多台汽水两用锅炉并联运行动态特性分析及数理模型研究

王昭俊 王文宇 董 珊
(哈尔滨建筑大学)

[摘要] 在深入分析了多台汽水两用锅炉并联运行的动态特性[1]的基础上,建立了三台汽水两用锅炉并联运行动态数理模型,并对该模型求解方法进行了探讨,仿真计算结果与锅炉运行测试结果基本相符,表明所建模型是正确可行的。这一课题的研究成果,将有利于进一步推广使用汽水两用锅炉。

关键词 汽水两用锅炉 水位变化 压力变化速度
中图法分类号 TK227. O242. 1

0 前言

汽水两用锅炉能同时供应蒸汽和热水,也可单独供应蒸汽或热水,且汽、水负荷比例可任意调节,对于既需要热水又需要蒸汽的用户,可减少锅炉型号和备用锅炉,既节约了投资又便于锅炉房运行管理。

汽水两用锅炉并联运行时,取消水平衡管最有利于水位平衡[1],但由于从水空间引出了热水管,通过锅炉房供水干管,使并联锅炉的水空间连通,当并联运行的锅炉燃烧负荷不同时,上锅筒汽空间压力就不同,通过连通管(供水管)造成各锅炉水位差异,严重时会使锅炉无法维持正常运行。

文献〔1〕论证了"汽水两用锅炉并联运行时,两台锅炉燃烧负荷相差不超过 30% 时,手动操作完全可控制水位,维持其正常运行";但文献〔1〕未讨论多台汽水两用锅炉并联运行情况。而实际运行中,已有 3台 SHW6-360-13/130/70-H型汽水两用锅炉并联运行的高温水汽水两用管路系统投入使用,当两台锅炉燃烧负荷相差约 30% 时,两台锅炉的水位差约为 6 cm,手工操作可调至水位基本平衡。

现试图根据文献〔1〕中的结论,建立起三台汽水两用锅炉并联运行的动态数理模型,从而对上述运行实践中得出的结论从理论上进行分析论证,以利于进一步推广使用汽水两用锅炉。

1 三台锅炉并联运行动态特性分析

三台锅炉并联运行时,首先应将供汽干管、供水干管、回水干管并联起来,为维持各台锅炉的水位平衡,相邻两锅炉间引出一根汽平衡管[1],如图 1所示。

当 1号锅炉燃烧负荷突然增加时,由于其产汽量增大,蒸汽通过汽平衡管 1由 1号锅炉流向 2号锅炉,使 2号炉压力增高;同理,部分蒸汽通过汽平衡管 2由 2号锅炉流向 3号锅炉,使 3号炉压力增加。

由于 1号炉压力最高,其供水量也最大,2号炉压力次之,供水量也相应减少,3号炉压

收稿日期 1997-07-17 收修改稿 1997-08-08
本文联系人 王昭俊 女 1965年 讲师 博研 150008 哈尔滨建筑大学八系新区 617#

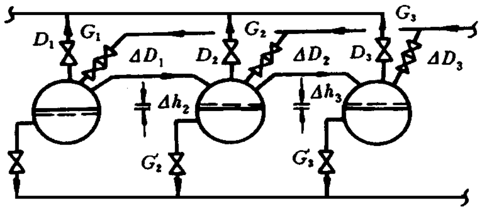

图 1　三台锅炉并联运行动态模型简图

力最低,其供水量最少。这样在相邻两台锅炉供汽干管、供水干管交点处压力平衡状态改变了。

由于 1号炉汽空间压力增大,供水量加大,其水位呈下降趋势; 2号炉压力较 1号炉低,其供水量较 1号炉少,其水位相对 1号炉呈上升趋势;同理, 3号炉水位应比 2号炉水位高。

2　三台锅炉并联运行动态数理模型建立

为使模型既合理又简单,在建立模型时,作了以下几点假设:

(1) 在同一瞬间,锅筒中工质处于平衡状态,即各点工质状态参数皆相同;

(2) 锅筒壁温与工质温度同步变化,并等于饱和水温度;

(3) 锅炉给水焓值一定;

(4) 三台锅炉型号相同,扰量增加的前一瞬间,三台锅炉压力、水位均相同;

(5) 在不稳定工况持续时间 f秒内,扰量 ΔQ按抛物线变化;汽平衡管中工质流速 V与 ΔQ同步变化,即流速曲线亦为抛物线;

(6) 锅炉热损失忽略不计;供汽量、供水量、回水量的变化忽略不计,排污量忽略不计。

质量平衡方程:

$$G_1 - D_1 - G'_1 - \Delta D_1 = \frac{d}{df}(V'd' + V''d'') \quad (1)$$

$$G_2 - D_2 - G'_2 + \Delta D_1 - \Delta D_2 = \frac{d}{df}(V'd' + V''d'') \quad (2)$$

$$G_3 - D_3 - G'_3 + \Delta D_2 = \frac{d}{df}(V'd' + V''d'') \quad (3)$$

能量平衡方程:

$$G_1 i_{gs} + Q_1 + \Delta Q - D_1 i''_b - G'_1 i'_b - \Delta D_1 i''_b = \frac{d}{df}(V'd'i' + V''d''i'' + M_j C_j t_j) \quad (4)$$

$$G_2 i_{gs} + Q_2 - D_2 i''_b - G'_2 i'_b + \Delta D_1 i''_b - \Delta D_2 i''_b = \frac{d}{df}(V'd'i' + V''d''i'' + M_j C_j t_j) \quad (5)$$

$$G_3 i_{gs} + Q_3 - D_3 i''_b - G'_3 i'_b + \Delta D_2 i''_b = \frac{d}{df}(V'd'i' + V''d''i'' + M_j C_j t_j) \quad (6)$$

以 1号炉与 2号炉的上锅筒及其汽平衡管 1为研究对象,得:

$$P_1 + \int_0^f \frac{\partial P_1}{\partial f} df = P_2 + \int_0^f \frac{\partial P_2}{\partial f} df + \int_0^f SP_1 \Delta D_1^2 df \quad (7)$$

以 2号炉与 3号炉的上锅筒及其汽平衡管 2为研究对象,得:

$$P_2 + \int_0^f \frac{\partial P_2}{\partial f} df = P_3 + \int_0^f \frac{\partial P_3}{\partial f} df + \int_0^f SP_2 \Delta D_2^2 df \quad (8)$$

由假设条件 6,锅炉水位变化仅与锅炉压力变化有关,其公式为:

$$\int_0^f \frac{\partial h_1}{\partial f} df = \frac{1}{F(d' - d'')}\left[V'\frac{\partial d'}{\partial P} + V''\frac{\partial d''}{\partial P}\right]\int_0^f \frac{\partial P_1}{\partial f} df \quad (9)$$

$$\int_0^f \frac{\partial h_2}{\partial f} df = -\frac{1}{F(d' - d'')}\left[V'\frac{\partial d'}{\partial P} + V''\frac{\partial d''}{\partial P}\right]\int_0^f \frac{\partial P_2}{\partial f} df \quad (10)$$

$$\int_0^f \frac{\partial h_3}{\partial f} df = -\frac{1}{F(d' - d'')}\left[V'\frac{\partial d'}{\partial P} + V''\frac{\partial d''}{\partial P}\right]\int_0^f \frac{\partial P_3}{\partial f} df \quad (11)$$

对同一台锅炉有:

$$\frac{\partial V''}{\partial f} = -\frac{\partial V'}{\partial f} \quad (12)$$

$$\left.\begin{aligned} \frac{\partial i'}{\partial f} &= \frac{\partial i'}{\partial P}\cdot\frac{\partial P}{\partial f} \\ \frac{\partial d}{\partial f} &= \frac{\partial d}{\partial P}\cdot\frac{\partial P}{\partial f} \\ \frac{\partial t_j}{\partial f} &= \frac{\partial t_j}{\partial P}\cdot\frac{\partial P}{\partial f} \end{aligned}\right\} \quad (13)$$

将上述 13个方程联立,并引用文献〔1〕中单台锅炉压力变化速度公式简化计算结果,可得三台锅炉并联运行动态数理模型:

$$
\left.
\begin{aligned}
&\frac{\partial P_1}{\partial f}=\frac{G_1\left[\frac{d''V}{d'-d''}-\Delta i\right]+(Q_1+\Delta Q)-(D_1+\Delta D_1)\frac{d'V}{d'-d''}-G'_1\frac{d''V}{d'-d''}}{V'd'\frac{\partial i'}{\partial P}+V''\frac{d'V}{d'-d''}\frac{\partial d''}{\partial P}+M_jC_j\frac{\partial t_j}{\partial P}}\\
&\frac{\partial P_2}{\partial f}=\frac{G_2\left[\frac{d''V}{d'-d''}-\Delta i\right]+Q_2-(D_2-\Delta D_1+\Delta D_2)\frac{d'V}{d'-d''}-G'_2\frac{d'V}{d'-d''}}{V'd'\frac{\partial i'}{\partial P}+V''\frac{d'V}{d'-d''}\frac{\partial d''}{\partial P}+M_jC_j\frac{\partial t_j}{\partial P}}\\
&\frac{\partial P_3}{\partial f}=\frac{G_3\left[\frac{d''V}{d'-d''}-\Delta i\right]+Q_3-(D_3-\Delta D_2)\frac{d'V}{d'-d''}-G'_3\frac{d'V}{d'-d''}}{V'd'\frac{\partial i'}{\partial P}+V''\frac{d'V}{d'-d''}\frac{\partial d''}{\partial P}+M_jC_j\frac{\partial t_j}{\partial P}}\\
&\int_0^f\frac{\partial h_1}{\partial f}\,df=-\frac{1}{F(d'-d'')}\left[V'\frac{\partial d'}{\partial P}+V''\frac{\partial d''}{\partial P}\right]\int_0^f\frac{\partial P_1}{\partial f}\,df\\
&\int_0^f\frac{\partial h_2}{\partial f}\,df=-\frac{1}{F(d'-d'')}\left[V'\frac{\partial d'}{\partial P}+V''\frac{\partial d''}{\partial P}\right]\int_0^f\frac{\partial P_2}{\partial f}\,df\\
&\int_0^f\frac{\partial h_3}{\partial f}\,df=\frac{1}{F(d'-d'')}\left[V'\frac{\partial d'}{\partial P}+V''\frac{\partial d''}{\partial P}\right]\int_0^f\frac{\partial P_3}{\partial f}\,df\\
&\frac{\partial P_1}{\partial f}-\frac{\partial P_3}{\partial f}=SP_1\Delta D_1^2+SP_2\Delta D_2^2
\end{aligned}
\right\}
\qquad (14)
$$

3 模型求解方法探讨

式(14)中未知量个数多于方程个数,且未知量皆为非线性的,该类问题属于非线性多元函数最优化问题,可采用非线性规划法(迭代法)求解。

求解该模型的关键在于合理地假设汽平衡管中工质的流速。因锅炉实际运行中,汽平衡管中工质流速变化范围较大,不能简单地假设其为一定值,可先求出汽平衡管1中工质流速的最大值 V_{1max} 和最小值 V_{1min},然后在此范围内假设若干个工质流速值 V_1,最后通过迭代法求出汽平衡管2中相对应的工质流速 V_2。

4 仿真计算结果分析

本文以三台 SHW6 360-13/130/70-H型汽水两用锅炉并联运行为例,在计算机上进行了模拟计算,根据文献〔1〕中结论,在计算过程中不妨设扰量平均值 $\Delta Q=30\% Q$,不稳定工况持续时间 = 150秒,汽水负荷比 $B=0.5$, $D_1=0.159$ m, $D_2=0.159$ m, $\lambda=0.02$,其计算结果见表1。

表 1

	$P=0.4$ MPa	$P=1.3$ MPa
Δh_1	−3.47	−4.47
Δh_2	0.20	0.30
Δh_3	0.30	0.40

注: Δh_i ($i=1,2,3$)— 锅炉水位变化, cm。

由表1可见: 1. 当锅炉运行压力为0.4MPa(约为4表压)时,1 2号锅炉水位差为3.5 cm, 2

3号锅炉水位差为 0.1 cm。

2. 当锅炉在额定压力 1.3MPa(约为 13表压)下运行时,1、2号锅炉水位差为 4.5cm,2、3号锅炉水位差为 0.1 cm。

5　结　论

仿真结果表明:当三台锅炉并联运行时,其中一台锅炉燃烧负荷变化不超过 30% 时,相邻两台锅炉水位差均不超过 6 cm,完全可用手动操作控制其水位,维持正常运行,这与锅炉运行测试结果[1]基本相符,表明所建模型是正确可行的。仿真结果为多台汽水两用锅炉并联运行提供了理论依据,这对于进一步推广使用汽水两用锅炉将具有一定的理论意义和实用价值。

主要符号见文献〔1〕

参考文献

1　董　珊,王昭俊. 汽水两用锅炉并联运行动态数理模型研究. 热能动力工程, 1992, 7(5)

2　董　珊,凌人滨. SHW 6 360 -10 /160-H(A)型汽水两用锅炉的设计与运行. 热能动力工程, 1989, 4(3)

(复　编)

舰用锅炉

舰用增压锅炉

“Теплоэнергетика” 1996年 11月号报道了俄罗斯舰用增压锅炉的研制历史及其在海军主蒸汽动力装置上的应用情况。

文章详述了增压锅炉的设计、构造及其工作原理。增压锅炉内烟气的能量用于炉膛内空气的增压。它是利用由包含在经济器后的锅炉烟气通道内并利用烟气工作的燃气轮机驱动的压气机实现的。烟气的大部分热能已给于锅炉受热面。压气机和燃气轮机组合成一体的涡轮增压装置(THA)。大气空气在该THA中被压缩,并沿空气通路供入锅炉壳体,该壳体是按承受锅炉满负荷下压气机发出的空气最大压力设计的。经过壳体之间的空间,空气通过空气导向装置进入锅炉炉膛并与经由喷油嘴雾化的燃料混合,从而保证了重油高质量的燃烧。燃料燃烧产物在锅炉炉膛和烟气通路中把自己的部分热量给于受热面,沿锅炉出口在烟气净化装置中经受净化除去固体颗粒,然后流向燃气轮机做功,以后沿烟气出口管道进入烟囱。

舰用增压锅炉低的重量尺寸指标、良好的动态特性、高的经济性、可靠性和可维护性表明它良好地适用于海军大中型舰船的主动力装置。在增压锅炉后安装热水或蒸汽余热锅炉,可使锅炉装置的经济性达到当代水平。　(思娟　供稿)

and pre-separation collectors on the role and performance of recirculation tubes. Key words: corner-tube boiler, recirculation tube, experimental study

文丘利管内外流场的数值计算及实验研究= **Numerical Calculation and Experimental Study of Venturi Inner and Outer Tube Flow Fields** [刊,中]/Cai Jiyong, Chen Tingkuan, et al (Xi'an Jiaotong University)// Journal of Engineering for Thermal Energy & Power, 1998, 13 (2). -96~99

By way of a numerical calculation of Venturi inner and outer tube flow fields this paper makes a theoretical analysis of the effect of structural parameters of the Venturi tube on its inner flow field and air duct flow field. In addition, through tests key factors influencing the performance have been identified and verified. The calculation results agree well with the cold-state simulation test results. Key words: numerical calculation, simple algorithm, experimental study

多台汽水两用锅炉并联运行动态特性分析及数理模型研究= **An Analysis of the Dynamic Characteristics and a Study of the Mathematical Model for Three Dual-Purpose Steam-Water Boilers in Parallel Operation** [刊,中]/Wang Zhaojun, Wang Wenyu, Dong Shan (Harbin University of Architectural Engineering)// Journal of Engineering for Thermal Energy & Power. -1998, 13(2). - 100~103

Based on an in-depth analysis of the dynamic characteristics of three dual-purpose steam-water boilers in parallel operation the authors have set up for them a dynamic mathematical model. An exploratory study was conducted of the method for solving the model. The simulation computation results are found to be in good agreement with the test results, which attests to the correctness of the established model. The related research results can be helpful for the further popularization of dual-purpose steam-water boilers. Key words: dual-purpose steam-water boiler, water level fluctuation, pressure change rate

带有小螺旋角的内外螺旋翅片管高压加热器的工业试验= **The Industrial Test of an Internal and External Spiral-Finned Tube High-Pressure Heater with a Small Spiral Angle** [刊,中]/ Liang Ping, Zhu Dongshang, et al (Southeastern University of Science & Technology), Ma Guangping, et al (Zhaoguan Power Station)// Journal of Engineering for Thermal Energy & Power. -1998, 13(2). - 104~107

The results of an on-site industrial test have shown that the use of internal and outer spiral-finned tubes (called IOSF tube for short) with a small spiral angle for power station high-pressure heaters can bring about a significant heat transfer intensification effect. With a measured total heat transfer factor being 1.43 times of that of a bare tube heater the resulting economy in heat exchanger heating surface can be as high as 30% . It use under an equivalent heat exchange surface area may result in notable energy-savings. Key words: internal and outer spiral-finned tube, spiral-grooved tube, bare tube, intensified heat transfer, total heat transfer factor

一种应用于三联产系统的新型的物料回送阀的试验= **A Test on a New Type of Raw Material Return Feed Valve for a Steam-Gas-Electricity Triple Production System** [刊,中]/Zhang Ji, Cao Yuanquan, Qian Jianqing, et al (Zhejiang University)// Journal of Engineering for Thermal Energy & Power. -1998, 13(2). - 108~111

A brief description is given of the characteristics of the test operation of a novel return feed valve in combination with the features of other raw material return feed valves. Discussed are