

船用汽轮机冷态启动过程中热膨胀的研究

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摘 要: 应用 ANSYS 软件建立船用汽轮机缸体和转子三维模型, 进行了冷态启动过程中的热膨胀分析计算, 给出了汽缸和转子在慢速级组、全速级组、后轴端汽封随时间变化的热膨胀位移曲线和相对热膨胀曲线。计算结果可用于汽轮机动态特性研究、启动程序设计。

关 键 词: 船用汽轮机; 热膨胀; 冷态启动

中图分类号: TK262 文献标识码: A

1 前 言

文中研究了船用汽轮机缸体和转子在冷态启动过程中的热膨胀变化。缸体和转子的相对膨胀差量过大易造成汽封的磨损和动静部件碰摩, 不仅会降低机组的效率, 影响机组出力, 同时也危及机组安全运行。影响相对膨胀量主要因素是船舶的启动时间长短、启动程序的合理性和汽缸结构及汽封的设计。船舶的冷态紧急启动时间长短, 影响舰船的机动性能, 一般规定冷态紧急启动时间应不超过 20 min。启动时间越短, 机动性能越好, 但启动速度越快温度场越不均匀, 会引起较大的温度梯度, 随之产生较大的热应力和热变形。启动程序编制的不合理也会加大温度梯度, 汽缸的结构设计与热变形也有直接关系, 如果汽缸设计不合理就易于产生较大的翘曲热变形, 尤其是排气缸部分, 破坏轴系的对中造成机组的振动, 汽缸热应力过大也容易发生永久性的塑性变形; 汽封齿间的距离的大小及相对位置是保证汽封齿的重要因素。所以热膨胀的研究对于缩短启动时间, 完善汽封结构设计具有重要意义。

建立了高压缸三维网格模型, 确定了其合理的边界条件, 利用 ANSYS 进行了瞬态的温度场、应力场和动、静部件相对膨胀量计算, 计算结果可应用到机组启动程序设计、汽轮机动态特性研究和汽封的

设计中。对提高汽轮机可靠性、机动性和经济性具有重要作用。

2 汽轮机模型

汽轮机的缸体和转子的相对固定位置为前端的推力盘处; 转子模型是从前端的推力盘到后端的支撑轴承。汽缸是以子午面为对称结构, 简化为原汽缸的一半^[1], 上下汽缸中分面法兰设为一体结构。转子和汽缸的结构比较复杂, 在划分网格时采用四面体单元, 如图 1 和图 2 所示。

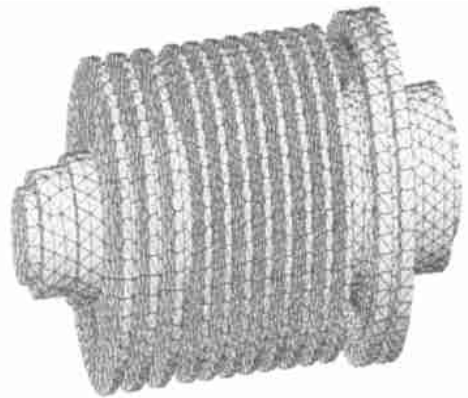


图 1 转子有限元模型图

3 边界条件

3.1 热边界条件

- (1) 缸体的外壁按绝热处理;
- (2) 缸体的内壁和转子按第三类边界条件给定, 给出蒸汽的温度和对流换热系数;
- (3) 工作介质为过热蒸汽, 每一处的蒸汽温度都是按该机组的热力计算书给定。

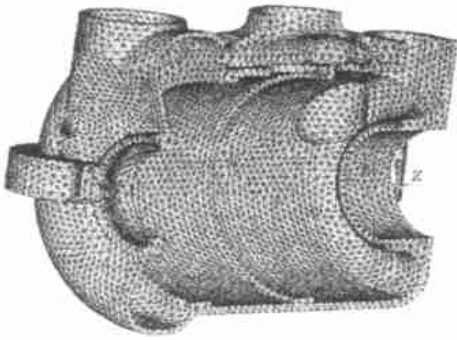


图 2 高压缸有限元模型图

3.2 对流换热系数

3.2.1 汽缸与蒸汽的放热系数

按文献 [2] 给出的方法计算。

3.2.2 转子和汽流的换热系数

(1) 轮盘外圆柱面与汽流的换热系数:

$$\alpha = \frac{1}{\frac{1}{\alpha_{pp}} \frac{R_p}{R_d} + \frac{R_p}{\lambda_d} n \ln \frac{R_b}{R_p}}$$

(2) 汽流与轮面的放热系数:

$$\alpha = \frac{Nu_0 \lambda_c}{R_b}$$

当 $Re < 2.4 \times 10^5$ 时, $Nu_0 = 0.675 Re^{0.5}$

当 $Re \geq 2.4 \times 10^5$ 时, $Nu_0 = 0.0217 Re^{0.8}$

$$Re = \frac{u R_b}{\nu}$$

其中: u 为外圆 R_b 处的圆周速度; R_b 为外圆半径。

(3) 对于无汽封段的光轴, 汽流与轴表面的放热系数:

$$\alpha = \frac{Nu \lambda_c}{R_a}$$

$$Nu = 0.1 Re^{0.68}$$

$$Re = \frac{u R_a}{\nu}$$

其中: u 为光轴外半径 R_a 处的圆周速度, m/s; R_a 为光轴外半径。

3.3 位移边界条件

取垂直汽缸子午面方向的位移为零。

4 计算结果

文中对船用汽轮机缸体和转子进行了温度场和应力场计算, 计算方法主要参照文献 [1] 的实验数

据。图 3~图 5 为计算结果, 在这 3 个图中分别给出了后轴端汽封、低航速级组和全航速级组自启动到全工况时轴向热膨胀位移曲线和动、静相对膨胀量。

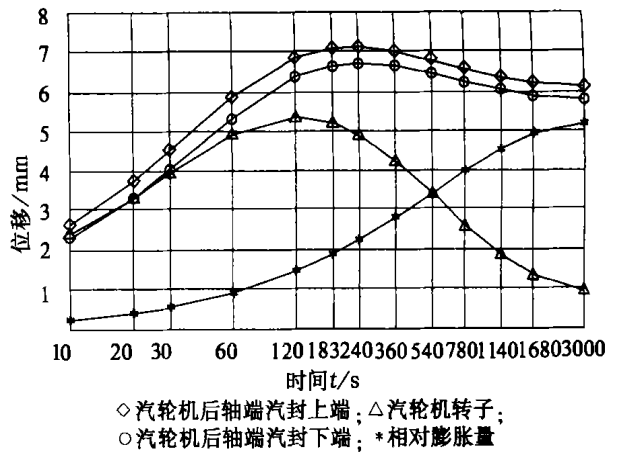


图 3 全航速工况汽轮机后轴端汽封轴向热膨胀位移曲线

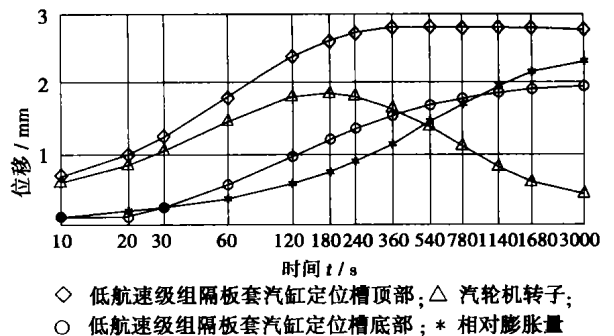


图 4 全航工况汽轮机低航速级组轴向热膨胀位移曲线

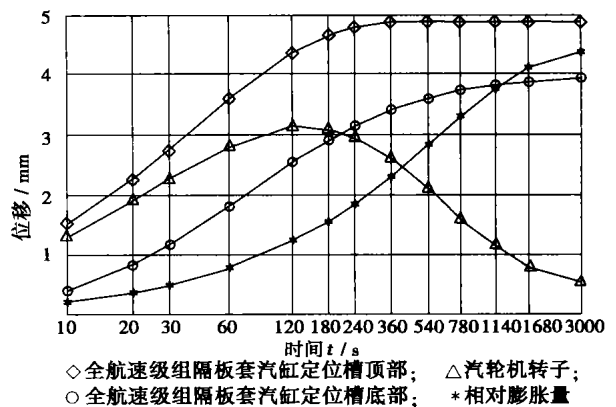


图 5 全航速工况汽轮机全航速级组轴向热膨胀位移曲线

图3是全航速工况汽轮机后轴端汽封上下端、同一轴向位置处转子热膨胀量及相对膨胀量随启动时间的曲线,后轴端汽封上下端最大的轴向位移是出现在第240s;后轴端汽封和转子的最大相对膨胀量为5.38mm,出现在启动后第120s。

图4中低航速级组相对最大膨胀量为1.87mm,出现在启动后第120s。低航速级组隔板套汽缸定位槽顶部在启动后第540s轴向位移趋于稳态。

图5中全航速级相对最大膨胀量为3.14mm,出现在启动后第120s。全航速级组隔板套汽缸定位槽顶部在启动后第540s轴向位移趋于稳态。

5 结果分析

由上述计算结果看出汽缸上半热膨胀量较汽缸下半大,这是由于上半有内旁通、进汽管和排汽管,温度相对上升比较快,上半汽缸高于下半汽缸温度,这种上、下温差引起了上下缸热膨胀的不同步,造成了隔板套和汽封环的倾斜,随着时间的变化温差在增加,隔板套和汽封环的倾斜程度也在加大,当温差达到最大时倾斜度也达到最大。汽缸热膨胀和转子热膨胀也不同步,由于汽缸壁厚度较小温度上升较快,热膨胀也较快;而汽轮机转子是刚性的,直径较大热容量较大,温度上升较慢,热膨胀速度也较慢。汽缸和转子产生了一定的胀差,刚开始时这种胀差

随着时间变化而增加,当汽缸和转子温度上升速度相同时即热膨胀速度相同时胀差达到最大,随即胀差在减小。如果汽封齿之间的间距设计不合理,必然造成汽封的损坏。

在图3中,汽轮机后轴端汽封上下端在第240s时轴向位移出现了一个峰值,这主要是因为开始时,排汽涡壳内壁温度上升较快,外壁温度相对较低,造成内壁热膨胀量大于外壁,外壁受拉应力,内壁受压应力,使得排气缸向外伸展变形,造成后轴端汽封轴向位移量加大,随着内外壁温差逐渐减小,外壁承受的拉应力和内壁承受的压应力变小,排气缸向外伸展变形量也变小,后轴端汽封向内收缩,收缩量大于缸壁热膨胀量,后轴端汽封总位移还是向内收缩,所以在图3中出现了一个峰值。设计和启动程序都应注意尽量降低这个峰值。

从动、静部件相对热膨胀位移曲线可得出:当机组正常启动50min后,汽轮机动、静部件差胀趋于稳定。当然,改变启动方式或启动程度时,动、静部件相对热膨胀位移曲线会发生相应变化,从中可以制定合理的启动程序。

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(渠源 编辑)

燃气轮机温度测量的新系统

据《Diesel & Gas Turbine Worldwide》2002年7—8月号报道,美国纽约州的布法罗市Conax Buffalo Technologies (CBT)多年来一直是航改型和重型结构燃气轮机传感器及相关安装连接件的供应者。随着燃气轮机技术逐渐向更高温度、更低排放和经常频繁的周期性变化发展,精确测量温度的必要性也日益增加。

当前, CBT已开发出用于燃气轮机高温燃气通路测量的基于光纤的传感器系统。光纤温度传感器系统由在探头套内的传感元件、光纤电缆和光电信号处理器组成。传感器技术是基于热辐射,在光辐射材料被燃气流加热,从而产生热辐射。光能向下传递给支承在探头套内的蓝宝石光控制件。绕性光纤把热辐射传递给信号器,并将其转变成与探头端部温度对应的数值。

光纤传感器探头元件安装在燃气轮机第一级涡轮进口,并且系统被设计成测量正好在燃烧室下游的燃气温度。基于光纤的系统不受校准漂移的影响,也不受热冲击和热循环的影响。

(吉桂明 供稿)

calibration standard difference of the model is 1.41. **Key words:** near infrared spectrum, coal rank, on-line monitoring, volatile content

微燃烧器内甲烷催化燃烧的数值模拟 = **Numerical Simulation of Catalytic Combustion of CH₄ in a Micro-burner** [刊, 汉] / ZHONG Bei-jing, HONG Ze-kai (Engineering Mechanics Department, Tsinghua University, Beijing, China, Post Code: 100084) // Journal of Engineering for Thermal Energy & Power. — 2003, 18(6). — 584 ~ 588

By making use of software CHD FLUENT and chemical reaction dynamics software DETCHEM a numerical simulation was conducted of the catalytic combustion of a mixture of CH₄ and air in a micro-burner featuring counter-flow heat exchange. During the calculations only the reaction of CH₄ on a catalytic surface has been taken into account. The stoichiometric ratio of fuel-air mixture is 0.4. Isothermal boundary condition and ambient convection heat-exchange boundary condition have been adopted for the burner outer wall surface. The impact of these two kinds of boundary condition on the burning of combustible fuel-air mixture was compared. Calculation results show that catalytic combustion has made it possible to realize the low-temperature and high-efficiency conversion of CH₄, which cannot be carried out by a conventional method.

Key words: micro-burner, catalytic combustion, numerical simulation

油页岩流化床燃烧 N₂O 生成特性 = **Experimental Investigation on N₂O Emission Characteristics during the Operation of an Oil Shale-fired Fluidized Bed Boiler** [刊, 汉] / DING Nai-jin, JIANG Xiu-min, WU Shao-hua (School of Energy Sources under the Harbin Institute of Technology, Harbin, China, Post Code: 150001) // Journal of Engineering for Thermal Energy & Power. — 2003, 18(6). — 589 ~ 591

On a small-sized (diameter 20mm and height 450mm) thermal-state fluidized bed combustion test rig an experimental investigation was carried out to ascertain the impact of different operating parameters on N₂O emission characteristics during the operation of a oil shale-fired fluidized bed boiler. The investigation results indicate that an increase in combustion temperature and circulation ratio, a decrease in excess air factor and the desulfurization of in-boiler limestone, etc can be conducive to decreasing N₂O generation quantity. The above finding has provided essential basic data for the design and operation of oil shale-fired circulating fluidized bed boilers. **Key words:** oil shale, N₂O, fluidized bed combustion

鼓泡式烟气脱硫原理性试验台气体流动冷模试验 = **Cold Model Tests of Gas-liquid Flows in a Wet Bubbling Flue-gas Desulfurization Test Rig** [刊, 汉] / ZHONG Zhao-ping, JIN Bao-sheng, LAN Ji-xiang, et al (Education Ministry Key Laboratory of Clean Coal Power Generation and Combustion Technology under the Southeastern University, Nanjing, China, Post Code: 210096) // Journal of Engineering for Thermal Energy & Power. — 2003, 18(6). — 592 ~ 596

Cold model tests and test results are described of gas-liquid flows in a wet bubbling flue-gas desulfurization test rig. Through the tests it is found that with regard to tube-outside jets the variation of injection pipe bubbling layer height and pressure drop at a bottom seal in three kinds of test tubes is very stable. As for tube-inside jets the injector pressure drop fluctuates dramatically with the change of injection speed and insertion depth of the jet pipe, thus being regarded as very unstable. In view of the above it is recommended to employ tube-outside jets for engineering applications. Measurements were taken of the jet velocity field of jet pipe tube-outside injection at a bottom seal with the use of a PIV (particle imaging velocimetry) instrument. It was discovered that in a gas-liquid fully mixed zone the motion trajectory of the gas bubbles are very complicated with a large quantity of vortex groups being formed accompanied by an intensive perturbation of gas-liquid. When the speed is in excess of 16 m/s, the vortex groups mainly appear in the neighborhood of tube walls and the intermediate gas-liquid assumes the form of surge waves, which is very unfavorable for gas-liquid contact. **Key words:** bubbling, flue gas desulfurization, gas-liquid flow, cold model test, particle imaging velocimetry

船用汽轮机冷态启动过程中热膨胀的研究 = **A Study of Thermal Expansion in the Cold-state Startup Process of a Marine Steam Turbine** [刊, 汉] / LIU Shu-yi, LI Jian-zhao (Harbin No. 703 Research Institute, Harbin, China,

Post Code: 150036), GAO Pu-zhen (Harbin Engineering University, Harbin, China, Post Code: 150001) // Journal of Engineering for Thermal Energy & Power. — 2003, 18(6). — 597 ~ 599

By using software ANSYS a three-dimensional model was set up for the turbine cylinder and rotor of a marine steam turbine. The thermal expansion during a cold-state startup was calculated and analyzed. Presented are the time-dependent thermal expansion displacement curves and relative thermal expansion curves of the turbine cylinder and rotor at the gland seal of a rear shaft end, and also at other locations. The calculation results may be used for the research of steam turbine dynamic characteristics and the design of startup procedures. **Key words:** marine steam turbine, thermal expansion, cold-state startup

湿压缩压气机特性的研究 = Research on the Characteristics of a Wet Compression Compressor [刊, 汉] / LI Shu-ying (School of Electronic Engineering under the Harbin Institute of Technology, Harbin, China, Post Code: 150001), ZHU Jian-hong, LU Wei (College of Power & Nuclear Engineering under the Harbin Engineering University, Harbin, China, Post Code: 150001) // Journal of Engineering for Thermal Energy & Power. — 2003, 18(6). — 600 ~ 604

Compressor compression work can be decreased by the injection of water into a compressor. The change of working medium properties after the water injection will lead to a change in compressor characteristics. To identify the compressor characteristics following the water injection, a simulation of such characteristics was conducted by using an approximate analogous theory in order to ascertain the effect of the water injection on the compressor pressure ratio and flow rate, etc. As a result, the wet compression compressor characteristics were identified through the above-mentioned approximate modeling. The above work can provide a solid basis for the applied research of wet compression technology in gas turbines, turbocharged diesels and turbocharged gasoline engines. **Key words:** wet compression, compressor, characteristics, simulation

N6135 柴油机进口加湿技术中压气机的性能研究 = An Investigation of the Impact on Compressor Performance of Water Injection at a Diesel Inlet [刊, 汉] / ZHANG Zheng-yi, ZHENG Qun, ZHANG Wei (College of Power & Nuclear Engineering under the Harbin Engineering University, Harbin, China, Post Code: 150001) // Journal of Engineering for Thermal Energy & Power. — 2003, 18(6). — 605 ~ 607

A theoretical calculation and an experimental study were performed concerning the water injection at the inlet of a turbocharged diesel. On this basis the authors have developed a method for studying the evaporation/compression process in a compressor and preliminarily verified the theory that the above-mentioned water injection can lead to a reduction of compressor outlet temperature and also compression work. The foregoing provides a solid basis for the reliable operation of turbocharged diesel engine under poor environmental conditions. **Key words:** diesel engine, water injection, compressor

自转清洗扭带管对流传热强化机理的实验研究 = Experimental Investigation of the Mechanism of Intensified Convective Heat Transfer in a Tube with Self-rotating Twisted Tapes for Cleaning Purposes [刊, 汉] / ZHANG Lin, XUAN Yi-min (College of Power Engineering under the Nanjing University of Science & Technology, Nanjing, China, Post Code: 210094), YU Xiu-min, PENG De-qi (Research Institute of Mechanical Cleaning under the Zhuzhou Engineering College, Zhuzhou, China, Post Code: 412008) // Journal of Engineering for Thermal Energy & Power. — 2003, 18(6). — 608 ~ 611

Fouling prevention technology involving the use of self-rotating spiral-twisted cleaning tapes featuring an intensified heat transfer function has seen a relatively rapid development these days. The authors have with the help of a Laser Doppler velocimeter performed an experimental investigation of the fluid turbulent characteristics in a tube with self-rotating cleaning twisted tapes. The results of the investigation indicate that under the driving force of the self-rotating twisted tapes the fluid flow structure in the tube undergoes an abnormal change. The axial velocity component in the ring-shaped zone near a tube wall is markedly higher than that in the tube central zone with the axial turbulence being greater than in the case