

# 用“过程能量组合”方法 优化电厂热力系统的设计

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〔摘要〕本文利用“过程能量组合方法”对某热电联产装置的热力系统的设计进行了改造,新方案取得了明显的节能效果。

关键词 热力系统 过程能量组合 加热器

分类号 TM621

## 1 引言

电厂热力系统的优化设计对节能有着重要的意义。近年来,国内、外推行的“过程能量组合”方法能够较方便地评价和改进系统的设计。笔者利用该方法对某电厂原拟定的热电联产装置的热力系统的设计方案提出了改进意见,取得了十分明显的节能效益,得到了用户的赞同。

## 2 原设计方案

原拟定的热力系统原则性示意图见图1。

汽轮机有一级抽汽(2.4 MPa, 315℃),由工厂返回的0.6 MPa饱和蒸汽一部分进入汽轮机中做功,其余部分加热给水。加热器设计要求把244.3 t/h的水加热至170℃送往锅炉,同时把84 t/h的水加热至 $P = 0.22$  MPa下的饱和温度送往用户。为此,系统中设

置了一台0.22 MPa的除氧器和两台表面式加热器。利用0.6 MPa的工厂回汽先在除氧器中把水加热到123.27℃,从中引出84 t/h热水供用户使用,再在2#加热器中把水加热至130℃,最后,利用2.4 MPa的汽轮机抽汽在1#加热器中将给水加热到170℃。

对1#加热器做热平衡计算:

$$244.3 \times (725.9 - 555) \\ = m_1 \times (3049.3 - 951.93)$$

$$\therefore m_1 = 19.906 \text{ t/h}$$

对2#加热器做热平衡计算:

$$m_2 \times (2755.6 - 670.4) + 19.906 \\ \times (951.93 - 670.32) \\ = 244.3 \times (555 - 517.62)$$

$$\therefore m_2 = 1.692 \text{ t/h}$$

$$m_1 + m_2 = 21.598 \text{ t/h}$$

对除氧器做热平衡:

$$m_2'(2755.5 - 191.837) + 21.598 \\ \times (670.42 - 191.83) = (244.3 + 84) \\ \times (517.62 - 191.83)$$

$$\therefore m_2' = 37.688 \text{ t/h}$$

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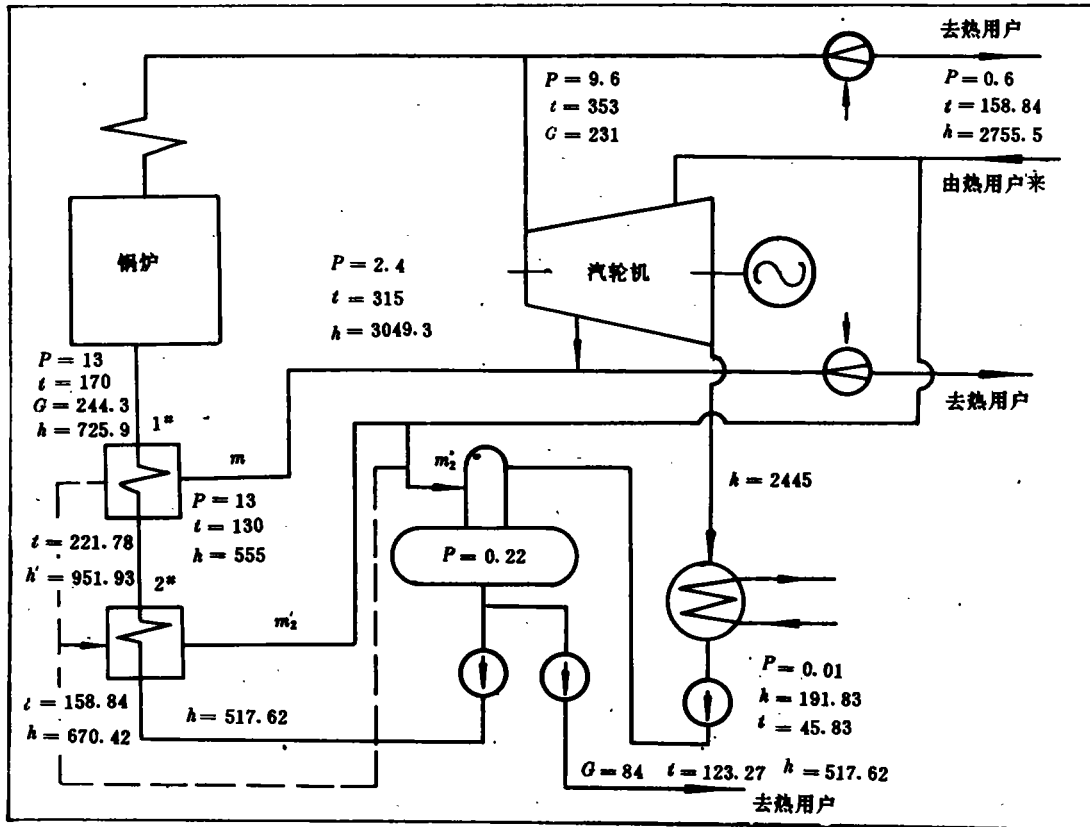


图 1 原设计原则性热力系统示意图

$$m_1' + m_2' = 39.38 \text{ t/h}$$

$$m_1 + m_2 + m_2' = 59.286 \text{ t/h}$$

为了分析该系统的能量利用情况,按过程能量组合方法,作冷、热流体的综合曲线。

对于冷流体:

由 45.83 °C 至 123.27 °C 的总焓变为:

$$\begin{aligned} \Delta H_1 &= (244.3 + 84 - 59.286) \times 10^3 \\ &\quad \times (517.62 - 191.83) \\ &= 8.76 \times 10^7 \text{ kJ/h} \end{aligned}$$

由 123.27 °C 至 130 °C 的总焓变为:

$$\begin{aligned} \Delta H_2 &= 244.3 \times 10^3 \times (555 - 517.62) \\ &= 9.13 \times 10^6 \text{ kJ/h} \end{aligned}$$

由 130 °C 至 170 °C 的总焓变为:

$$\begin{aligned} \Delta H_3 &= 244.3 \times 10^3 \times (725.9 - 555) \\ &= 4.18 \times 10^7 \text{ kJ/h} \end{aligned}$$

冷流体总吸热量为:

$$\begin{aligned} \sum \Delta H_c &= (8.76 + 0.91 + 4.18) \times 10^7 \\ &= 13.85 \times 10^7 \text{ kJ/h} \end{aligned}$$

对于热流体:

由 315 °C 至 221.78 °C 的总焓变为:

$$\begin{aligned} \Delta H^{(1)} &= 19.906 \times 10^3 \times (3049.3 \\ &\quad - 2800.4) = 4.96 \times 10^6 \text{ kJ/h} \end{aligned}$$

在  $t=221.78$  °C 时蒸汽放出的潜热为:

$$\begin{aligned} \Delta H^{(2)} &= 19.906 \times 10^3 \times (2800.4 \\ &\quad - 915.93) = 3.68 \times 10^7 \text{ kJ/h} \end{aligned}$$

由 221.78 ℃ 至 158.84 ℃ 的总焓变为:

$$\Delta H^{\text{②}} = 19.906 \times 10^3 \times (951.93 - 670.42) = 5.60 \times 10^6 \text{ kJ/h}$$

在  $t = 158.84 \text{ }^{\circ}\text{C}$  时蒸汽放出的总潜热为:

$$\Delta H^{\text{③}} = 39.38 \times 10^3 (2755.5 - 670.42) = 8.21 \times 10^7 \text{ kJ/h}$$

由 158.84 ℃ 至 123.27 ℃ 的总焓变为:

$$\Delta H^{\text{④}} = 59.286 \times 10^3 \times (670.42 - 517.62) = 9.06 \times 10^6 \text{ kJ/h}$$

热流体总放热为:

$$\begin{aligned} \sum \Delta H_h &= (0.496 + 3.68 + 0.56 + 8.21 + 0.9067) \times 10^7 \\ &= 13.85 \times 10^7 \text{ kJ/h} \end{aligned}$$

$\sum \Delta H_c = \sum \Delta H_h$ , 说明上述热平衡计算是正确的。

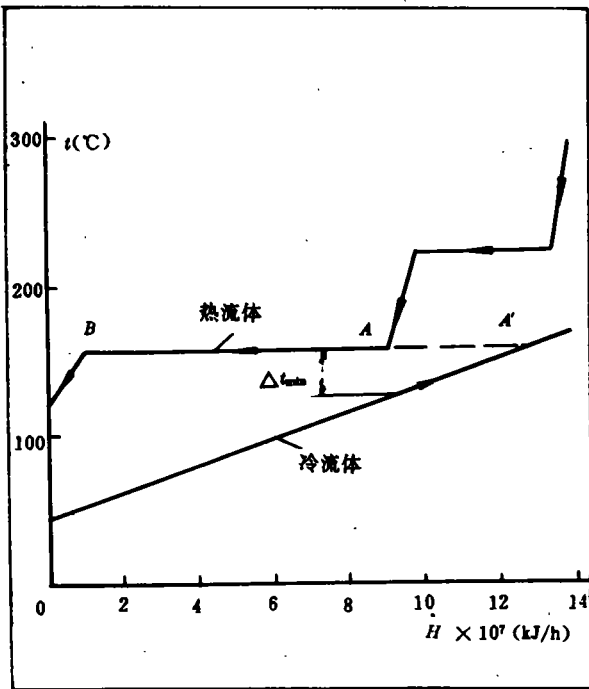


图2 原方案冷热流体综合曲线

由上述各温度范围的吸、放热量在  $T$  (温

度)— $H$  (焓) 坐标图上作出冷、热综合曲线, 得到图 2。由图 2 可见, 原方案系统的窄点出现在热流体为 158.8 ℃, 冷流体为 125.9 ℃ 处, 最小传热温差  $\Delta t_{\min} = 32.9 \text{ }^{\circ}\text{C}$ , 系统的窄点出现在 2<sup>#</sup> 表面式加热器中, 其  $\Delta t_{\min}$  的大小由表面式加热器的经济传热温差所决定。这么大的  $\Delta t_{\min}$  值导致低品位的 0.6 MPa 饱和蒸汽的利用受到了限制, 同时, 必然增加了高品位的 2.4 MPa 过热蒸汽的消耗量。

由上可见, 要使低品位能量得到充分利用就要设法降低系统的窄点温差。最好能使  $\Delta t_{\min}$  趋于零。实现该方法是用混合式换热器代替 2<sup>#</sup> 表面式加热器, 把图 2 所示的热流体的综合曲线的 A、B 线段的 A 点沿虚线延伸至 A' 点。这样, 在完成相同加热量的前提下必然增加了 0.6 MPa 蒸汽的消耗量, 减少了 2.4 MPa 蒸汽的抽汽量。

### 3 改进方案

根据上述思想, 本文提出了如图 3 所示的改进系统。

图 3 与图 1 相比较, 将原 0.22 MPa 的低压除氧器改为 0.40 MPa 的高压除氧器, 同时取消 2<sup>#</sup> 加热器, 用户所需的 84 t/h, 123 ℃ 的热水根据热平衡计算可由高压除氧器出来的 143.620 ℃ 热水 66.29 t/h 与 45.8 ℃ 的补给水 17.71 t/h 混合后得到。

对高压加热器做热平衡:

$$\begin{aligned} m_1(3049.3 - 951.93) &= 244.3(725.9 - 604.67) \end{aligned}$$

得  $m_1 = 14.12 \text{ t/h}$

对高压除氧器做热平衡:

$$\begin{aligned} m_2(2755.5 - 191.83) + 14.12(951.93 - 191.83) &= (244.3 + 66.29)(604.67 - 191.83) \end{aligned}$$

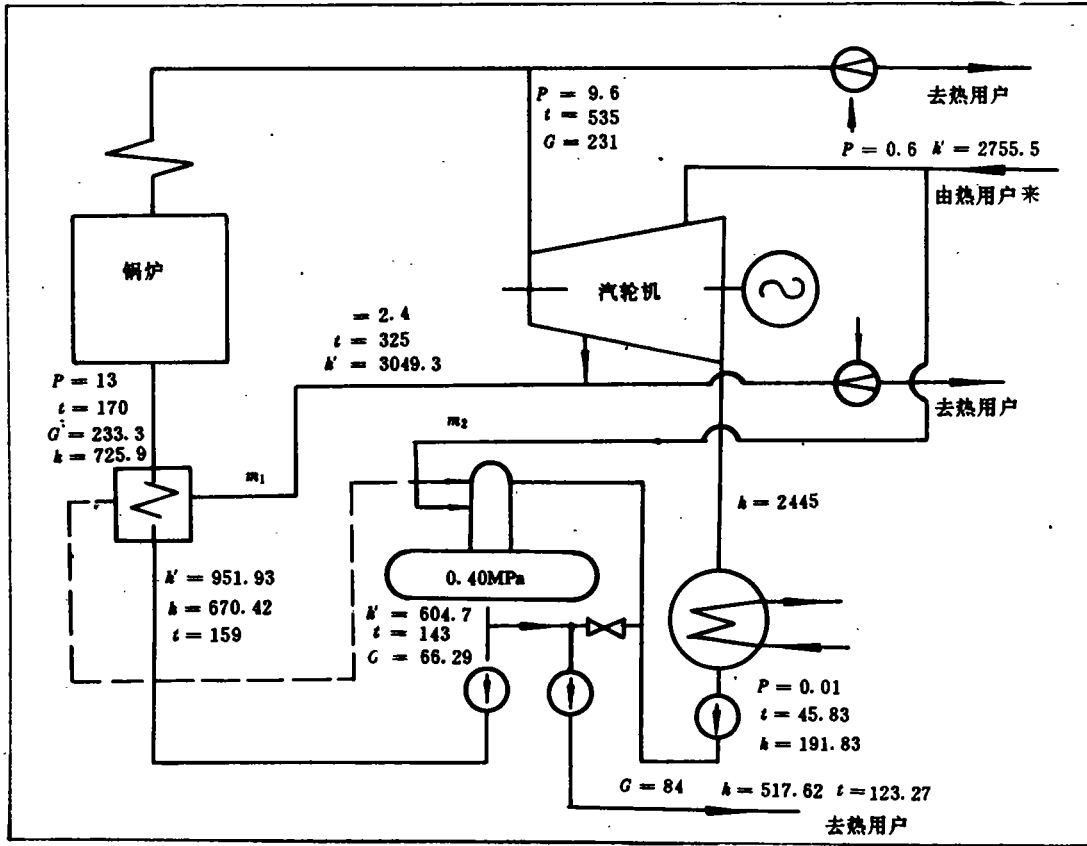


图3 改进后原则性热力系统示意图

得  $m_2 = 45.83 \text{ t/h}$

$m_1 + m_2 = 59.95 \text{ t/h}$

对冷流体:

由  $45.83 \text{ }^\circ\text{C}$  至  $143.62 \text{ }^\circ\text{C}$  的总焓变为:

$$\begin{aligned} \Delta H_1 &= (244.3 + 66.29 - 59.95) \times 10^3 \\ &\quad \times (604.67 - 191.83) \\ &= 10.35 \times 10^7 \text{ kJ/h} \end{aligned}$$

由  $143.62 \text{ }^\circ\text{C}$  至  $170 \text{ }^\circ\text{C}$  的总焓变为:

$$\begin{aligned} \Delta H_2 &= 244.3 \times 10^3 \times (725.9 \\ &\quad - 604.67) = 2.96 \times 10^7 \text{ kJ/h} \end{aligned}$$

冷流体总吸热为:

$$\sum \Delta H_c = 13.31 \times 10^7 \text{ kJ/h}$$

对热流体:

由  $315 \text{ }^\circ\text{C}$  至  $221.78 \text{ }^\circ\text{C}$  的焓变为:

$$\begin{aligned} \Delta H^{\text{①}} &= 14.12 \times 10^3 (3049.3 - 2300.4) \\ &= 3.51 \times 10^6 \text{ kJ/h} \end{aligned}$$

在  $t = 221.78 \text{ }^\circ\text{C}$  时蒸汽放出的潜热为:

$$\begin{aligned} \Delta H^{\text{②}} &= 14.12 \times 10^3 \times (2800.4 \\ &\quad - 951.93) = 2.61 \times 10^7 \text{ kJ/h} \end{aligned}$$

由  $221.78$  至  $143.62 \text{ }^\circ\text{C}$  的焓变为:

$$\begin{aligned} \Delta H^{\text{③}} &= 14.12 \times 10^3 \times (951.93 \\ &\quad - 604.67) = 0.49 \times 10^7 \text{ kJ/h} \end{aligned}$$

在  $t = 145.62 \text{ }^\circ\text{C}$  时蒸汽放出的显热和潜热为:

$$\begin{aligned} \Delta H^{\text{④}} &= 45.83 \times 10^3 (2755.5 - 604.67) \\ &= 9.86 \times 10^7 \text{ kJ/h} \end{aligned}$$

热流体总放热:

$$\sum \Delta H_h = 13.31 \times 10^7 \text{ kJ/h}$$

$\sum \Delta H_c = \sum \Delta H_h$ , 说明上述热平衡计算正确。

由上述数据, 可得出放热改进后系统的冷、热流体的综合曲线(见图 4)。图 4 和图 2 相比较, 显然, 高品位能量的消耗大大降低。

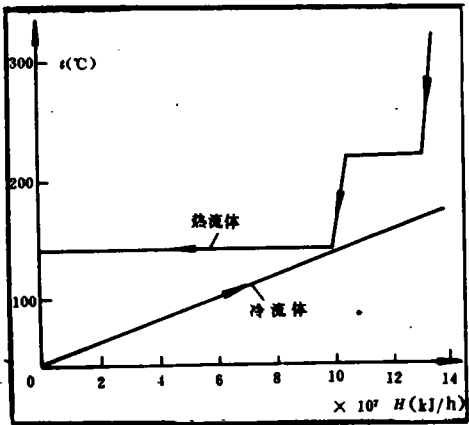


图 4 改进方案的冷、热流体综合曲线

#### 4 结果分析及结论

在满足供给锅炉 244.3 t/h, 170 °C 的给水及供给工厂 84 t/h, 123 °C 热水前提下, 改进方案与原方案比较, 可得:

2.4 MPa 抽汽的节省量为:

$$\Delta m_1 = 19.906 - 14.12 = 5.786 \text{ t/h}$$

该汽量在汽机中可多做功为:

$$\Delta H_1 = \Delta m_1 \times (h_1 - h_n) = 5.786 \times 10^3 \times$$

$$(3049.3 - 2445) = 3496 \times 10^3 \text{ kJ/h} = 971 \text{ kW}$$

0.6 MPa 回汽消耗的增加值为:

$$\Delta m_2 = 45.83 - 39.38 = 6.45 \text{ t/h}$$

该汽量在汽机中少做功为:

$$\begin{aligned} H_2 &= \Delta m_2 (h_2 - h_n) = 6.45 \times 10^3 \\ &\times (2755.5 - 2445) \\ &= 2003 \times 10^3 \text{ kJ/h} = 556 \text{ kW} \end{aligned}$$

改进后工质在汽机中净多做的功量为:

$$\begin{aligned} \Delta H &= \Delta H_1 - \Delta H_2 = 971 - 556 \\ &= 415 \text{ kW} \end{aligned}$$

考虑到汽轮发电机的效率(取  $\eta = 0.95$ ), 改进后的热力系统每小时可增发 394 度电, 全年可多供约 276 万度电(按年利用小时为 7 000 计)。如果发电量不变, 则每年可节省标准煤约 1 024 吨。

在初次投资方面, 由于取消了 2# 加热器, 而且减小了高压加热器的面积, 由此节省的投资可弥补除氧器容量和压力的增加而增加的费用。同时, 改进后的热力系统简单, 因此运行, 检修的工作量以及备品备件都可以相应地减少。

从上述例子看, 笔者认为“过程能量组合”方法是分析和改进电厂热力系统的一种简捷和有效的手段。

#### 参 考 文 献

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- 2 林万超. 火电厂热力系统定量分析. 西安交通大学出版社, 1985 年 5 月

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and rear arch can be considered as proper. Tests have shown that in such a case the a-shaped combustion flame will result. **Key words:** *combustion, grate firing furnace, furnace arch design*

**(285) Optimization Design of a Power Plant Thermodynamic System by Using "Process Energy Combination" Method**..... Zhang Yongde (*Northwestern Electric Power Design Institute*)

A so-called "Process Energy Combination" method is employed to improve the design of a thermodynamic system for a cogeneration power plant, which plays a significant role in enhancing energy-saving effects. **Key words:** *thermodynamic system, Process energy combination, heater*

**(290) A Study on the Optimization for Preliminary Design of a Nuclear Power Plant Steam Generator** ..... Shi Hongshen (*Shanghai Naval Standards and Specifications Design Institute*), Chen Lingen, Zong Qingchang (*Naval Engineering Academy*)

With the minimum total weight of a steam generator set as a target function the authors have proposed a method for optimizing the preliminary design of a nuclear propulsion plant steam generator. Given in the paper are the optimization and sensitivity analysis results. The computation results have substantiated the validity of the recommended method. **Key words:** *steam generator, design optimization, sensitivity analysis*

**(297) The Specific Features of Industrial Steam Turbines and Their Technical Retrofitting**..... Luo Yigen, Lan Ruji, Zhang Zhitong (*Harbin Marine Boiler & Turbine Research Institute*)

The present paper briefly deals with the design features of mechanical — drive industrial steam turbines and the experience gained by the authors in recent years in the course of implementing the technical modification of steam turbines for some domestic petrochemical enterprises. Proceeding from the specific conditions existing in Chinese petrochemical works the authors have proposed some feasible measures and approaches for conducting energy-saving and power uprating-oriented modifications of industrial steam turbines. **Key words:** *industrial steam turbines, high efficiency, energy-saving, power uprating*

**(300) The Application of STD Bus Microcomputer-based Industrial Control Unit on a Grain Drying Production Line** ..... Yang Chengyi, Zhao Aijun (*Harbin Marine Boiler & Turbine Research Institute*)

In connection with the design, commissioning tests and operational effectiveness of a microcomputer-based monitoring and control system installed on a grain drying production line of District NO. 8 Grain Depot in Harbin city the authors make some observations on the proper selection of microcomputer type and the method of interface design when such factors as serious dust-borne surroundings and electric appliance interference are to be taken into account. **Key words:** *grain drying, microcomputer-based control, STD industrial control unit*

**(304) An Exploratory Study on a Thermistor Nonlinearity Correction Method**..... Zhang Guodong (*Harbin Marine Boiler & Turbine Research Institute*)

Three practical methods are proposed for correcting the nonlinearity of thermistors, namely: optimum parameter method, transformation function method and similarity function method. Theoretically, the above-cited methods are also suitable for the correction of nonlinear hardware