技术交流

文章编号: 1001－2060(2004)04－0421－03

900 MW 锅炉水冷壁鳍片超宽问题分析及处理

冯伟忠
(上海外高桥第二发电有限责任公司, 上海　200137)

摘　要: 介绍了上海外高桥二期工程锅炉局部水冷壁鳍片宽度超标的问题, 经理论分析和研究, 推导出了鳍片中心点运行温度与鳍片的宽度和厚度之间的关系, 分析了鳍片超宽会产生的后果, 找到了兼顾质量和工期的堆焊鳍片解决方案。

关　键　词: 锅炉; 水冷壁; 鳍片

中图分类号: TK223　　文献标识码: B

1　锅炉简介

上海外高桥电厂 900 MW 燃煤超临界汽轮发电机组中锅炉由德国 Alstom 能源公司设计并供货, 为直流塔式、一次再热、单炉膛、四角切圆、固态排渣煤粉炉。首台机组于 2004 年 4 月投产。其基本数据如下:

最大连续出力:	2 788 t/h
主蒸汽/再热蒸汽温度	542/568 ℃
主蒸汽压力	24.955 MPa(BMCR 工况)
炉顶标高	114.5 m
炉膛截面	21.48 m×21.48 m

2　问题的原由

2003 年 3 月, Alstom 公司派设计部门的专家对锅炉本体的安装进行了全面检查, 并以书面的形式通知施工单位对过渡段垂直水冷壁 7 个鳍片宽度超标处进行整改。

根据设计, 锅炉水冷壁以接近炉膛出口的 63.85 m 为分界(炉膛出口标高 68.4 m), 下部采用螺旋水冷壁, 螺旋角为 26.2°, 上部仍为传统的垂直水冷壁。两者之间采用一种特殊的铸钢件(见图 1)进行机械联接, 管内工质通过铸件中间引出管引至外侧联箱进行混合。制造厂对水冷壁采用分片方式出厂, 每片约 3 m 宽。在安装过程中, 为满足对炉膛总尺寸的要求, 将部分片间鳍片进行了加宽处理。

图 1　铸钢联接件(背火侧)

Alstom 设计专家和总部对这一问题的意见非常明确, 必须使这部分的鳍片宽度全部调整到最大允许值以内。

3　Alstom 的处理方案与工期的问题

过渡段垂直水冷壁管的设计尺寸为:
管径: Φ33.7×6.3 mm
节距: 60 mm; (最大允许值: 64 mm)
鳍片: 26.3×6 mm

对于各鳍片超宽处的处理, Alstom 的现场专家根据设计人员的要求制定了一个工艺方案。总思路是将超宽处的鳍片调减至允许值内, 同时将超过允许值的部分均摊至相邻的鳍片。又因垂直段与螺旋管的相连按 2∶1 配置, 故垂直段需每两根(与一根螺旋管对应)设一处切割调整点。另外, 在垂直段鳍片宽度调整的同时, 还必须相应调整较长的一段垂直管所对应的螺旋管的角度和鳍片的宽度。由于每个铸钢联接件对应四根垂直管, 还需在其中间进行切割。

收稿日期: 2003－11－20;　修订日期: 2004－02－22
作者简介: 冯伟忠(1954－), 男, 上海宝山人, 上海外高桥第二发电厂总工程师.

对于此方案, 施工单位认为整个工艺涉及面广且修改工作量大, 技术要求高, 难度大。按测算, 不考虑铸钢联接件的切割, 完成该项任务也至少需两个月。而德方表示可承担铸钢件的切割, 但对工期却不能保证。在 4 月初, 按计划月底应完成锅炉水压前的全部准备工作。如果实施这一方案, 工期就将推迟一个多月, 且不提在缺电形势下项目推迟投产所造成的社会影响和损失, 仅发电的直接收益损失就要上亿元人民币。但如果不解决这一问题, Alstom 明确表示将不能保证设备的性能和质量, 由此而产生的风险和后果将由业主来承担。

4 鳍片超宽的后果分析及对策

要对上述问题作出正确的决策, 首先必须就鳍片超宽所产生什么后果进行分析和评估。

炉内燃烧热主要以辐射的方式传递于水冷壁表面(见图 2), 再通过金属的导热由水冷壁传导至管道内侧。而管内工质(水)通过和管道内壁间以对流放热的形式吸收热量并将其带走(水冷壁背火侧敷有保温材料, 可以视为绝热体)。由图可见, 鳍片段所吸收的辐射热, 是以点 a 为中心, 向两侧传导至管壁。鳍片的温度分布是向火侧的 a 点温度为最高, 并沿两侧逐步降低。由此可见, 当鳍片宽度增加后, 在相同的炉内辐射热强度下, 传递于鳍片表面的热量上升, 这部分热量都将以 a 点为对称轴沿鳍片内向两侧传导。显而易见, 由于传导热阻的存在, 热量越高, 传导温差越大, 相应的 a 点温度将越高。

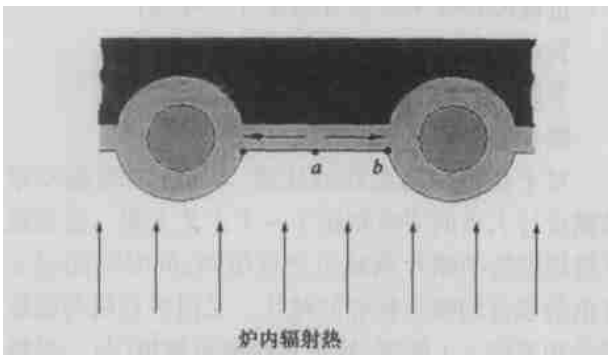

图 2 水冷壁工作示意图

为研究鳍片表面温度分布的规律, 可截取宽度为 1/2(图中 $a-b$ 段)的单位长度的鳍片作为研究对象, 如图 3 所示。

现观察图中 x 点处的断面热通量, 根据图 3 知, 背火侧为绝热面; 鳍片的中心截面(图 3 的 $a-h$ 面)则由于对称的原因无热量传导, 亦可视为绝热面。因此, 鳍片的向火面投射到的热量只能在鳍片内沿 x 轴的正方向传导, x 点截面向右侧所传导的热量就等于 $a-x$ 面所传递的辐射热。即:

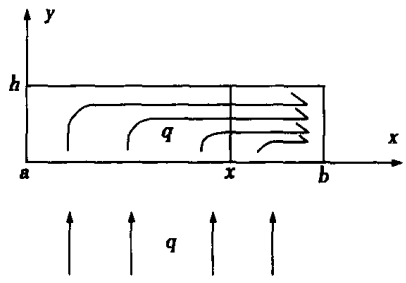

图 3 鳍片内传热示意图

$$Q_C(x) = Q_R(x) \tag{1}$$

式中: $Q_C(x)-x$ 断面片鳍片传导热量;

$Q_R(x)-a-x$ 面辐射热量。

根据传热学:

$$Q_C(x) = \int_0^h q_x(y)\mathrm{d}y = \int_0^h -\lambda \frac{\partial t(y)}{\partial x}\mathrm{d}y \tag{2}$$

式中: $q_x(y)-x$ 截面 y 点处传热量; λ — 鳍片导热系数; $\partial t(y)/\partial x-x$ 截面 y 点处温度梯度。

为简化分析, 若忽略 y 轴方向的温度梯度差, 则可用 x 截面处的平均温度梯度 $\mathrm{d}t(x)/\mathrm{d}x$ 取代 $\partial t(y)/\partial x$。则因 $\int_0^h \mathrm{d}y = h$, 式(2)便转为:

$$Q_C(x) = -\lambda h \frac{\mathrm{d}t(x)}{\mathrm{d}x} \tag{3}$$

又, 根据辐射传热公式:

$$Q_R(x) = \int_0^x K(T_0^4 - T_S^4(x))\mathrm{d}x \tag{4}$$

式中: K — 综合辐射传热系数; T_0 — 炉内辐射源平均温度(绝对); $T_S(x)-x$ 点表面温度(绝对)。

因为炉内辐射源平均温度 T_0 远高于鳍片表面温度 T_S, 则 $T_0^4 \gg T_S^4$

因此, 当 T_S 沿壁面变化时, $T_0^4 - T_S^4$ 几乎不变, 令:

$$q_R = K(T_0^4 - T_S^4(x))$$

式中: q_R — 平均辐射传热强度。

则式(4): $Q_R(x) = q_R \cdot x$; 将式(3)代入式(1)得:

$$q_R \cdot x = -\lambda h \frac{\mathrm{d}t(x)}{\mathrm{d}x} \tag{5}$$

解此方程得:

$t(x) = -\frac{q_R}{2\lambda h}x^2 + c$; 当 $x = b$ 时, 有 $t = t_b$, 代入得: $c = t_b + \frac{q_R}{2\lambda h}b^2$

即: $t(x) = t_b + \frac{q_R}{2\lambda h}(b^2 - x^2)$　　(6)

当 $x = 0$ 时, $t(0)$ 即为鳍片中心表面温度:

$t(0) = t_b + \frac{q_R}{2\lambda} \cdot \frac{b^2}{h}$　　(7)

在式(7)中, 辐射传热强度 q_R 和鳍片导热系数 λ 均为常数, 而水冷壁管表面温度 t_b 受管内工质温度影响(通常工质温度约 50 ~ 60 ℃), 由式可知, 鳍片中心表面温度 $t(0)$ 与鳍片宽度的平方成正比, 与鳍片的厚度成反比。

至此, 实际上鳍片超宽的后果已经明朗, 如鳍片宽度增加, 鳍片中心表面温度将呈平方关系上升, 仅以节距为 72 mm 为例, 则鳍片宽度为 38.3 mm。与设计宽度 26.3 mm(节距 60 mm)的平方比达 2.12。也就是说, 鳍片表面中心相对于根部的温升将上升一倍余, 鳍片材料不可能有如此的耐温裕度。由此证明, Alstom 关于超宽鳍片必须处理的意见是正确的, 否则在机组启动后不久就可能将鳍片烧坏。

公式(7)同时也指出了解开这个两难问题的新途径: 若要维持 $t(0)$ 不变, 可通过加厚鳍片的方法来补偿宽度的增加。如此处理, 不必去考虑原先的设计值, 包括炉内辐射热强度、材料允许温度和水冷壁面温度等, 只要满足几何条件 b^2/h 不变即可。当然, 在实际操作时, 更换鳍片的方法并不可取, 因为不可能有各种厚度的现成鳍片供选用, 但是这可以通过在鳍片的两面进行堆焊的方法来达到增加厚度的目的。同样以节距 72 mm 为例, 考虑最大设计节距 64 mm 为补偿基准, 则鳍片厚度可为 $h = (38.3^2/30.3^2) \times 6 = 9.6$ mm, 即堆焊总厚度只需 3.6 mm 便可, 其工作量远小于原方案。在同样达到解决问题的前提下, 工作量已是解决问题的关键所在。

当"堆焊增厚鳍片"方案在多方协调会上一提出, 便立即得到了 Alstom 的现场技术经理和施工单位的积极响应。而后, Alstom 总部针对该方案, 采用有限元法, 用计算机进行了校核计算, 验证了方案的可行性。

至此, 该问题被解决。

5　结　语

(1) 由于水冷壁鳍片中心运行温度与其宽度的平方成正比, 在安装过程中, 鳍片宽度应严格控制在设计值以内。

(2) 鉴于水冷壁鳍片中心运行温度与其厚度成反比, 在鳍片超宽且难以返工的情况下, 可采取堆焊的方法予以处理。

(3) 对于涉外工程, 外商对设计和设备的质量负责, 经常会遇到上述一类的问题, 通常情况下, 应尊重外商的意见。但在特殊情况下, 尤其是工期与质量风险发生矛盾时, 应尽可能采用理论研究的方法, 分析问题的实质, 评估各种风险, 从中找出更有效的解决问题的途径。

参考文献:

[1]　杨世铭. 传热学[M]. 北京: 高等教育出版社, 1987.

燃气轮机输出功率的新雾化系统

据《Diesel &Gas Turine Worldwide》2003 年 6 月号报道, 燃气轮机在高温地区或夏季运行时, 它的输出功率将会减少。为了克服这一问题, 瑞典的 Camfil Farr 空气过滤公司推出了一种优化喷水控制并具有最新喷嘴技术设计的新的喷雾系统(Camfog)。

该雾化系统的主要优点是减少所需要的空间并且没有附加的压力损失。它利用了最新的旋流喷嘴设计, 其提供更均匀的水雾分布和更微小的水滴。

除盐水从高压泵橇经过不锈钢管系统供应到 Camfog 系统喷嘴。阀门打开需要喷入所要求水量的一些喷嘴, 并且泵的电动机是频率控制的。

产生必要的高压是所有喷雾系统的关键, Camfog 系统使用独特的具有频率控制电动机的 5 级高压活塞泵。喷水量可从 5 L/min 变化到 50 L/min, 压力可以达到 14 MPa。泵橇被设计成简单、可靠并易维护。运行表明, 使用 Camfog 雾化系统可使燃气轮机在夏季的输出功率增加 15%。

(吉桂明　供稿)

length, condensing section length, heat dissipation conditions and their layout location. It was found that when the heat-pipe fins are horizontally placed and allowed to dissipate heat in a natural environment, then due to the influence of a non-condensing gas, there could appear an excessively low temperature at the end portion of the heat-pipe fin condensing section. If the evaporating section is excessively long, there will emerge overheating points with a simultaneous occurrence of temperature rise. If the condensing section of the heat-pipe fin is allowed to dissipate heat in a finite space, the temperature rise phenomenon will disappear. If placed in an inclined position, the heat-pipe fins will attain an optimum performance. **Key words**: heat pipe, heat-pipe fin, shaped high-temperature heat-pipe fin.

脉动热管运行可视化及传热与流动特性的实验研究＝**Experimental Investigation of the Visualization of Pulsating Heat-pipe Operation as well as Heat Transfer and Flow Characteristics** [刊, 汉] / CAO Xiao-lin, XI Zhan-li (Institute of energy and Power Engineering under the Zhongnan University, Changsha, China, Post Code: 410083), ZHOU Jin, YAN Gang (Department of Refrigeration and Cryogenics Engineering, Xi' an Jiaotong University, Xi' an, China, Post Code: 710049) // Journal of Engineering for Thermal Energy & Power. — 2004, 19(4). — 411 ~ 415.

A visualization experiment is conducted with respect to the operation of pulsating heat pipes. Under different conditions of filling rate, inclination angles, section shape and heating rate, tests are conducted on the operation of the pulsating heat pipes. The results of the tests indicate that the pulsating heat pipes represent a kind of very effective heat dissipation technology. There exists a heat transfer limit for the pulsating heat pipes. During operations at an optimum filling rate (50%) and an optimum inclination angle (50°), the pulsating heat pipes have a maximum heat transfer limit with a minimum heat transfer resistance under a high heat flux density. In the case of a relatively small heat flux density the pulsating heat pipe with a triangular channel will be superior to that with a square-shaped channel. However, when the heat flux density is relatively great, the shape of the channel will not have any significant influence on heat resistance and unit section heat-transfer limit. The size of the channel exercises a very small influence on the thermal performance of the heat pipes. **Key words**: pulsating heat pipe, visualization, operation mechanism.

基于多参数的电站风机监测技术的试验研究＝**Experimental Investigation of Multiple Parameter-based Monitoring Technology for a Power Plant Air Blower** [刊, 汉] / WANG Shong-ling, HOU Jun-hu, AN Lian-suo (Power Engineering Department, North China Electric Power University, Baoding, China, Post Code: 071003) // Journal of Engineering for Thermal Energy & Power. — 2004, 19(4). — 416 ~ 420.

By using a experimental study method an investigation was conducted of a multiple parameter-based monitoring technology involving the performance, non-steady state flow and mechanical vibrations of a power station air blower. On the basis of the stable and good mapping mechanism existing among the performance parameters as reflected by non-dimensional performance curves, a RBF (Radial Basis Function) network featuring excellent approximation characteristics was employed to approximate the non-dimensional performance curves of the air blower. As a result, a parameter mapping-based flow-monitoring model was derived, thereby realizing the on-line monitoring of the air blower performance. Through a study of the rotating stall at the 4-73 air blower suction and pressure side and the frequency characteristics of inlet vortex flow and an analysis of three kinds of non-steady flow specific features given are combined eigen parameters capable of accurately describing three kinds of non-steady state flows. Mechanical vibration characteristics of the air blower are divided into harmonic, energy and singularity characteristics. By using frequency-division section technology and a binary small-wave transformation method derived are harmonic monitoring indexes, energy and singularity indexes. **Key words**: air blower, parameter monitoring, RBF network, small wave transformation, experimental study.

900 MW 锅炉水冷壁鳍片超宽问题分析及处理＝**Analysis and Treatment of the Problem Relating to Excessive Width of Water Wall Fins in a 900 MW Boiler** [刊, 汉] / FENG Wei-zhong (Shanghai Waigaoqiao No. 2 Power Generation Co. Ltd., Shanghai, China, Post Code: 200137) // Journal of Engineering for Thermal Energy & Power. — 2004, 19(4). — 421 ~ 423.

Described is the problem relating to the excessive fin width in some parts of the boiler water wall used in a Shanghai

Waigaoqiao Second-stage Engineering Project. The relationship between fin central-point operating temperature and fin width and thickness has been deduced after a theoretical analysis and investigation. On the basis of analyzing the unfavorable consequences of using fins with an excessive width a problem-solving scheme involving the adoption of built-up welded fins was adopted, which can meet both the quality and project time-schedule requirements. **Key words**: boiler, water wall fin.

少油点火与水平浓淡燃烧器相结合在一台 600 MW 机组锅炉上的应用=**Low Oil Consumption-based Ignition in Combination with a Rich/lean Combustion Burner as Applied on a** 600 **MW Boiler** [刊, 汉] / JIANG Jia-ren, QIN Ming, WU Shao-hua, et al (College of Energy & Power Engineering under the Harbin Institute of Technology, Harbin, China, Post Code: 150001) // Journal of Engineering for Thermal Energy & Power. — 2004, 19(4). —424 ~ 426.

In an effort to reduce oil consumption during the startup of a pulverized coal-fired boiler a louver structured horizontal rich/lean combustion-based pulverized-coal burner in combination with a low oil consumption for ignition has been used on a 600 MW boiler. The design and tests in connection with the above scheme are described. As opposed to their traditional location in a lower primary-air port, the small oil guns for ignition are mounted in a secondary-air port in close proximity to the lower primary-air port. By taking advantage of the special features of horizontal rich/lean combustion, the small oil gun flame is made by all means possible to plunge toward the rich-combustion side of pulverized coal-air stream to achieve a complete mixing. Tests indicate the above technique is conducive to a reliable ignition of pulverized coal and stable combustion, attaining a significant oil-savings effect. Moreover, as each small oil gun has been provided with a special flame detector and incorporated into a furnace safeguard supervisory system (FSSS), a safe and reliable operation of the boiler is fully guaranteed. **Key words**: 600 MW boiler, ignition based on a low consumption of oil, small oil gun, louver structured horizontal rich/lean combustion-based pulverized coal burner.

有机酸废液水煤浆在工业锅炉上的应用=**Organic Acid Waste and Coal -water Slurry Used as Fuel in Industrial Boilers** [刊, 汉] / XIE Yong-gang, ZHAO Xiang, SUN Fen-mei, et al (Thermal Energy Engineering Institute under the Zhejiang University, Hangzhou, China, Post Code: 310027) // Journal of Engineering for Thermal Energy & Power. — 2004, 19(4). — 427 ~ 428.

A 20t/h chain grate steam boiler has been retrofitted to operate on organic acid waste and coal-water slurry. Clear and lucid, the coal-water slurry assumes a orange-yellow color. The retrofitted boiler features a reliable and continuous stable operation. The retrofitting makes it possible to both properly dispose the waste liquid and utilize its heating value, achieving a full utilization of energy. **Key words**: coal-water slurry, organic acid waste liquid, boiler retrofit, organic acid waste and coal-water slurry.

网络图优化及在电厂设备检修中的应用=**Network Chart Optimization and Its Application in the Maintenance and Repair of Power Plant Equipment** [刊, 汉] / WANG Yun-min, LI Lu-ping, HUANG Zhi-jie (Changsha University of Science & Technology, Changsha, China, Post Code: 410076) // Journal of Engineering for Thermal Energy & Power. — 2004, 19(4). — 429 ~ 432.

Network chart optimization is widely used in the maintenance and repair of power plant equipment. However, the issue of how to optimize a prepared network chart remains unsolved. The authors have, by studying the relationship between project completion date and costs, introduced a method for optimizing network chart. Furthermore, with the overhaul of power plant feedwater pumps serving as an example, some explanations are given concerning the specific application of network chart optimization. The results of this application indicate that the optimization method used for the overhaul of power plant equipment proves to be simple, effective and feasible. **Key words**: network chart, equipment maintenance and repair, optimization.