# Influence of Extraction Steam Pressure Loss on Exergy Economy of PWR Nuclear Power Plant

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**Abstract.** Reheat system of PWR nuclear power unit in use of steam reheat method.Heat recovery system and reheat steam system of PWR nuclear power units with strong coupling, so the impact of changes in heat recovery steam extraction pressure loss of nuclear power plants is more complex than thermal power.According to the characteristics of the secondary circuit of PWR nuclear power plant , the exergy loss distribution matrix and steam-water distribution matrix of the reheat and heat recovery system has been listed. Based on the small disturbance analysis method, taking a 1000MW nuclear power plant thermal system as an example, when the heat recovery extraction steam pressure loss of a heater decreased by 5%, the variation of exergy loss and extraction coefficient of heat recovery and reheat system is quantitatively calculated.

## Introduction

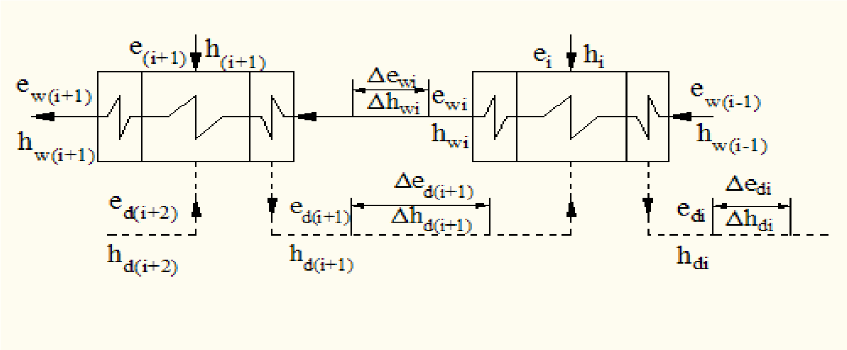
When the steam from the extraction steam mouth of cylinder flowing to the heater,the reasons such as throttle of vavle and friction of pipe will cause the pressure loss of the extraction steam. Due to the pressure loss of heat recovery extraction steam,the ability to work of steam and the economy of the PWR nuclear power unit will decline.Extraction steam pressure loss is a subtle thermal power loss，but it will lead to decrease in working capacity of steam and thermal economy of a power plant[1,2].

Some scholars have analyzed the influence of extraction steam pressure loss on exergy efficiency of thermal power unit. The influence of changes of extraction steam pressure loss on PWR nuclear power unit is more complex than thermal power unit because of the coupling of heat recovery system and reheat system of PWR nuclear power unit. Through the quantitative calculation of 1000 mw PWR nuclear power unit[3],we have analyzed that t Influence of extraction steam pressure Loss on exergy economy of PWR nuclear power unit.

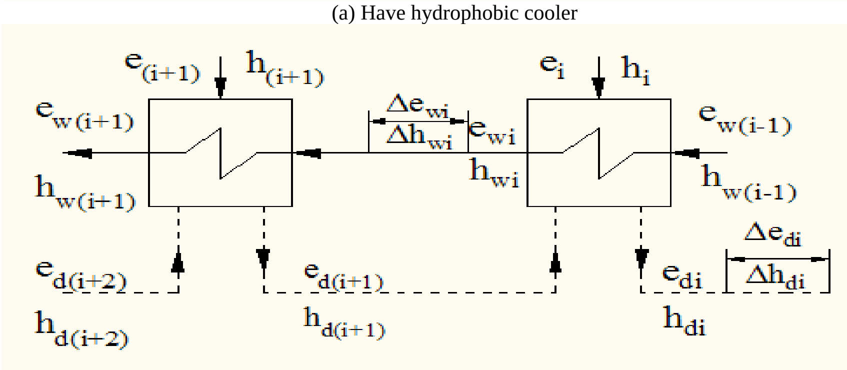
## Influence of Extraction Steam Pressure Loss on the parameters of the heater

According to the relevant literature we know that, when the extraction pressure loss of No.i heater changing,if the heater No.i with a drain cooler ,the hydrophobic temperature will remain constant;if not, the hydrophobic temperature will be changed.For the heater No.i+1,if the heater with a drain cooler, the hydrophobic temperature will be changed;if not,the hydrophobic temperature will remain constant[4]. The variation of hydrophobic temperature and feed water temperature are the same.When the extraction pressureloss of No.i heater changing , we can use hydrophobic temperature and feed water temperature of No.i heater as the independent variable,so we can compute the change of the unit economy. The calculation model of heater is shown in figure.1.




(a) Have hydrophobic cooler




(b) No hydrophobic cooler

Figure.1 calculation model of the heater

## Quantitative Calculation of 1000MW nuclear power unit

Reheat system of PWR nuclear power unit in use of steam-steam reheat is the main difference of thermal system of secondary circuit between PWR nuclear power unit and thermal power unit. High parameters steam of reheat system come from new steam and extraction steam of high pressure cylinder.Drain of moisture separator reheater flowing to deaerator and high pressure heater. Quantitative Calculation of PWR nuclear power unit is complex because of the coupling of heat recovey system and reheat system. As shown in Figure.2,the No. 1, No. 2, No. 3, No. 4 heater is low pressure heater. The No.5 heater is deaerator. The No.6 and No.7 heater is high pressure heaters. The No.8 and No.9 heater is reheaters.The No.10 is separator.The exhaust steam of high pressure cylinder what flowing to moisture separator reheater is separated into saturated steam and water.Drain from the separator flowing to deaerator,and saturated steam from the separator flowing to reheater No.8 and No.9. After reheated,the micro superheated steam what flowing into the low pressure cylinder will continue to go to work. Steam heating source of reheater No.8 and No.9 come from new steam and extraction steam of high pressure cylinder,and drain from the reheater flowing to the high pressure heater No.7.

Because of the coupling of heat recovery system and reheat system,when extraction steam pressure loss changing, the steam-water distribution and exergy loss distribution of both heat recovery system and reheat system also change.

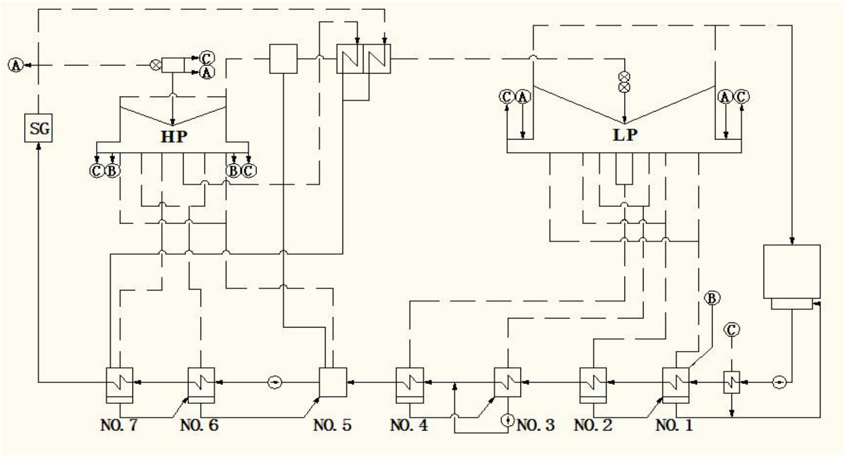



Figure.2 Thermal system of 1000MW PWR nuclear power unit

**Steam-water distribution matrix of secondary-circuit thermal system.**The steam-water distribution matrix expression of secondary circuit is [5,6]:

$$A\alpha + A_f\alpha_f + A_\tau\alpha_\tau + \Delta q = b \tag{1}$$

In the formula: $A$, $A_f$ and $A_\tau$ are the structure matrix, auxiliary steam matrix and auxiliary water matrix respectively; $\alpha$, $\alpha_f$ and $\alpha_\tau$ are the extraction coefficient vectors, auxiliary steam coefficient vectors and auxiliary water coefficient vectors respectively; $\Delta q$ is pure heat matrix; $b$ is feature vectors.

**Exergy loss distribution matrix of secondary-circuit thermal system.** According to the characteristics of the PWR nuclear power units thermal system,the exergy loss matrix equation is established:

$$I = E\alpha + E_f\alpha_f + E_\tau\alpha_\tau + \Delta e - be \tag{2}$$

In the formula: $E$ is exergy distribution structure matrix; $E_f$, $E_\tau$ are auxiliary steam exergy distribution matrix and auxiliary water distribution matrix respectively; $\Delta e$ is pure exergy vector; $be$ is exergy distribution feature vector.

**The influence of extraction steam pressure loss on the extraction coefficient and exergy loss.** Through to calculate the partial derivative for formula No.1 and No.2, when extraction steam pressure loss changing, we can get the variation of extraction coefficient and exergy loss.

The variation of extraction coefficient is:

$$\Delta\alpha = \Delta\alpha_w + \Delta\alpha_d \tag{3}$$

The variation of exergy loss is:

$$\Delta I = \Delta I_w + \Delta I_d \tag{4}$$

In the formula: $\Delta\alpha_w$ and $\Delta I_w$ are the variation of extraction steam coefficient and exergy loss respectively when feed water temperature changing; $\Delta\alpha_d$ and $\Delta I_d$ are the variation of extraction coefficient and exergy loss respectively when hydrophobic temperature temperature changing.

**The influence of extraction steam pressure loss on the unit economy.** The variation of power of the unit is:

$$\Delta W_i = \frac{\partial W_i}{\partial t_{wi}}\Delta t_{wi} + \frac{\partial W_i}{\partial t_{di}}\Delta t_{di} \tag{5}$$

The variation of absolute internal efficiency is:

$$\Delta\eta_i = \frac{\partial\eta_i}{\partial t_{wi}}\Delta t_{wi} + \frac{\partial\eta_i}{\partial t_{di}}\Delta t_{di} \tag{6}$$

The variation of absolute exergy efficiency is:

$$\Delta\eta_{ei} = \frac{\partial\eta_{ei}}{\partial t_{wi}}\Delta t_{wi} + \frac{\partial\eta_{ei}}{\partial t_{di}}\Delta t_{di} \tag{7}$$

**Calculate.** According to the partial differential mathematical model of steam-water distribution matrix equation and exergy loss distribution matrix equation, when extraction steam pressure loss of a feed water heater decreased by 5%,we can calculate that the variation of extraction steam coefficient , exergy loss and the unit economy. The calculation results as shown in table 1 , table 2 and table 3.

Table 1 The variation of extraction steam coefficient

| name | No.1 | No.2 | No.3 | No.4 | No.5 | No.6 | No.7 |
|---|---|---|---|---|---|---|---|
| $\Delta\alpha_1\times10^{-4}$ | 57.607 | -2.535 | -0.178 | -0.209 | 0.002 | -0.381 | -5.154 |
| $\Delta\alpha_2\times10^{-4}$ | -62.68 | 66.591 | -0.095 | -0.111 | 0.001 | -0.203 | -2.743 |
| $\Delta\alpha_3\times10^{-4}$ | 0 | -44.843 | 41.778 | -0.661 | 0.002 | -0.275 | -3.719 |
| $\Delta\alpha_4\times10^{-4}$ | 0 | 0 | -39.407 | 47.383 | 0.002 | -0.276 | -3.732 |
| $\Delta\alpha_5\times10^{-4}$ | 0 | 0 | 0 | -54.053 | 44.643 | -19.881 | -8.996 |
| $\Delta\alpha_6\times10^{-4}$ | 0 | 0 | 0 | -0.253 | -44.695 | 122.451 | -5.857 |
| $\Delta\alpha_7\times10^{-4}$ | 0 | 0 | 0 | -0.529 | -0.001 | -95.565 | 109.382 |
| $\Delta\alpha_8\times10^{-4}$ | 0 | 0 | 0 | 3.119 | 0.003 | -0.398 | -5.376 |
| $\Delta\alpha_9\times10^{-4}$ | 0 | 0 | 0 | 1.779 | 0.002 | -0.398 | -3.068 |

Table 2 The variation of exergy loss

| name | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| $\Delta I_1$/kJ | 0.342 | -0.033 | -0.003 | -0.004 | 0.001 | -0.006 | -0.088 |
| $\Delta I_2$/kJ | -1.061 | 0.823 | -0.001 | -0.002 | 0.001 | -0.003 | -0.042 |
| $\Delta I_3$/kJ | 0 | -0.621 | 0.151 | -0.002 | 0.001 | -0.002 | -0.027 |
| $\Delta I_4$/kJ | 0 | 0 | -0.593 | 0.024 | 0.001 | -0.001 | --0.026 |
| $\Delta I_5$/kJ | 0 | 0 | 0 | -0.562 | 0.081 | -0.084 | -0.034 |
| $\Delta I_6$/kJ | 0 | 0 | 0 | 0.001 | -0.339 | 1.922 | -0.017 |
| name | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| $\Delta I_7$/kJ | 0 | 0 | 0 | 0.001 | 0.001 | -1.941 | 2.731 |
| $\Delta I_8$/kJ | 0 | 0 | 0 | 0.031 | 0.001 | -0.004 | -0.053 |
| $\Delta I_9$/kJ | 0 | 0 | 0 | 0.018 | 0.001 | -0.002 | -0.031 |

Table 3 Unit Economy

| name | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| $w_i$ /kJ | 0.378 | 0.095 | 0.473 | 0.569 | 0.376 | 0.188 | -5.934 |
| $\eta_i\times10^{-4}$ | 2.090 | 0.530 | 2.620 | 3.149 | 2.082 | 1.041 | 3.311 |
| $\eta_{ei}\times10^{-4}$ | 4.567 | 1.158 | 5.727 | 6.883 | 4.550 | 2.277 | -23.080 |

**Analysis.** For heat recovery heater No. 1, No. 2, No. 3 , when the extraction pressure loss of a heater changing, only extraction steam coefficient and exergy loss of heater No.i+1 and the lower pressure heater behind it are changed. For heat recovery heater No. 4, No. 5, No. 6 , No. 7 , when the extraction pressure loss of a heater changing, the extraction steam coefficient and exergy loss of all the heaters are changed.

## Summary

1) Because of the coupling of heat recovery system and reheat system, when the extraction pressure loss of heater No.4, No.5, No.6, No.7 changing, the parameters of all the heat recovery heater and reheat heater are changed.

2) The heater what has the largest influence on the unit economy is No.4 low pressure heater. When the extraction steam pressure loss of No.4 heater was reduced by 5%, absolute internal efficiency and absolute exergy efficiency are increased by 0.031% and 0.069% respectively.So we should reduce the extraction steam pressure loss of No.4 heater.

3) The method what this article uses can be used in the quantitative analysis of PWR nuclear power unit,and provide a theoretical guidance for the operation of the PWR nuclear.

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