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空气物理参数对电厂风量测量的影响

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摘　要: 针对火电厂风量测量问题, 研究温度、压力和相对湿度对电厂风量测量的影响。结合云南某电厂 300 MW 锅炉的风烟系统, 计算了各测点的温度、压力修正系数以及冷热风混合不均对磨入口风量造成的最大偏差值, 分析了不引入相对湿度修正对于冷、热风流量测量可能造成的偏差。结果表明, 准确测量风量需要合理引入温度、压力及相对湿度修正。当风温不高于 50 ℃时, 不引入相对湿度修正将使云南该厂风量测量产生 0~3% 的偏差。

关　键　词: 流量测量; 温度; 压力; 相对湿度; 电厂

中图分类号: TK313; TM621　　　文献标识码: A

引　言

在锅炉侧, 需要对风烟系统中的风量进行准确测量, 以便对锅炉的燃烧状况进行调整和控制。作为过程控制的重要参数, 风量测量的准确与否也将影响到现代大型机组运行的可靠性和稳定性。现有大型火力发电厂多采用差压式流量测量装置对风量进行测量。图1为一种插入式多喉径流量装置[1], 图2为其在系统中的安装示意图。

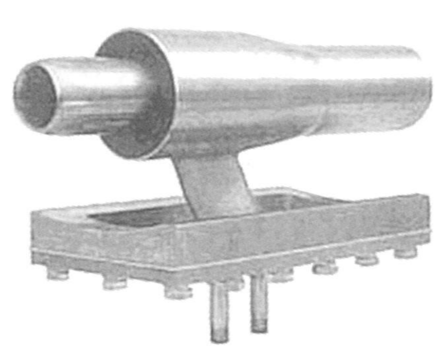

图1　插入式多喉径流量装置

对于差压式流量测量装置, 有 $q_m = K\sqrt{\Delta P \cdot \rho}$[1~2], 其中 q_m、K、ΔP、ρ 分别为流过介质的质量流量、测量装置的质量流量系数(与管道结构、面积、流量计特性有关, 在测量范围内可以认为是常数[1,3])、测得的差压以及流过介质的密度。由于风烟系统中介质(空气)的状态参数受到大气环境参数及实际燃烧状况的影响, 因此代入准确的空气密度参与计算是获得准确流量的关键。现代大型电厂锅炉的风烟系统中, 在流量测量装置附近均布置了温度和压力测点, 以尽可能准确地对空气密度进行修正。

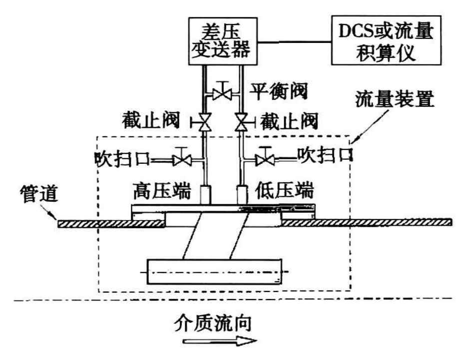

图2　流量装置在系统中的安装

对于工质状态十分均一的管道, 引入密度修正可以获得准确的风量值。但是对于磨入口的风量测量, 由于受到结构的限制, 温度、压力测点经常布置在冷热风初步混合后的管道上, 于是可能出现密度修正不准确的情况。另外, 实际空气含有一定量的水蒸气, 其相对湿度的变化也会导致湿空气密度的变化。

本文将系统的分析温度、压力和相对湿度对电厂风量测量的影响, 并以云南某电厂(以下简称A厂)300 MW 锅炉的风烟系统为例, 具体分析各参数工况下可能的流量偏差大小。

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1　数学模型

风量测量装置出厂前在当地大气条件下进行了标定, 也就是确定了差压与流量的函数关系。当风量装置在电厂安装完成后, 还需要进行二次标定, 目的就是较为准确地测量并获得一组"参考点"数据, 以便对密度进行修正。

以下标"ref"表示参考点的参数, 无下标时为实际参数, 则有:

$$\frac{q_m}{q_{mref}}=\frac{K\sqrt{\Delta P\cdot\rho}}{K\sqrt{\Delta P_{ref}\cdot\rho_{ref}}}=\sqrt{\frac{\Delta P}{\Delta P_{ref}}}\cdot\sqrt{\frac{\rho}{\rho_{ref}}} \quad (1)$$

如果不考虑温度、压力等对空气密度的影响, 即 $\rho=\rho_{ref}$, 则有:

$$q_v=\frac{q_m}{\rho}=\sqrt{\frac{\Delta P}{\Delta P_{ref}}}\cdot q_{vref} \quad (2)$$

式中: q_v —体积流量, m^3/s。

但空气密度与温度、压力和气体常数都有关系。对于理想气体, 有:

$$PV=nRT=\frac{m}{M}RT=mR_gT,\text{ 即:}$$

$$\rho=\frac{P}{R_gT} \quad (3)$$

式中: R —湿空气的摩尔气体常数, J/(mol·K); R_g —湿空气的气体常数, J/(kg·K)

$$R_g=\sum\omega_iR_{g,i}=\frac{1}{1+d}R_{g,a}+\frac{d}{1+d}R_{g,v}=\frac{287+461d}{1+d} \quad (4)$$

式中: $R_{g,a}=287$ —干空气的气体常数, J/(kg·K); $R_{g,v}=461$ —水蒸气的气体常数, J/(kg·K); d —湿空气的含湿量, kg/kg 干空气, 它表示 1 kg 干空气所带有水蒸气的质量。

根据式(1)有:

$$q_v=\frac{q_m}{\rho}=\left(q_{mref}\cdot\sqrt{\frac{\Delta P}{\Delta P_{ref}}}\cdot\sqrt{\frac{\rho}{\rho_{ref}}}\right)/\rho=\left[(q_{verf}\times\rho_{ref})\cdot\sqrt{\frac{\Delta P}{\Delta P_{ref}}}\cdot\sqrt{\frac{\rho}{\rho_{ref}}}\right]/\rho=q_{vref}\cdot\sqrt{\frac{\Delta P}{\Delta P_{ref}}}\cdot\sqrt{\frac{\rho_{ref}}{\rho}}$$

代入式(3)得:

$$q_v=q_{vref}\cdot\sqrt{\frac{\Delta P}{\Delta P_{ref}}}\cdot\left(\sqrt{\frac{P_{ref}}{R_{gref}T_{ref}}}/\sqrt{\frac{P}{R_gT}}\right)=K_{Rg}\times K_T\cdot K_P\cdot\left(\sqrt{\frac{\Delta P}{\Delta P_{ref}}}\cdot q_{vref}\right) \quad (5)$$

式(5)中 $K_T=\sqrt{\frac{T}{T_{ref}}}$, $K_P=\sqrt{\frac{P_{ref}}{P}}$, $K_{Rg}=\sqrt{\frac{R_g}{R_{gref}}}$ 分别为温度、压力、气体常数修正系数, 比较式(5)和式(2)可以看出, 密度对流量测量的影响。对于密度的修正最终是通过对温度、压力及气体常数的修正来实现。而由式(4)可以看出, 气体常数修正实际上是对含湿量进行修正。

对于上述需要引入修正的 3 个参数, 温度和压力可以直接测量, 但含湿量不能直接测量获得, 下面确定大气相对湿度与含湿量的关系。为了描述方便, 分别以下标"a"、"v"、"s"表示干空气、水蒸气和饱和水蒸气的参数。

相对湿度 φ 的定义为: $\varphi=\frac{p_v}{p_s}$(当 $p_s>p_b$ 时, $\varphi=\frac{p_v}{p_b}$), 其中 p_b($p_b=p_a+p_v$)、p_a、p_v、p_s 分别为大气压力、湿空气中干空气分压力、湿空气中水蒸气分压力、同一温度同样总压力下饱和湿空气中水蒸气的分压力。p_s 可由水蒸气图表查出, 也可由下述经验公式计算(误差不超过 ±0.15%)[4]:

$$\{p_s\}_{kPa}=\frac{2}{15}\exp\left[18.5916-\frac{3991.11}{\{t\}_{℃}+233.84}\right] \quad (6)$$

需要指出的是, 由于湿空气中水蒸气的分压力至多等于总压力, 所以当 $p_s>p_b$ 时, φ 的定义为 $\frac{p_v}{p_b}$。在电厂的风烟系统中, 从一二次风入口引入的湿空气可能被加热到相当高的温度, 这时就有 $p_s>p_b$。根据含湿量 d 的定义有:

$$d=\frac{m_v}{m_a}=\frac{M_vn_v}{M_an_a} \quad (7)$$

式中: n_v、n_a、M_v、M_a —湿空气中水蒸气的物质的量、湿空气中干空气的物质的量、水蒸气的摩尔质量、干空气的摩尔质量。由于 $M_v=18.016\times10^{-3}$ kg/mol, $M_a=28.97\times10^{-3}$ kg/mol, 同时理想气体混合物中各组分的摩尔数之比等于分压力之比, 所以 $d=0.622\frac{p_v}{p_a}$, 根据相对湿度的定义, 有:

$$d=0.622\frac{\varphi p_s}{p_b-\varphi p_s}$$

$$(\text{当 } p_s>p_b \text{ 时, } d=0.622\frac{\varphi}{1-\varphi}) \quad (8)$$

2　温度和压力对风量测量的影响

表 1 列出了 A 厂 300 MW 锅炉风烟系统中各风量测量装置的标定参数、满负荷下的实际运行参数以及相应的温度和压力修正系数。

可以看出, 在电厂的风烟系统中压力对风量测量的影响不大, 而温度对风量测量的影响很大。在

电厂的工作条件下，风烟系统管道内压力的变化量相对于绝对压力(A 厂当地多年平均大气压力 80.92 kPa)来说是很小的，因此压力对风量测量的影响很小。通常对风量测量装置进行的是冷态标定，所以对于工作温度较高的风量测量装置，如果不考虑温度变化对密度的影响，将使风量测量值与实际值产生较大的偏差，表 1 工况下偏差可以达到 37%。目前电厂的风量测量系统均引入了温度和压力修正。

表 1　风量的温度及压力修正系数

风量测点	标定静压 /kPa	标定温度 /℃	运行静压 /kPa	运行温度 /℃	K_T	K_P
一次冷风	4.943	26.5	10.918	33.4	1.012	0.967
一次热风	4.801	20.3	9.326	274.9	1.367	0.975
二次风	0.230	19.4	0.597	274.9	1.369	0.998
1 号磨	4.102	23.2	6.629	262.3	1.344	0.985
2 号磨	4.142	23.2	7.285	267.2	1.350	0.982

但是对于磨入口的风量测量，由于受到结构的限制，温度、压力测点经常布置在冷热风初步混合后的管道上。同时该区域管道的弯段较多，因此测点处测得的温度、压力值并不能反映整个截面的平均状况，或者说测得温度、压力值对应的密度值不能反映整个截面的平均状况。此时对于温度、压力的修正就不准确。

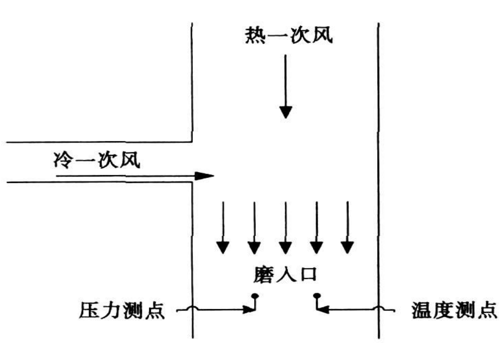

图 3　磨入口温度及压力测点位置

图3 示意了磨入口冷热风的混合情况。从理论上分析两种极端情形，当冷风门关闭时，以热风密度对磨入口风量进行修正是准确的，但如果冷风门有很小的漏风，极端情况下测点处流过的是冷风，不考虑相对湿度对气体常数的影响有：

$$\frac{q_{v测}}{q_{v真}}=\sqrt{\frac{\rho_{真}}{\rho_{测}}}=\sqrt{\frac{\rho_{热}}{\rho_{冷}}}=\sqrt{\frac{P_{热}}{P_{冷}}\cdot\frac{T_{冷}}{T_{热}}}$$

以表 1 的运行参数为例，此时的风量测量偏差为 26%。

同理，当热风门关闭时，极端情况下测点处流过的是热风，同样有：

$$\frac{q_{v测}}{q_{v真}}=\sqrt{\frac{\rho_{真}}{\rho_{测}}}=\sqrt{\frac{\rho_{冷}}{\rho_{热}}}=\sqrt{\frac{P_{冷}}{P_{热}}\cdot\frac{T_{热}}{T_{冷}}}$$

以表 1 的运行参数为例，此时的风量测量偏差为 35%。

当风道设计及测点布置较为合理时，出现上述两种极端情况的可能性很小。但从上述分析可以看出，冷热风混合不均造成的不合理修正可能使风量测量值与真实值出现较大偏差。在设计磨入口风道时，应该尽量保证各流量测量相关测点处流动较为稳定，冷热风混合较为均匀。如果条件允许，在同一测量截面上布置多个测点进行测量，并以平均值代入计算，将在很大程度上缩小风量测量值与真实值的偏差。

3　湿度对风量测量的影响

在大气参数测量中，通常仅测量大气的相对湿度。在确定的温度和相对湿度下含湿量是确定的，因此下面讨论相对湿度对风量测量的影响。

表 2 假设了 4 个工况：标定温度取值接近环境温度，工况 1、2 的运行温度取值反映冷风实际可能处于的温度水平，工况 3、4 的运行温度取值反映热风实际可能处于的温度水平。

表 2　假定工况的温度水平

工况	标定温度/ ℃	运行温度/ ℃
1	30	30
2	20	50
3	10	100
4	30	300

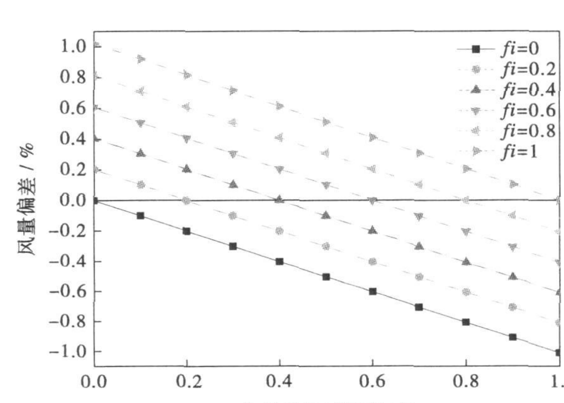

图 4　工况 1 风量偏差随相对湿度的变化

仍以 A 厂为例，当地多年平均大气压力 80.92 kPa。图 4～图 7 显示了工况 1～工况 4 下相对湿度对于风量测量值的影响。横坐标为标定时流动介质的相对湿度，纵坐标为引入湿度修正后风量计算值与未引入时的偏差，正值表示引入修正后风量计算值大于未引入时的计算值。*fi* 为实际运行时流动介质的相对湿度。

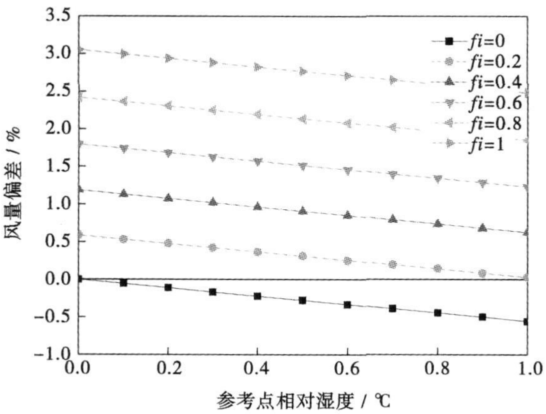

图 5　工况 2 风量偏差随相对湿度的变化

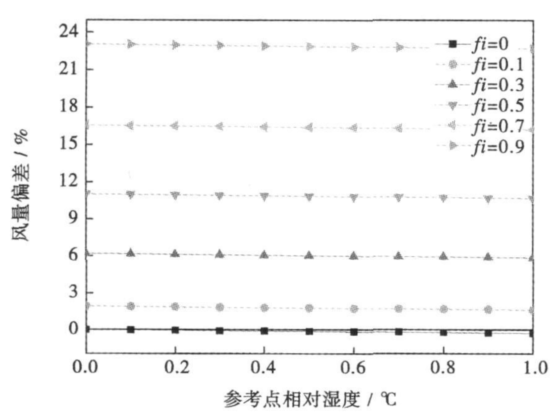

图 6　工况 3 风量偏差随相对湿度的变化

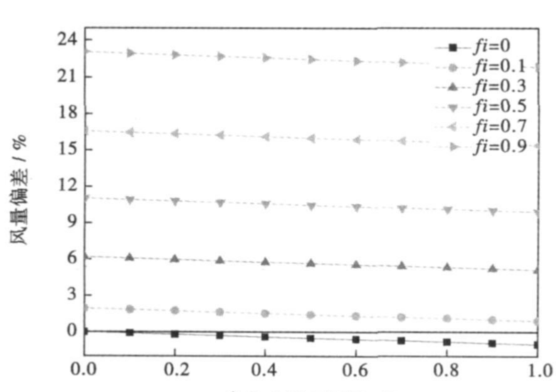

图 7　工况 4 风量偏差随相对湿度的变化

由图 4 和图 5 可以看出，工况 1 下风量偏差最大为 1.02％，工况 2 下风量偏差最大为 3.05％，上述最大值均在参考点相对湿度为零，实际相对湿度为 1 时出现。风量偏差的最大值只与参考点及实际运行时的温度有关，温度越高，偏差最大值越大。这是由于随着温度的升高，同样相对湿度下的含湿量增加。需要指出的是，这种规律只有在 $p_s < p_b$ 时成立。对于 $p_b = 80.92$ kPa，当 $T < 93.75$ ℃时才能保证 $p_s < p_b$。由图 6 和图 7 可以看出，*fi* 在 0～0.9 范围内时，工况 3、工况 4 下风量偏差最大均为 23.06％，上述最大值均在参考点相对湿度为零，实际相对湿度为 0.9 时出现。风量偏差的最大值与参考点及实际运行时的温度无关，这是由于此时运行温度大于 93.75 ℃，有 $p_s > p_b$，因此含湿量只与相对湿度有关，如式（8）所示。这种情况下，当相对湿度接近 1 时含湿量趋于无穷大，所以仅在 $0 \leqslant fi \leqslant 0.9$ 的范围内进行了分析。

现有电厂在对风量进行测量时并没有引入相对湿度或者说含湿量修正，从上述结果可以看出，由于流动介质的温度及相对湿度状况在流量装置进行标定时与实际运行时并不相同，忽略相对湿度的影响将使流量测量产生一定的偏差。对于 A 厂，当实际运行时的冷风温度不高于 50 ℃时，不引入相对湿度修正将使冷风流量测量产生 0～3％的偏差。

从理论上讲，不引入相对湿度修正将使 A 厂热风流量测量产生 0～23％的偏差。这是由于高温时干空气容纳水蒸气的能力急剧增强。若相对湿度为 0.9，则 50 ℃时含湿量为 0.1 kg，而介质温度高于 93.75 ℃时的含湿量将高达 5.6 kg。电厂的热风系统工作温度可以高至 200～300 ℃，但是由于介质取自于温度较低的大气环境，同时在风烟系统中没有水分输入，因此含湿量不可能很高，也就是说热风的相对湿度较低。所以从实际状况来说，不引入相对湿度修正对热风流量测量的影响并不像理论预测的那样大。

4　结　论

（1）在电厂的风烟系统中压力对风量测量的影响不大，而温度对风量测量的影响很大。不引入温度修正将使 A 厂满负荷运行时风量测量值与实际值的偏差达到 37％。

（2）对于磨入口的风量测量，冷热风混合不均造成的不合理修正可能使风量测量值与真实值出现

较大偏差。极端情况下 A 厂风量偏差可达 35%。在设计磨入口风道时, 应该尽量保证各流量测量相关测点处流动较为稳定, 冷热风混合较为均匀。如果条件允许, 应该在同一测量截面上布置多个测点进行测量。

(3) 不引入相对湿度修正将使风量测量产生偏差。从理论上讲, 相对湿度对热风流量测量影响较大, 对于 A 厂, 不引入相对湿度修正的偏差为 0 ~ 23%。但是由于热风的含湿量不可能很高, 因此相对湿度对热风流量测量的影响并不像理论预测的那样大。相对湿度对冷风流量测量影响较小, 对于 A 厂, 当实际运行时的冷风温度不高于 50 ℃时, 不引入相对湿度修正将使冷风流量测量产生 0 ~ 3%的偏差。

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新技术、新工艺

中间再热蒸汽温度调节方法经济性估算的数学模型

据《Энерґетика》2008 年 1 ~ 2 月号报道, 在适用于 250 MW 功率动力机组的中间再热温度各种调节方法经济性分析时, 必须得到用于燃料过耗量的分析表达式:

$\Delta B = f(\Delta Q, N)$

式中: ΔB—燃料过耗量, 它是由用于动力机组抽风机的电能消耗量、中间蒸汽再热器的流体阻力、把给水喷入中间蒸汽再热器通路和废烟气温度变化引起的燃料损失, m^3/h;

ΔQ—锅炉机组炉膛出口烟气温度偏离计算值的偏差, ℃;

N—锅炉机组的负荷, %。

上式得到的分析表达式允许确定在动力机组任何负荷和在负荷变化整个范围内炉膛出口烟气温度偏离计算值的任何偏差值下燃料过耗量 ΔB 的离散值。

建立的数学模型允许估算提议的各种调节中间再热温度方法的经济性。在该模型中, 用积分式计算燃料过耗量, 以此作为估算经济性的标准。

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By using the proven commercial software Thermoflex, a simulation was performed of an IGCC (integrated gasification combined cycle) demonstration unit rated at 200 MW, which is to be built in China. A mass and heat balance calculation of the unit was also conducted. By adopting an IGV (inlet guide vane) regulation mode during a load reduction featuring a constant T3 (temperature before a steam turbine), which is currently often used by combined cycle gas turbines, the authors have first analyzed the changes of T3, T4 (exhaust gas temperature) and QGe (gas turbine exhaust gas flow rate) caused by gas turbine off-design operating conditions under the present control mode and then calculated the influence of the change of T3, T4 and QGe on the efficiency, power output, fuel consumption of the system as well as on the main parameters at the steam side. As a result, the off-design characteristics of the IGCC system and a general law governing the change of its main parameters were obtained. A requisite analysis of the safety and cost-effectiveness of the system operating under off-design conditions was performed. It has been found that the regulation modes can directly affect the off-design performance of the IGCC system. To ensure the cost-effectiveness and safety of the IGCC system when it is operating under off-design conditions, the gas turbine should be controlled as much as possible within the IGV regulation limits. **Key words**: integrated gasification combined cycle (IGCC), gas turbine, load variation, off-design condition performance

F-T 燃料/电联产系统集成特性分析＝**An Analysis of the Integrated Characteristics of a F-T (Fischer-Tropsch) Fuel/Electricity Cogeneration System**[刊, 汉] / YUE Chen, SHI Yi-xiang, CAI Ning-sheng (Education Ministry Key Laboratory on Thermal Sciences and Power Engineering, Thermal Energy Engineering Department, Tsinghua University, Beijing, China, Post Code: 100084)// Journal of Engineering for Thermal Energy &Power. — 2009, 24(3). —320 ~ 325

Established was a model for coal gasifiers, F-T (Fischer-Tropsch) synthetic reactors and power generation units. A thermodynamic performance calculation was conducted of a coal-gasification-based pure IGCC (integrated gasification combined cycle) power generation system, a F-T fuel synthetic system and a F-T fuel/electricity cogeneration system, and the integrated characteristics of the F-T fuel/electricity cogeneration system were analyzed. The results of the analysis indicate that the F-T fuel/electricity cogeneration system can improve the stepped utilization of thermal energy by decreasing the averaged heat-exchange temperature difference in a waste heat boiler, thus enhancing the energy utilization of the cogeneration system. The F-T synthetic unit in the tail gas circulation process has been simplified, facilitating the pressure matching between the gasification unit and the power generation unit and also effectively expanding the regulation range of the chemical/electricity ratio up to 2.3. **Key words**: coal gasification, fuel/electricity cogeneration system, Fischer—Tropsch synthesis, power generation unit, integrated characteristics

负荷与燃尽风对 NO 影响的数值模拟＝**Numerical Simulation of the Influence of Loads and Burn-out Air Flow on Nitrogen Oxide**[刊, 汉] / GAO Zheng-yang, CUI Wei-chun, YANG Yi-li, SONG Wei (College of Energy Source and Power Engineering, North China University of Electric Power, Baoding, China, Post Code: 071003)// Journal of Engineering for Thermal Energy &Power. — 2009, 24(3). —326 ~ 331

To study the concerted action regularity of loads and burn-out air flow on NO emissions, a numerical simulation was performed of the combustion process of a 1025 t/h pulverized coal boiler. The distribution characteristics of the in-furnace temperature, thermodynamic type NO and fuel type NO were analyzed under different operating conditions when the burn-out air flow was put into use and disused. The calculation results were compared with the actual measured ones. The research results show that for the boiler under investigation, the burn-out air flow can more effectively control the emissions of fuel type NO, and at 100% load, the effectiveness is more conspicuous. At 80% load, the burn-out air flow can also reduce the NO emissions of the thermodynamic type. At 100% load, the burn-out air feed has a notable influence on the O_2 and CO in the furnace, while at 80% load, the burn-out air flow exercises a more conspicuous influence on the temperature field. **Key words**: pulverized coal boiler, load, burn-out air flow, numerical simulation, nitrogen oxide

空气物理参数对电厂风量测量的影响＝**Influence of Physical Parameters of Air on Power Plant Air Flow Measurement**[刊, 汉] / QIN Le, LI Ming-liang, ZI Yun-jiang, YAN Zheng-bo (Electric Power Research Institute, Yunnan

Electric Power Test Academy (Group) Co. Ltd., Kunming, China, Post Code: 650217)// Journal of Engineering for Thermal Energy & Power. — 2009, 24(3). —332～336

Studied was the influence of temperature, pressure and relative humidity on the air flow measurement in a power plant. For the air and flue gas system of a 300 MW boiler in a power plant in Yunnan Province, the temperature and pressure correction coefficient at various measuring points as well as the maximum deviation value of air flow rate at the inlet caused by the non-uniform mixing of cold and hot air were calculated and the possible deviation of cold and hot air flow measurements caused by refraining from introducing a relative humidity correction coefficient, analyzed. It has been found that an accurate measurement of the air flow rate demands a rational introduction of temperature, pressure and relative humidity correction coefficient. When the air temperature is not higher than 50 ℃, the non-introduction of a relative humidity correction coefficient will result in a deviation of 0～3% in the air measurement of the Yunnan Province power plant. **Key words**: flow rate measurement, temperature, pressure, relative humidity, power plant

智能控制算法对加热炉温度控制研究＝**A Study of the Temperature Control of a Heating Furnace Based on an Intelligent Control Algorithm**[刊，汉]/SUN Feng-cang, YUE Kai, JIANG Ze-yi, ZHANG Xin-xin (Thermal Energy Department, Beijing University of Science and Technology, Beijing, China, Post Code: 100083)// Journal of Engineering for Thermal Energy & Power. — 2009, 24(3). —337～341

In the light of such problems as a big overshoot and a high oscillation frequency etc. currently existing in the temperature control of a heating furnace, on the basis of the development of intelligent control theory and by combining the expert, fuzzy and neural network control in the above control theory with PID (Proportional-Integral-Differntial) control, intelligent PID control algorithms were designed. In addition, a numerical simulation and experimental verification were performed of those control algorithms in question. It has been found that the intelligent PID control algorithm can achieve a control effectiveness obviously superior to that of the traditional PID control algorithm. Among the control algorithms, the fuzzy self-tuning control algorithm and the immune, fuzzy PID control one are relatively feasible for the temperature control of heating furnaces. The neural network PID control algorithm has also a great potential for future development and applications. **Key words**: heating furnace, PID (proportional, integral and differential) control, fuzzy control, expert control, neural network control

燃煤电站锅炉的吹灰策略研究＝**Research on Soot-blowing Tactics for Coal-fired Utility Boilers**[刊，汉]/OU Zong-xian, YAN Wei-ping, ZHU Yu-dong (College of Energy Source and Power Engineering, North China University of Electric Power, Baoding, China, Post Code: 071003)// Journal of Engineering for Thermal Energy & Power. — 2009, 24(3). —342～346

On the basis of realizing an on-line monitoring of boiler heating surface pollution and an on-line analysis of entropy generation, from the standpoint of securing a safe and stable operation for a boiler and attaining maximum soot blowing benefits, proposed were the basic principles to be followed when implementing soot blowing tactics. According to these basic principles and boiler actual operation characteristics, the optimized soot blowing tactics were formulated, and three soot blowing modes suitable for different heating surfaces, established. Then, the optimized soot blowing tactics were used for the computer-based monitoring system of a coal-fired utility boiler to change the original fixed-time soot blowing mode, thus realizing an optimized soot blowing for various main heating surfaces of the boiler. **Key words**: utility boiler, optimized soot-blowing, soot-blowing tactics, pollution monitoring, entropy generation analysis

脉动热管的流型及流向分析＝**An Analysis of Flow Patterns and Directions of a Pulsating Heat Pipe**[刊，汉]/LI Jing-tao, LI Zhi-hong, HAN Zhen-xing, LIU Shi (Education Ministry Key Laboratory on Power Plant Equipment Condition Monitoring and Control, North China University of Electric Power, Beijing, China, Post Code: 102206)// Journal of Engineering for Thermal Energy & Power. — 2009, 24(3). —347～351

Through visual tests of three types of pulsating heat pipe with different structures, the flow patterns and directions of the working medium in the heat pipe were studied. The variation range of the liquid filling rate and heat load was widened by