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船用主汽轮机组测速泵改进的试验研究

刘全恩, 刘　江, 宋成林, 裘祖发
(哈尔滨·第七〇三研究所, 黑龙江 哈尔滨 150036)

摘　要: 通过理论计算片式和浮动式两种密封结构测速泵的漏油量, 比较两种结构的漏油量受密封间隙变化的影响程度, 提出改进方案。对浮动式密封结构的测速泵进行试验并得出结论, 为船用主机组超速保护装置的改造提供理论和试验依据。

关　键　词: 船用; 汽轮机; 测速泵; 密封; 试验
中图分类号: TK263.8　　文献标识码: A

1　前言

某船在检修过程中发现: 主机测速泵出口油压达不到使油遮断器动作的油压(主机组超速 107%～110%时, 要求油遮断器动作, 此时测速泵进出口油压差为 0.54 MPa 表压), 无论怎样调整, 均不能满足出口油压所需值(调整弹簧的紧力有限)。检查测速泵(径向钻孔泵), 发现片式密封片(材料为 ZQSn3－7－5－1)磨损较为严重, 漏油间隙过大, 难以维持正常压差。设计间隙最大为 0.135, 运行过程中, 由于轴承存在间隙, 必然会导致泵轮磨损密封片, 使间隙过大, 漏油量增加。为达到油遮断器动作的油压值, 就必需增加转速, 结果导致机组飞车, 酿成事故。更换新的密封片后, 情况有所好转, 油遮断器动作正常, 但工作一段时间后, 又磨损而使油压降低, 不能起超速保护作用, 需要及时更换备件, 否则将影响机组的安全性。

2　测速泵的原理

某船主机组超速保护装置的测速泵, 实际上就是径向钻孔泵。这种泵的压力—流量特性非常平坦。其工作原理是, 利用离心泵的进出口油压差和转速的平方成正比的特性, 使油泵出口油压随泵的转速作相应的变化, 然后利用油压的变化控制油遮断器的滑阀, 当机组转速超过额定值的 7%～10%时, 测速泵进出口油压差达到 0.54 MPa, 油遮断器动作使速关阀速关, 达到保护机组的目的。

3　原设计测速泵的密封结构

原设计采用了最简单的密封结构, 如图 1 所示, 这种结构的缝隙漏油量较大。为了减小缝隙泄漏量, 原设计给出了较小的间隙 0.095～0.135(直径方向), 而轴承间隙为 0.4, 汽封间隙 0.2～0.3。当汽轮机开始启动时, 由于轴承的油膜尚未建立起来, 会产生较大的轴扰动, 这样会不断的磨损密封片, 超过了设计所要求的间隙, 导致油泄漏量增大, 影响出口油压。

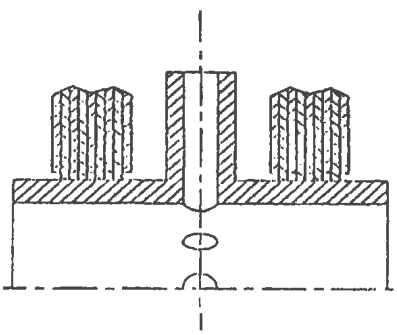

图 1

4　改进后测速泵的密封结构

改进后测速泵的密封结构采用浮动式密封结构(如图 2 所示), 该结构几乎没有磨损, 运行的可靠性大大提高, 并具有结构简单, 可随泵轮的扰动而调整位置, 密封效果好等特点。采用这种结构, 密封间隙一般为 0.05～0.13(直径方向), 密封面浇注巴氏合金, 摩擦阻力很小, 但缝隙漏油量比叶片式密封稍大, 泄露量稳定。这种密封结构只需在原有的测速泵上稍作改动, 有利于船舶的改造。

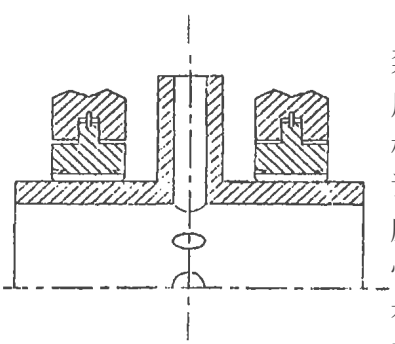

图 2

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作者简介: 刘全恩(1969－), 男, 黑龙江哈尔滨人, 哈尔滨·第七〇三研究所高级工程师。

5 测速泵密封泄漏量计算

5.1 原设计测速泵叶片密封缝隙漏油损失计算

(1) 密封片处单侧泄漏量

$$q = C_y \cdot f \cdot \sqrt{2g\Delta H_i} \tag{1}$$

式中: C_y — 缝隙的速度系数,

$$C_y = \frac{1}{\sqrt{1.5 + 1.1Z + \frac{\lambda L}{2S}}} \tag{2}$$

λ — 水力阻力系数, 与雷诺数有关, $\lambda = 64/Re$,

$$Re = 2SC/\gamma \tag{3}$$

L — 密封片的总宽度, 0.8 cm; S — 密封片与泵轮间隙半径宽度, cm; Z — 密封片数, $Z = 4$; γ — 动力粘度, 40 号透平油 45 ℃时为 57.51×10^{-6} m^2/s; f — 密封片处间隙过流断面面积, m^2;

ΔH_i — 缝隙中的压力降,

$$\Delta H_i = H - \frac{\omega^2}{8g}(R_2^2 - R_0^2) \tag{4}$$

H — 泵的压头, 米油柱; $\omega = \frac{\pi n}{30}$ — 泵的旋转角速度, 1/s; R_2 — 泵出口半径, m; R_0 — 泵轮半径, m。

(2) 由调节系统油量计算知道油遮断器动作所需油量为 407.37 cm^3/s。

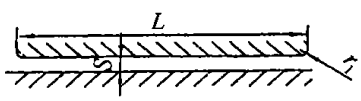

图 3

当 $2S = 0.135$, $n = 6\,050$ r/min 时, 缝隙泄漏量 $2q = 16.4$ cm^3/s, 占总油量 4%;

当 $2S = 0.2$, $n = 6\,050$ r/min 时, 缝隙泄漏量 $2q = 52.57$ cm^3/s, 占总油量 12.9%;

可见此种密封结构, 随着径向间隙的增大, 其缝隙漏油量成倍地增大, 这样就可能导致测速泵出口油压达不到要求值。这种密封结构的缝隙漏油受密封间隙的影响较大, 不利于长期运行。

5.2 浮动式密封环缝隙漏油损失计算

密封环间隙图如图 3 所示, 这里 $L = 28$, $r = 1$, $2S = 0.05 \sim 0.13$, 按 $2S = 0.13$ 计算。

(1) 缝隙中油流的速度系数

$$C_y = \frac{1}{\sqrt{1 + 0.5\eta + \frac{\lambda L}{2S}}} \tag{5}$$

S — 间隙宽度, cm; η — 圆角系数, 见表 1; L — 间隙长度, cm; λ — 水力阻力系数。

表 1 圆角系数 η

r/S	0	0.02	0.04	0.06	0.08	0.1	0.15	0.2
η	1	0.72	0.52	0.38	0.28	0.2	0.08	0.06

本计算中 $r/S = 0.036$, $\eta = 0.62$

(2) 水力阻力系数 λ 与间隙内油流的雷诺数有关, 当泄漏量 q 尚未计算出来之前, 雷诺数也无法求得, 通常先取 $\lambda = 0.04$, 计算出流速 C, 而后由下式计算雷诺数

$$Re = \sqrt{C^2 + (\frac{C_0}{2})^2}/\gamma \tag{6}$$

(3) 由式(1)、式(4) ~ 式(6) 反复迭代计算间隙泄漏量, $f = 1.1435 \times 10^{-5}$ m^2, 当 $2S = 0.13$, $n = 6\,050$ r/min 时, 间隙泄漏量 $2q = 29.2$ cm^3/s。

两种密封结构的间隙漏油量在间隙为 0.135 或 0.13 时, 浮动式密封结构的间隙漏油量比片式密封结构的间隙漏油量稍大, 但片式密封结构很容易磨损, 漏油量会成倍增加; 而浮动式密封结构的间隙可以保持不变, 使得漏油量保持稳定, 保证了泵的压头, 油遮断器控制滑阀处的脉冲信号不致衰减, 实现超速保护的功能。

6 试验验证

对浮动式密封结构进行油系统试验, 以检验该结构的密封性能。

6.1 试验原理

调整测速泵进口油压在 0.04 ~ 0.08 MPa 范围内, 利用变频调速电机通过增速器带动测速泵, 使转速在 1 000 ~ 6 050 r/min 范围内, 测量泵出口油压, 作出泵进出口油压差与转速的关系曲线。

6.2 试验装置如图 4 所示

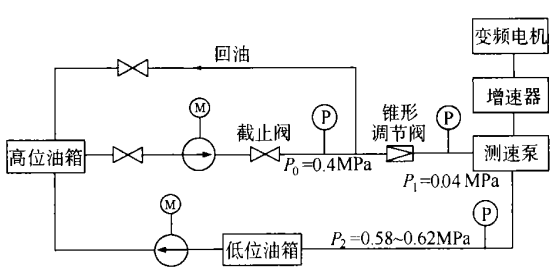

图 4

6.3 试验条件

主油泵出口压力 2.3 MPa; 回油总管压力 $P_0 =$

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(1) 改进运行及维护: 严格的按照要求进行检修, 根据爆漏部位决定堵管根数, 避免堵管管束及周围管束因检修工艺而再次发生爆漏; 损坏的部件要及时更换。严格按照标定的高压加热器运行水位进行控制, 保证高加疏水存在一定的过冷度; 控制高加启停温度变化率。总结运行的经验, 制定合理的设备管理措施。

(2) 电力部门实施可靠性管理, 电力部门从 1984 年起开展电力可靠性管理工作, 从电力系统的规划、设计、设备选用、安全施工、运行维护、检修、改造、人员培训等方面入手来改善电力设备的可靠性。从 1994 年起, 电力部门每年召开新闻发布会, 定期公布电力设备的可靠性指标, 对提高电力设备的可靠性起到了推动作用, 对提高火电站高压加热器的可靠性作出了应有的贡献。

4 结语

通过以上分析, 可以得到:

(1) 本文作者提出的可靠性增长模型符合大型火电站高压加热器的可靠性增长规律。

(2) 要提高加热器运行可靠性, 除了要提高加热器本身设计、制造质量外, 运行及维护方式也至关重要。通过本文的分析, 机械和电力行业的制造和使用部门采取的可靠性完善和改善措施是有效的, 使得 200 MW 以上的火电站加热器的可靠性呈增长趋势。

(3) 电站高压加热器在大型火电站中被广泛使用, 其运行可靠性对发电厂的稳定运行至关重要。因此利用历史运行可靠性数据所得的可靠性增长模型, 可以预测加热器未来几年内的可靠性增长趋势。

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0.4 MPa; 油泵出口平均流量 28 m^3/h; 油系统油温 37 ~ 60 ℃; 测速泵进口油压分别为 0.04, 0.06, 0.08 MPa。

6.4 试验曲线如图 5 所示

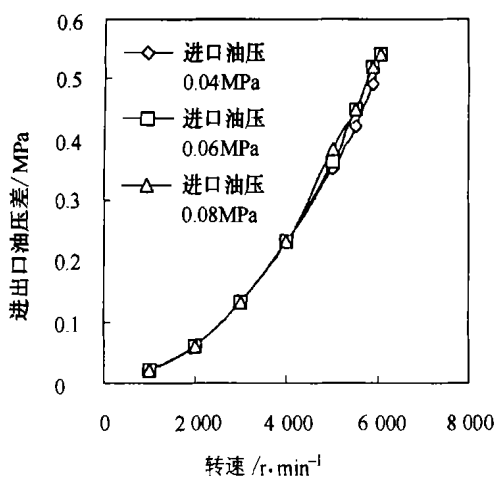

图 5 进出口油压差—转速关系曲线

6.5 试验结论

从试验曲线中可以看出, 测速泵在不同的转速下, 其进出口油压差随转速增加而增加, 并趋于平稳。在不同的进口压力下, 其进出口压差基本一致, 也就是进口油压对压差的影响不大, 正好符合压差与转速平方成正比的关系; 还进行了超速试验, 即 6 050 r/min连续运行 30 h, 检查密封环无磨损, 证明了该结构的合理性。

7 结论

通过计算比较和试验证明, 采用浮动式密封结构的测速泵, 具有结构简单密封效果好, 缝隙漏油量稳定等特点。浮动式密封结构经过长时间运行无磨损, 而原片式密封因磨损导致间隙过大, 超速保护失效。该研究从根本上解决了原片式密封因漏油量过大而引起的油压过低问题, 而且浮动式密封在结构上易于实现。该研究也为改造船用测速泵提供了可靠的理论和试验依据。

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laden Gas Turbine and the Prediction of the Change in Blade Vibration Frequency [刊, 汉] / LU Jia-hua, LING Zhi-guang (Air Transport Institute under the Shanghai University of Engineering Technology, Shanghai, China, Post Code: 200336) // Journal of Engineering for Thermal Energy & Power. —2002, 17(4): 379 ~382

The movement loci of two different density distribution-diameter particles after a gas-solid dual-direction coupling of low particle concentration were solved based on Euler-Lagrange solution basic idea and the simulation calculation of the three-dimensional viscid turbulent flow field of a dual-stage transonic gas turbine. This has been accomplished through the use of a particle random trajectory model and PSIC method. On this basis the erosion rate of the blades was calculated. Its distribution law relatively approximates to the erosion condition of full-scale blades. Then, by utilizing the interrelationship of the established blade erosion rate and vibration frequency the time-dependent variation of blade vibration frequency with erosion was forecast. As a result, a fruitful attempt has been made to identify the influence of blade erosion on blade vibration frequency. **Key words**: particle-laden gas turbine, gas-solid dual-direction coupling, numerical simulation of blade erosion, blade vibration frequency

船用三级气水分离器阻力特性计算＝**Calculation of the Resistance Characteristics of a Three-stage Moisture Separator for Marine Applications** [刊, 汉] / SUN Hai-ou (Harbin Engineering University, Harbin, China, Post Code: 150001), SUN Jun (Shanghai No. 708 Research Institute, Shanghai, China, Post Code: 200011), LIU Xue-yi (Harbin No. 703 Research Institute, Harbin, China, Post Code: 150036) // Journal of Engineering for Thermal Energy & Power. —2002, 17(4): 383 ~386

The numerical calculation of resistance characteristics was performed for a two-stage inertial stage followed by the numerical calculation of a mesh-pad stage resistance characteristics by the use of a newly built multi-layer gauze model. As a result, the numerical calculation has been completed for the total resistance characteristics of a three-stage moisture separator. On the basis of relevant requirements an optimum construction version of the moisture separator was selected and a sample unit manufactured. The measured resistance characteristics of this unit indicate that the numerical calculation accuracy has met the engineerig design requirements. All the above has made it possible to provide a simple, rapid and high-precision analytical means for the prediction of resistance characteristics during the development of a new type of moisture separators. **Key words**: moisture separator, resistance characteristics, numerical calculation

大容量蒸汽机械雾化喷油器控制系统设计研究＝**Design Study of the Control System of Mechanical-atomization Oil Sprayers for a High-capacity Steam Turbine** [刊, 汉] / LI Lai-chun, WEI Shao-jie (Harbin No. 703 Research Institute, Harbin, China, Post Code: 150036), DENG Cai-xia (Automation Research Institute under the Harbin Engineering University, Harbin, China, Post Code: 150001) // Journal of Engineering for Thermal Energy & Power. —2002, 17(4): 387 ~390

To date, a control system of mechanical-atomization oil sprayers has never found application in China for large-capacity marine steam turbines. On the basis of drawing on relevant overseas technology coupled with the present development level of automation instrumentation the authors have conducted a design study of the above-mentioned control system. A brief account is given of the composition, working principles and the control mode of various automatic regulating loops of an all-electric control system. Also presented are the relationship curves of relevant parameters. **Key words**: supercharged boiler, large-capacity oil sprayer, control system

船用主汽轮机组测速泵改进的试验研究＝**Experimental Investigation on the Improvement of a Speed Measuring Pump for a Marine Steam Turbine Unit** [刊, 汉] / LIU Quan-en, LIU Jiang, SONG Cheng-lin, QIU Zu-fa (Harbin No. 703 Research Institute, Harbin, China, Post Code: 150036) // Journal of Engineering for Thermal Energy & Power. —2002, 17(4): 391 ~392, 398

The theoretical calculation of oil leakage of a speed-measuring pump with either plate-type or floating-type seal construction has been performed and the oil leakage as influenced by the seal gap change in these two types of seal construction compared and identified. On this basis the authors have come up with an improved version. A test was conducted of the

speed-measuring pump with a floating type seal construction and reliable conclusions obtained. All the above has provided a theoretical and experimental basis for the improvement of an overspeed protection device for a main steam turbine. **Key words**: main steam turbine over-speed protection, speed-measuring pump, seal, test

寒区太阳能—土壤源热泵系统太阳能保证率的确定=**Determination of the Solar Energy Assurance Factor of a Solar Energy - Ground Soil-source Heat Pump System in Frigid Regions** [刊, 汉] / YU Yan-shun, LIAN Le-ming (Department of Architectural Thermal Energy Engineering, Harbin Institute of Technology, Harbin, China, Post Code: 150090) // Journal of Engineering for Thermal Energy & Power. —2002, 17(4): 393 ~ 395

In frigid regions the use of solar energy and ground soil-source heat as a low-level heat source of heat pumps is of great significance from the perspective of environmental protection and the development and utilization of new and renewable energy sources. The authors have for the first time put forward the concept of ground-soil temperature restoration rate of the ground soil-source heat pump system under different ratios of operation/shutdown. With the above-cited restoration rate serving as an index the restoration degree of ground soil temperature field is evaluated of the ground soil-source heat pump under various operation/shutdown ratios. On this basis, the optimum operation/shutdown ratio of the said heat pump and solar energy assurance factor were identified, and thereby the capacity of solar energy heat-collection device was determined. **Key words**: frigid region, solar energy - ground soil-source heat pump, solar energy assurance factor, ground soil temperature restoration rate

大型火电站高压加热器可靠性增长模型验证及预测=**Verification of a Reliability Enhancement Model and its Prediction for High-pressure Heaters at a Large-sized Thermal Power Plant** [刊, 汉] / CAO Xian-chang, ZHONG Zhi-qiang, JIANG An-zhong (Department of Energy Sources, Shanghai Jiaotong University, Shanghai, China, Post Code: 200240), SHI Jin-yuan (Shanghai Power Equipment Design and Research Institute, Shanghai, China, Post Code: 200240) // Journal of Engineering for Thermal Energy & Power. - 2002, 17(4). // Journal of Engineering for Thermal Energy & Power. —2002, 17(4): 396 ~ 398

A reliability enhancement model is proposed for high-pressure heaters at a large-sized thermal power plant along with a detailed discussion of the model parameter estimation and fitting inspection. According to the statistics data of Electric Power Reliability Management Center the model fully conforms with the reliability-enhancement change tendency of high-pressure heaters under statistical evaluation. The results of analysis also indicate that the reliability of the heaters has been gradually enhanced through the introduction of such measures as eradication of defects in product design and fabrication, enhancement of personnel quality, improvement of operational level, production facilities and operating conditions. **Key words**: high-pressure heaters, reliability, growth model, prediction

移动—流化型组合阀工作特性的研究=**A Study Concerning the Test of the Operating Characteristics of a Shifting-fluidized type of Combination Valve and Its Model** [刊, 汉] / ZHANG Jing-yuan (Power Engineering Department, Taiyuan Electric Power High Technical School, Taiyuan, China, Post Code: 030013), YE Gui-zhen (Guangdong Provincial Electric Power Test Research Institute, Guangzhou, China, Post Code: 510006) // Journal of Engineering for Thermal Energy & Power. —2002, 17(4): 399 ~ 401, 413

A shifting-fluidized type of combination valve is a kind of novel non-mechanical valve for transporting solid-particle raw materials. The key technique affecting its operating characteristics involves the provision of a sort of slackening air at the bottom of the shifting bed. The present paper mainly focuses on an experimental investigation regarding the provision of the slackening air device and a mathematical model for calculating raw material flow rate. **Key words**: valve, slackening air, non-Newton fluid

获取知识的一种新方法——粗糙集(Rough Set)=**"Rough Set" as a New Method of Machine Self-learning** [刊, 汉] / DONG Cai-feng WNAG Tian-yu (Aerospace Institute under the Harbin Institute of Technology, Harbin, China, Post Code: 150001) // Journal of Engineering for Thermal Energy & Power. —2002, 17(4): 402 ~ 404

A difficult issue encountered during the diagnosis of rotating machine failures consists in the acquisition of diagnostic