

热容、加热器水位、加热器中空气、加热器泄露等因素对换热影响。根据图1加热器简单的物理模型,在全面考虑加热器结构参数、工质物性参数对传热过程的影响的前提下,采用了分段集总参数法。

3 加热器动态数学模型的建立

3.1 过热段的动态数学模型

过热段的蒸汽在传热过程中没有相变,因而可以把过热段的蒸汽出口温度作为过热段与凝结段的分界点。该段壳侧无其它传热介质,故可建立如下过热段数学模型。

(1) 过热段蒸汽冷却时放热量 Q_{s1} :

$$Q_{s1} = \frac{1}{\frac{1}{\alpha_{\text{IDSH}}} + K_{\text{fl}} R_{\text{h}}} A_1 (T_{\text{sov1}} - T_{\text{m1}}) \quad (1)$$

式中: T_{sov1} — 过热段蒸汽平均温度, $^{\circ}\text{C}$;

K_{fl} — 壳侧污垢系数;

A_1 — 过热段壳侧换热面积, m^2 ;

T_{m1} — 过热段管壁温度, $^{\circ}\text{C}$ 。

(2) 管内给水吸热量 Q_{w1} :

$$Q_{w1} = \frac{1}{\frac{1}{\alpha_2} + K_{\text{L}} R_{\text{h}}} A_1 \frac{d_i}{d_o} (T_{\text{m1}} - T_{\text{wov1}}) \quad (2)$$

式中: T_{wov1} — 过热段给水平均温度, $^{\circ}\text{C}$;

K_{L} — 水侧污垢系数。

(3) 过热段管壁金属温度 T_{m1} :

$$T_{\text{m1}} = T'_{\text{m1}} + \frac{Q_{s1} - Q_{w1}}{M_{\text{m1}} c_{\text{pm}}} dt \quad (3)$$

式中: T'_{m1} — 前一时刻的金属温度, $^{\circ}\text{C}$;

M_{m1} — 过热段传热管金属质量, kg ;

c_{pm} — 金属定压比热容, $\text{kJ}/(\text{kg} \cdot ^{\circ}\text{C})$;

dt — 计算步长。

(4) 过热段蒸汽出口焓 H_{s2} (忽略蒸汽的密度和流速变化):

$$H_{s2} = H'_{s2} + \frac{F_{s1}(H_{s1} - H_{s2}) - Q_{s1} - Q_{ls1}}{F_{s1} + \frac{M_s}{DT}} \quad (4)$$

式中: H'_{s2} — 前一时刻的蒸汽出口焓, kJ/kg ;

F_{s1} — 过热段蒸汽流量, kg/h ;

H_{s1} — 过热段蒸汽入口焓, kJ/kg ;

M_s — 过热段壳侧存放量, kg ;

DT — 时间步长。

(5) 给水出口焓 H_{w4} :

$$H_{w4} = H'_{w4} + \frac{F_{ws}(H_{ws} - H'_{w4}) + Q_{w1}}{F_{ws} + \frac{M_{w1}}{DT}} \quad (5)$$

(6) 过热蒸汽对环境的散热量 Q_{ls1} :

$$Q_{ls1} = K_{ls1}(T_{\text{sov1}} - T_{\text{omb}}) \quad (6)$$

式中: T_{omb} — 环境温度, $^{\circ}\text{C}$;

K_{ls1} — 过热段散热系数。

3.2 凝结段和疏水段的动态数学模型

进入凝结段时蒸汽还有一定的过热度,在计算凝结换热系数时必须加以考虑。凝结段属于相变换热,疏水段属于单相介质的对流换热,根据凝结段和疏水段的这些特点建立下述模型。而凝结段的饱和蒸汽凝结放热量、管内给水吸热量、凝结段管壁金属温度、凝结段平均蒸汽焓和疏水段疏水冷却时的放热量、疏水段管壁温度的模型可以依据过热段类似的推导和整理方法得出。

(1) 凝结段凝结流量 F_{cond} :

$$F_{\text{cond}} = Q_{s2} / (H_{\text{sov2}} - H_{\text{sw}}) \quad (7)$$

(2) 加热器压力 P_t :

$$P_t = P_{\text{stm}} + P_{\text{air}} \quad (8)$$

式中: P_{stm} — 加热器蒸汽分压力, Pa ;

P_{air} — 加热器空气分压力, Pa 。

(3) 疏水焓 H_{dout} :

$$H_{\text{dout}} = H'_{\text{dout}} + \left[\begin{array}{l} (F_{\text{cond}} + F_{\text{as}} + F_{\text{d}} + F_{\text{dh}}) H_{\text{ss}} \\ F_{\text{v}} H_{\text{ss}} - Q_{s3} - Q_{ls3} + \\ F_{\text{leak}} (H_{w2} + H_{ws}) - (F_{\text{cond}} + \\ F_{\text{d}} + F_{\text{os}} + F_{\text{d}} + F_{\text{leak}}) H'_{\text{dout}} \end{array} \right] / \left(\frac{M_{\text{htr}}}{DT} \right) \quad (9)$$

式中: H'_{dout} — 前一时刻的疏水焓, kJ/kg ;

F'_{leak} — 给水泄露量, kg/h ;

M_{htr} — 加热器壳侧疏水量, kg ;

K_1 — 加热器折算系数。

4 加热器的仿真试验

本文应用所开发的动态数学模型表达式,开发了相应的加热器的算法,参考深圳妈湾电厂300MW机组的数据资料,搭接成给水回热系统模型,选取系统中1号高压加热器和5号低压加热器,在武汉大学仿真中心的仿真机上进行试验,系统在4种运行工况下的试验结果见表1和表2。

表 1 300 MW 机组 1 号高加仿真试验数据

	抽汽量/ $t \cdot h^{-1}$			出水温度/ $^{\circ}C$			疏水温度/ $^{\circ}C$			疏水焓/ $kJ \cdot kg^{-1}$		
	设计值	仿真值	误差 /%	设计值	仿真值	误差 /%	设计值	仿真值	误差 /%	设计值	仿真值	误差 /%
300 MW	83.19	82.9	0.3	247	246.2	0.3	209	208.6	0.2	894.13	890.78	0.4
210 MW	49.5	48.8	1.4	226.8	225.7	0.5	192	191.2	0.4	818.78	815.01	0.5
150 MW	31.5	30.9	1.9	210.2	209.4	0.4	178	177.3	0.4	756.41	753.90	0.3
90 MW	17.3	17.1	1.2	187.5	186.7	0.4	159	158.4	0.4	674.78	671.43	0.5

表 2 300 MW 机组 5 号低加仿真试验数据

	抽汽量/ $t \cdot h^{-1}$			出水温度/ $^{\circ}C$			疏水温度/ $^{\circ}C$			疏水焓/ $kJ \cdot kg^{-1}$		
	设计值	仿真值	误差 /%	设计值	仿真值	误差 /%	设计值	仿真值	误差 /%	设计值	仿真值	误差 /%
300 MW	46.29	45.72	1.2	154.3	153.8	0.3	153	152.4	0.4	646.32	643.39	0.5
210 MW	29.28	29.11	0.6	141.5	140.9	0.4	140	139.5	0.4	590.64	587.71	0.5
150 MW	19.43	19.36	0.4	130.6	129.9	0.5	129	128.4	0.5	543.76	541.25	0.5
90 MW	11.22	11.18	0.4	114.3	113.7	0.5	114	113.7	0.3	480.97	477.62	0.7

分析上述两表的结果可以发现所开发的模型具有较高的精确性,设计值与仿真值误差小于 2%,能够很好的满足仿真培训及研究分析问题的要求。

另外还对加热器的动态特性进行了加热器给水流量扰动和进汽流量扰动的仿真验证。

从图 2 中曲线变化可以发现在进入加热器蒸汽流量不变的情况下,当给水流量突然增大时,加热器压力、给水出口温度、疏水温度、下端差随之下降;而上端差随之上升。这种现象同实际现场现象是一致的。出现这种现象的原因是由于蒸汽放热量一定,给水流量增大后,给水出口温度必然降低;加热器中凝结流量加大,会造成加热器的压力降低;而给水进口温度不变,疏水温度的降低必然导致下端差的减小;加热器压力变化较小,加热器中蒸汽的饱和温度下降幅度较给水出口温度小,因而上端差增大。

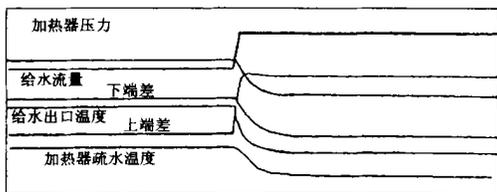


图 2 加热器给水流量动态扰动试验曲线

在进入加热器给水流量和给水温度等条件不变的情况下,会出现图 3 中进入加热器的抽汽流量突然减小时,加热器压力、给水出口温度、疏水温度、上端差、下端差均随之下降的现象。这种现象也和实际相吻合。这种现象是因为蒸汽的放热量有较大幅度的减小,引起给水出口温度的降低;疏水温度降低必导致下端差的减小;而加热器压力变化相对较大,

加热器中蒸汽的饱和温度下降幅度较给水出口温度大,因此上端差减小。

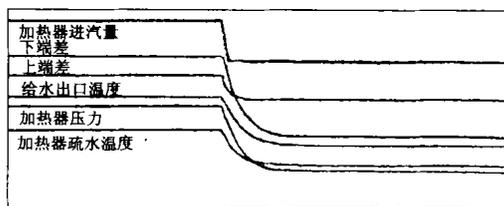


图 3 加热器进汽流量动态扰动试验曲线

5 结论

(1) 通过上述静态仿真实验数据和动态仿真实验结果证明所开发的加热器动态仿真数学模型具有较高的精确性和良好的动态特性、实时性,它可用于不同仿真机回热加热系统模型开发及仿真分析研究中。

(2) 通过仿真实例对加热器动态数学模型进行验证,结果表明该模型静态精度高,动态响应特性良好。此外它除了能够用于仿真机工程模型的开发,也能为回热加热系统变工况下经济性分析服务。

(3) 本文介绍的加热器动态数学模型具有广泛的适用性;实现了利用数学模型较为完整地模拟了大型机组加热器的运行特性。但由于加热器结构和工作过程的复杂性,有些问题如加热器结构优化和经济性指标的准确定量分析尚需进一步深入研究。

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(5). —485~488

Wavelet analysis represents a new tool of mathematical analysis. The use of this numerical calculation method for the transient thermodynamic calculation and analysis of vapor-liquid two-phase flows is of major practical significance. The comparison of the transient calculation results of vapor-liquid two-phase flows by a wavelet numerical method with those of Mini-TRAC calculation method has shown that the wavelet numerical method is fully suited to perform the transient calculation of coupled differential equations for vapor-liquid two-phase flows. **Key words:** wavelet analysis, numerical calculation, vapor-liquid two-phase flow

现场测试地下岩土平均热物性参数方法 = **A Method for the On-site Testing of Average Thermo-physical Parameters of Underground Rock Soil** [刊, 汉] / YU Ming-zhi, FANG Zhao-hong (Shandong Architectural Engineering Institute, Jinan, China, Post Code: 250014) // Journal of Engineering for Thermal Energy & Power. — 2002, 17(5). —489~492

The magnitude of average thermo-physical parameters exerts a significant influence on the number and depth of holes to be drilled, thus affecting the capital investment outlays for a ground-source heat-pump system. To realize the on-site measurement of the average thermo-physical parameters of underground rock soil, a set of on-site measuring equipment was put into use. With its help measurements were taken of the heat flow an underground embedded pipe loop is subjected to and of the temperature change of the circulating water in the loop with the passage of time. Moreover, a piece of software developed by the authors was utilized to calculate and determine the average thermo-physical parameters of the underground rock soil by using a parameter-evaluation method. **Key words:** geothermal heat exchanger, average thermo-physical parameter of rock soil, measuring method

多背压凝汽器的平均冷凝温度 = **The Mean Condensation Temperature of a Multi-pressure Condenser** [刊, 汉] / XU Zhi-ming, YANG Shan-rang, LUO Zhen, et al (Northeast Institute of Electric Power Engineering, Jilin, China, Post Code: 132012) // Journal of Engineering for Thermal Energy & Power. — 2002, 17(5). —493~495

Through a theoretical analysis the authors have derived a relationship for calculating the mean condensation temperature of a multi-pressure condenser, which has taken into account the variation of heat transfer factor with the change of condenser construction scheme and cooling water inlet temperature. Analyzed is the influence of the heat transfer area and the circulation ratio of various stages on the mean condensation temperature. Moreover, with the mean condensation temperature of the multi-pressure condenser serving as a target function an optimized construction of the condenser has been worked out. **Key words:** multi-pressure condenser, condensation temperature, circulation ratio, optimization

大型火电机组表面式加热器动态数学模型研究与开发 = **Research and Development of a Mathematical Model for the Surface Heater of a Large-sized Thermal Power Plant** [刊, 汉] / WANG Jian-mei, LIU Guang-lin, CAI Kai, et al (Wuhan University, Wuhan, China, Post Code: 430072) // Journal of Engineering for Thermal Energy & Power. — 2002, 17(5). —496~498

With a simulation supporting system STAR-90 serving as a platform developed is a fairly accurate mathematical model to study a regenerative heating system. The model is capable of not only meeting a given static precision, but also accurately reflecting and reproducing the major features of various operating conditions of a specific regenerative heating system. Furthermore, it is also feasible to employ the above mathematical model for the research of certain dynamic characteristics of heaters. **Key words:** heater, mathematical model, dynamic characteristics, regenerative heating system