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# 中速磨煤机漏粉原因与密封改造

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摘　要: 煤粉制备系统是火力发电厂燃煤锅炉必不可少的主要系统之一, 其运行的安全可靠性和经济性直接影响到锅炉机组的性能, 而磨煤机又是制粉系统中关键设备。介绍了中速磨煤机的密封现状, 指出了漏粉原因, 并提出了相应的改造方案, 同时对磨煤机改造前后进行了对比分析。通过改造, 不仅有效地消除了漏风和漏粉现象, 而且改善了工作环境, 提高了运行的经济性。因此对中速磨煤机进行密封改造具有十分重要的意义。

关　键　词: 锅炉制粉系统; 中速磨煤机; 漏粉; 密封改造
中图分类号: TK223.25　　文献标识码: B

## 引　言

磨煤机是将煤块破碎并磨成煤粉的机械, 是锅炉制粉系统的关键设备。随着国内外火电机组向大容量发展, 中速磨煤机因系统简单、占地面积小、省电、钢材消耗少、操作方便和噪音低等优点, 正在逐渐取代钢球磨煤机, 成为大型火电厂的主要制粉设备。

在运行中, 中速磨煤机中的密封因受负荷大、可靠性差, 难以适应高温、热粉含煤渣的密封工况, 经常出现漏风漏粉及磨损传动盘的现象, 密封件的使用周期也比机组的大修期短得多。因此, 对其进行改造势在必行。本文以 MPS 型中速磨煤机为例进行说明。

## 1　中速磨煤机的工作原理

中速磨煤机的结构各不相同, 沿高度方向可分为 3 个部分: 传动装置、碾磨装置、干燥分离和煤粉分配装置, 而且具有共同的工作原理, 即都是两组相对运动的研磨部件。在弹簧力、液压力或其它外力的作用下, 把它们之间的原煤研磨成煤粉; 然后通过研磨部件的旋转运动, 把磨碎的煤粉甩到周围的风环室, 流经风环室的热风把这些煤粉带到位于中速磨上部的粗粉分离器。在粗粉分离器中, 粗煤粉被分离出来重新再磨, 合格的煤粉送往燃烧器; 在磨粉过程中, 还伴随有热风对煤粉的干燥; 同时, 被甩出来的原煤中少量的石块和铁块等杂物, 落入杂物箱并定期排出。

## 2　中速磨煤机的密封现状

中速磨煤机一般用于正压直吹式制粉系统, 磨内压力约 9 kPa, 为了防止正压的一次热空气携带着粉尘泄漏, 每套制粉系统都配有专门的密封风机, 并且在与传动盘同心的专供装密封环的支架上装了 3 道密封装置, 如图 1 所示。

A 密封装置由硅酸铝耐火纤维绳构成的固定支架外缘密封;

B 密封装置(又称内泄口)由转动的传动盘与固定的气环之间的缝隙密封, 密封间隙为 1.5 ~ 2.5 mm;

C 密封装置(又称外泄口)为迷宫式密封, 是用传动盘的外径与迷宫式密封环的内径组成密封间隙, 该间隙量要求为 0.10 ~ 0.25 mm, 靠零件的加工精度及安装精度保证。迷宫密封装置由镶铜片的迷宫环、迷宫支架等组成, 迷宫支架装在减速机上部的 4 个平台上, 支持上部的迷宫环。

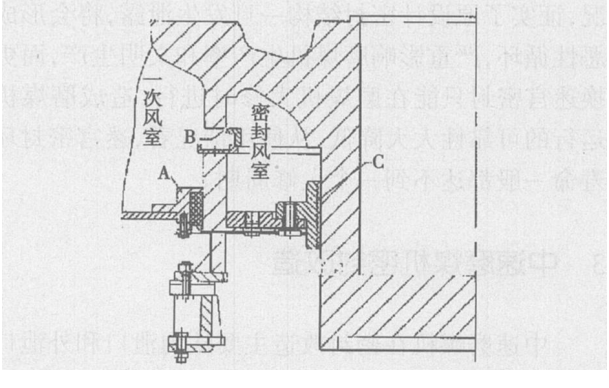


图 1　中速磨煤机密封装置

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磨煤机正常运行时，由密封风机提供的密封风进入内泄口与外泄口两组密封装置之间的环室内充压。密封风压要求大于一次风压至少 2 kPa，因此密封风大部分经内泄口进入一次风室，小部分从迷宫处漏入大气中，既防止一次风从外泄口泄漏，同时也防止一次风粉进入密封风室。由于我国的能源政策要求发电厂锅炉使用劣质煤，因而自磨煤机投运以来，煤中含有石子煤现象不断，有时石子煤多到难以及时排放的程度，随着煤粉石子不断对内泄口进行冲撞与摩擦，内泄口逐渐磨损，而且磨损会越来越快。此时密封风已托不住一次风粉，从而有可能使石子煤颗粒从内泄口进入密封风室，并挤入迷宫环铜齿片中，使磨损加剧；另一方面由于磨煤机传动轴运行一般处于轻微的晃动中，有时也有可能在磨煤机负荷变化较大时，因一次风量风压的不足，向上的风旋转托浮力减弱，部分煤粉颗粒下落，造成煤粉颗粒积累而进入迷宫间隙，这些因素都会加速传动轴和迷宫环的磨损，从而最终造成迷宫间隙的增大。当迷宫环密封与传动盘磨损到一定程度时，密封风基本失去功能，大量的一次风密封风的混合风会从该间隙处向外泄漏，严重时由于进入磨煤机的一次风量低于额定风量，造成磨煤机出力降低，出口风温达不到设计值，使煤粉着火困难；而且由于一次风量的不足，磨煤机渣量增大，进一步加剧了传动轴与迷宫环的相互摩擦，最终导致磨煤机被迫进行大修，更换迷宫环密封及传动轴，浪费了大量的物力、财力。同时，密封环处填压的硅酸铝耐火纤维绳因直接接触高温容易老化，经常发生泄露，其更换工作极不方便。

磨煤机传动盘与迷宫环配合的工作面磨损情况，证实了原设计密封结构一旦发生泄露，将会形成恶性循环，严重影响磨煤机生产率和文明生产，而更换迷宫密封只能在磨煤机大修时进行，造成磨煤机运行的可靠性大大降低，从使用情况看，迷宫密封环寿命一般都达不到一个大修周期。

## 3 中速磨煤机密封改造

中速磨煤机在密封改造主要从内泄口和外泄口两方面进行。

### 3.1 内泄口改造

目前现场主要有两种方案，由于相对于外泄口改造比较简单，因此未给出图片说明。

（1）文献[1]提供的改造方案，在通向一次风室处（内泄口）加一环形挡煤板和一环形挡煤环，挡煤环上设有弧形导流槽，以防止煤粉颗粒在热一次风作用下进入密封风室，经密封环泄出而磨损迷宫密封。

（2）江苏徐塘电厂的改造方案是将原来的气环通过焊接加高了 60 mm 之多，气环上部与传动盘留有间隙为 1.3 ~ 1.5 mm，为了减小加高的气环与传动盘磨损，气环的上部仍设计为直角。

### 3.2 外泄口改造

图 2 为改造后的浮动式密封装置。浮动密封装置主要由新型复合材料浸锑碳精密封环和弹簧组成，碳精密封环安装在磨煤机机座密封壳体的环形槽中。碳精环的内径面与磨煤机的内圆柱转轴面接触，碳精环的外径面嵌在密封座槽内，其功能是将磨煤机内部热风与外界大气隔绝。每环碳精密封环根据传动盘外径的大小不同分别由十多片组成，每片之间用销钉连接，靠弹簧使其与传动盘保持很小的间隙（或无间隙）。所谓浮动，主要指两个方面：一是密封环可随传动盘的轻微晃动在气封室滑道中自由运动；另一方面由密封环本身的结构决定，它可以在弹簧力和密封风共同作用下，作径向运动，避免了浸锑碳精密封环与磨盘的硬磨损。

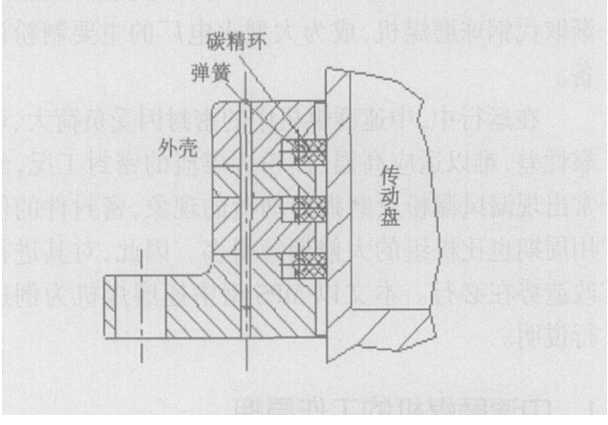


图 2 改造后的密封装置

## 4 改造效果

（1）从有隙密封变为无隙密封，最大限度地减少漏风，可确保密封风风压，减少煤渣的漏入，避免磨煤机转轴的磨损；

（2）磨擦副从径向固定间隙密封变为径向浮动密封，有效避免磨煤机转轴径向摆动带来的密封环啃轴现象，实现了无隙密封的动态补偿；

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多变量的不确定性。

(2) 以换热器结构应力和疲劳可靠性为优化目标,通过随机有限元模拟获得最佳结构形式和尺寸,对换热器安全运行有着重要意义。

(3) Monte Carlo 直接模拟法虽然计算效率低,但鲁棒性强、普适性好,在通用计算机平台即可模拟工程问题。反应面法效率高,但内存开销大,且要求随机输出变量为输入量的光滑函数。

(4) 概率有限元数值模拟技术具有效率高、方案调整或修改参数方便、准确性和可靠性都比较高等优点,能够减少或省去大量试验测量工作,是换热器等压力容器安全评估的有利工具。

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(3) 磨擦副从硬质金属变为浸锑碳精,碳精密封环的耐高温、自润滑特性有效避免了密封件对磨煤机转轴的摩损和啃蚀;

(4) 密封风的能耗可以大大降低;

(5) 碳精密封环可实现一个大修周期内免维护,更换密封环可以与磨煤机检修同时进行,不会增加维护难度;

(6) 磨煤机内部磨损也有所下降,磨煤机耗能减少;

(7) 节省了开支。以连云港新海电厂为例,2×200 MW, 2×300 MW 机组共有 ZGM95 型中速磨煤机 18 台,据估算,改造后一个大修周期内可节省原有迷宫密封装置 4 套,备品费用按每套 1.8 万元计算,材料费用按每套 2000 元计算,一台磨煤机仅此一项可节约 8 万元。一套制粉系统将节约 30 多万。

## 5 结 语

中速磨煤机漏粉是电厂常见的通病,其原因可以追溯到制造厂的设计本身不完善,存在设计缺陷。

目前,江苏徐塘电厂、彭城电厂以及连云港新海电厂已采用浸锑碳精密封环和弹簧组成的浮动式密封代替了原有的金属迷宫密封对中速磨煤机进行改造。经过改造后的磨煤机,不但提高了运行的经济性,改善了磨煤机的运行工况,而且对存在类似问题的其它磨煤机,该经验也值得借鉴和参考。

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燃煤 $PM_{10}$在磁场中聚并脱除理论与实验研究= **Theoretical and Experimental Study of Aggregation and Removal of Fuel Coal $PM_{10}$ in Magnetic Fields**[刊, 汉] / LI Yong-wang, ZHAO Chang-sui, WU Xin, et al (Education Ministry Key Laboratory on Clean Coal Power Generation and Combustion Technology under the Southeast University, Nanjing, China, Post Code: 210096)// Journal of Engineering for Thermal Energy & Power. — 2007, 22(2). —176 ~180

A two-dimensional collision and aggregation model has been presented for fuel-coal inhalable particles in uniform magnetic fields. Through a direct tracking of particles in relative motion under the action of a magnetic dipole force, gas drag force, Brown force and gravity force, the model can determine the aggregation coefficient among fuel-coal-produced fine fly ash particles according to the relative motion trajectory of the particles. On the basis of the aggregation coefficient obtained from a numerical calculation, a regional algorithm was employed to seek solutions to the particle aggregation dynamic equation to calculate the aggregation and removal efficiency of fine fly ash particles produced in the combustion of Dongsheng-origin bituminous coal. A comparison has been made between the calculated efficiency and experimental one. The result shows that in the particle diameters ranging from 0.098 to 9.314μm, the fly ash particles with a diameter between 0.578 and 3.758μm have a maximal aggregation and removal efficiency. The total removal efficiency will increase with an increase in intensity of external magnetic fields, particle mass concentration and residence time of particles in the magnetic fields. When the particles are saturation magnetized, the total removal efficiency attains a maximum value. The test results are in good agreement with the numerical simulation ones. The forecast made by using the model under discussion indicates that when the particle mass concentration attains 40 g/m$^3$, the total removal efficiency of fuel-coal-produced fly ash fine particles can reach 52%. **Key words**: fuel coal inhalable particle, magnetic aggregation, removal efficiency, aggregation coefficient

高压浓相粉煤气力输送试验研究= **Experimental Study of the Pneumatic Conveyance of High Pressure Dense-phase Pulverized Coal**[刊, 汉] / LIANG Cai, ZHAO Chang-sui, CHEN Xiao-ping, et al (Education Ministry Key Laboratory on Clean Coal Power Generation and Combustion Technology under the Southeast University, Nanjing, China, Post Code: 210096)// Journal of Engineering for Thermal Energy & Power. — 2007, 22(2). —181 ~184

On a high-pressure pneumatic conveyance test stand with a conveyance pressure and solid-gas ratio being respectively as high as 4.0 MPa and 500 kg/m$^3$, an experimental study of pulverized coal high-pressure dense-phase pneumatic conveyance has been conducted by using nitrogen. The conveyance tests have been performed at different conveyance differential pressures, air-filling flow rates and fluidized air flow rates etc., investigating the effect of operating parameters on such pneumatic-conveyance characteristic parameters as pulverized coal mass flow rate and solid-gas ratio etc. The results of the study indicate that the pulverized coal mass flow rate increases with the increase of the conveyance differential pressure and air-filling flow rate. The higher the conveyance pressure, the more notable the effect of any change in differential pressure on the pulverized-coal mass flow rate. The solid-gas ratio rises with the increase of the conveyance differential pressure and air-filling flow rate, and with the increase of fluidized air flow rate, the solid-gas ratio first increases and then decreases. The higher the conveyance pressure, the greater the solid-gas ratio. Under the condition of the total gas quantity entering the material transmission tank being kept unchanged, when $Q_f$ is less than 0.55 m$^3$/h, the change of air-filling air flow rate will have a major influence on the conveyance parameters. When $Q_f$ is greater than 0.55 m$^3$/h, the change of fluidized air flow rate will have a comparatively big influence on the conveyance parameters. **Key words**: pneumatic conveyance; high pressure; solid-gas ratio; mass flow rate

中速磨煤机漏粉原因与密封改造= **Causes of Pulverized-coal Leakage from a Race Pulverizer and Its Seal System Modification**[刊, 汉] / DU Zhong-xuan, HU Ya-fei, XIONG Jian-jun, et al(College of Electromechanical Engineering under China State Mining University, Xuzhou, China, Post Code: 221008)// Journal of Engineering for Thermal Energy & Power. —2007, 22(2). —185 ~186, 200

A pulverized coal preparation system is one of the indispensable main systems for coal-fired boilers in thermal power plants and its operation safety, reliability and cost-effectiveness directly affect the safety and reliability of boiler units. Moreover, the pulverizer constitutes a main link in the milling system and meanwhile is also regarded as a weak one. The

status quo of seal systems of race pulverizers is described with the causes of pulverized-coal leakage being pinpointed and corresponding modification schemes proposed. In the meantime, a contrast analysis is conducted of two cases, i.e. before and after the modification of the pulverizer. Through the modification, the air and pulverized-coal leakage phenomena have been effectively eliminated with the working environment being improved and operation cost-effectiveness enhanced. Therefore, it is of major significance to conduct a modification of the seal system for the race pulverizer. **Key words**: boiler milling system, race pulverizer, pulverized-coal leakage, seal system modification

不同动态叶片倾角下动静态分离器的试验研究= **Experimental Study of a Static/Dynamic Pulverized Coal Separator with Different Dynamic Blade Inclination Angles**[刊, 汉] / YANG Long-bin, WU Shao-hua, QIU Peng-hua (Combustion Engineering Research Institute under Harbin Institute of Technology, Harbin, China, Post Code: 150001), GAO Zhen-sen (Clean Coal Technology Research Center under Heilongjiang College of Science and Technology, Harbin, China, Post Code: 150027) // Journal of Engineering for Thermal Energy & Power. — 2007, 22(2). —187 ~189

A test stand to determine the performance of a dynamic/static rotor separator is described. An experimental study has been conducted of the separator at different dynamic blade inclination angles and rotor rotating speeds with pulverized coal serving as a raw material. Through a sorting-out and analysis of the test results, it has been found that the separator has a best comprehensive performance when its dynamic blade inclination angle is set at 45 degrees. In such a case, $R_{45}$ can be as high as 3.95% with the comprehensive separation efficiency being 55.32% and the resistance head 846 Pa. An increase of the dynamic blade inclination angle and rotor rotating speed can both increase the fineness of the pulverized coal at the outlet of the separator. Furthermore, there exists a maximal value of the comprehensive separation efficiency but there is a minimal value for the resistance head. **Key words**: pulverized coal, separator, gas-solid flow, experimental study

连续螺旋折流板管壳式换热器动态特性研究及预测= **A Study and Forecast of Dynamic Characteristics of Heat Exchangers with Continuous Spiral Baffle Plates**[刊, 汉] / WU Feng, WANG Qiu-wang, Chen Qiu-yang, et al (National Key Laboratory on Multiple-phase Flow in Power Engineering under Xi'an Jiaotong University, Xi'an, China, Post Code: 710049) // Journal of Engineering for Thermal Energy & Power. — 2007, 22(2). —190 ~196

A system has been established to conduct the experimental study of dynamic characteristics of shell-and-tube heat exchangers. Through experimental methods, an experimental study has been performed of the dynamic characteristics of heat exchangers with continuous spiral baffle plates, which have water and oil to serve as heat exchange working media. With the inlet flow disturbance representing equal percentage flow rate characteristics, studied were the dynamic responses to water and oil temperature at the outlet in four modes of flow rate disturbance. In the meantime, the effect of fluid disturbing quantity on the temperature rise at heat exchanger inlet and outlet at a certain *Re* number was also studied with a correlation equation between the temperature rise at the inlet and outlet of the heat exchanger and fluid disturbing quantity being obtained. The tests show that the dynamic response to the temperature of a liquid-liquid heat exchange system needs a comparatively long time. It has been found through the study that under a disturbance with a positive or negative flow rate, the change of temperature at the inlet and outlet of spiral-baffle plate heat exchangers assumes a linear relationship and the variation curve featuring temperature rise at the inlet and outlet has a symmetric feature at a positive or negative flow rate disturbance. A finite-difference numerical forecast model and artificial neural network one have been established respectively to dynamically forecast the outlet temperature at the heat exchanger oil side. The forecast results are in good agreement with the test values. The forecast results obtained from the neural network is better than those from the numerical simulation with the absolute value of the deviation being less than 1.3%, indicating that artificial neural network has a definite merit for engineering reference and applications when performing the discrimination of complicated systems. **Key words**: shell-and-tube heat exchanger, continuous spiral baffle plate, dynamic characteristics, numerical forecast, artificial neural network, dynamic forecast

换热器可靠性三维热—力耦合概率有限元模拟= **Three Dimensional Thermal-mechanical Coupled Probability-based Finite Element Simulation of Heat Exchanger Reliability**[刊, 汉] / LIU Tong, LIU Min-shan, DONG Qi-wu