the load by corrected minimum secondary fitting method, which has been inspected to be precise enough.

The fitting curve can be expressed as a secondary curve $S(x) = ax^2 + bx + c$, where a, b, c are unknown, and x is the load of the unit. According to the condition

$$R = \sum_{i=0}^m [S(x_i) - y_i] = \min, \quad i = 1, 2, 3, 4 \quad (4)$$

$[a, b, c]^T$ can be worked out by matrix method.

Setting $z_i = 1/2(x_i + x_{i+1})$, in reference to $S_i(x) = a_i x^2 + b_i x + c_i, \quad i = 1, 2, 3$, and a equation follows as

$$\begin{bmatrix} S(x_i) \\ S(z_i) \\ S(x_{i+1}) \end{bmatrix} = \begin{bmatrix} x_i^2 & x_i & 1 \\ z_i^2 & z_i & 1 \\ x_{i+1}^2 & x_{i+1} & 1 \end{bmatrix} \begin{bmatrix} a_i \\ b_i \\ c_i \end{bmatrix} \quad (5)$$

Working out $[a_i, b_i, c_i]^T$, then the correction curve can be shown as

$$S_i(x) = a_i x^2 + b_i x + c_i, \quad x_i \leq x < x_{i+1}, \quad i = 1, 2, 3 \quad (6)$$

With the corrected fitting curve, not only the tendency of the former curve can be maintained, but also

the ends can be kept exactly on the curve. It successfully avoids the abnormal error in actual energy loss calculation.

3.2 The Coefficients of Heat Consumption Deviation

The principle of the coefficients of heat consumption deviation of the parameters is the equivalent enthalpy drop method. Firstly, get the coefficients of heat consumption deviation by the equivalent enthalpy drop calculation on four loads (100%, 75%, 50% and 30%THA). Then, set the maximum and minimum deviation of the parameter as the initial values of energy loss calculation. Thus the calculation model of the heat consumption augment can be built, which is related to both the load and the deviation of the parameter.

The maximum range of the parameter is set as $[0, \Delta X]$, and it is divided into N spans. Thus the deviation marked as j is

$$\Delta x_j = j\Delta X / N \quad j = 1, 2, \dots, N \quad (7)$$

Its corresponding heat consumption augment is expressed as

$$D_{ij} = f(p_i, \Delta x_j) \quad (8)$$

where D_{ij} : the heat consumption augment when the load is p_i and the deviation is Δx_j , and $f()$: the calculation model of the heat consumption augment.

If $p_i \leq p_s < p_{i+1}$ (p_s is the actual load) and $\Delta x_j \leq \Delta x_s < \Delta x_{j+1}$ (Δx_s is the actual deviation), the actual heat consumption augment D_s can be gained by twice linear interpolation, which is simple calculation.

4. ENERGYLOSS ANALYSIS ON AUXILIARY EQUIPMENT FAILURE CONDITION

The precondition of using the equivalent enthalpy drop method is that the flow of the live steam is basically steady. When one or several heaters are shutdown because of fault, the corresponding extraction steams are out of service, which results in the change of the thermal process of the steam turbine. On these special conditions, the equivalent enthalpy drop method cannot be employed. Facing the problem, we introduce the off-design condition calculation of the steam turbine and its thermal system, and perform the energy loss and heat consumption deviation analysis on three loads (100%, 75% and 50%THA). Hence, the curves of the increase of the coal consumption rate can be gotten.

Here are two of the heater failure conditions: the curve in Fig. 3 shows the increase of the coal consumption rate on various loads when all of the three high pressure heaters are shutdown (In the thermal system of the 1000MW USC steam turbine unit, the three high pressure heaters share a by-pass, so they had to be shutdown together when one of them breaks down), and the curve in Fig. 4 shows the increase of the coal consumption rate on various loads when No.6 low pressure heater is shutdown (The No.5 and No.6 low pressure heaters in the system have their own by-passes, so they can be shutdown respectively when one of them breaks down).

Figure 3 The energy loss causing by shutdown of No.1~3 heaters.

Figure 4 The energy loss causing by shutdown of No.6 heaters.

5. CONCLUSION

Energy loss and heat consumption deviation analysis of the 1000MW USC steam turbine unit on off-design condition guarantees the accuracy of the operating economy results and meets the demand of the flexibility and economy of the unit. Furthermore, the results can provide a firm basis for the development of a performance detection system for steam turbine units.

6. REFERENCES

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NOMENCLATURE

b_b	The coal consumption rate, g/(kWh)
H	The equivalent enthalpy drop of the live steam, kJ/kg
H_j	The equivalent enthalpy drops of the extraction steams of the steam turbine, kJ/kg

Q	The heat absorption of the cycle change, kJ/kg
η_i	The internal efficiency of the steam turbine unit, %
η_j	The efficiency of the extraction steams of the steam turbine, %