

TCDF—33.5 型 300 MW 汽轮机首次大修中的故障处理

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摘 要:介绍了一台 TCDF—33.5 型 300 MW 汽轮机首次大修中发现的主要故障:轴系标高的变动和叶片围带发生裂纹。简要分析了问题发生的原因,并给出了现场的处理措施及进一步完善的建议。同型机组在国内数量较多,文章介绍内容将为同型机组的检修维护提供有益的参考。

关 键 词:汽轮机; 检修; 故障处理

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1 概 述

TCDF—33.5 型 300 MW 汽轮机是亚临界、一次中间再热、冲动式、单轴、两缸两排汽的凝汽式汽轮机。汽轮机高、中压缸采用合缸结构,低压缸为对称分流式。高、中压缸间设有中间再热。机组的通流部分由高、中、低压三个部分组成。汽机的高、中、低压缸均为双层缸结构。各级隔板安装在内缸上。高压部分由 1 个单列级和 7 个压力级组成,中压部分共 6 个压力级,低压部分为对称分流式,每一分流有 6 个压力级。共计 26 级。机组采用喷嘴调节配汽方式,新汽通过两个单独支撑的高压主汽门和安装在高压外缸上的 4 个高压调速汽门进入不同的喷嘴室,然后进入高压缸做功。汽机有两个转子:高中压转子和低压转子。两个转子都为整锻实心转子,转子采用刚性联轴器联接。1999 年 1 月 20 日结束满负荷试运后移交试生产运行。2001 年 5 月起首次大修。累计运行约 9 000 余小时。汽机大修前运行稳定,未见任何缺陷的征兆。随着大修过程的进行,陆续暴露出一些问题。

2 汽机转子轴系中心问题

设计的汽机转子轴系中心配合情况如图 1,中低压对轮低压侧高 $d_1 = 0.43\text{ mm}$, 低压转子发电机转

子对轮低压侧高 $d_2 = 0.13\text{ mm}$ 。基建安装轴系配合情况同设计要求相同。本次大修发现下述问题。

2.1 高中 — 低压转子对轮中心问题

表 1 高中压、低压转子对轮解体后测量结果 (mm)

上张口	左张口 *	低压转子高	低压转子偏右
0.037 5	0.015	0.025	0.02

* 机头向机尾看。

设计值为: 低压转子高: $d_1 = 0.43\text{ mm}$ 。查该机安装记录情况, 低压转子比高压转子高 0.425 mm。安装符合设计要求, 安装记录和本次修前比较发现低压转子下沉约 0.40 mm 左右。

2.2 低压转子与发电机转子中心问题

表 2 低压 — 发电机转子对轮解体后测量结果 (mm)

上张口	左张口 *	电机高	电机转子偏右
0.028	0.011	0.57	0.24

* 机头向机尾看

设计值为: 低压转子高: $d_2 = 0.13\text{ mm}$, 左右外圆偏差不得超过 0.03 mm。查该机安装记录情况, 电机转子比低压转子低 0.13 mm。安装符合设计要求, 安装记录和本次修前比较发现低压转子下沉约 0.70 mm 左右。

1 号 ~ 4 号轴承油档洼窝中心同安装值比较, 变化不大。

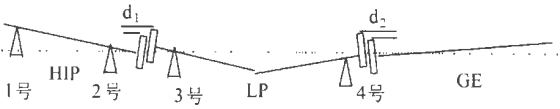


图 1 汽机转子中心标高示意图

整个低压转子下沉, 高中压端下沉量 0.40 mm, 电机端下沉量 0.70 mm。低压转子的下沉有多种可

能的原因,可能是基础的下沉,也可能是凝汽器投入运行,长时间凝结水自重力导致。要解决的问题是,机组回装时轴系标高该如何分配。在试运行阶段和大修前,机组振动情况均为优良,2号瓦瓦温偏高。从振动情况分析,依设计标准回装和依大修的修前值回装都是可行的,但从降低2号瓦瓦温的角度出发,有抬高低压转子高中压端的对轮以减轻2号瓦荷载的需要。在引进型国产300 MW机组上,也发生过低压转子下沉的问题,依设计标准恢复后,运行情况良好。依本机的实际情况和以前经验,决定依设计标准回装。通过调整研刮垫铁使中、低对轮中心测量结果符合设计要求;通过调整发电机标高,低压转子发电机转子的标高达到标准要求。

3 低压转子围带裂纹

汽轮机低压转子围带经磁粉、超声波探伤,发现低压转子18 G级有8条裂纹,18 T级有3条裂纹,具体位置及编号如下:

汽机侧:第4组第4叶片,第5组第4叶片,第12组第5叶片,共三处。

发电机侧:第5组第5叶片,第6组第5叶片,第8组第5叶片,第9组第5叶片,第11组第4、5、6叶片,第12组第4叶片,共计八处。裂纹均发生在8片一组围带上;而在7片一组、6片一组围带上没有裂纹。裂纹自围带的外缘向中心发展,长度大约4~5 mm,边缘穿透,铆钉孔周围无裂纹产生。

所有裂纹都发生在8片成组的叶栅上,而叶栅的振动频率是叶栅的固有特性,由叶片、围带的质量、叶栅的成组叶片数、叶片叶栅转子的装配工艺等所决定。分析实测的静频数据(见表3),频率分散度 $\Delta f=8.13\%$,略大于8%的合格标准,这主要是由于18 T级第12组频率低至295 Hz所至,除此叶栅外,其它叶栅的频率还是比较集中的,而且,也并不是仅仅这一组产生裂纹,因而这不是矛盾的主要方面。分析表3可知,发生围带裂纹的叶栅频率较其它未产生裂纹的围带频率偏低,接近6倍工频,这是导致围带产生裂纹的主要原因,围带的振动倍率 k 接近整数,易于落入共振区域。因而导致围带产生裂纹的是叶栅的一阶 A_0 型振动。由此分析裂纹产生的原回,主要由一阶 A_0 型振动频率和倍频振动频率避开率不足共振引起。裂纹主要集中在叶栅的中间叶片附近,这是由于叶片受力差异导致,叶栅两端的叶片围带为自由端,不受剪切力作用,而叶栅中

间叶片受力最大。中间围带的弯矩较两端高40%以上。

由于大修工期、现场条件的限制,决定在现场对裂纹围带进行现场更换。更换方法是取下有裂纹的围带,把叶片顶部的铆接头向下磨削,换上新的围带后,用冲击捻打铆钉头。铆钉头的捻打有较高的工艺要求,铆钉头与围带的间隙符合不可过大,同时铆接用力不可过大,否则会引起铆钉头应力过大或产生裂纹。重新铆接后转子的频率变化不大,因而问题并没有从根本上得到解决。

表 3 第 18 级叶片组静频实测值 (Hz)

编号*	第 18 T 级	组内片数	裂纹位置**	第 18 G 级	组内片数	裂纹位置
1	302.5	7		298.7	7	
2	320.0	8		317.5	8	
3	320.0	8		317.5	8	
4	303.7	8	4	317.5	8	
5	303.7	8	4	305.0	8	5
6	317.5	8		305.0	8	5
7	317.5	8		312.5	8	
8	315.0	8		300.0	8	5
9	315.0	8		302.5	8	5
10	317.5	8		315.0	8	4、5、6
11	317.5	8		305.0	8	4
12	295.0	8	5	300.0	8	
13	316.2	8		315.0	8	
14	320.0	8		315.0	8	
15	320.0	6		312.5	6	

* 叶片锁位销为第一组 机头向机尾看, 顺时针编号。
* * 裂纹位置以组内叶片序号标记, 方向同上。

更换围带会使转子产生动平衡问题,为此进行了初步校正,在发电机侧20级处68°方向加装一块73 g配重块。启动后根据机组状况未作调整。

对轴系标高和叶栅围带进行处理后,大修后首次启动机组振动情况良好。

机组首次冲转,在1 200 r/min暖机时,2号瓦轴振由0.029 mm缓慢升至0.19 mm,打闸停机后机组盘车运行2 h,再次冲转后2号瓦振动值稳定在0.03 mm以下。机级3 000 r/min时,各瓦轴振动值如表4。1号~4号瓦见图1,5号、6号为发电机两端轴承,7号、8号为励磁机两端轴承。以后的机组大负荷运行,其振动情况良好。

表 4 机组启动振动情况 (mm)

	1号	2号	3号	4号	5号	6号	7号	8号
3 000 r/min	0.32	0.037	0.033	0.032	0.033	0.041	0.083	0.018
100 MW	0.010	0.015	0.027	0.023	0.036	0.037	0.066	0.019

为了从根本上防止 18 级围带产生裂纹, 叶栅需要进行调频。为把切向 A_0 型振动频率调开第一类激振力频率, 一般采用在围带、叶片连接处加焊; 改变叶片成组的叶片数; 在叶片中心钻减荷孔等。对于本机组, 不宜采用改变叶片成组数的方法, 因为从表 3 分析, 叶栅的频率同组内叶片数没有明显的对应关系, 而且理论上在组内叶片到达 6 片后, 增加组内叶片数对频率的增加并不明显。在叶片中心钻孔工艺要求高、风险大。而在围带、叶片连接处加焊则简单而有效。8 片组叶栅存在不同的振动频率说明叶栅的安装质量并不稳定, 而围带更换前后叶栅频率的微小变化说明现场围带的更换对叶栅的安装质量并没有提高。理论分析和实践证实, 提高安装质量对叶片组的自振频率有很大影响。当连接刚性系数相差 0.2 时, 叶片组的切向 A_0 型振动频率相差 10%~20%。为提高安装质量, 对频率偏低的叶栅在围带和叶片连接处加焊是行之有效的方法。烧焊时应将焊接处清洗干净, 焊透焊牢, 焊接温度不可过高, 否则可能使材料变质以及产生较大的残余应力。

4 其它问题

大修过程中, 还发现其它问题, 主要有高压缸调门裂纹、高中压外缸间隙较大等。

机组解体后发现高压缸 1 号、3 号调门阀芯有裂纹。进行了整体更换处理。高压外缸作严密性检查时, 发现左侧 27 号~29 号、右侧 28 号~30 号螺栓之间各有 0.50~0.60 mm 左右的间隙。在螺栓把紧三分之一的情况下左侧 27 号~29 号螺栓处之间间隙为 0.10 mm。右侧 28 号~30 号螺栓之间间隙为 0.07~0.10 mm。经研究认为这种间隙可不进行中分面研刮, 回装热紧螺栓时把上述有间隙的两个地方螺栓伸长量取大值(0.73 mm)。运行中没有漏汽情况发生, 说明处理的措施是有效的。

这次大修问题的出现也给目前提出的状态检修课题提供了新的思路, 状态检修不仅仅要分析机组的故障征兆, 更要掌握机组的特性, 历史统计特征。这台机组调门裂纹、围带裂纹几乎没有任何征兆, 如果没有积极主动的定期检修, 酿成重大事故并不是没有可能的。

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(何静芳 编辑)

新 机 组

S109H 即将投入运行

据《Gas Turbine World》2001 年 11—12 月号报道, 被设计作为具有 1430 °C 级涡轮进口温度的蒸汽冷却电力生产技术全球陈列窗口的 S109H 型联合循环装置将于 2002 年夏天在威尔士地区塔尔博特港巴格兰湾电站投入运行。

该电站使用 1 台 S109H 型单轴联合循环装置, 以 1 台蒸汽冷却的 MS9001H 作为动力源。以天然气作为燃料, S109H 基本负荷额定输出功率为 480 MW, 热效率为 60%, 从而使它成为迄今为止世界上第一型单机功率最大、热效率最高的联合循环装置。

MS9001H 型燃气轮机长 12 m, 直径 5 m, 重 370 t, 以联合循环运行时能生产 480 MW 电力。

蒸汽冷却转子的技术是 GEPS(通用电气动力系统)公司于 1995 年推出的创新技术。在发运到南威尔士前, 第 1 台 MS9001H 燃机于 1998 和 1999 年在美国南卡罗来纳州格林维尔市经受了广泛的试验。

使用先进的材料和创新的蒸汽冷却系统, 使 MS9001H 能够在更高的涡轮进口温度(1430 °C 级)和压比(23:1)下运行, 从而保证了 S109H 的热效率突破 60% 大关。

(思娟 供稿)

duct has been fitted with flow-guide blades. Owing to the low intensity of the secondary flow and its small change along the ducts the flow condition has been improved. **Key words:** turbulent flow, large eddy simulation, flow field, finite element method, curved duct flow, flow-guide blade

确定船用蒸汽动力装置辅机余度系数的新方法 = **A New Method for Determining the Redundancy Factor of Auxiliary Machines for a Marine Steam Power Plant** [刊, 汉] / SHU Li-wei, JIN Jia-shan (Naval Engineering University, Wuhan, China, Post Code: 430033), JI Guang (Military Representative Office Stationed at Harbin Steam Turbine Works, Harbin, China, Post Code: 150046) // Journal of Engineering for Thermal Energy &Power. — 2002, 17(5). — 514~516

With a turbine-driven feedwater pump serving as an example discussed is a method for determining the rated performance-based redundancy factor of auxiliaries for a marine steam power plant. The method under discussion takes into account in a comprehensive way several factors. They include: the discrete character of equipment rated performance during its manufacture, the degeneration mechanism of the rated performance with the passage of usage time, the discrete character as demanded of the equipment, etc. With performance-reliability serving as an objective the redundancy factor can be determined in a more rational way. This may provide guidance for the design of the thermodynamic system of a marine steam power plant as well as the type selection of other similar equipment items. **Key words:** performance reliability, degeneration, redundancy factor, marine steam power plant, turbine-driven feedwater pump

自动可调浓淡燃烧器低负荷稳燃特性 = **Low-load Stable Combustion Characteristics of an Automatic-adjustable Bias-combustion Pulverized-coal Burner** [刊, 汉] / LI Yong-hua, CHEN Hong-wei (North China Electric Power University, Baoding, China, Post Code: 071003), LIANG Hua-zhong, et al (Shandong Luneng Development Company, Jinan, China, Post Code: 250000) // Journal of Engineering for Thermal Energy &Power. — 2002, 17(5). — 517~520

A new type of automatic-adjustable bias-combustion pulverized-coal burner is presented along with its service conditions in a power plant. The results of its operation has shown that the burner features an ability to regulate the distribution of air and pulverized coal during boiler operation, thus achieving the aim of operating at a drastically reduced load. **Key words:** burner, boiler, load

300 MW 机组 UP 型直流锅炉变压运行探讨 = **An Exploratory Study of the Variable-pressure Operation of an UP-type Once-through Boiler for a 300MW Unit** [刊, 汉] / KUANG Jiang-hong (College of Mechanical Engineering under the Shanghai University of Engineering &Technology, Shanghai, China, Post Code: 200336) // Journal of Engineering for Thermal Energy &Power. — 2002, 17(5). — 521~523

Through a thermal calculation and analysis investigated are the operating characteristics of a UP-type once-through boiler and its feedwater pumps during its variable-pressure and peak-shaving operation. The authors concluded that a Chinese-made 300MW unit employing UP type once-through boilers basically possesses the ability to conduct a variable-pressure and peak-shaving operation. **Key words:** peak shaving, variable-pressure operation

TCDF-33.5 型 300 MW 汽轮机首次大修中的故障处理 = **Fault Treatment during the First-time Overhaul of a Model TCDF-33.5 300 MW Steam Turbine** [刊, 汉] / ZHANG Cai-wen, HUANG Hai-zhou, WANG Shu-shen (Hubei Provincial Electric Power Testing Research Institute, Wuhan, China, Post Code: 430077) // Journal of Engineering for Thermal Energy &Power. — 2002, 17(5). — 524~526

Described are the following main faults detected during the first-time overhaul of a model TCDF-33.5 300MW steam tur-

bine; the change of shaft system elevation and cracks in blade shrouds. The underlying causes of the above faults are briefly analyzed with on-site treatment measures and proposals for further improvement being presented. As in China there exist many units of the above model, the information provided by the authors may serve as helpful reference data during their maintenance and overhaul. **Key words:** steam turbine, maintenance and overhaul, fault treatment

W 型火焰锅炉结渣分析及对策 = Analysis of the Slag-formation in a W-shaped Flame Boiler and Measures Taken for its Alleviation [刊, 汉] / YANG Xiong-wen (Huaneng Yueyang Power Plant, Yueyang, Hunan Province, China, Post Code: 414002) // Journal of Engineering for Thermal Energy & Power. — 2002, 17(5). — 527 ~ 529

Serious cases of slag-formation may occur in W-shaped flame boilers owing to the change of types of coal being fired. Taking into account the specific features of the above-cited boiler and based on a relevant combustion theory and the test results of optimized combustion the authors have adjusted the control parameters of boiler combustion, breaking away from certain traditional ideas prevalent in the field of boiler combustion control. Such an adjustment has brought about some satisfactory results. **Key words:** slag formation, W-shaped flame, combustion

SHW4.2-0.7/115/70 锅炉改为 SHW4.2-0.7/95/70 技术特性及经济性分析 = Analysis of Technical Characteristics and Cost-effectiveness in Connection with the Modification of Model SHW4.2-0.7/115/70 Boiler into a Model SHW4.2-0.7/95/70 Boiler [刊, 汉] / XU Chuan-zhao, LIU Feng-ling, ZHAO Bo-yu, et al (Harbin Boiler Inspection Institute, Harbin, China, Post Code: 150076) // Journal of Engineering for Thermal Energy & Power. — 2002, 17(5). — 530 ~ 532

In connection with the modification of a Model SHW4.2-0.7/115/70-AII hot-water boiler into a Model SHW4.2-0.7/95/70-AII hot-water boiler the technical characteristics and cost-effectiveness of the boilers are analyzed. This has been followed by the adoption of some measures aimed at the saving of energy and financial resources as well as the enhancement of boiler thermal efficiency. **Key words:** low-temperature hot-water boiler, hydrodynamics, thermodynamic performance, flue gas speed

电厂输煤皮带落煤点吸尘装置的改进与实践 = The Improvement of a Dust Collecting Device at the Coal Dropping Point of a Power Plant Coal-transport Belt [刊, 汉] / LU Tai, SHA Peng, WANG Gui-ling, et al (Power Engineering Department, Northeast Electric Power Institute, Jilin, China, Post Code: 132012) // Journal of Engineering for Thermal Energy & Power. — 2002, 17(5). — 533 ~ 535

Analyzed are the major problems currently existing in a dust collecting device located at the coal dropping point of a thermal power plant coal-transport belt. Several measures aimed at the enhancement of dust collecting efficiency are proposed along with a description of their actual service effectiveness. **Key words:** coal transport belt, seal, dust remover, negative-pressure air fan

大型往复炉排运行故障分析及排除措施 = An Analysis of Operating Failures of Large-sized Reciprocating Boiler Grates and an Exploration of Measures for Their Elimination [刊, 汉] / WANG Yu (Harbin Hongqi Boiler Works, Harbin, China, Post Code: 150080) // Journal of Engineering for Thermal Energy & Power. — 2002, 17(5). — 536 ~ 538

With regard to the operating failures occurring in reciprocating boiler grates of a capacity ranging from 10 t/h to 65 t/h an analysis was performed from various aspects, such as material selection and structural design, etc. On this basis some measures were proposed to eliminate such failures. In addition, an exploratory study was conducted to reduce the weight of boiler parts and components. **Key words:** reciprocating boiler grate, failure, material quality, design