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两相流垂直下降横掠“T”形柱体的斯特罗哈数

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摘　要:试验研究了两种规格梯形柱体,在垂直下降气液两相流中,发生气液两相涡街时,气液两相斯特罗哈数的变化规律。在测得大量数据的基础上,得出了发生气液两相涡街时,气液两相斯特罗哈数的通用关系式。研究表明,气液两相斯特罗哈数在两相工况下为一变数,与来流截面含气率、涡街发生体形状与特征尺寸和来流方向等因素有关。应用此关系式,根据测得的两相涡街频率可将涡街发生体作为测量两相流流量与组分的测量元件。

关　键　词:气体－液体混合物;卡门涡;斯特罗哈数;柱

中图分类号:O359^{+}.1;TK124　　　文献标识码:A

1　引言

斯特罗哈数是研究流体绕流的一个重要特征参数。研究气液两相斯特罗哈数不仅在工程上有应用价值,而且在学术上对气液两相涡街的研究和发展有重大意义。此外,过去人们通过对单相流体斯特罗哈数的研究,制成了性能良好的单相流体涡街流量计,如今被广泛应用。同样对气液两相斯特罗哈数的研究,也有可能为利用气液两相涡街特性测量两相流量与组分开辟新的思路。气液两相绕流在工业设备中常可遇到,如电厂凝汽器、核电站中燃料棒子通道间的流动,以及相变换热器中气液两相混合物横向冲刷管子的流动工况等。

由于气液两相绕流运动非常复杂,目前国内外对两相斯特罗哈数的研究甚少,主要有 Yokosawa(1986)等[1]和 Hulin 等[2]研究了垂直上升气液两相绕流发生气液两相涡街时,斯特罗哈数的变化规律,他们的研究并未涉及到垂直下降气液两相绕流的情况。然而研究垂直下降的绕流工况对改善电厂凝汽器很有帮助,在当前研究垂直下降气液两相绕流工况非常迫切。

本文作者在内径为 50 mm 管内,研究了垂直下降气液两相流流过梯形柱体,发生气液两相涡街时,斯特罗哈数的特性。其研究结果对气液两相绕流物体的力学及传热特性以及发展两相流测试技术均有重要意义。

2　试验装置和检测方法

2.1　试验条件[3]

2.2　试验系统

试验工质由已测定流量的水及空气分别送入混合器形成混合物,然后再送入试验管段进行试验。其总体装置图见文献[4]。其中空气流量利用转子流量计测量,水流量利用笛形管测量。本文作者试验中采用的两相涡街发生体如图 1 所示,W 表示发生体宽度。试验时将柱体分别放入试验段测试,其装置实验图见文献[3]。图中只画出了 B1 型柱体的位置,B2 型柱体的安装位置与 B1 型柱体的位置相同。

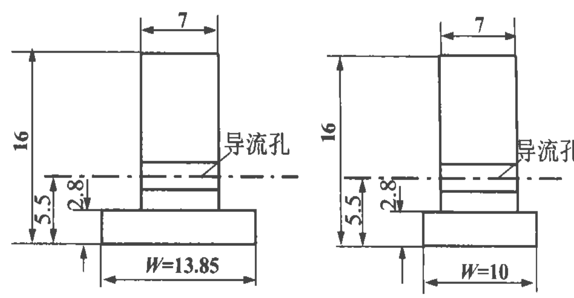

图 1　两相涡街发生体

2.3　两相旋涡检测的原理和方法

每当柱体两侧交替产生旋转方向相反的旋涡时柱体就交替地受两个方向相反的压力,即存在压差。如果在物体上开有小孔,则孔中会有流体往复流动,

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该小孔称为导流孔（见图 1）。在本试验中，每个涡街发生体上均开有导流孔，孔内装有敏感元件热敏

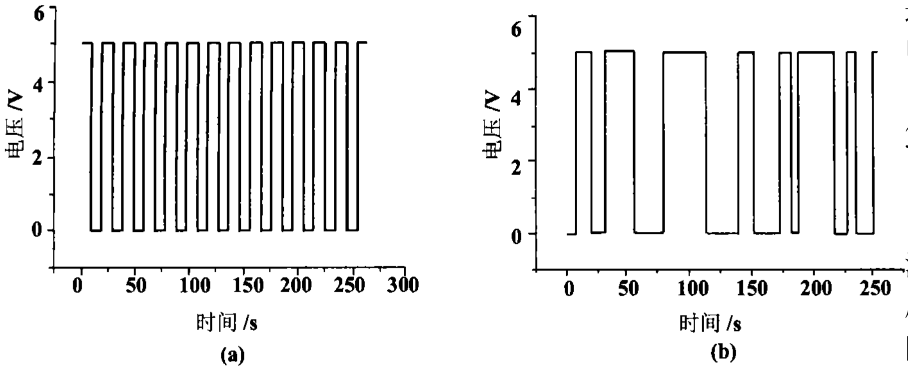

图 2　混合物垂直下降流时 B1、B2 型物体涡街检测结果

（Q_L = 25.0 m/h^3, α = 0.040）

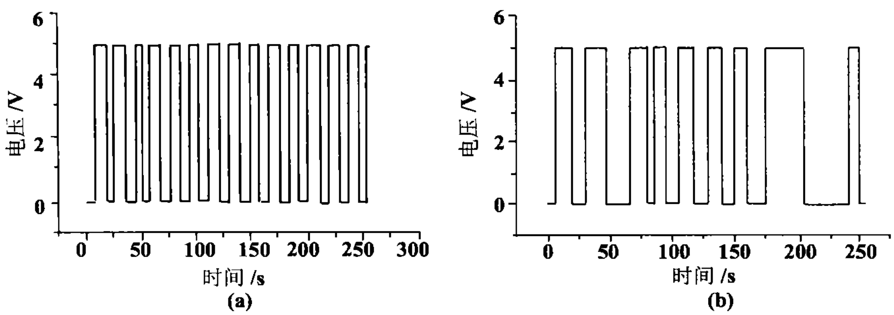

图 3　混合物垂直下降流时 B1、B2 型物体涡街检测结果

（Q_L = 25.0 m^3/h; B1 型, α = 0.080; B2 型, α = 0.78）

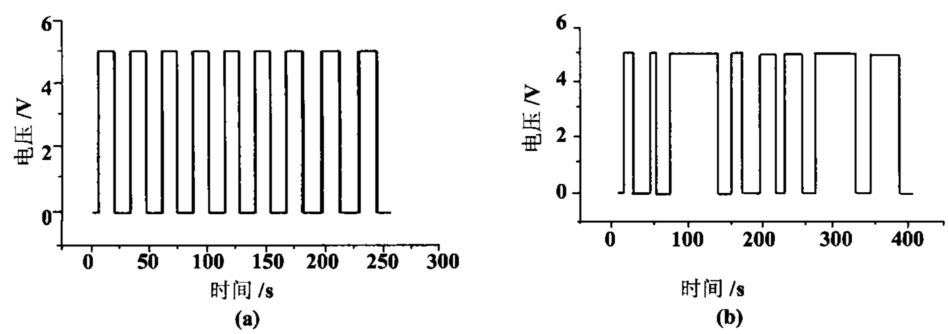

图 4　混合物垂直下降流时 B1、B2 型物体涡街检测结果

（Q_L = 14.0 m^3/h, α = 0.040）

电阻，仪表电路提供的恒定电流将热敏电阻加热到高于被测介质的温度。这样当柱体两侧交替有旋涡脱落时，小孔中就会有流体介质的往复流动，流体便将热敏电阻冷却，使电阻值发生变化，从而热敏电阻两端的电压也会发生变化。由于电压变化较为微弱，所以电压变化的信号需经放大、滤波和触电整形等环节，然后再输出二次仪表所需的矩形脉冲频率信号。因频率在这一整个变换过程中不变，故信号与管道内旋涡同步同频，信号处理电路见文献[5]。

3　试验结果与分析

由流体力学可知，流体绕流时产生的涡街，其形成和发展与绕流物体的形状、尺寸等因素有关。为了便于比较，本文将采用图 1 所示的两种型式的梯形柱体进行气液两相涡街试验。试验方法如前所述，所得结果用图 2 ~ 图 4 所示的矩形脉冲频率信号表示。

从这三个图可以看出 B1 型物体的涡街比较稳定，而 B2 型物体检测到的都是不规则的涡街。在垂直下降气液两相流中，B1 型柱体的两相斯特罗哈数 St_{TP}，来流截面含气率 α 及水流量 Q_L 三者之间的关系如图 5 所示。

图 5 中 St_{SP} 为单相斯特罗哈数，在本文工况下对 B1 型柱体其大小经实验确定为 0.236 5，而两相斯特罗哈数可用下式表示：

$$St_{TP} = \frac{fwA(1-\alpha)}{Q_L} \quad (1)$$

式中：A — 管道流通面积，m^2；f — 涡街频率，Hz；α — 来流截面含气率；w — 涡街发生体迎流面宽度，m；Q_L — 液相体积流量，m^3/h

式（1）中的截面含气率 α，根据文献[6] 的介绍，其计算方法如下：

$$已知\frac{\beta^*}{1-\beta^*} = 2.62F_{r0}^{-3/8} = 2.62(\frac{u_0^2}{g\alpha})^{-3/8} \quad (2)$$

若 $\beta < \beta^*$，则 α 可由式 $\frac{\alpha}{\beta^* - \alpha} = C\frac{\beta}{\beta^* - \beta}$ 计算

设 P 为绝对压强，当 $P \leqslant 7$ MPa 时

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上式 $C = 0.519\left(\frac{\rho_g}{\rho_L}\right)^{-0.5}\left(\frac{u_0^2}{g^{\alpha}}\right)^{-0.324\sqrt{1-O/22.1}}$

当 $P > 7$ MPa 时

$$C = \left(\frac{\rho_g}{\rho_L}\right)^{-0.287}\left(\frac{u_0^2}{g^{\alpha}}\right)^{-0.324\sqrt{1-O/22.1}}$$

若 $C < 1$ 则取 $C = 1$

若 $\beta > \beta^*$, 则 α 按下式计算

$$\frac{\alpha}{1-\alpha} = C^1\frac{\beta^*}{1-\beta^*} + (1-C')\frac{\beta}{1-\beta}$$

式中　$C' = 1-\left(\frac{\rho_g}{\rho_L}\right)^n,\ n = 0.275\left(\frac{u_0^2}{g^{\alpha}}\right)^{-0.267}$

由于气体体积受压力及温度影响很大, 根据状态方程, 气相体积流量按如下方法计算:

$$Q_G = \frac{P_1 T_1}{P_2 T_2} Q'_G \qquad (3)$$

P_1— 空气进入混合器前的绝对压强, Pa

P_2— 实验段入口处的压强, Pa

T_1— 空气温度, K; T_2— 混合物温度, 近似取液相温度, K;

Q'_G— 空气转子流量计测出的流量, m^3/h

图 5 中 St_{TP} 的实验关系曲线可以用下式表示:

$$\frac{St_{TP}}{St_{SP}} = 1.000 - 1.080\,\alpha \quad (\alpha \leqslant 25\%) \qquad (4)$$

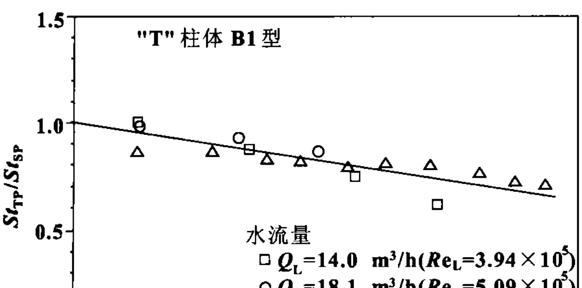

图 5　混合物垂直下降流时, B1 型柱体 St_{TP} 数与试验值的关系

$Q_L = 25.0\ m^3/h$; $Q_L = 18.0\ m^3/h$; $Q_L = 14.0\ m^3/h$; $Q_L = 5.00\ m^3/h$

由图 5 可以看出, 在同一截面含气率下, 不同流量的试验值基本上分布在同一高度处, 即 St_{TP}/St_{SP} 的值近似相等; 而在同一流量下, 含气率不同, St_{TP}/St_{SP} 的值变化很大。由此可以认为, 在垂直下降流中 $B1$ 型物体的两相斯特罗哈数在实验范围内与水流量 Q_L 关系不大, 而主要与截面含气率 α 有关。根据误差分析, 式(4) 的误差大约为 16%。

另外, 需要说明的是本试验中采用的流型为细泡状。细泡状流体中的气泡尺寸较小, 当小于绕流物体的特征尺寸时, 对绕流产生的旋涡的脱落影响不大。$B2$ 型柱体的特征尺寸较 $B1$ 型的小, 气泡尺寸对其影响相对较大, 故试验中检测到的涡街不稳定。气泡尺寸大小对涡街的影响是个较困难的课题, 目前还无研究结果。

4　结论

(1) 根据实验的结果, 两相斯特罗哈数 St_{TP} 如式(4) 所表示。而且 St_{TP} 数受水流量影响较小, 而主要受截面含气率 α 的影响。

(2) 两相斯特罗哈数 St_{TP} 与截面含气率 α 可以近似地用直线表示, 直线斜率与来流方向、涡街发生体的形状及大小有关。

(3) 混合物中若含气量过多, 便会影响涡街的形成和脱落, 致使产生的涡街极不稳定。

(4) 应用式(4), 再由测出的涡街频率, 便可用涡街发生体作为测量两相流流量及组分的测量元件。

参考文献:

[1] YOKOSAWA M, KOZAWA Y, INOUE A, *et al*. Studies on two-phase cross flow, part III: characteristics of unsteady flow behavior [J]. **Int J Multiphase Flow**, 1986, **12**(2): 185—202.

[2] HULIN J P, FIERFORT C, CONDOL R. Experimental study of vortex emission behind biuff obstacles in a gas-liquid vetical two-phase flow [J]. **Int J Multiphase Flow**, 1982, **8**(5): 475—490.

[3] 李永光, 林宗虎. 垂直上升气液两相流中三角形柱体两相斯托拉赫数的研究[J]. 水动力学研究与进展. 1999, **14**(4): 439.

[4] 李永光, 林宗虎. 流动方向对三角形柱体气液两相涡街的影响[J]. 华东工业大学学报, 1996, **18**(4): 23.

[5] 李永光, 林宗虎. 气液两相涡街稳定性的研究[J]. 力学学报, 1998, **30**(2): 139.

[6] 林宗虎. 气液两相流和沸腾传热[M]. 西安: 西安交通大学出版社, 1987.

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with $DeNO_x$ efficiency being higher than 60%. The overall $DeNO_x$ efficiency of the system can hit 80% after an alkali solution scrubbing. **Key words**: radical, plasma reactor, De_x process, absorption

压气机级间喷水燃气轮机的实验研究= **Experimental Investigation of Gas Turbine Compressor Interstage Water Spray** [刊, 汉] / LI Shu-ying, SUN Yu-feng, ZHANG Zheng-yi, WANG Song (Harbin Engineering University, Harbin, China, Post Code: 150001) // Journal of Engineering for Thermal Energy &Power. — 2002, 17(2). —143～146

An experimental scheme is proposed for a compressor interstage water spray on an S1A-02 gas turbine. Also given is the law of variation of the turbine various main performance parameters as a function of spray water flow rate under various operating regimes, including the operation under a constant power and constant turbine outlet temperature. On the basis of the test results some conclusions are drawn concerning the influence of compressor interstage water spray on the gas turbine performance. **Key words**: compressor, interstage water spray, gas turbine test

方形旋风分离器内气固两相流湍流特性的研究= **Experimental Study of the Turbulent Flow Characteristics of Gas-solid Dual-phase Flows in a Square-shaped Cyclone Separator** [刊, 汉] / SU Ya-xin (Institute of Engineering Thermophysics under the Chinese Academy of Sciences, Beijing, China, Post Code: 100080), LUO Zhong-yang, CEN Ke-fa (Institute of Thermal Power Engineering under the Zhejiang University, Hangzhou, China, Post Code: 310027) // Journal of Engineering for Thermal Energy &Power. — 2002, 17(2). —147～150

A three-dimensional particle dynamics analyzer was employed to study the gas-solid dual flow field in a square-shaped cyclone separator along with a discussion of the distribution of the flow field, pulsation velocity, particle concentration, turbulent kinetic energy and turbulent flow intensity, etc. The flow in the square-shaped cyclone separator has the features of a Rankine vortex, i.e., a forced swirling vortex zone at the central portion and a quasi-free vortex zone near a lateral wall. The quasi-laminar flow movement at the corners due to particle/wall face mutual collision gives rise to an intense particle turbulent-flow pulsation. The turbulent flow kinetic energy and local turbulent-flow intensity attain a relatively great magnitude near the corners. This indicates that the dual-phase flow has consumed a comparatively large amount of gas flow energy near the corners. The latter are the chief zones, where the pressure loss of the separator takes place. These corners were also found to be beneficial to particle separation, mainly because the intense pulsation consumes the kinetic energy of the particle and gas flow vortex movement. The study results can provide basic data for the structural optimization and also experimental contrast information for performing further numerical simulation research. **Key words**: square-shaped separator with downward gas exhaust, gas and solid dual-phase turbulent flow movement, three-dimensional particle dynamic analyzer

两相流垂直下降横掠"T"形柱体的斯特罗哈数= **Strouhal Number of a Transversely Swept T-shaped Cylinder with a Vertically Downward Two-phase Flow** [刊, 汉] / HE Dan, XU Hua-ming, MA Xin-xia, LI Yong-guang (Power Engineering Department, Shanghai Electric Power Institute) // Journal of Engineering for Thermal Energy & Power. — 2002, 17(2). —151～153

With respect to two different specifications of trapezoidal cylinder an experimental study was conducted of the variation law of gas-liquid two-phase Strouhal number in case of the occurrence of gas-liquid two-phase vortex street in a vertically downward gas-liquid two-phase flow. On the basis of a huge amount of measured data a general relation was obtained of the gas-liquid two-phase Strouhal number when a gas-liquid two-phase vortex street occurred. The study results indicate that the gas-liquid two-phase Strouhal number is a variable under a two-phase operating condition. It is related to the gas

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content rate of an incident flow cross-section, the shape and characteristic dimensions of a vortex-street generating entity, the direction of incident flow, etc. By utilizing the above-mentioned relation and on the basis of the measured two-phase vortex street frequency it is possible to use the vortex-street generating entity as a measuring element for the measurement of two-phase flow rates and components. **Key words**: gas-liquid mixture, Karman vortex, Strouhal number, cylinder

切向炉内小分隔屏后涡量分布的实验研究= **Experimental Investigation of the Vorticity Distribution Behind the Small Partition Panel of a Tangentially Fired Furnace** [刊, 汉] / HE Bo-shu, CHEN Chang-he (State Key Lab of Coal Clean Combustion under the Tsinghua University, Beijing, China, Post Code: 100084), DIAO Yong-fa, XU Jin-yuan (Energy Source and Power Engineering Institute under the Xi' an Jiaotong University, Xi' an, China, Post Code: 710049) // Journal of Engineering for Thermal Energy & Power. — 2002, 17(2). —154 ~ 158

A 6-wire vorticity probe was used for the first time to measure the velocity and vorticity distribution behind the partition panel of the cold model of a HG—2008—YM2 tangentially fired furnace. Parameters depicting the characteristics of turbulent flow have been obtained, which include turbulent flow intensity, skewness factor and flatness factor, etc. The presence of a partition panel has a significant effect on the velocity and vorticity field behind it. The test results indicate that a separation vortex has emerged behind the right half panel due to airfoil effects. **Key words**: tangentially fired furnace, partition panel, vorticity, skewness factor, flatness factor

柴油、渣油和沥青的脉动燃烧对比试验研究= **Contrast Experimental Research on the Pulsating Combustion of Diesel Oil, Residual Oil and Asphalt** [刊, 汉] / TU Jian-hua, CHEN Fu-lian, WANG Qin-yong (Energy Source and Power Engineering Research Institute under the Zhejiang Polytechnical University, Hangzhou, China, Post Code: 310014) // Journal of Engineering for Thermal Energy & Power. — 2002, 17(2). —159 ~ 160, 165

Contrast tests of pulsating combustion of diesel oil, residual oil and asphalt were conducted in a shape-changing Rijke pipe. It is discovered that easy-to-burn fuels can excite pulsation easily. By contrast, difficult-to-burn fuels are hard to excite pulsation owing to the delayed ignition of such fuels and it is necessary to lengthen the tail pipe in order to achieve a good pulsation. When the ratio of air feed area and combustion chamber cross-section area is reduced to a certain degree, the pulsation characteristics of such difficult-to-burn fuels (such as residual oils, etc.) will transit to those of 1/4 wave-length pipe. On the other hand, there is no change in pulsation characteristics for easy-to-burn fuels, such as diesel oils, etc. The tests indicate that valve-absent pulsation combustion technology makes it possible to realize clean and highly effective burning of such difficult-to-burn fuels as residual oils and asphalt, etc. This is of great significance for the utilization of difficult-to-burn fuels, such as residual oils, etc. **Key words**: pulsation combustion, residual oil, Rijke pipe

利用面阵 CCD 进行火焰温度分布测量(II)——三维截面温度场的测量= **Measurement of Flame Temperature Distribution Using Array CCD (II)— Three-dimensional Cross-section Temperature Field Measurement** [刊, 汉] / WEI Chen-ye, YAN Jian-hua, SHANG Min-er, CEN Ke-fa (Thermal Power Engineering Institute under the Zhejiang University, Hangzhou, China, Post Code: 310027) // Journal of Engineering for Thermal Energy & Power. — 2002, 17(2). —161 ~165

A practical model is set up with the help of a simplified measurement/test system designed for measuring flame cross-section temperature distribution using array charge-coupled levice. After the slight improvement of a genetic algorithm the latter is employed to solve the above model in order to reestablish the flame cross-section temperature distribution to be measured. Then, the numerical character of the genetic algorithm is analyzed and a test conducted on an oil/coal mixed

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