Compare the Calculations of Steam Extraction Efficiency of Power Plant Turbine by Simple Heat Balance Method and Equivalent Enthalpy Drop Method

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Abstract. At present, the calculation method of steam extraction efficiency of power plant turbine have five methods: heat balance method, equivalent enthalpy drop method, cyclicfunctional method, composite structure method and matrix method. In this paper, a 600MW grade subcritical thermal power plan is take as an examplefor comparing the calculation by the simple heat balance method and the equivalent enthalpy drop method. The result shows that the computational results of simple heat balance method agree with equivalent enthalpy drop method. So simple heat balance method can be used to replace equivalent enthalpy drop method in order to reduce calculation amount in practicalapplication.

Keywords: Power Plant Turbine, Steam Extraction Efficiency

1 Introduction

The efficiency of steam extraction is the percentage between lost work and steam extraction heat when steam extraction is used for steam supply or heat supply. It can be calculated by heat balance method, equivalent enthalpy drop method, cyclic functional method, composite structure method and matrix method. The physical object of these methods is identical and the basic thought of these methods is based on the first law of thermodynamics. However, there are still many differences in the point of view and the ease or complexity of calculation.

Heat balance method is a basic analysis methods of thermodynamic systems for coal fired power plants. It is a simple steam-water mass balance and energy balance method. It focuses on singly heater, the steam-water mass balance and energy balance formulas of every heater are derived in order to calculate the steam extraction coefficients. The heat economic indicators are calculated by the power formulas the absorbed heat formulas. The simple heat balance method is simple calculation method based on heat balance method.

The essence of equivalent enthalpy drop method is thermal power conversion principle, the same as the heat balance method. Based on the quality of equipment, the thermodynamic system structure and the parameters, some thermal parameters are obtained.

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The equivalent enthalpy drop is used to analy the heat economical efficiency of thermodynamic system with a premise which are invariable new steam flow, invariable initial and final parameters of cycle and invariable steam condition curve.

Cyclic functional method is a new simplify thermal calculation method. According to the second law of thermodynamics, it is built base on the concept of heating unit. It can qualitative analyse the economics of steam cycle by cycle irreversibility and quantitative analyse the economics of steam cycle by cycle functional. The thermodynamic system is computed by series method, and steam extraction of heat recuperator and cycle efficiency are computed by cycle functional. Thermodynamic system can be divided into heat recuperator cycle and assist cycle. Then the added amount of this two value is calculation.

Matrix method is a general term, and not a specific method. It combine heat balance equations of every regenerative heater and can completes the thermodynamic calculation by solving linear parametric equations[1].

2 The calculation of steam extraction efficiency

In this paper, a 600MW grade subcritical thermal power plan is take as an examplefor comparing the calculation by the simple heat balance method and the equivalent enthalpy drop method. The simple heat balance method is simple calculation method based on heat balance method and can be used to separate calculate the efficiency of steam extraction. For convenience, the heaters from highest mass to lowest mass are numbered 1-8 according to preference of coal-fired power plants . The original parameters are shown in turbine.

Table 1. The original parameters.

Steam extraction enthalpy	Unit	Value	Steam extraction mass	Unit	Value
h_0	kJ/kg	3396.0	D_0	t/h	1830.67
h_1	kJ/kg	3062.5	D_1	t/h	94.82
h_2	kJ/kg	2989.4	D_2	t/h	152.82
h_{zl}	kJ/kg	2989.4	D_{zl}	t/h	1566.46
h_{zr}	kJ/kg	3595.8	D_{zf}	t/h	1566.46
h_3	kJ/kg	3405.1	D_3	t/h	73.88
h_4	kJ/kg	3194.0	D_4	t/h	85.71
-	-	-	D_x	t/h	84.39
h_5	kJ/kg	2972.4	D_5	t/h	90.53
h_6	kJ/kg	2741.0	D_6	t/h	43.22
h_7	kJ/kg	2630.9	D_7	t/h	58.47
h_8	kJ/kg	2481.0	D_8	t/h	54.31
h_c	kJ/kg	2314.7	D_c	t/h	1077.51
h_c'	kJ/kg	136.3	-	-	-
Inlet drainage	Unit	Value	Outlet drainage	Unit	Value

enthalpy			enthalpy		
h_{d1}	kJ/kg	1130.8	h_{w1}	kJ/kg	1208.3
h_{d2}	kJ/kg	939.4	h_{w2}	kJ/kg	1104.5
h_{d3}	kJ/kg	810.5	h_{w3}	kJ/kg	923.1
-	-	-	h_{w4}'	kJ/kg	800.7
-	-	-	h_{w4}	kJ/kg	765.5
h_{d5}	kJ/kg	454.3	h_{w5}	kJ/kg	593.6
h_{d6}	kJ/kg	376.6	h_{w6}	kJ/kg	432.0
h_{d7}	kJ/kg	268.2	h_{w7}	kJ/kg	354.6
h_{d8}	kJ/kg	162.9	h_{w8}	kJ/kg	246.4

The notes:
h_0 ——Main steam enthalpy,kJ/kg; h_c —— Exhaust steam enthalpy of condenser, kJ/kg;
h_i ——NO.i steam extraction enthalpy, kJ/kg; h_{di} ——Inlet drainage enthalpy, kJ/kg;
$h_{d(i+1)}$ ——Outlet drainage enthalpy,kJ/kg; h_{wi} ——Outlet water enthalpy,kJ/kg;
$h_{w(i+1)}$ ——Intlet water enthalpy,kJ/kg; h_c' ——Condensation water enthalpy.kJ/kg;
h_{zl} ——The cold section enthalpy of reheat steam,kJ/kg; h_{zr} ——The hot section enthalpy of reheat steam,kJ/k;
h_{w4}' ——Outlet water enthalpy of pump,kJ/kg; D_0 ——Main steam mass,t/h;
D_c ——Waste steam mass,t/h; D_x ——Exhaust steam mass of small turbine,t/h.

2.1 The calculation of simple heat balance method

The main content of simple heat balance method is as follows[2]:

This should be view main steam as the sum of multipart coordinate steam. Each part of steam follow the main vale into the turbine and out from different location of steam extraction. The path of steam in turbine is inlet of main steam to the location of steam extraction. In this paper, the turbine have eight-stage steam extraction. With the steam which is not extracted , there are nine stage steam are shown in Fig.1. α_i is extraction steam ratio. The sum for each content of extraction steam ratio should be equal to 1, such as formula (1):

$$\alpha_c + \alpha_1 + \alpha_2 + \alpha_3 + \cdots + \alpha_8 = 1 \tag{1}$$

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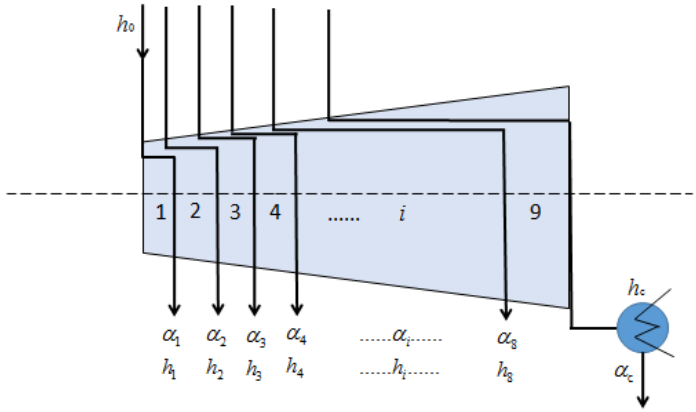

Fig. 1. Steam extraction of the turbine.

The external work of the turbine is the sum of steam extraction work:

$$H_i = \sum \alpha_i \Delta h_i \tag{2}$$

$$H_{\mathrm{T}} = \sum H_i \tag{3}$$

The steam mass in turbine can be calculated by formula (4):

$$D_i = D_{i-1} - D_{ei} \tag{4}$$

D_i is NO.i steam mass in turbine,t/h; D_{i-1} is NO.i-1 steam mass in turbine,t/h; D_{ei} is NO.i steam extraction mass in turbine,t/h.

NO.i steam enthalpy-drop in turbine can be calculated by formula (5):

$$\Delta h_i = h_i - h_{i+1} \tag{5}$$

Δh_i is NO.i steam NO.i steam extraction enthalpy -drop,kJ/kg; h_i is NO.i steam extraction enthalpy,kJ/kg; h_{i+1} is NO.i+1 steam extraction enthalpy,kJ/kg.

NO.i steam extraction efficient can be calculated by formula (6)and the main steam extraction efficient can be calculated by formula (7):

$$\eta_i = \frac{\sum_i^n \Delta h_i D_i}{\sum_i^n \Delta h_i D_i + D_n (h_c - h_c')} \times 100 \tag{6}$$

$$\eta_i = \frac{\sum_i^n \Delta h_i D_i}{\sum_i^n \Delta h_i D_i + D_n (h_c - h_c') + \prod} \times 100 \tag{7}$$

η_i is NO.i steam extraction efficient,%; h_c is Steam extraction enthalpy of condenser,kJ/kg; $\prod$ is Steam supply mass of small turbine,kJ/h; h_c' is Condensation water enthalpy,kJ/kg.

The calculations of steam mass and enthalpy -drop in turbine are shown in Table.2.

Table 2. The calculations of steam mass and enthalpy -drop in turbine.

Steam mass	Unit	Value	Enthalpy -drop	Unit	Value
D_1	t/h	1732.25	Δh_1	kJ/kg	73.1
D_2	t/h	1579.43	Δh_2	kJ/kg	132.66
D_3	t/h	1505.55	Δh_3	kJ/kg	211.1
D_4	t/h	1335.45	Δh_4	kJ/kg	221.6
D_5	t/h	1244.92	Δh_5	kJ/kg	231.4
D_6	t/h	1201.70	Δh_6	kJ/kg	110.1
D_7	t/h	1143.23	Δh_7	kJ/kg	149.9
D_8	t/h	1088.92	Δh_8	kJ/kg	166.3

The steam extraction efficiens are shown in Table.3

Table 3. The steam extraction efficients

The steam extraction efficiens	Unit	Value
η_0	%	48.51
η_1	%	41.28
η_2	%	39.52
η_3	%	36.37
η_4	%	30.90
η_5	%	24.57
η_6	%	16.97
η_7	%	12.94
η_8	%	7.09

2.2 The calculation of equivalent enthalpy drop method

The equivalent enthalpy drop method is widely used to calculate the steam extraction efficients, So the principles won'tbe covered in this paper. The equivalent enthalpy drop of new steam can be calculated by formula (8) and the steam extraction efficients can be calculated by formula (9)[3] :

$$H_i = (h_i - h_c) - \sum_{i+1}^{n} \frac{A_r}{q_r} H_r - \sum \Pi \tag{8}$$

$$\eta_i = \frac{H_i}{q_i} \tag{9}$$

The calculation of steam extraction efficients by equivalent enthalpy drop method are shown in Table.5.

Table 5. The steam extraction efficients

Equivalent enthalpy drop	Unit	Value	The steam extraction efficients	Unit	Value
H_1	kJ/kg	795.37	η_1	%	41.17
H_2	kJ/kg	796.65	η_2	%	38.86
H_3	kJ/kg	948.49	η_3	%	36.56
H_4	kJ/kg	804.49	η_4	%	30.94
H_5	kJ/kg	621.13	η_5	%	24.67
H_6	kJ/kg	402.98	η_6	%	17.04
H_7	kJ/kg	306.96	η_7	%	12.99
H_8	kJ/kg	166.30	η_8	%	7.10

3 Conclusion

The calculate differences of steam extraction efficients between simple heat balance method and equivalent enthalpy drop method are shown in Table.6. As the table shows, there is little differences between simple heat balance method and equivalent enthalpy drop method. The equivalent enthalpy drop method has higher precision. So equivalent enthalpy drop can be replaced by simple heat balance method to calculate steam extraction efficients in order to reduce calculation amount.

Table 6. The difference value of steam extraction efficients between simple heat balance method and equivalent enthalpy drop method

The difference value	Value	The difference value	Value
$\Delta\eta_1$	-0.00108	$\Delta\eta_5$	0.00093
$\Delta\eta_2$	-0.00662	$\Delta\eta_6$	0.00075
$\Delta\eta_3$	0.00187	$\Delta\eta_7$	0.00056
$\Delta\eta_4$	0.00036	$\Delta\eta_8$	0.000051

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Table 4. The feed-water enthalpy, steam released heat in heater, drainage released heat in heater

Steam released heat in heater	Unit	Value	Drainage released heat in heater	Unit	Value	The feed-water enthalpy	Unit	Value
q_1	kJ/kg	2343.0	γ_1	kJ/kg	130.2	τ_1	kJ/kg	108.4
q_2	kJ/kg	2362.7	γ_2	kJ/kg	108.4	τ_2	kJ/kg	108.2
q_3	kJ/kg	2364.4	γ_3	kJ/kg	77.7	τ_3	kJ/kg	77.4
q_4	kJ/kg	2518.1	-	-	-	τ_4	kJ/kg	161.6
q_5	kJ/kg	2600.4	γ_5	kJ/kg	216.9	τ_5	kJ/kg	171.9
q_6	kJ/kg	2594.6	γ_6	kJ/kg	128.9	τ_6	kJ/kg	122.4
q_7	kJ/kg	2050.0	γ_7	kJ/kg	191.4	τ_7	kJ/kg	181.4
q_8	kJ/kg	1931.7	-	-	-	τ_8	kJ/kg	103.8