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一种新的流量管标定方法

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摘　要: 流量管是用于气动试验测量进气流量的设备, 其精度对整 个测试结果具有重要影响。为提高流量管标定精度, 对其标定方法进行了研究, 介绍了 一种新的流量管标 定装置及原理, 在考虑流体压缩性及比 热比变 化的前提下推 导出流量计算公式, 实际流量的测试采用 积分法, 并与 旧方法 进行了分析比较, 表明新方法是 一种原理完善、精度高、适用范围广、切实可行的流量管标定方法。

关　键　词: 气动试验台; 设备; 流量管标定

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1　引　言

流量管是一种应用于气动试验测量进气流量的设备, 具有压力损失低、不干扰气流和使用方便的特点, 其精度对整个测试结果具有重要影响。随着测试及计算技术的进步, 旧的标定方法已不能满足日益提高精度的要求, 探索新的标定方法非常有必要。为此, 在参考有关文献和旧的标定方法的基础上, 提出了一种新的流量管标定方法。

2　试验装置

标定流量管的试验装置见图 1。0－0、1－1、2－2 为测量截面, 分别代表进口截面、壁面静压取压截面和标定截面。0－0 截面用 PSI9600 大气压力计测量大气压 P_a 及大气温度 T_a; 1－1 截面采用 PSI9016 扫描阀测量壁面静压 ΔP_b; 2－2 截面用毕托管作为一次测量元件, 用 PSI9016 扫描阀测得各点的总压 ΔP_{02ij} 和静压 ΔP_{C2ij}, 通过加权平均求得 2－2 截面平均总压 ΔP_{02} 和平均静压 ΔP_{C2}。1－1 截面、2－2 截面测得的压力为表压, 加上大气压 P_a 便获得相应的绝对压力, 如壁面静压 P_b、2－2 截面平均总压 P_{02}、平均静压 P_{C2}。

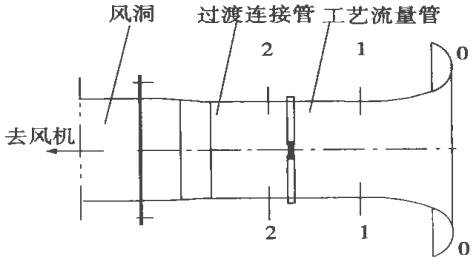

图 1　流量管试验系 统图

3　试验原理

3.1　原理简介

流量管是通过大气压、大气温度和某截面的壁面静压三个参数来测试流量的。大气压、大气温度为流量管进口截面上的参数, 在稳定的环境条件下精确确定标定截面处的实际气流流量, 建立进口截面参数、壁面静压与标定截面参数以及标定截面计算流量与实际流量之间的关系, 为应用流量管测量流量提供计算依据。

3.2　计算公式推导

流量管计算公式比较复杂, 推导的基本思路如下:

质量流量流程: $G_j = A_2 \rho_2 V_2$　　(1)

气体状态方程: $\rho_2 = \dfrac{P_{C2}}{RT_2}$　　(2)

伯努利方程: $\dfrac{V_2^2}{2} = \displaystyle\int_{PC2}^{P_{02}} \frac{dP_{C2}}{\rho_2}$　　(3)

总压恢复系数:

$\sigma = P_{02}/P_{00} = (\Delta P_{02} + P_a)/P_a$　　(4)

流量系数: $\Phi = G_s/G_j$　　(5)

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壁面静压修正系数: $K_b = \frac{P_{C2}}{P_b} = \frac{P_a + \Delta P_{C2}}{P_a + \Delta P_b}$　　(6)

折合流量: $G_{\Pi p} = G_s \frac{P_{as}\sqrt{T_a}}{P_a\sqrt{T_{as}}}$　　(7)

将式(1)、(2)、(3)联立, 通过积分及多项式回归求得 G_j 的计算公式, 再与式(4)、(5)、(6)、(7)联立, 获得折算流量:

$$G_{\Pi p} = A\Phi\sigma b^c\sqrt{\ln b} \tag{8}$$

其中:

G_j、$G_{\Pi p}$— 计算流量、折合流量;

A_2、ρ_2、V_2—2－2 截面面积、平均密度、平均速度;

P_{as}、T_{as}、T_2、R— 标准大气压、标准大气温度、2－2 截面平均温度、气体常数;

A— 常数, $A = A_2\frac{P_{as}}{\sqrt{T_{as}}}\left\{\frac{2}{R}\right\}^{\frac{1}{2}}$;

b— 压比,

$b = \frac{kb(P_a + \Delta P_b)}{\sigma P_a}$

G_s— 实际流量, 利用 2－2 截面的多点测试数据, 通过面积分求得, 各面微元流量计算公式与 G_j 类似;

C— 温度, 比热比修正因子;

$C = 0.775\ 5 + [3.45T_2 - 24(1 - b)\sqrt{T_2}] \times 10^{-5}$。

4　新方法的技术优势

4.1　流量计算方法同时考虑可压缩性和变比热比

计算方法对流量管标定的精度有重要影响, 由于受计算水平的制约, 以前的流量计算一般以两种假设为前提: (1)假设流体是不可压的, 忽略压缩性; (2)考虑压缩性, 假设流体的比热比不变。这些假设都会带来一定的误差, 前者当马赫数约 0.4 时, 误差为 0.4%; 后者马赫数约 0.85 时, 误差为 0.12%。而新方法由于同时考虑压缩性及比热比的变化, 在马赫数 0.85 时, 误差不超过 0.01%, 计算误差精度高一个数量级, 能更好地满足流量标定的精度要求, 具有很大的优越性。

4.2　采用积分法计算实际流量

实际流量的计算方法直接影响流量管标定的精度, 新、旧方法在此方面有重要不同。旧方法实际流量的计算采用面积修正法, 修正公式(1)中的通流面积 A_2 采用下式计算:

$$A_2 = \pi(r - \delta')^2 \tag{9}$$

$$\delta' = 0.095^{\delta} \tag{10}$$

其中:

r、δ'—2－2 截面处的半径、紊流附面层排挤厚度;

δ—2－2 截面附面层厚度, 在 $V_i = 0.99V_2$ 处距壁面的距离称为附面层厚度。

新方法采用积分法求得实际面积。沿测量截面周内均布若干个测孔, 每个测孔沿径向布置若干个测点, 利用测点的气流参数及所在扇环的面积算出各扇环的质量流量, 整个截面质量流量的总和即为实际质量流量。由于测量截面不是理想的圆形, 最靠近壁面的扇环面积根据测试予以修正, 以使流量计算的更加精确。

4.3　新旧方法对比

旧方法采用经验公式修正通流面积计算实际流量, 使用中往往会由于附面层流态不满足经验公式适用条件而引入误差, 经验公式只是一定程度上正确, 具有近似性, 因此旧方法比较适用于精度要求不是很高的工程项目; 新方法没有应用经验公式, 能够更准确地依据 2－2 截面的实际流动情况获得实际流量, 更充分地将流动的平面性反映到实际流量测量结果中, 因而更准确, 具有优越性, 更适用于准确测试流量的流量管的标定。

5　结　语

(1)新方法比旧方法原理完善, 适用范围广;

(2)新方法可通过计算机快捷准确地进行数据处理, 测量精度高, 是一种切实可行、很有价值的流量管的标定方法。

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The structure of a gas-filled heat-pipe air preheater is analyzed along with a description of its applications. By using a flat interface model it is possible to determine the effective length of a gas-filled heat pipe cooling section. Under the condition of identical initial parameters the gas-filled heat-pipe heat exchangers and those not being gas-filled are tested and the difference among the heat-pipe minimum operating-control temperature, exhaust gas temperature and heat exchange area is analyzed. The results of industrial tests and practical use indicate that under off-design operating conditions and when firing coal of high sulfur content (5% - 7%) the gas-filled heat-pipe air preheaters excel in corrosion-prevention and ash-fouling resistance performance. **Key words**: gas-filled heat pipe, air preheater, corrosion prevention, ash fouling resistance

2.8 MW 热水链条锅炉改烧水煤浆燃烧试验分析= **The Combustion Test and Analysis of a 2.8MW Hot-water Traveling-grate Boiler Retrofitted for Firing Coal-water Slurry** [刊, 汉] / XIE Yong-gang, ZHAO Xiang (Institute of Thermal Power Engineering under the Zhejiang University, Hangzhou, China, Post Code: 310027), ZHANG Chuan-ming, WANG Feng-yin (Xinwen Mining Group Corporation, Xinwen, Shandong Province, China, Post Code: 271219) // Journal of Engineering for Thermal Energy & Power. — 2004, 19(3). — 309 ~ 311

Coal-water slurry is a new type of clean fuel, which enjoys very good usage prospects. Its use on a retrofitted 2.8MW hot-water boiler in the central hospital of Xinwen Mining Group Corp. is credited with a stable combustion even at low loads. The combustion process of coal-water slurry in the above-mentioned boiler is described along with an analysis of the flame center and length as well as slag-forming characteristics, etc. After its retrofitting the boiler has attained a thermal efficiency of 80.04% and a combustion efficiency of 99.36%. It is noted that the secondary-air swirl intensity, atomization air pressure, slurry pressure, air feed rate and boiler load, etc have a significant impact on the combustion of the coal-water slurry, and, hence, combustion efficiency. The retrofitting of this hot-water boiler can serve as a fine example for the retrofitting of other analogous boilers. **Key words**: coal water slurry, combustion process, boiler modification and upgrading

鳞片式锅炉链条起拱问题及预紧力分析= **An Analysis of the Humping of Fish Scale-shaped Boiler Chains and the Application of a Pretension Force** [刊, 汉] / ZHANG Yao-wen (Yantai Bing Lun Boiler Co. Ltd., Yantai, China, Post Code: 264002), WANG Xu-dong (College of Mechanical Engineering under the Xi'an University of Electronic Science & Technology, Xi'an, China, Post Code: 710071) // Journal of Engineering for Thermal Energy & Power. — 2004, 19(3). — 312 ~ 315

Through the solution for a catenary equation and the clarification of the rigidity relationship between the upper and lower chains the mechanics problem of humping of boiler grate chains was analyzed and discussed. On this basis a critical pretension force along with its simple assessment and control has been proposed, which can be used as a target index for the design and safe operation of front-drive boiler chains. A comparison of the two drive modes, namely, the front and rear shaft drives, has led to the conclusion that a front shaft drive is more rational for use on industrial boiler chain grates. **Key words**: fish scale-shaped chain, chain rigidity, chain pretension, catenary

一种新的流量管标定方法= **A New Method for Calibrating Air Flow-rate Measuring Tubes** [刊, 汉] / LI Dian-xi, WANG Hong (Harbin No. 703 Research Institute, Harbin, China, Post Code: 150036), WANG Shi-an, YOU Ke-quan (Naval Representative Office Resident at No. 703 Research Institute) // Journal of Engineering for Thermal Energy & Power. — 2004, 19(3). — 316 ~ 317

Key words: aerodynamic test rig, air flow-rate measuring tube, calibration, equipment

工业锅炉给水泵选型的方法= **Type Selection Method for the Feedwater Pumps of Industrial Boilers** [刊, 汉] / LIU Xue-hai, YAN Feng-zhen (Equipment Engineering Department, Wondersun Milk Products Industrial Co. Ltd., Harbin, China, Post Code: 150090) // Journal of Engineering for Thermal Energy & Power. — 2004, 19(3). — 318 ~ 319

Key words: industrial boiler, feedwater pump, type selection