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工业汽轮机增容改造技术研究

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摘　要: 介绍了 EC－301T 汽轮机增容 15% 额定功率而进行的改造。通过保留原有转子, 仅改变喷嘴箱、隔板、阀门及联轴器等部件。实现了汽轮机的增容。

关　键　词: 汽轮机; 增容

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1　引言

1.1　机组情况

大修中发现该汽轮机部分喷嘴出汽边有不同程度的冲刷磨损, 并逐年趋向严重, 第四级隔板因变形较大, 与汽轮机转子叶轮进气侧端面严重擦伤磨损, 曾在前次大修时更换了第四级隔板, 但运行后该级隔板同样出现变形问题。此外, 正常运行工况时汽轮机的轴向位移保护装置经常处于报警值, 严重时被迫降负荷运行。同时还存在机组出力不足等问题。

1.2　改造目标

应厂家需求对汽轮机组通流部分进行技术改造, 提高汽轮机的功率, 使汽轮机组的轴端额定输出功率由 20.79 MW 提高到 24 MW。

2　汽轮机增容改造的方案论证

2.1　进行现场的仔细测绘

2.2　核算原汽轮机的强度和热力性能核算结果如下:

机组发出的功率在 19～20.4 MW 之间, 验证了在机组改造前运行参数条件下, 机组已经发出了接近原设计 20.79 MW 的额定功率。

机组第四级隔板前后压差达 1.55 MPa(15.85 kgf/cm^2), 隔板的计算挠度值达 3.33 mm。由此可见原设计的第四级隔板应力及挠度偏大才导致隔板的严重变形。

2.3　技术改造方案

根据多方案比较优选的结果, 采用的方案是: 只需改造更换第一级喷嘴箱、第二至七级隔板, 调节抽汽阀(V2 阀)和三套联轴器。由于此方案不改造转子, 使价值数百万元的在用转子和备用转子依旧可以使用; 改造静子造价低, 使改造费用大幅度降低。由于转子结构不改变, 转速不变, 因此由离心力引起的应力保持不变; 虽然增大功率所需的蒸汽流量也相应增加, 但各级叶片的蒸汽弯曲应力及转子轴径的扭应力, 仍均在设计规范要求范围内。

3　通流部分增容改造的施工设计

3.1　热力设计

在保证通流部分安装间隙, 转子和冷凝器不作任何改动的情况下, 汽轮机增容 15%额定功率。

在诸多因素限制的条件下, 增加功率就是设法增加流量即增大通流面积。在设计中采用两个途径: 第一, 静叶在允许的动叶超高限定范围内, 适当增加高度; 第二, 在部分进汽度进汽的隔板中, 增大部分进气度, 对全周进汽的隔板则适当增大静叶出口角度(该角度增加在叶型性能允许范围内)。在热力设计中, 对汽轮机各级焓降重新作了合理的分配, 使原第四级隔板压差过大的问题得到解决。由于流量的增大、叶片出口角的增大, 导致了轴向推力的增大。在设计中通过调整级内反动度及控制静叶叶根反动度的方法, 使轴向推力尽可能减少增加量, 保证了推力轴承负荷在允许的范围内。

3.2　强度与结构设计

机组第一级喷嘴室和第三级调节抽汽隔板采用 20CrMoV 耐高温铸钢材料, 第二、四、五、六、七级的隔板体均采用 15CrMoA 铸件, 第一级喷嘴均采用 Cr11MoV 耐热不锈钢材(原设计第一级喷嘴经化学成分分析为铬不锈钢)。

原设计的隔板是带内外围带的焊接隔板, 改造后的上述诸级隔板为整锻铣制的装焊隔板, 即在整锻板体上的进汽侧端面上铣制出加强筋和进汽道,

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静叶片直接镶装在出汽侧的槽道内再与板体焊牢，从而使隔板的结构刚度得以提高。此外，在通流部分的轴向间隙许可下，还适当增加了隔板的厚度，使得改造后的隔板静挠度和工作应力均小于原机组设计值。

机组第三级调节抽汽阀(V2)的技术改造：通过理论计算及阀门台架试验，第一是获得了流量系数曲线，以计算阀门的气动特性；第二是获得了提升力系数曲线，用以正确计算阀门的提升力。改造后的V2 阀压损与原阀相当，阀门提升力满足了原机调控系统的要求。

原机的三段联轴器，在历次检修中均发现无键锥面过盈联接处有相对滑移现象，即在锥轴锥面上发现明显擦伤。经复核计算，原设计安全系数偏小，为了在改造中解决此问题，经过台架试验及精确计算，确定了严格的安装要求和新的过盈等参数，增加了联接传扭能力，确保了增容后的可靠性。

在热力设计的基础上，对汽轮机进行了全面的强度计算，计算结果表明，改造后的汽轮机强度、振动均在安全范围内。

经过施工设计，实现了在保证机组安全可靠运行的条件下，机组功率增大到 24 MW(见表 1)。

表 1 机组改造前后主要性能指标

序号	名 称	符号	单位	设计结果		
				改造后	原计算	改造后按原工况运行
1	额定功率	N_T	MW	24	20.792	
2	额定转数	n	r/min		5223	
3	调节阀前压力	P_0	MPa		9.6(表压)	
4	调节阀前温度	t_0	℃	491	495	491
5	高压段流量	G_0	t/h	173	154	154
6	抽汽压力	P_z	MPa		4.32	
7	抽汽流量	G_z	t/h		95	
8	高压段内功率	N_1	MW	7.978	7.233	6.974
9	高压段内效率	内 η_1	%	73.3	~73 5	72 8
10	低压段流量	G_L	t/h	78	59	59
11	排汽压力	P_2	MPa	0 018 64	0.011 87	0.013 73
12	排汽干度	X		0.893		0.889
13	低压段内功率	N_2	MW	17.185	13.886	13.729
14	低压段内效率	η_2	%	81	~82	80
15	机组内功率	N	MW	25.163	21.120	20.702
16	机组有效功率	N_0	MW	24.000	20.792	20.357
17	机组绝热焓降	H_a	kJ/kg	1 197.425	1 241 4	1 233
18	机组有效焓降	H_1	kJ/kg	963.38	1 013 2	9 885.0

4 原设计和运行中存在的问题及解决

第一级喷嘴出汽边冲刷磨损严重，因此对原机组喷嘴进行了分析试验，改进设计更换成新的喷嘴；对喷嘴流道作了改进；对喷嘴材质提高了机械性能，并作了表面处理(渗氮)，增强了抗冲刷磨损等综合性能。

原设计机组第四级隔板变形，曾发生与第四级叶轮接触磨损。经复核计算，原机隔板最大理论计算挠度值为 3.33 mm，经技术改造后新隔板在设计制造上增强了结构刚度，计算挠度值为 2.19 mm，台架实物试验挠度值为 1.75 mm。经过二次检修期(45 000 小时运行)的检测未发现隔板残余变形。

原机组轴向位移偏大，经常处于报警值。通过对机组安装运行的分析，查明了引起轴向位移值过大的原因。为减小轴向推力，对改造设计通过热力计算进行了多方案的最佳选择，并在安装隔板时，精确地校准了安装中心，使隔板汽封实际运行的间隙减小。此外，调整了推力轴承间隙，减小了转子轴向位移的空行程。经实践验证，采取上述技术措施后，六年来汽轮机的轴向位移值均在原设计范围内。因此解决了多年来轴向位移过大的难题。

5 结论

(1) 以不改变转子结构的前提下，仅只在静子上作一定量的改动，对工业汽轮机进行的增容技术改造是成功的。由于保留原转子的应用，节省了数百万元的资金。

(2) 在技术改造中，对静子的改造以改变通流设计的方法，能够纠正原机组设计中的某些设计缺陷。

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An experimental study was conducted of the nozzle button temperature distribution on a fluidized bed test facility under start-up conditions with the under-bed ignition being carried out with the help of high-temperature gases. The heat resistance of the material used for the nozzle button is also assessed. In view of the increasing use of under-bed ignition mode for the start-up of fluidized bed boilers the above study is of great significance in providing guidance for practical engineering applications. **Key words**: temperature distribution, nozzle button, fluidized bed

压气机进气用雾化式蒸发冷却器实验研究= **Experimental Study of a Fog-atomizing Evaporative Cooler for Compressor Inlet Air** [刊, 汉] / Lin Feng, Li Weishun, Xiao Dongmin, Wen Xueyou (Harbin No. 703 Research Institute, Harbin, China, Post Code 150036) //Journal of Engineering for Thermal Energy &Power. —2000, 15(3). —256~259

From an experimental viewpoint a study has been performed of evaporative coolers for the cooling of compressor air. Discussed are some methods for measuring the wetness of water drop-containing air. With respect to different schemes of wetness addition by way of evaporation at a constant temperature the authors have investigated the effect produced by different water spray quantity on the evaporative cooling effectiveness. An experimental analysis is also conducted of the evaporative cooling effectiveness resulting from the different types of atomizing nozzles under different spray directions. **Key words**: compressor, inlet air cooling, heat transfer, mass transfer, evaporative cooler

中心进气旋转盘的冷却效果实验研究= **Experimental Study of the Cooling Effectiveness of a Rotating Disc with a Central Cooling-air Feed** [刊, 汉] / Xu Guoqiang, Ding Shuiting, Tao Zhi, *et al* (Power Engineering Department under the Beijing University of Aeronautics and Astronautics, Beijing, China, Post Code 100083) //Journal of Engineering for Thermal Energy &Power. —2000, 15(3). —260~263

With regard to the cooling of turbine engine high-temperature components it is essential to meet the following main requirements: a minimal overall temperature of the hot components and a minimal temperature difference within the various parts of the hot components. In view of the foregoing one has to address the above-cited main requirements in addition to the study of convection heat transfer factor of the disc surface. In the present paper an engine turbine disc has been simplified to a rotating disc model with a central cooling-air feed. Under this simplification an experimental study is conducted of the effect of rotating Reynolds number, air inlet Reynolds Number, disc cowl clearance ratio and outlet air clearance ratio on the non-dimensional excessive body average temperature and non-dimensional radial temperature difference. In addition, a relevant criterion relation has also been given in the paper. **Key words**: rotating disc, heat exchange, non-dimensional excessive body average temperature, non-dimensional radial temperature difference

新型双流化床锅炉运行煤种变换仿真试验研究= **Experimental Study of the Simulation of Fired-coal Rank Variation for a New Type of Double Fluidized-bed Boilers** [刊, 汉] / Zhao Jian, Suo Yisheng, Jiang Zikang, *et al* (Department of Thermal Engineering, Qinghua University, Beijing, China, Post Code 100084) //Journal of Engineering for Thermal Energy &Power. —2000, 15(3). —264~266, 271

A general mathematical model has been set up for a circulating double fluidized-bed boiler. On this basis a simulation test of the fired-coal rank variation was performed as a new pioneering attempt in the area of fluidized-bed boiler simulation. The results obtained can serve as useful information and data for the design and operation of fluidized beds, providing guidance for their further advancement. **Key words**: simulation, test, fluidized bed, coal

工业汽轮机增容改造技术研究= **Technical Study of a Power Output Uprating-oriented Modification of Industrial Steam Turbines** [刊, 汉] / Qin Xiaocheng, Gao Lei, Qiu Zufa (Harbin No. 703 Research Institute, Harbin, China, Post Code 150036) //Journal of Engineering for Thermal Energy &Power. —2000, 15(3). —267~268

Described in this paper is the technical modification of a Model EC-301T steam turbine for enhancing its rated power output by 15%. The power uprating of the steam turbine has been achieved through a technical modification of such components as nozzle box, diaphragms and couplings, etc. However, the steam turbine rotor has been kept unchanged. **Key**

words: steam turbine, power output uprating

应用于 PRSTIG 循环化 SIA－02 燃气轮机组上的喷射器＝**An Ejector Used for the Model SIA-02 Gas Turbine Unit of a Partial Regeneration Steam Injected Gas Turbine (PRSTIG) Cycle** [刊, 汉] / Wen Xueyou, Lu Ben (Harbin No. 703 Research Institute, Harbin, China, Post Code 150036) // Journal of Engineering for Thermal Energy & Power. －2000, 15(3). －269 ~271

A major constituent element of a partial regeneration steam injected gas turbine (PRSTIG) cycle system, the ejector was designed in adaptation for a model SIA-02 small-sized gas turbine. An analysis of the ejector design is also presented in the paper. **Key words**: partial regeneration steam injected gas turbine cycle, steam injected gas turbine cycle, ejector

油田射孔器材试验装置加热系统的数学模型与仿真分析＝**Mathematical Modeling and Simulation Analysis of the Heating System of an Oil Field Perforation Equipment Test Rig** [刊, 汉] / Liu Cuiling, Wang Zicai, Sun Xingbo *et al* (Simulation Technology Research Center under the Harbin Institute of Technology, Harbin, China, Post Code 150001) // Journal of Engineering for Thermal Energy & Power. －2000, 15(3). －272 ~275, 283

Based on the technical requirements of a perforation equipment test rig concerning its ability to bear high-temperature and high-pressure, the authors have designed a well-type dual-circulation electric heating furnace. A mathematical model of the heating-furnace heat transfer process has been set up. By way of simulation an analysis was conducted of the effect of the heating system process parameters on the temperature field profile along the flow path of the furnace. Such an analysis plays a significant role in providing guidance for high-precision control and prediction of the oil temperature in the heating system. The validity of the mathematical model has been verified by the actually measured results. **Key words**: heat transfer, mathematical model, heating furnace, temperature field, simulation

锅炉过热器系统的动态仿真模型＝**Dynamic Simulation Model for a Boiler Superheater System** [刊, 汉] / Chen Xiaodong, Wang Zicai (Simulation Technology Research Center under the Harbin Institute of Technology, Harbin, China, Post Code 150001) // Journal of Engineering for Thermal Energy & Power. －2000, 15(3). －276 ~277, 297

As a mechanism model can hardly reproduce the complicated dynamic characteristics of a boiler superheater system, the authors have come up with a new modeling method. The proposed method consists in taking the mechanism model as a main guide and supplementing it with an on-line correction through the use of a dynamic neural network. The results of simulation indicate that such a model building method can provide an ideal approach for the dynamic simulation of a huge complicated system. **Key words**: boiler, superheater, simulation, model building method

汽轮机本体分段式通用模块化建模与仿真＝**Modeling and Simulation of a Steam Turbine Proper through the Use of a Sectionalized General-modularization** [刊, 汉] / Zhu Wei, Jiang Zikang, Cheng Fangzhen, *et al* (Department of Thermal Engineering, Qinghua University, Beijing, China, Post Code 100084) // Journal of Engineering for Thermal Energy & Power. －2000, 15(3). －278 ~280, 293

Described in this paper is the modeling of a steam turbine proper with the help of a sectionalized general-modularization. Furthermore, with a model C50-90/13 steam turbine being selected as an example, simulation results are given of the steam turbine under various operating conditions and pertinent analyses were also performed. Currently, the above-cited model has been successfully employed for an actual simulation object. Featuring a relatively high precision and versatility in engineering applications, it is suited for simulating steam turbines under various operating conditions. **Key words**: steam turbine, simulation, general modularization, modeling

二次风喷射角度对切向燃烧炉膛出口烟气流量偏差的影响＝**The Effect of a Secondary Air Injection Angle on the Deviation of Flue Gas Flow Rate at a Tangentially Fired Furnace Outlet** [刊, 汉] / Zhao Yuan, Dong Peng, Qin Yukun, *et al* (College of Energy Science and Engineering under the Harbin Institute of Technology) // Journal of Engineering for Thermal Energy & Power. －2000, 15(3). －281 ~283

In a tangentially fired large-sized boiler there generally occurs a common phenomenon of flue gas flow deviation on the