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二次风喷射角度对切向燃烧炉膛出口烟气流量偏差的影响

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摘　要:针对四角切向燃烧大容量锅炉普遍存在的由于烟气残余旋转造成的上炉膛及对流烟道中的烟气流量左右两侧偏差问题进行了分析研究。并以一台 410 t/h 锅炉为对象,用数值模拟方法,在原有设计方案基础上,改变某些流动参数,如不同的二次风喷射角度、最上层二次风反切流动,在计算机上进行模拟计算,分析总结模拟结果进而提出降低炉膛出口烟气速度偏差的可行方案。

关　键　词:切向燃烧;数值模拟;三维流场;煤粉锅炉

中图分类号:TK224.11,229.63　　　文献标识码:A

1　前言

四角切圆燃烧的大容量锅炉实际运行经常存在以下共性问题:上炉膛及水平烟道中,沿烟道宽度方向存在左右侧汽温偏差。对于逆时针旋转切圆锅炉,位于炉膛上部的辐射受热面,沿炉膛宽度方向汽温呈左高右低分布,而位于出口窗之后的水平烟道中的过热器及再热器汽温均为右高左低,对于顺时针切圆燃烧,情形恰好相反。其理论解释如下:

(1)　由于四角切圆燃烧,烟气在炉内混合强烈,对于配风正常的运行工况,可认为截止到分隔屏底,没有偏差现象;

(2)　由于残余旋转的存在及分隔屏的导流作用,出现了烟气及温度场的偏差。对右旋切圆燃烧锅炉,上炉膛左侧烟气向炉后运动的趋势小于右侧,从而造成左侧烟气流量低于右侧。气流在左侧气室中有一个减速,停滞,反向加速的过程,而已经反向加速的气流又会与旋转回流的气流产生相对碰撞。这种过程会形成较强的气流扰动,强化了对流换热作用。而右侧气室内气流运动情形简单,进入屏区后,平稳的加速流向炉后。此外,由于残余旋转存在,左侧区烟气主流先流向前墙,再返回流向炉后。而右侧区主气流流向炉后,并且大部分由出口窗下部形成烟气短路流走。这就造成上炉膛左侧烟气充满度大大好于右侧,这一点由锅炉冷态模拟已清楚看出。这些都是造成屏区受热面吸热量左高右低进而造成屏区出口烟温右高左低的定性原因;

(3)　当烟气进入水平烟道后,水平烟道入口右侧区体积流量,流速都高于左侧区,而右侧烟温水平高于左侧这一事实更强化了右侧的对流换热,于是造成对流过热器左右侧出口工质的较大温差。

2　消除流场偏差的措施及数值模拟

在弄清了偏差的原因后,本文从重新组织炉内空气动力场的角度出发,对一台辽阳石化公司的 410 t/h 煤粉锅炉应用 SIMPLE 方法进行数值模拟[1~3],比较各种配风方案消除偏差的效果及可行性,得出了有益的结论。

本文选择的流动方案有以下两种:

(1)　改变所有二次风的喷射角度;

(2)　只改变最上层二次风的喷射角度,使其与其它下层二次风形成大角度反切。

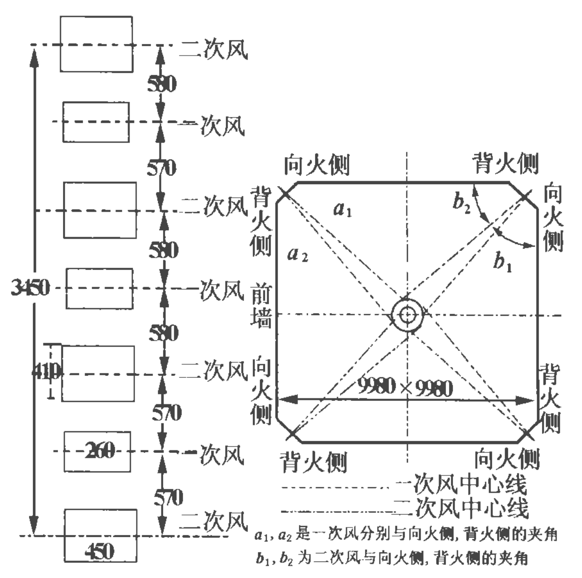

图 1　燃烧器布置及燃烧方式示意图

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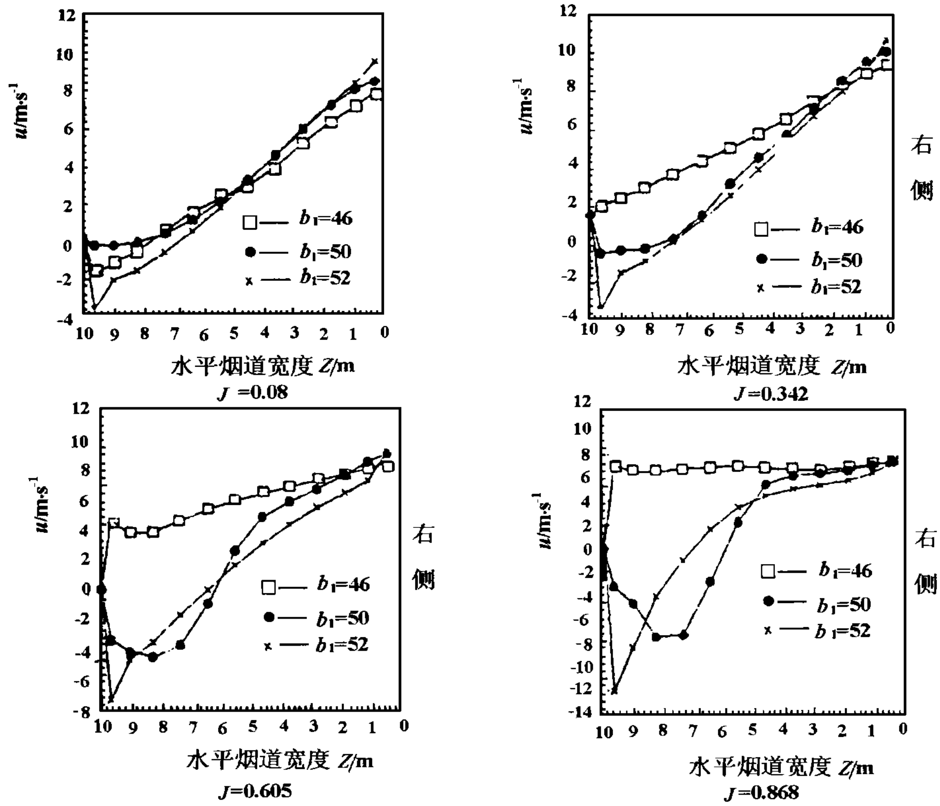

图 2　不同二次风入射角时不同高度的水平烟道宽度方向速度分布

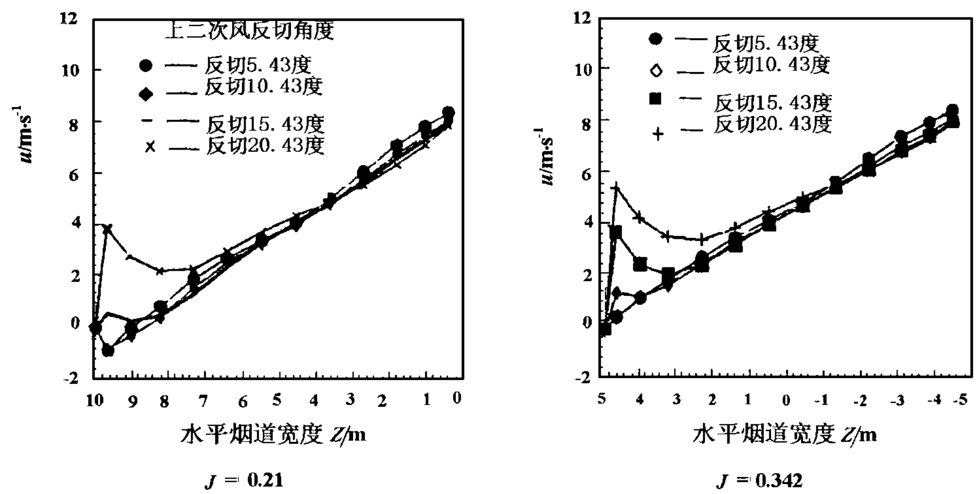

图 3　最上层二次风反切时水平烟道速度分布

上述方案均对二次风做改动，而一次风与原设计值不变。因为炉内空气动力场主要是靠二次风来组织的。

2.1　改变二次风喷射角度

辽化锅炉设计一次风与前墙夹角为 42°，二次风与前墙夹角 47°26′，两者反切 5°34′，见图 1。新的模拟方案有三种：二次风与前墙夹角分别为 46°，50°，52°。为了对比，绘出水平烟道宽度方向不同二次风入射角度下速度分布图，详见图 2。

我们定义炉膛出口窗相对高度 $J = h/H$，H 为炉膛出口窗全高，h 为计算截面距离出口窗底部的垂直高度。

从图中可以看出，对于消除水平烟道两侧速度偏差的效果来说，入射角度越小越好，也就是假想切圆直径越小，炉膛出口烟气速度偏差越小。由图 2 看出，当假想切圆较大时，即当 b_1 等于 50° 和 52° 时，水平烟道内的速度偏差随烟道高度增加而急剧增加，上部烟道左侧气流严重回流而流向前炉墙，这说明随着假想切圆增大，炉膛内气流旋转越强烈，直至顶部炉膛出口旋转仍无明显衰减，气流甩出点也较高。可以这样说，对假想切圆较小的流场来说水平烟道内速度分布不均程度在烟道下方较严重，而对假想切圆较大的流场，水平烟道速度不均在烟道上方更为严重。因此，从减小水平烟道内两侧气流速度不均性考虑，假想切圆越小越好，但这又将造成燃烧器区流场分布较差的问题。实际设计应选择两种倾向的最佳结合点。

2.2　改变最上层二次风入射角度，使之与下部主流二次风呈大角度反切

具体模拟方案是仅将最上层二次风入口边界条

件的入射角度值改变，而其余下层一次风，二次风仍取设计值，这样构成上层二次风与下层二次风的反切。分四种工况，见表 1。

表 1　上层二次风反切工况

工况	与背火侧夹角	与向火侧夹角	与下层二次风反切角度
1	48°	42°	5.43°
2	53°	37°	10.43°
3	58°	32°	15.43°
4	63°	27°	20.43°

模拟这四种工况并比较水平烟道下部相对高度 $J = 0.21$，$J = 0.342$ 两个水平截面中沿烟道宽度方向速度的分布，见图 3。从图中 $J = 0.21$ 截面看出第四工况反切角度最大时，烟道左侧气流速度明显增加，水平不均匀性有所降低。这说明上层二次风反切角度增大时，水平烟道横向烟气速度分布不均得到改善。为了能更深入地分析水平烟道烟气流量偏差问题，我们定义速度不增匀系数 $\varepsilon = (V_{max} - V_{min})/V$，各参数分别代表同一计算截面内速度的最大值、最小值与平均值。表 2 给出了当最上层二次风反切角为 20.43° 时 ε 的计算结果。而四个反切工况与原设计工况 ε 的对比则见表 3。从表中可以看出随着反切角度增大，下部水平烟道的速度不均匀性明显降低，中上部更趋于均匀，但 $J = 0.08$ 截面，也就是最下层水平烟道的 ε 仍在 2.0 以上，这是由于折焰角转弯后右侧气流的烟气短路造成的。总的来说，上层二次风大角度反切有利于降低炉膛出口水平烟道的气流偏差。

表 2　工况 4，反切角度为 20.43 度时的水平烟道中的 ε

参数＼相对高度	J = 0.08	J = 0.21	J = 0.342	J = 0.473	J = 0.605	J = 0.736	J = 0.868	
m/s	6.8	7.78	7.95	7.77	7.46	7.11	6.57	max
m/s	0.45	2.15	3.40	4.22	4.89	5.55	5.95	min
m/s	2.91	4.43	5.31	5.79	5.98	6.15	6.24	
ε	2.18	1.27	0.85	0.61	0.43	0.25	0.09	

表 3　最上层二次风四个反切工况与原设计工况 ε 的对比

工况＼ε＼高度	J = 0.08	J = 0.21	J = 0.342	J = 0.473	J = 0.605	J = 0.736	J = 0.868
原设计	3.34	2.84	2.59	2.23	1.66	0.74	0.39
反切 5 度	3.36	2.40	1.75	1.07	0.65	0.31	0.08
反切 10 度	3.53	2.46	1.55	0.95	0.57	0.26	0.09
反切 15 度	3.39	2.07	1.26	0.79	0.49	0.25	0.06
反切 20 度	2.18	1.27	0.85	0.61	0.43	0.25	0.09

3　结论

本文数值模拟计算表明，采用适当减小炉内假想切圆直径或将最上级二次风相对下部二次风反切引入的方法可以降低炉膛出口水平烟道的烟气流量偏差。当采用最上层二次风反切时，反切角为 20～25 度时基本可以抵消炉内主气流旋转从而降低水平烟道内的速度不均匀性，然而，采用上述方法后，炉内用于组织燃烧的流场旋转强度将会下降。因此，如何选取炉内假想切圆直径与最上级二次风反切角度需综合考虑燃烧组织和气流偏差的问题。

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（渠　源　编辑）

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度场数学模型，并通过数字仿真分析了炉膛沿程方向温度场的分布。与实测结果比较，证明了该模型的可行性，基本反映了井式加热炉炉膛内的辐射—对流复合传热的实际工况。从理论上分析了炉膛温度的均匀性。

(2)通过该模型仿真，讨论了环形空间大小、电热功率、空气流量对温度场的影响情况，为工艺设计及控制方案的确定起到了很好的参考指导作用。

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words: steam turbine, power output uprating

应用于 PRSTIG 循环化 SIA－02 燃气轮机组上的喷射器＝**An Ejector Used for the Model SIA-02 Gas Turbine Unit of a Partial Regeneration Steam Injected Gas Turbine (PRSTIG) Cycle** [刊, 汉] / Wen Xueyou, Lu Ben (Harbin No. 703 Research Institute, Harbin, China, Post Code 150036) // Journal of Engineering for Thermal Energy & Power. －2000, 15(3). －269～271

A major constituent element of a partial regeneration steam injected gas turbine (PRSTIG) cycle system, the ejector was designed in adaptation for a model SIA-02 small-sized gas turbine. An analysis of the ejector design is also presented in the paper. **Key words**: partial regeneration steam injected gas turbine cycle, steam injected gas turbine cycle, ejector

油田射孔器材试验装置加热系统的数学模型与仿真分析＝**Mathematical Modeling and Simulation Analysis of the Heating System of an Oil Field Perforation Equipment Test Rig** [刊, 汉] / Liu Cuiling, Wang Zicai, Sun Xingbo *et al* (Simulation Technology Research Center under the Harbin Institute of Technology, Harbin, China, Post Code 150001) // Journal of Engineering for Thermal Energy & Power. －2000, 15(3). －272～275, 283

Based on the technical requirements of a perforation equipment test rig concerning its ability to bear high-temperature and high-pressure, the authors have designed a well-type dual-circulation electric heating furnace. A mathematical model of the heating-furnace heat transfer process has been set up. By way of simulation an analysis was conducted of the effect of the heating system process parameters on the temperature field profile along the flow path of the furnace. Such an analysis plays a significant role in providing guidance for high-precision control and prediction of the oil temperature in the heating system. The validity of the mathematical model has been verified by the actually measured results. **Key words**: heat transfer, mathematical model, heating furnace, temperature field, simulation

锅炉过热器系统的动态仿真模型＝**Dynamic Simulation Model for a Boiler Superheater System** [刊, 汉] / Chen Xiaodong, Wang Zicai (Simulation Technology Research Center under the Harbin Institute of Technology, Harbin, China, Post Code 150001) // Journal of Engineering for Thermal Energy & Power. －2000, 15(3). －276～277, 297

As a mechanism model can hardly reproduce the complicated dynamic characteristics of a boiler superheater system, the authors have come up with a new modeling method. The proposed method consists in taking the mechanism model as a main guide and supplementing it with an on-line correction through the use of a dynamic neural network. The results of simulation indicate that such a model building method can provide an ideal approach for the dynamic simulation of a huge complicated system. **Key words**: boiler, superheater, simulation, model building method

汽轮机本体分段式通用模块化建模与仿真＝**Modeling and Simulation of a Steam Turbine Proper through the Use of a Sectionalized General-modularization** [刊, 汉] / Zhu Wei, Jiang Zikang, Cheng Fangzhen, *et al* (Department of Thermal Engineering, Qinghua University, Beijing, China, Post Code 100084) // Journal of Engineering for Thermal Energy & Power. －2000, 15(3). －278～280, 293

Described in this paper is the modeling of a steam turbine proper with the help of a sectionalized general-modularization. Furthermore, with a model C50-90/13 steam turbine being selected as an example, simulation results are given of the steam turbine under various operating conditions and pertinent analyses were also performed. Currently, the above-cited model has been successfully employed for an actual simulation object. Featuring a relatively high precision and versatility in engineering applications, it is suited for simulating steam turbines under various operating conditions. **Key words**: steam turbine, simulation, general modularization, modeling

二次风喷射角度对切向燃烧炉膛出口烟气流量偏差的影响＝**The Effect of a Secondary Air Injection Angle on the Deviation of Flue Gas Flow Rate at a Tangentially Fired Furnace Outlet** [刊, 汉] / Zhao Yuan, Dong Peng, Qin Yukun, *et al* (College of Energy Science and Engineering under the Harbin Institute of Technology) // Journal of Engineering for Thermal Energy & Power. －2000, 15(3). －281～283

In a tangentially fired large-sized boiler there generally occurs a common phenomenon of flue gas flow deviation on the right and left side of both the upper furnace and the convection flue. This is generally attributed to the flue gas residual rotation. An analytical study was conducted to address this issue. Moreover, a 410 t/h boiler was selected as a specific object of study in this regard. By the use of a numerical simulation method and based on an initial design scheme, the authors have made changes in such flow parameters as secondary air injection angle and the secondary air inverse tangential flow at the furnace uppermost layer. After a summing-up and analysis of the simulation results a feasible scheme was proposed to lower the deviation of the flue gas speed at the furnace outlet. **Key words**: tangential firing, numerical simulation, three-dimensional flow field, pulverized coal-fired boiler

炉内流场对水冷壁高温腐蚀影响的数值模拟和分析＝**Numerical Simulation and Analysis of the Effect of an In-furnace Flow Field on the High-temperature Corrosion of Water Walls in a Tangentially Fired Boiler Furnace** [刊, 汉] / Wang Ying, Qin Yukun, Wu Shaohua (College of Energy Science and Engineering under the Harbin Institute of Technology) // Journal of Engineering for Thermal Energy & Power. —2000, 15(3). —284～286, 303

With the help of a numerical simulation method for gas-solid dual-phase flows an analysis was performed of the cause of high-temperature corrosion in water walls of a tangentially fired 1000 t/h once-through boiler. The main cause of such corrosion has been identified as the rectangular layout of the burners at the front and rear walls, which leads to the impingement of flue gases on the water walls. The lack of oxygen in the neighborhood of the wall surface due to an irrational air distribution has also been found to be a main culprit. **Key words**: boiler, water wall, high-temperature corrosion, numerical simulation

舰用燃气轮机排气蜗壳流场数值模拟＝**Numerical Simulation of the Flow Field of a Naval Gas Turbine Exhaust Volute** [刊, 汉] / Liu Xueyi, Liu Min (Harbin No.703 Research Institute, Harbin, China, Post Code 150036), Sun Haiou, Zheng Hongtao, *et al* (Harbin Engineering University, Harbin, China, Post Code 150009) // Journal of Engineering for Thermal Energy & Power. —2000, 15(3). —287～289

Based on a N-S equation and K - e turbulent flow model the authors have conducted the numerical simulation of two types of exhaust volute. Through an analysis of pressure loss and flow field status a performance evaluation was given of the above-cited exhaust volutes. **Key words**: gas turbine, exhaust volute, pressure loss, numerical simulation

适用于燃煤气的 STIG 循环中湿燃气的状态方程＝**Status Equation of the Wet Gas in a Steam Injected Gas Turbine (STIG) Cycle Plant Fit for Burning Gases** [刊, 汉] / Chen, Anbin, Shang Demin, Yan Jialu, *et al* (Teaching and Research Department of Thermal Engineering, Harbin Institute of Technology, Harbin, China, Post Code 150001) // Journal of Engineering for Thermal Energy & Power. —2000, 15(3). —290～293

The wet gas in a gas-fired steam injected gas turbine cycle plant is treated as a real gas. Set up is the wet gas status equation by utilizing the corresponding status mode of a two-term Virial equation. The thermodynamic properties of the wet gas have been calculated by the use of the above-cited status equation and a complementary function correction method. Moreover, a comparison was conducted of the wet gas thermodynamic properties with those calculated on the basis of an ideal gas. **Key words**: gasification, steam injected gas turbine cycle, wet gas, status equation

蒸汽蓄热器容积最优化研究＝**Optimization Study of Steam Accumulator Volume** [刊, 汉] / Cao Jiacong, Zhong Wei (China National Textile University, Shanghai, China, Post Code 200051) // Journal of Engineering for Thermal Energy & Power. —2000, 15(3). —294～297

An algorithm model was set up for minimizing the essential heat storage of a steam accumulator with a computer program being applied to a specific example to illustrate this approach. The results of computation indicate that with the help of the above-mentioned program one can determine a minimal heat storage capacity required, which is considerably less than that obtainable by a manual calculation. This makes it possible to attain a minimized heat storage capacity required of an accumulator, creating the necessary conditions for the optimization of a steam accumulator design. **Key words**: industrial boiler, steam accumulator, heat storage capacity, volume, optimization, computer program