应用技术

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冷却空气导流技术在直接空冷机组中的应用研究

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摘 要：针对某电厂330 MW直接空冷机组的运行条件，设备状况和凝汽器Λ型结构内部空气流场的特点，在空冷单元中风机上方对称加装导流板、空冷单元四周加装不同角度的挡板，通过空冷凝汽器的性能试验对加装导流装置前后机组的背压情况进行了计算分析。结果表明：加装导流装置后，空冷单元内的空气场及换热器表面温度场分布趋于均匀，运行背压降低约1.1 kPa，平均供电煤耗下降1.9 g/(kW·h)。

关 键 词：直接空冷；导流装置；背压
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引 言

汽轮机的排汽压力是直接空冷机组冷端系统的综合指标，其排汽压力的高低直接影响到系统的热经济性。直接空冷机组以环境空气作为汽轮机排汽的冷却介质，在环境参数不变的情况下，换热管的换热效果影响凝汽器的真空变化。由于风机导风筒出口是圆形结构，而由单排换热管束组成的空冷单元的底部是正方形结构，在单元内部的四个角区域产生空气涡流，导致流场不均匀，降低了换热管的迎面风速。针对机组背压过高提出的一些解决措施有[1－2]：(1)定期进行真空严密性试验，加强空冷系统查漏工作，主要针对系统严密性特别差的机组，对真空严密性合格的机组效果不明显。(2)定期进行空冷翅片清洗工作提高空冷凝汽器的清洁度，对空冷岛进行定期清洗可显著降低机组运行背压，但用水量大、对空冷凝汽器翅片管使用寿命有影响较大。(3)在空冷凝汽器增加喷雾降温装置，虽然效果明显，但用水量大，且消耗厂用电。(4)增加空冷防风墙，但初始改造投资大。

在直接空冷机组空冷单元内部加装冷却空气导流板[3]，通过对轴流风机强迫对流空气流场的主动诱导，实现对空冷单元三角区内流场的优化组织目的，改善空冷凝汽器翅片管束传热的均匀性，最终提高空冷凝汽器单元的散热能力，降低机组的背压。文献[4]对直接空冷单元内加装导流装置进行了数值模拟。本研究针对某电厂330 MW直接空冷机组的运行条件、设备状况和凝汽器单元Λ型结构内部空气流场的特点，在空冷单元内部加装冷却空气导流板，并通过热力试验分析其应用效果。

1 机组概况

某电厂汽轮机为CZK330－16.7/0.43/538/538型亚临界、一次再热、双缸双排汽、直接空冷、抽汽凝汽式机组，是某汽轮机厂制造的引进优化型汽轮机，额定输出功率为330 MW。汽轮机回热抽汽共8段，依次供给3台高压加热器、1台除氧器和4台低压加热器。机组采用机械通风直接空冷系统(ACC)，主要技术规范如表1所示。

2 存在问题

(1)机组夏季运行背压与设计值相差过大。机组夏季背压设计值为34.0 kPa，而实际运行背压最高至38.2 kPa，整个夏季运行背压平均值约为36.4 kPa，与设计值相差2.4 kPa。背压过高，则低压缸排汽温度升高，使汽缸中心线变化而引起机组振动，严重时甚至会使高背压保护动作，造成机组非正常停机，同时还使凝结水品质恶化，严重影响机组运行的经济性。

(2)空冷凝汽器外表面污染严重。空冷凝汽器表面沾染污垢，一方面减少了空气通道的面积，另一

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方面也增大了凝汽器管的传热热阻，从而大大降低了凝汽器的热交换能力。在机组日常运行中发现积垢厚度可达 0.4 mm，使机组背压上升约 1.5 kPa。

(3) 大风对机组背压的影响。空冷凝汽器受风向和风速影响较敏感，当风速超过 3.0 m/s 时，在凝汽器上部形成对其散热的压抑作用，阻碍散热。同时，大风在凝汽器进风口扰动形成负压区增加了空气供应阻力，导致空气密度、风机进风量不均匀和风机进风量减少，从而使机组背压升高。

表 1　汽轮机和空冷凝汽器主要技术规范

Tab. 1 Main technical specifications for the steam turbine and air-cooled condenser

参数	设计值
主蒸汽流量/ $t \cdot h^{-1}$	1 036.9
再热蒸汽流量/ $t \cdot h^{-1}$	873.8
主蒸汽压力/ MPa	16.7
主蒸汽温度/℃	538.0
保证热耗率/$kJ \cdot (kW \cdot h)^{-1}$	8210.1
额定背压/ kPa	15.0
夏季背压/ kPa	34.0
低压末级叶片长度/ mm	665.0
凝汽器形式	单排管
冷凝单元长度/mm	11 844
冷却单元宽度/mm	11 600
翅片管总散热面积(顺流/逆流) / m^2	735 951/165 589
平台高度/m	35
翅片管表面冷却空气速度/ $m \cdot s^{-1}$	2.16
平均传热系数/ $W \cdot (m^2 \cdot K)^{-1}$	31.7
每个单元中管束的数量	12
每一管束迎风面面积(顺流/逆流) / m^2	19.740 /17.766
翅片管面积与迎风面积之比	129
翅片外形尺寸/mm	200 × 19
翅片厚度/mm	0.26
翅片间距/mm	2.30
风机直径/mm	9 144
风机叶片尖速度/$m \cdot s^{-1}$	33.4
空气流量/ $m^3 \cdot s^{-1}$	511.7

3　冷却空气导流技术

针对现有机组的运行条件和设备状况，以及凝汽器单元 Λ 型结构内部空气流场的特点，先对机组在不同条件下空冷单元、空冷岛温度场和空气流场进行详细分析和数值模拟，开发空气流场导流板，并进行导流板结构、布置方式和安装位置的优化设计。同时，在不影响机组正常运行、原有支撑结构强度和风机能耗基本不变的前提下安装和调试空气导流板，不需要额外消耗能量和水资源; 加装导流板后，将空冷岛附加载荷和框架支撑结构原有结构强度的影响控制在设计范围内。以一个空冷单元为例，在空冷风机上方对称布置 8 块 500 mm × 500 mm 的导流板，在空冷单元四周加装不同角度的挡板。该空冷单元导流板形式和效果如图 1 – 图 2 所示。

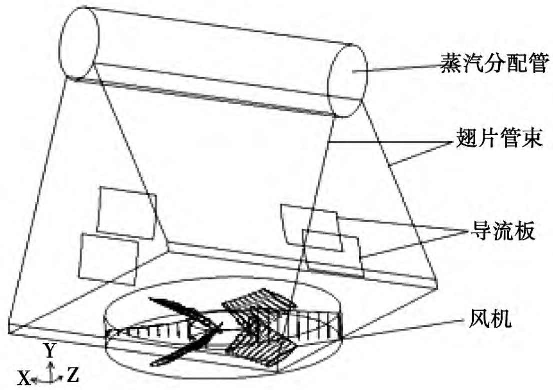

图 1　空冷单元导流板布置形式

Fig. 1 Type of the flow guide plate in the air-cooled unit

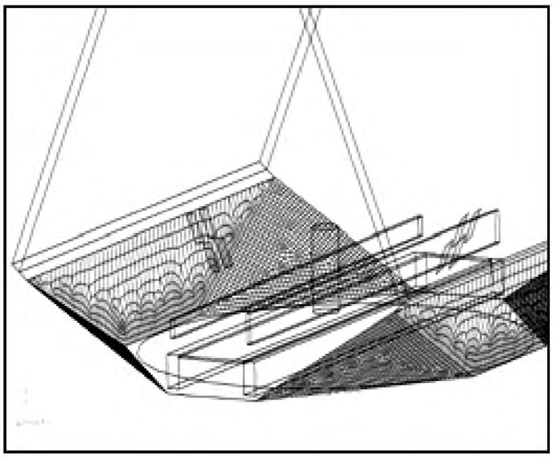

图 2　导流装置总体 3D 效果图

Fig. 2 3D overall rendering drawing of the flow guide device

4 改造效果

4.1 温度场分布情况

在加装导流板前后分别用红外热像仪测量了相同边界条件(机组负荷为 330 MW、入口空气温度为 30 ℃、风速分别为 1、2、3 和 4 m/s、风机频率为 50 Hz)下的空冷凝汽器翅片内的空气温度场和翅片管束表面的温度分布,凝汽器出口最高温度以及温度变化范围随风速的变化如图 3、图 4 所示。

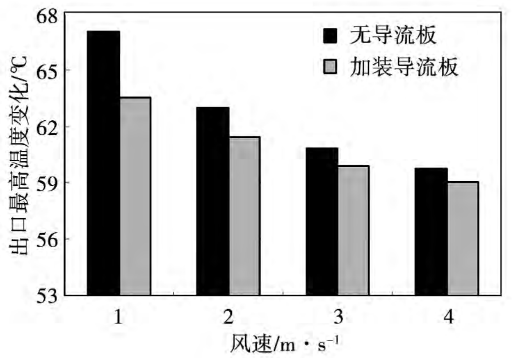

图 3 出口最高温度随风速的变化

Fig. 3 Changes of the maximum temperature at the outlet with the air speed

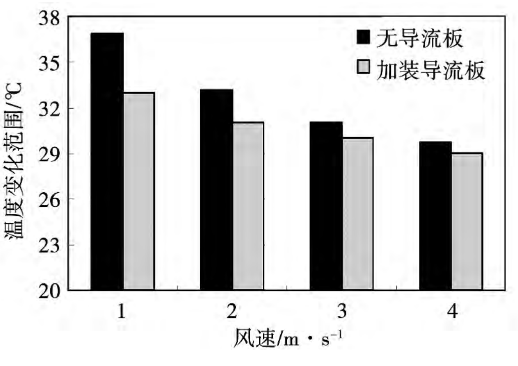

图 4 温度变化范围随风速的变化

Fig. 4 Changes of the temperature variation range with the air speed

从图 3、图 4 可以发现,加装导流装置后,随着环境风速的增大,凝汽器出口的最高温度在减小,温度分布更加均匀。在 3 m/s 的风速下,加装导流板后的凝汽器出口最高温度比加装前降低了 0.9 ℃,加装前后凝汽器温度变化由 31.1 ℃ 降低到29.9 ℃。

4.2 节能效果

利用空冷凝汽器考核验收试验方法[5]对机组加装导流板前后进行了对比试验,由于受到试验条件的限制,无法在完全相同工况下进行试验。只能将两次试验测得试验数据通过修正公式将其对试验结果的影响量修正到同一设计工况额定参数下进行对比分析,主要对排汽中蒸汽含量、大气压力、风机驱动功率、排汽压力和空气入口温度的修正,具体修正公式见式(1) - 式(4)。空冷单元加装导流板前后的试验数据如表 2 所示。

$$\xi_1 = \left(\frac{x_A}{x_{AG}}\right) \tag{1}$$

式中: ξ_1 —排汽中蒸汽含量修正系数; χ_{AG}、χ_A —设计、测量排汽蒸汽含量,kg/kg。

$$\xi_2 = \left\{\left(\frac{p_L}{p_{LG}}\right)\cdot(1-\Gamma)+\Gamma\cdot\left(\frac{p_L}{p_{LG}}\right)^{m_k}\right\}^{-1} \tag{2}$$

式中: ξ_2 —大气压力修正系数; p_{LG}、p_L —设计、测量大气压力,kPa; m_k 取 0.45,Γ —附属值。

$$\xi_3 = \left(\frac{P_{LV}}{P_{LG}}\right)^{\frac{-1}{(3-n)}}\cdot\left\{(1-\Gamma)+\Gamma\cdot\left(\frac{P_{LV}}{P_{LG}}\right)^{\left(\frac{m_k-1}{3-n}\right)}\right\}^{-1} \tag{3}$$

式中: ξ_3 —风机驱动功率修正系数; P_{LG}、P_{LV} —设计、测量风机驱动功率,kW; n 取 0.33。

$$\xi_4 = \frac{\dot{m}_{AG}}{\dot{m}_{AV,4} \pm \Delta\dot{m}_{AV,4}} \tag{4}$$

式中: ξ_4 —排汽压力和空气入口温度的修正系数; $\dot{m}_{AG}$、$\dot{m}_{AV,4}$、$\Delta\dot{m}_{AV,4}$ —设计排汽质量流量、试验空气入口温度和背压下查性能曲线的比较值、试验空气入口温度和背压下查性能曲线的比较值的测量不确定度,kg/s。

从表 2 可以看出,空冷单元加装导流板改造后的空冷凝汽器在 THA 工况(热耗保证工况)下的低压缸排汽质量流量修正到设计条件下(空气入口温度 18.3 ℃)为 197.2 kg/s,大于改造前的 188.9 kg/s;改造后修正到设计条件下的低压缸排汽压力为 14.238 kPa,比改造前低压缸排汽压力(15.337 kPa)低 1.099 kPa。改造后在 TRL 工况(空冷凝汽器出力保证工况)下的低压缸排汽质量流量修正到设计条件下(空气入口温度 33℃)为 210.4 kg/s,大于改造前的 206.0 kg/s;改造后修正到设计条件下的低压缸排汽压力为 33.239 kPa,比改造前(34.371 kPa)低 1.132 kPa。

表 2 空冷单元加装导流板前后不同工况下试验数据

Tab. 2 Test data at various operating conditions before and after the air-cooled unit is additionally installed with a flow guide device

项目	THA 工况			TRL 工况		
	设计值	改造前	改造后	设计值	改造前	改造后
大气压力/ kPa	95.3	97.0	93.5	95.3	95.9	93.2
汽轮机输出功率/MW	330.0	329.9	325.7	330.0	329.6	322.0
风机消耗功率/kW	2 450.0	2 574.2	2 386.3	2 320.0	2 457.4	2 254.5
转换为设计点的消耗功率/kW	2 450.0	2 412.7	2 395.9	2 450.0	2 304.9	2 219.6
机组背压/kPa	15.0	11.3	28.5	34.0	16.6	35.2
过冷度/℃	0.5	0.4	0.2	0.5	0.7	0.1
低压缸排汽质量流量/ kg · s^{-1}	191.4	192.1	216.1	207.5	198.5	218.9
低压缸排汽蒸汽含量/%	93.0	93.0	91.4	96.0	94.8	93.4
入口空气温度/℃	18.3	9.1	27.0	33.0	17.7	30.8
测量风速/m · s^{-1}	4.0	1.69	2.98	4.0	2.65	2.58
测量风速高度/m	44.5	43.0	43.0	44.5	43.0	43.0
凝汽器顶部高度 +1m 的风速/m · s^{-1}	4.0	1.71	3.00	4.0	2.66	2.59
低压缸排汽饱和蒸汽流量/kg · s^{-1}	191.4	188.9	197.2	207.5	206.0	210.4
修正后最大排汽质量流量/kg · s^{-1}	191.4	192.0	200.4	207.5	209.6	214.0
修正后最小排汽质量流量/kg · s^{-1}	191.4	185.8	194.0	207.5	202.5	206.9
排汽质量流量转化为排汽压力/ kPa	15.0	15.337	14.238	34.0	34.371	33.239
转化后排汽压力最大值/kPa	15.0	15.791	14.692	34.0	34.865	33.733
转化后排汽压力最小值/kPa	15.0	14.883	13.784	34.0	33.877	32.745

5 结 论

(1) 空冷单元加装导流板改造效果显著,使机组背压降低 1.1 kPa,使得机组供电煤耗率下降 1.9 g/(kW · h),同时提高了机组效率和出力。因此,应进一步推广空冷单元加装导流板改造技术。

(2) 采用空气导流技术,有效抑制环境风场作用下空冷岛局部区域空冷单元传热能力的恶化,从而提高了空冷机组抵御环境风不利影响的能力,降低空冷机组的非计划停机率,提高机组运行的安全性和可靠性。

(3) 与传统的优化空冷凝汽器方法相比,空冷单元内通过空气导流板重新组织空冷单元内流场,提高风量的使用效率,从而强化凝汽器散热。同时,单个空冷单元安装导流板时不影响机组的安全稳定运行,实现了不停机情况下的设备安装,避免了机组停运对电厂造成的经济损失。

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To realize a rational utilization of the biomass energy from Xinjiang-originated cotton stalk, with Xinjiang, Wusu City, Huanggong Town-originated cotton stalk serving as the typical sample, studied were the biomass combustion characteristics. The cotton sample was industrially and thermogravimetrically analyzed and the ash sample-combustion product was put into a melting and sintering characteristic test and mercury content analyzed. By using an X-ray fluorescence spectrometer, the trace elements as the constituents of the ash sample were analyzed when the full combustion temperature of the cotton sample was 400, 600 and 800 ℃ respectively and the heavy metal mercury content of the ash sample was determined. It has been found that the combustion process of the cotton stalk meets with two weight-losing peak values and when the combustion temperature arrives at 800 ℃, the weight-losing rate of the cotton stalk is almost zero and the K element content of the ash sample will decrease with a rise of the combustion temperature. The Cl element content of the ash sample at the combustion temperature of 400 ℃ is basically identical to that at the combustion temperature of 600 ℃. When the combustion temperature increases to 800 ℃, almost all the Cl is precipitated while other element contents of the ash sample basically do not change. The metal elements in the ash sample at 400 ℃ exist mainly in the form of carbonate, silicate and chloride. The compounds formed in the ash sample at 600 ℃ are relatively complex and the metal elements in the ash sample at 800 ℃ exist mainly in the form of oxide. The mercury content of the cotton stalk is far lower than that of coal burned in power plants and the mercury content of the solid product ash during the combustion is also lower than that of the coal ash. **Key Words**: cotton stalk, ash, alkaline metal, mercury

冷却空气导流技术在直接空冷机组中的应用研究 = Study of Applications of the Cooling Air Guide Technology in Direct Air Cooled Units [刊, 汉] GAO Ning (Electric Power Science Research Institute, Xinjiang Electric Power Company, National Power Grid Corporation, Urumqi, China, Post Code: 830000) //Journal of Engineering for Thermal Energy & Power. -2014,29(5). -577-580

In the light of the conditions for operating a 330 MW direct cooled unit in a power plant, status of equipment items and the characteristics of the air flow field inside the ∧-shaped structure of the condenser, additionally installed were guide plates symmetrically over the fan in the air cooled unit and baffles at various angles around the air cooled unit. Through a performance test of the air cooled condenser, the back pressure of the unit before and after the installation of the guide device was calculated and analyzed. It has been found that after the additional installation of the guide device, the distribution of the air field inside the air cooled unit and the temperature field on the surface of the heat exchanger tends to be uniform, the back pressure in operation drops by around 1.1 kPa and the average power supply coal consumption decreases by 1.9 g/kW. h. **Key Words:** direct air cooled, flow guide device, back pressure

某电厂 SCR 脱硝催化剂严重磨损原因分析 = Analysis of the Causes for Serious Tear and Wear of Denitrification Catalyzer During the Selective Catalyzer Reduction (SCR) Process in a Power Plant [刊, 汉] DENG Jun-ci, LI De-bo (Electric Power Science Research Institute, Guangdong Power Grid Company, Guangzhou, China, Post Code: 510060) //Journal of Engineering for Thermal Energy & Power. -2014, 29(5). -581 -586

In the light of the phenomenon that a serious tear and wear of the denitrification catalyzer happened during the SCR process in a power plant, used was a self-designed catalyzer activity measuring device to perform the performance evaluation with the NO removal rate, SO_2 and SO_3 conversion rate and specific surface area being measured and the microscopic morphology, crystal type and element composition being analyzed. It has been found that the main causes for serious tear and wear of the catalyzer lie in a serious blockage of the reactors, the blockage area accounting for about 1/4 to 1/3 of the total area and the catalyzer in the lower part of various reactors being relatively seriously collapsed. The serious tear and wear of catalyzer led to a conspicuous drop in denitrification rate of the denitrification system. **Key Words:** catalyzer, activity, tear and wear, corrugated plate type

600 MW 机组锅炉暖风器及疏水系统改造与运行优化 = Modification of the Air Heaters of a 600 MW Boiler Unit and Its Water Drainage System and Operation Optimization [刊, 汉] WANG Rong (Inner Mongolia Jinglong Power Generation Co. Ltd., Fengzhen, China, Post Code: 012100), LI Chun-guang (Heilongjiang Provincial Thermal Power No. 3 Engineering Co., Beijing, China, Post Code: 150001), CHEN Xiao-hong (CSIC No. 703 Research Institute, Harbin, China, Post Code: 150078) //Journal of Engineering for Thermal Energy & Power. -2014, 29(5). -587 -590

The original design of the air heaters of 2 × 600 MW boiler units in Jinglong Power Plant was horizontal and non-adjustable and the water drainage system adopted the traditional arrangement mode in operation: "water drain pump→deaerator", which often caused a series of problems such as the water drained from the air heaters was not smooth and free in flow and the water drain pumps malfunctioned during operation, needing a great deal of maintenance expense in each year. Through a modification of the air heaters and steam traps, rearrangement of the water drainage system, optimization of its operation logic, the reliability and cost-effectiveness of the air heater and water drainage system were enhanced, thus saving a cost of RMB 700 000 yuan in each year. The forgoing can offer certain reference for power plants being under construction or in operation. **Key Words:** water drainage system, equipment modification, cost-effectiveness analysis