锅炉过热器汇流集箱流动机理研究

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[摘要] 锅炉集箱中的流体均匀分布是锅炉过热器,再热器安全设计的关键技术之一。本文在动量守恒的基础上,研究汇流集箱的流动机理和集箱流体静压分析,锅炉汇流集箱流动的基本规律和设计参数。

关键词 锅炉 集箱 过热器 分支流 再热器
中图分类法 TK223.32

符号表

C_f	=	速度比(W_c/W)
E	=	长径比(L/D)
F_c	=	孔截面积
L	=	集箱开孔长度
N	=	孔数
$\overline{P}$	=	无量纲压力($P/\rho W_0^2$)
w	=	管内流速
w_0	=	入口处流速
x	=	轴向座标
f	=	管内摩擦系数
τ_w	=	壁面剪应力
D	=	集箱直径
F	=	管截面积
k	=	动量交换系数
M	=	特征参数(kD/fL)
p	=	管压力
u	=	孔速度
w_x	=	在点 x 处流速
w_c	=	孔入口处管内流速的轴向分量
$\overline{X}$	=	无量纲座标
ρ	=	流体密度
Re_0	=	入口雷诺数(Dw_0/ν)

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1 引言

锅炉过热器超温爆管是工业锅炉常见的事故之一。其爆管的原因之一是过热器集箱的流量分配不均。这种支管流量的不均匀引起局部支管中的流量减少或迟滞,最终导致超温爆管。设计计算锅炉集箱流量分配均匀性的关键是计算集箱内的轴向静压分布。在现在的锅炉过热器集箱设计标准中,设计计算方法是用一条简单的抛物线来进行描述的[1,2],并且往往很少考虑集箱结构尺寸的影响。近年来,锅炉分配集箱已做了较多的研究[3,4],但汇流集箱的研究相对较少,汇流集箱的流量均布问题已成为锅炉过热器设计计算的重要问题。本文通过建立汇流集箱的理论模型,计算集箱内的轴向静压分布,研究影响集箱静压分布的主要因素和改进措施。

2 理论分析

对如图 1所示汇流集箱,流体从支管进入集箱,

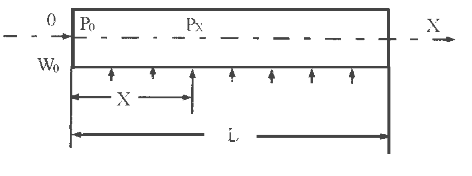

图 1 汇流集箱结构示意

沿封密端到出口端,流速逐渐增加,静压逐渐减少。在建立理论模型前,做以下假设:

(a) 支管的压力保持不变;

(b) 集箱是等截面的,支管沿集箱轴向是等间距分布的,而且支管的管径相同;

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(c) 流体在封闭端流速为零,在出口端流速最大。

由上述假设可知,集箱内流体达到均布的条件是集箱内的静压分布必须均匀。在支管附近取一微元控制体,如图 2 所示。应用文献 [5-6]的类似方法,建立质量守恒方程和动量守恒方程:

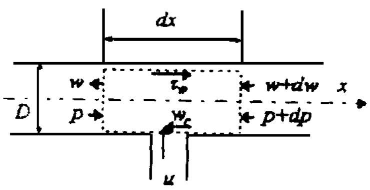

图 2　汇流点微元控制体

(1) 质量守恒方程:

$$\mathrm{d}Fw = \mathrm{d}F(w + \frac{\mathrm{d}w}{\mathrm{d}x}\mathrm{d}x) + \mathrm{d}F_c u$$

令 $\mathrm{d}x = L/n$,上式解得:

$$u = \frac{FL}{F_c n}\frac{\mathrm{d}w}{\mathrm{d}x} \qquad (1)$$

(2) 动量守恒方程:

轴向流体动量增量是轴向各力作用的结果,在微元控制体上,作用着静压力和壁面摩擦力。

$$\mathrm{d}F - (p + \frac{\mathrm{d}p}{\mathrm{d}x}\mathrm{d}x)F + f_W \mathrm{c}D\,\mathrm{d}x = \mathrm{d}F(w + \frac{\mathrm{d}w}{\mathrm{d}x}\mathrm{d}x)^2 - \mathrm{d}Fw^2 + \mathrm{d}F_c u w_c$$

对圆截面多孔管,管壁摩擦力 $f_w = f\mathrm{d}(w^2/8)$,忽略 dx 的高阶微量,方程简化为:

$$\frac{1}{\mathrm{d}}\frac{\mathrm{d}p}{\mathrm{d}x} - \frac{f}{2D}w^2 + 2w\frac{\mathrm{d}w}{\mathrm{d}x} + \frac{F_c n}{FL}uw_c = 0 \qquad (2)$$

w_c 表示支管分流带走的流体轴向分量,其大小依赖于管尺寸和所处的孔位置,可大于或小于 w,由此 w_c 可表示为:

$$W_c = C_f w \qquad (3)$$

在锅炉设计中,C_f 常称为压力恢复系数[6]。

将方程 (1) 和 (3) 代入方程 (2),动量方程化简:

$$\frac{1}{\mathrm{d}}\frac{\mathrm{d}p}{\mathrm{d}x} - \frac{f}{2D}w^2 + (2 - C_f)w\frac{\mathrm{d}w}{\mathrm{d}x} = 0 \qquad (4)$$

令 $2 - C_f = 2k$,式 (4) 化为下列形式:

$$\frac{1}{\mathrm{d}}\frac{\mathrm{d}p}{\mathrm{d}x} + \frac{f}{2D}w^2 + 2kw\frac{\mathrm{d}w}{\mathrm{d}x} = 0 \qquad (5)$$

3　解方程

若流体是连续、均匀地流出支管,则集箱内流体呈线性流动分布,即:

$$W = a(x + b)$$

由边界条件:

$$x = 0, w = w_0$$

$$x = L, w = 0$$

代入方程 (6),即得: $a = -w_0/L$

$$b = -L$$

$$w = w_0(1 - \frac{x}{L}) \qquad (7)$$

代入式 (5),并从 0到 x 积分得:

$$\Delta P_{x0} = \mathrm{d}w_0^2 k[1 - (1 - \frac{x}{L})^2] + \frac{\mathrm{d}w_0^2 Lf}{6D}[1 - (1 - \frac{x}{L})^3] \qquad (8)$$

或: $$Eu_{x0} = \frac{\Delta P_{x0}}{\mathrm{d}w_0^2} = k[1 - (1 - \frac{x}{L})^2] + \frac{Lf}{6D}[1 - (1 - \frac{x}{L})^3] \qquad (9)$$

引入无因次变量: $Eu_{x0} = \frac{\Delta P_{x0}}{\mathrm{d}w_0^2}$, $\overline{X} = \frac{x}{L}$

方程 (9) 化为:

$$Eu_{x0} = k[1 - (1 - \overline{X})^2] + \frac{Lf}{6D}[1 - (1 - \overline{X})^3] \qquad (10)$$

对方程 (10) 求一、二阶导数

$$Eu_{x0}' = (1 - \overline{X})[2k + \frac{Lf}{2D}(1 - \overline{X})] \qquad (11)$$

$$Eu_{x0}'' = -2k - \frac{Lf}{D}(1 - \overline{X}) \qquad (12)$$

令 $Eu_{x0}' = 0$,可得两个极值点

$$\overline{X}_1 = 1, 和 \overline{X}_2 = 1 + \frac{4kD}{Lf} = 1 + 4M$$

式中 $M = kD/Lf$

代入方程 (12) 可得:

$Eu_{x0}''|_{x_1} = -2k < 0$,方程 (10) 在 $\overline{X}_1$ 点有极大值:

$$Eu_{x0}|_{\bar{X}_1} = k + \frac{Lf}{6D} \qquad (13)$$

$Eu_{x0}''|_{\bar{X}_2} = 2k > 0$,方程 (10) 在 $\bar{X}_2$ 点有极小值:

$$Eu_{x0}|_{\bar{X}_{c2}} = k[1 - (\frac{4kD}{Lf})^2] + \frac{Lf}{6D}[1 - (\frac{4kD}{Lf})^3] \qquad (14)$$

4　计算结果与讨论

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按以上的数学分析,流体在汇流集箱内的流动完全不同于流体在分流集箱中的流动状况,流体在汇流集箱中流动可分为以下情况:

(1) $M \le 0$ ($\bar{x}_2 = 1 + 4M \le 1$)

$M < 0$是不存在的,因为 D、L、λ都为正数,k只有在封闭端的局部区域可能为负数,但实验指出,对整个锅炉汇流集箱,其值为正。在工程上,$M = 0$为L/D比为无限的特殊情况。此时,$\bar{x}_1$和$\bar{x}_2$重合,都等于1。其静压分布如图3所示。

(2) $M > 0$ ($\bar{x}_2 = 1 + 4M > 1$)

静压分布在$\bar{x}_1 = 1$处有极大值,在$\bar{x}_2 > 1$处有极小值。静压分布如图4所示。静压在出口端最小,沿集箱轴向逐渐增大,在集箱封闭端达到最大值 $k + fL/6D$。

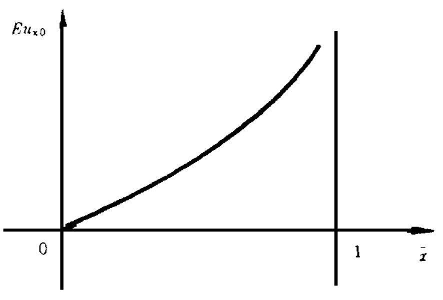

图 3 $M = 0$时汇流集箱的静压分布

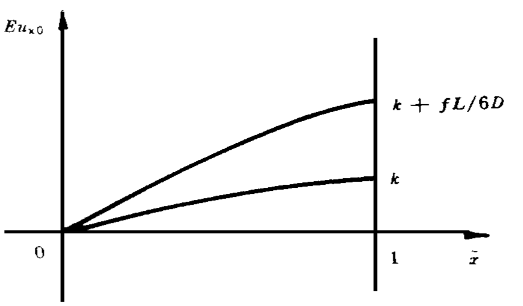

图 4 $M > 0$时汇流集箱静压分布

从上面的图可以看出,流体在过热器中静压均布的基础强烈地依赖于 $k + fL/6D$的值的大小。减小 k、f、L值或增大 D值,都能使$k + fL/6D$的值减少。明显地,当 $k + fL/6D$的值等于 0时,集箱内的静压就达到均匀分布,但是,这是不可能的,因为实验测得 $k \approx 1$,因此,汇流集箱设计只能达到近似的均匀分布或使流量偏差在一个允许范围。设计过热器汇流集箱均布的另一条途径是同分配集箱同时设计,以控制两集箱间的静压差值。

另一方面,$k + fL/6D = k(1 + fL/6Dk) = k(1 + L/6M)$。显然,静压偏差与$k$和$M$有关,当$k$一定时,静压偏差随着$M$值的增加而减少。如 $M \ge 1$,则 $Eu_{x0} = k$计算,最大误差 16%;如 $M \ge 2$,则 $Eu_{x0} = k$计算,最大误差只有 7%。

4 结论

锅炉过热器汇流集箱流量均布设计主要是控制$k + fL/6D$的值,其值越小,流量越均匀,其值为零时,即达到流量的均匀分布。一般来说,绝对的流量均匀分布是不可能达到的,但是,使流量偏差限制在工程上许可的范围内是可能的。现在设计计算是选择适当的长径比 L/D,使流量达到均匀分布。

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压气机的湿压缩特性及计算模型初步研究= **A Preliminary Study of Compressor Wet Compression Characteristics and its Calculation Model**[刊,中]/Lin Feng, Wen Xueyou (Harbin No. 703 Research Institute) // Journal of Engineering for Thermal Energy & Power). - 1998, 13(6). - 402~405

After analyzing a huge amount of information and data published abroad concerning water spray into a compressor flow path and on the basis of the preliminary test results already obtained the authors sum up the main features of the compressor performance after a water spray and key factors which can exercise an influence on the compressor performance. A theoretical analysis and argumentation/justification of these features have been conducted. Finally, a calculation model is proposed based on the features of "wet compression". Key words: compressor, wet compression, model

锅炉过热器汇流集箱流动机理研究= **A Study of the Flow Mechanism in the Collector of a Boiler Superheater**[刊,中]/Wang Junye, Wu Guojiang, Wang Deping, et al (Shanghai Jiaotong University) // Journal of Engineering for Thermal Energy & Power). - 1998, 13(6). - 406~408

The uniform distribution of flow in a boiler header constitutes one of the key technological factors ensuring the safe design of boiler superheaters and reheaters. On the basis of momentum conservation this paper focuses on the study of flow mechanism of the header and its flow static pressure distribution. Furthermore, an analysis is also conducted of the basic governing rules and design parameters of the flow in the boiler header. Key words: boiler, header, superheater, branch flow, reheater

电站辅机可靠性考核验证方案= **A Reliability Verification Scheme for Power Station Auxiliaries**[刊,中]/Xu Hongquan, et al (China National Aviation Comprehensive Technology Research Institute) // Journal of Engineering for Thermal Energy & Power). - 1998, 13(6). - 409~411

MTBF(mean time between failure) and AF (availability factor) indexes are employed to verify the reliability of power station auxiliaries. Presented is a scheme for reliability index verification of power station auxiliaries by the use of power station on-site operation data along with some pertinent practical examples. This can serve as a guide for power station auxiliaries manufacturers and electric power operation departments in formulating reliability verification methods. Key words: power station auxiliaries, mean time between failure, availability factor, reliability verification test

自然循环锅炉启动过程中过热器超温机理的研究= **A Study of the Overheating Mechanism of Superheaters During Start-up of Natural Circulation Boilers**[刊,中]/Yan Weiping (North China University of Electric Power Engineering) // Journal of Engineering for Thermal Energy & Power). - 1998, 13(6). - 412~414

On the basis of a heat balance principle presented in this paper is a simple and intuitive analytical method of calculation for analysing and substantiating the underlying cause of superheater overheating during a boiler start-up. The results obtained agree well with those of actual measurements. The essence of superheater overheating during the boiler start-up is hereby clarified, which can have a certain reference value for the study of the superheater overheaitng mechanism and the determination of measures for solving the superheater overheating issues. Key words: boiler, boiler start-up, superheater overheating

氢能燃气轮机循环低温能有效利用及热力学分析= **The Effective Utilization of Hydrogen Energy-based Gas Turbine Cycle Low-temeprature Energy and Its Thermodynamic Analysis**[刊,中]/Cao Huiling, Yu

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