

软—硬齿面齿轮的接触疲劳强度试验研究

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〔摘要〕 本文介绍42CrMo调质处理与20CrMnMo渗碳淬火齿轮的接触疲劳试验的过程。其中包括试验目的、试验条件和方法、CL-100型齿轮试验机和齿轮试验件的主要参数、试验结果和数据处理、试验成果评述等。

关键词 齿轮点蚀 疲劳强度 试验

1 前言

齿轮接触疲劳强度极限是齿轮承载能力计算中一项重要参数。国际标准化组织ISO/TC60/WG6编制齿轮强度计算标准特别强调强度试验的重要性。我国已颁布“渐开线圆柱齿轮承载能力计算方法”GB3480-83中接触疲劳强度极限 σ_{Hlim} 直接采用ISO268文件推荐的资料,并没有验证。

为了探索软—硬齿面齿轮承载能力,这次对齿轮材料42CrMo调质处理软齿面对20CrMnMo渗碳淬火硬齿面进行接触疲劳试验以取得该两种材料的接触疲劳强度极限 σ_{Hlim} 值。

(1)型式:功率流封闭式。

(2)动力电机型号:JD02-51-4/2双速交流电动机。

(3)功率与转数:

$$P_1 = 5.5 \text{ kW} \quad n_1 = 1460 \text{ r/min}$$

$$P_2 = 7.5 \text{ KW} \quad n_2 = 2900 \text{ r/min}$$

(4)加载方式:杠杆砝码加载。

(5)载荷:

$$\text{最大允许载荷 } T_{\max} = 980 \text{ N} \cdot \text{m}$$

$$\text{最大使用载荷 } T_{12} = 534.1 \text{ N} \cdot \text{m}$$

(6)润滑方式:液压油循环喷油润滑。

油压 0—1 MPa

流量 0—12 L/min

(7)双套滑油系统油泵电机:1A07124三相370瓦异步电机。

2.2 试验件

试验齿轮主要参数:

$$(1) \text{齿数: } Z_1 = 22 \quad Z_2 = 23$$

$$(2) \text{模数: } m = 4$$

$$(3) \text{分度圆压力角: } \alpha = 20^\circ$$

$$(4) \text{变位系数: } X_1 = 0.203$$

$$X_2 = 0.193$$

2 试验设备及试验件

2.1 试验设备

本试验在CL-100型齿轮试验机上进行。该机由河北承德试验机厂生产。

主要参数

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(5)齿宽: $b = 10$

(6)精度: $5 \begin{pmatrix} -0.007 \\ -0.107 \end{pmatrix}$ GB179-83

(7)材料及热处理:

小齿轮 20 CrMnMo 渗碳淬火 $H_{RC} 58-62$

大齿轮 42 CrMo 调质处理 HB240-260

接触疲劳试验结果离散较大,为缩小试验结果的离散性和避免在试验过程因齿根折断和齿面胶合而影响试验正常进行,故对齿轮试验件有一些特殊要求,这里不一一介绍。

3 试验条件和方法

试验按 GB3480-83 标准规定条件进行,即齿面粗糙度 R_z 为 $3 \mu\text{m}$ ($Z_R = 1$)、节点速度 V 为 10 m/min ($Z_v = 1$)、矿物油润滑运动粘度 $\gamma = 100 \text{ mm}^2/\text{s}$ ($Z_L = 1$) 获得在长期载荷作用下(通常不少于 5×10^7 次)失效概率为 1% 时的齿轮接触疲劳强度极限应力 σ_{Hlim} 值。

根据文献[1]介绍升降法可以比较简捷而准确地求得材料的疲劳强度极限。按升降法的要求,首先初选一个初始应力水平 σ_0 进行试验。如果经 5×10^7 次循环,齿面未出现点蚀,则认为该点越出。于是换下一对齿面继续试验,此时取应力水平 σ_1 ($\sigma_1 = \sigma_0 + \Delta\sigma$, 这里 $\Delta\sigma$ 为应力增量)。若按 σ_0 试验时,未达到 5×10^7 循环次数出现点蚀破坏,则认为该点失效。于是换下一次齿面继续试验时,取应力水平 σ'_1 ($\sigma'_1 = \sigma_0 - \Delta\sigma$)。如此反复多次,待试验件数量达一定值后就可以获得该材料的 σ_{Hlim} 值。

4 试验情况及数据处理

4.1 试验情况介绍

4.1.1 为防止试验用油的承载能力不足而引起齿面胶合损伤影响试验正常进行。故在

试验前曾对试验用油进行胶合载荷级试验,最后采用 N220 齿轮油其胶合载荷级大于 12 级。而我们试验载荷均小于 5 级,这就意味着不会因胶合损伤而影响试验正常进行。齿面胶合损伤形貌见图 1。

4.1.2 试验的初始应力水平 $\sigma_0 = 1150 \text{ MPa}$, 应力增量 $\Delta\sigma = 70 \text{ MPa}$ 。结果齿面应力在 800 MPa 以上试验点均发生点蚀失效。点蚀破坏均发生在软齿面。齿面点蚀破坏形貌见图 2。

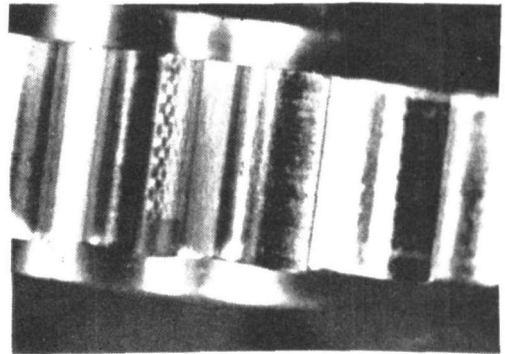


图1 齿面胶合形貌



图2 齿面点蚀形貌

4.1.3 应用质量管理的科学方法指导试验工作使试验顺利完成。

4.2 试验结果及数据处理

4.2.1 试验结果汇总成表如下

表 1 试验结果

序号	齿面应力 σ_H (MPa)	疲劳寿命 N	齿面状况	试验点编号	备注
1	1150	0.86×10^7	点蚀	I	
2	1010	0.32×10^7	点蚀	I	
3	940	1.09×10^7	点蚀	II	
4	870	1.22×10^7	点蚀	IV	
5	800	0.85×10^7	点蚀	V	
6	730	5×10^7	越出	VI	
7	800	0.72×10^7	点蚀	VI	
8	730	0.9×10^7	点蚀	VII	
9	660	5×10^7	越出	IX	
10	730	1×10^7	点蚀	X	
11	660	5×10^7	越出	XI	
12	730	5×10^7	越出	XI	

4.2.2 画升降图

剔除 870 MPa 以上的无效点画出升降图见图 3。

从图 3 中可以看到有效点可以组成四组对子,即 V 与 VI、VII 与 IX、X 与 XI、VII 与 XII。

4.2.3 有效数据表

表 2 有效数据表

σ	$X_i = \lg \sigma$	X_i^2
800	2.903 899 87	8.427 931 473
730	2.863 322 86	8.198 678 01
800	2.903 899 87	8.427 931 73
730	2.863 322 86	8.198 678 01
660	2.819 543 94	7.949 828 00
730	2.863 322 86	8.198 678 01
660	2.819 543 94	7.949 828 00
730	2.863 322 86	8.198 678 01
总计	22.898 559 29	65.549 990 16

4.2.4 计算平均值

$$\begin{aligned} \bar{X} &= \frac{1}{n} \sum_{i=1}^n X_i \\ &= \frac{1}{8} \times 22.898 559 29 \\ &= 2.862 319 911 \\ \mu_0 &= \lg^{-1} \bar{X} \\ &= \lg^{-1} 2.862 319 911 \\ &= 728 \text{ (MPa)} \end{aligned}$$

μ_0 为失效率是 50% 时试验齿轮的接触疲劳强度极限。

4.2.5 计算子样标准差

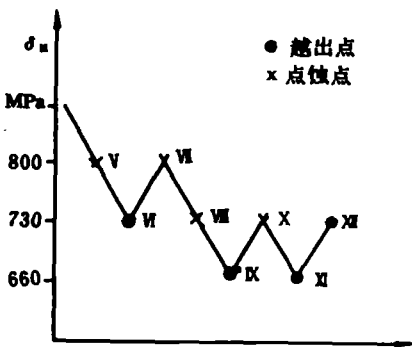


图 3 升降图

$$\begin{aligned}
 S &= \sqrt{\frac{\sum_{i=1}^n (X_i)^2 - 1/n(\sum_{i=1}^n X_i)^2}{n-1}} \\
 &= \sqrt{\frac{65.549\ 990\ 16 - 1/8(22.898\ 552\ 9)^2}{8-1}} \\
 &= 0.031\ 595\ 64
 \end{aligned}$$

4.2.6 估算安全疲劳极限

GB 3480—83 标准框图中推荐的接触疲劳强度极限的失效概率为 1%，由正态分量表可查对应此失效概率的标准正态偏量 $u_p = -2.326$ ，为此可算得在 1% 失效概率的疲劳极限的对数安全值 $X_{0.01}$ 。

$$\begin{aligned}
 X_{0.01} &= \bar{X} + u_p \cdot S \\
 &= 2.862\ 319\ 911 - 2.326 \times 0.315\ 956\ 4 \\
 &= 2.788\ 845\ 2 \\
 \sigma_{0.01} &= \lg^{-1} X_{0.01} \\
 &= \lg^{-1} 2.788\ 845\ 2 \\
 &= 615\ \text{MPa}
 \end{aligned}$$

这个安全疲劳强度极限的含意是用 42CrMo 调质处理 HB=250 与 20CrMnMo 渗碳淬火 $H_{rc} = 58$ 的齿轮中有 99% 的齿轮接触疲劳极限大于 615 MPa。这样处理的数据符合 GB3480—83 标准绘制疲劳极限 σ_{Hlim} 的框图的基本精神。

5 试验成果评述

5.1 经过试验和数据处理得到安全疲劳极限。由于试验方法、试验条件均符合 GB3480—83 标准所做的规定，所以在齿轮强度计算

中可将其 σ_{Hlim} 值做为该材料接触疲劳强度极限，同时与国内外各单位试验结果具有可比性。

5.2 42CrMo(包括 40CrMo)是一种综合性能较好的齿轮材料，但其接触疲劳强度极限较低，往往低于 σ_{Hlim} 框图的下限值，即已经脱离框图的范围。这次我们用软—硬齿面搭配作试验，取得 σ_{Hlim} 值是处于框图下限偏上位置。说明软—硬搭配齿面能有效提高齿面承载能力。

5.3 在正式试验前曾对同类材料只是软齿面硬度值不同做预备性试验，预备性试验齿轮的软齿面硬度为 HB 290、齿面应力 $\sigma_H = 762\ \text{MPa}$ 所作两个试验点均越出。从中可以看出，硬度值增加 16%，齿面应力也提高 15%，两者几乎同步增长。因此提高齿面承载力的另一个途径是在满足机组性能需要和加工工艺允许的条件下尽量采用高的齿面硬度值。

6 结束语

软硬齿面接触疲劳强度试验取得一定成果，同时提出一些提高齿面承载能力的措施。但是由于条件的限制测试工作还做的比较少。又由于时间限制未能进一步分析试验结果，只是提供一些试验资料。不当之处请批评指教。

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(李乡复 渠源沥 编辑)

- (183) **Preliminary Test Results of the World' s First Kalina Cycle Electric Power Station**
Wang Zhenhua (*Nanjing Gas Turbine Research Institute*)
This paper gives a brief description of the configuration and preliminary test results of the first Kalina cycle demonstrational power plant sited in the state of California of USA. **Key words:** *Kalina cycle, power generation, testing*
- (186) **The Application of Gas Turbines in Offshore Oil Fields and Specific Requirements To Be Met by Such Turbines** Zhang Xuchen (*Ocean Engineering Institute of South China Sea Eastern Petroleum Corporation*)
Based on the developments of Chinese offshore oil fields in recent years and engineering experiences gained during his participation in the exploration of some oil fields in China , the author has made a preliminary study and analysis of the application considerations and technical requirements to be met by the offshore oil field-oriented gas turbines. Given in this paper are also some proposals aimed at the development of gas turbines intended for use in Chinese offshore oil fields. **Key words:** *application of gas turbines, technical requirements, proposals*
- (191) **The Development of Coal-fired Gas Turbines** Zhang Chunlin (*Harbin Marine Boiler & Turbine Research Institute*)
Key words: *gas turbine, coal firing, pressurized fluidized bed combustion*
- (194) **Vibration Failure Diagnosis of a Turbogenerator set** Li Luping (*Electrical Engineering Department of Changsha Teacher' s College of Hydroelectric Power*)
This paper deals with a physical and mathematical model for the vibration failure diagnosis of rotary machines. The mathematical model can be used for the diagnosis of vibration failures of large-sized turbogenerator sets. **Key words:** *turbogenerator set, vibration, failure diagnosis, mathematical model*
- (200) **High-efficiency Low-pressure Steam Turbines** Zhang Chunlin (*Technical Information Research Institute of Water Resources and Electric Power under the Ministry of Energy Sources*)
Key words: *low-pressure steam turbine, efficiency*
- (202) **An Experimental study of Contact Fatigue Strength of Soft-Hard Tooth Face Gears**
Huang Qingrui, Huang Wei (*Harbin Marine Boiler & Turbine Research Institute*)
This paper describes in detail the contact fatigue tests of gears made of 42CrMo steel which had been subjected to a heat treatment of quenching and tempering and gears of carburized/quenched 20CrMnMo steel. Covered in the paper are such a variety of items as test aims, test conditions and method, main parameters of CL-100 gear testing machine and gear test pieces, test results and data processing, the evaluation of test results, etc. **Key words:** *gear*

pitting corrosion, fatigue strength, testing

(206) Static Analysis of a Gear Box Case Body Ke Jinhe ,You Guoying (*Harbin Marine Boiler & Turbine Research Institute*)

By the use of a finite element method the authors have calculated the stress and rigidity of a main reduction gear box case body for a certain type of cement mill. Under the three conditions, namely, sole weight, support reaction, combination of sole weight and support reaction, an analysis is made of the effect of case body strength and rigidity on the gear operation when the case body is of a hinged support, of a fixed support and also of different plate thickness. preliminary conclusions are given in this paper. **Key words:** *gear box case body, finite element method, static analysis*

(212) Several Tentative Ideas Concerning the Automation of a Navel Vessel Electrical Power System Sun Shifeng, et al (*Harbin Marine Boiler & Turbine Ressearch Institute*)

Taking into account the actual conditions of a naval vessel and the state-of-the-art automatic control technology, the authors have come up with several tentative ideas for the realization of automatic control of an electrical power system for a naval vessel. **Key words:** *microcomputer, integrated distribution control, electric generator, patallel installation*

(216) The Implementation of an Intellectualized Regulating Valve with the Help of a Single-chip Device Digital Regulator Li Pingkang, Liu Tuo (*Beijing Electrical Engineering Technical School*)

An analysis is made of the traditional regulating valve characteristics and the problems detected during its use. Based on the realization of servoamplifier functions by way of a software the authors proposed a method for the determination of valve working flow rate characteristics by means of system parameter identification. By utilizing the above-cited characteristics an intellectualized regulating valve can be realized. This paper also describes the hardware implementation and software function of the above approach. **Key words:** *single-chip device digital regulator, system parameter identification, implementation of an intellectualized regulating valve*

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