重载齿轮的最佳轮齿修形

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［摘要］ 本文给出了计算多对齿同时啮合轮齿接触线载荷分布的方法,并根据轮齿的啮合状态确定轮齿的最佳修形参数。利用作者编制的计算机程序研究了最佳轮齿修形参数对载荷分布系数的影响。

关键词　轮齿修形　重载齿轮　载荷分布
分类号　TH131.41

1　引言

由于传动齿轮速度和载荷的提高,其运转条件变得越来越苛刻。要想提高轮齿的抗表面失效能力,必须研究齿廓修形和齿向修形的问题。文献[1]中介绍的试验结果说明了齿廓修形的优点。经过适当齿廓修形,斜齿轮的胶合承载能力比未修形前高出约 2.5 倍[2]。文献[3]中所采用的计算载荷分布的方法考虑了制造误差和安装误差以及运转条件。文献[4]中给出了大重合度齿轮传动齿间载荷分配的分析模型。文献[5]是根据载荷分布是否均匀来评价最佳抛物线齿廓修正参数。文献[6]中研究了齿廓修形对赫芝应力分布的影响。本文首次提出了同时确定齿廓修形和齿向修形的计算方法。

2　用光滑化方法求解轮齿接触线载荷

为保证在啮合过程中两轮齿间接触的连续性,同一啮合位置诸接触线上任意一点处沿载荷方向的总变形均该相等,轮齿接触线载荷满足积分方程(1),如图 1 所示。

$$\int_{l_m} k(x,\xi)q(\xi)d\xi = \delta(x) = \delta_E(x) + \delta_0 \qquad (1)$$

式中:l_m— 第 m 对啮合轮齿的接触线长度;

$q(\xi)$— 接触线载荷;

δ_0— 啮合轮齿的静态变形;

$\delta(x)$— 啮合轮齿综合变形;

$\delta_E(x)$— 相邻啮合齿对的综合误差,包括制造、安装和轮齿修形等。

$k(x,\xi)$— 轮齿柔度系数。其中,

$$k(x,\xi) = k_b(x,\xi) + k_c(x,\xi) + k_{bs}(x,\xi)$$

$k(x,\xi)$ 是轮齿的弯曲与剪切综合变形系数,用三维有限元法计算。$k_c(x,\xi)$ 是轮齿综合接触变形系数,按文献[7]中方法计算。$k_{bs}(x,\xi)$ 是齿轮本体的弯曲和扭转变形以及支承轴的变形系数,利用文献[8]中介绍的方法计算。

总的传递法向载荷为:

$$F_n = \sum_{m=1}^{n}\int_0^{l_m} q(\xi)d\xi = T_1/r_{b1}\cdot\cos\beta_b \quad (2)$$

式中:n— 同时啮合齿对数;T_1— 小齿轮传递的扭矩,N·m;r_{b1}— 小齿轮基圆半径,mm;

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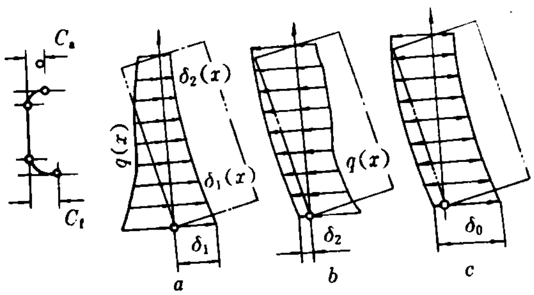

图 1　轮齿接触线载荷分布

β_b— 基圆螺旋角,°。

假设把 n 对啮合轮齿沿接触线等距离散成 N 个点,则有

$$[K]\{Q\} = \{\delta\} \tag{3}$$

$$\sum_{j=1}^{N} Q_j = F_n \tag{4}$$

式中:

$$[K] = \begin{bmatrix} k(x_1,\xi_1) & k(x_1,\xi_2) & \cdots & k(x_1,\xi_N) \\ k(x_2,\xi_1) & k(x_2,\xi_2) & \cdots & k(x_2,\xi_N) \\ \cdots & \cdots & \cdots & \cdots \\ k(x_N,\xi_1) & k(x_N,\xi_2) & \cdots & k(x_N,\xi_N) \end{bmatrix}$$

$$\{Q\}^T = [q(\xi_1)\Delta\xi_1, q(\xi_2)\Delta\xi_2, \cdots, q(\xi_N)\Delta\xi_N]$$

$$\{\delta\}^T = [\delta_0 + \delta_E(x_1), \delta_0 + \delta_E(x_2), \cdots, \delta_0 + \delta_E(x_N)]$$

利用光滑化方法修改后[9],方程(3) 变为:

$$([K]^T[K] + r[H])\{Q\} = [K]^T\{\delta\} \tag{5}$$

式中:r 为光滑因子,矩阵 $[H]$ 的表达式为:

$$\begin{bmatrix} 1 & -2 & 1 & 0 & 0 & 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ -2 & 5 & -4 & 1 & 0 & 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 1 & -4 & 6 & -4 & 1 & 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 1 & -4 & 6 & -4 & 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 1 & -4 & 6 & -4 & 1 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0 & 1 & -4 & 6 & -4 & 1 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0 & 0 & 1 & -4 & 5 & -2 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0 & 0 & 0 & 1 & -2 & 1 \end{bmatrix}_{N \times N}$$

当 $r = 0$ 时,$[K]$ 是正定对称矩阵时,方程(5) 就是方程(3),可见光滑化方法实质是相当于在原数学模型中加入稳定成分 $r \cdot [H]$,有效地克服了积分方程(1) 解的不完全确定的缺点[9]。

3　最佳轮齿修形计算

图 2 为齿廓修形的几何形状,用线性函数描述齿顶和齿根修形。齿向修形采用直线修形和抛物线修形两种形式,则接触线上任意一点 $x_i(i = 1,2,\cdots,N)$ 的轮齿修形量为:

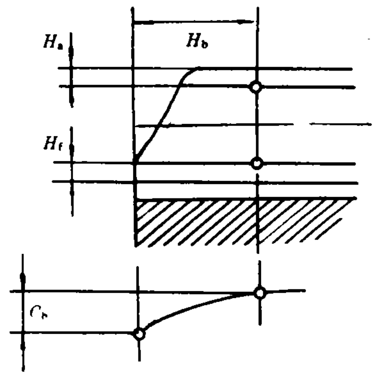

图 2　轮齿修形几何形状

3.1　齿向直线修形

$$p(x_i) = C_a \frac{r(x_i)-(r_a-H_a)}{H_a} + C_f \frac{r_f + H_f-r(x_i)}{H_f} + C_b \frac{(H_b-B(x_i))}{H_b} \tag{6}$$

3.2　齿向抛物线修形

$$p(x_i) = C_a \frac{r(x_i)-(r_a-H_a)}{H_a} + C_f \frac{r_f + H_f-r(x_i)}{H_f} + C_b \frac{(H_b-B(x_i))^2}{H_b^2} \tag{7}$$

不计上面两式中的负项。其中，

C_a、C_f、C_b— 分别为齿顶、齿根和齿向的修形量；

H_a、H_f、H_b— 分别为齿顶、齿根和齿向的修形长度；

r_a、r_f— 分别为齿顶和齿根修形起始点半径；

$r(x_i)$— 节点 x_i 处的半径；

$B(x_i)$— 节点 x_i 距齿端的距离(在近端一侧)。

载荷分布系数定义为：

$$k_p = \frac{\max(Q_i/\triangle\xi_i)}{F_s/L}(i=1,2,\cdots,N) \tag{8}$$

式中： L— 此瞬时的接触线总长度。

当轮齿中的一个齿刚进入啮合时，确定齿轮副在此瞬时位置的载荷分布，并根据轮齿平稳地进入啮合，没有干涉现象，降低载荷分布系数等条件来确定最佳轮齿修形参数。这里取 $C_a = C_f$，$H_a = H_f$，且暂不考虑制造和安装误差，则有：

$$C_a = \delta_0 - C_b \tag{9}$$

$$\delta_E(x_i) = p_1(x_i) + P_2(x_i) \tag{10}$$

4 计算结果及讨论

用上述方法编制和程序计算了一对渐开线外啮合斜齿圆柱齿轮，主要参数为：法面模数 $m_n = 8.8$ mm，齿数 $Z = 54/54$，分度圆螺旋角 $\beta = 30.5°$，齿宽 $b = 110$ mm，变位系数 $x = -0.08532/-0.08532$，齿顶高系数 $h_n^* = 1.15$，齿顶间隙系数 $C^* = 0.5$，弹性模量 $E = 2.06 \times 10^5$ N/mm²，传递扭矩 $T = 29150$ N·m。计算结果表明，不论是进行齿向直线修形(图 3)，还是抛物线修形(图 4)，其修形长度对最佳齿顶修形量、齿向修形量及相应的载荷分布系数有很大影响，但最小载荷分布系数数值相差不大，只是修形长度不同。齿顶修形的最佳长度为半个齿顶高，如图 5 所示，最佳齿顶修形量与传递扭矩成正比，如图 6 所示。

上述未修形齿轮副的载荷分布系数为 $k_p = 3.512$ 其最佳齿轮修形参数及相应的载荷分布系数为：

齿向直线修形

$C_a = 0.034$ mm；$H_a = 5$ mm；

$C_f = 5$ mm； $H_f = 5$ mm；

$C_b = 0.019$ mm；$H_b = 22$ mm；

$k_p = 2.213$

齿向抛物线修形

$C_a = 0.034$ mm；$H_a = 5$ mm；

$C_f = 0.034$ mm；$H_f = 5$ mm；

$C_b = 0.020$ mm；$H_b = 32$ mm；

$k_p = 2.135$

可见，采用最佳轮齿修形后载荷分布系数大幅度降低。

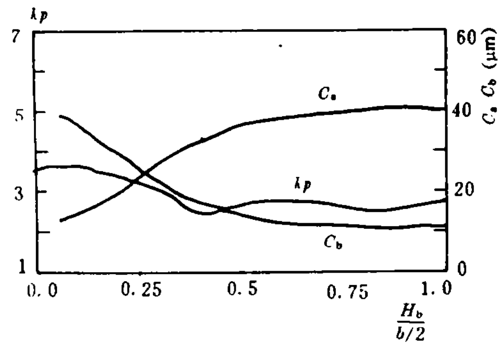

图 3 齿向直线修形长度对最佳轮齿修形和相应载荷分布系数的影响

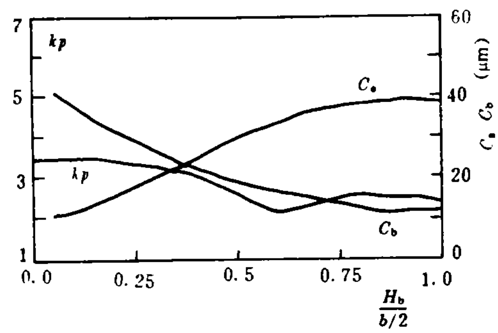

图 4 齿向抛物线修形长度对最佳轮齿修形和相应载荷分布系数的影响

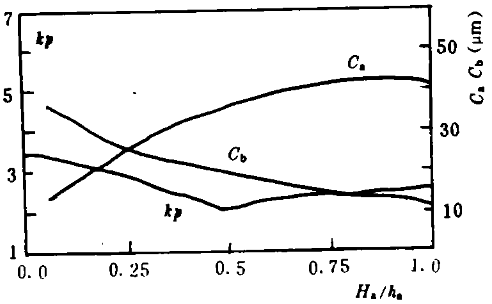

图 5　齿顶修形量对最佳轮齿修形和相应载荷分布系数的影响

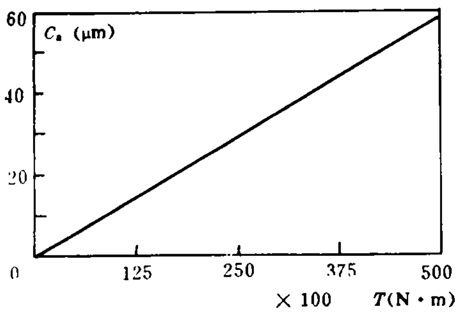

图 6　传递扭矩对最佳轮齿修形的影响

5　结论

1　最佳轮齿修形参数主要是齿向修形量和齿廓修形量及修形长度;

2　通过适当的轮齿修形,可有效地改善载荷分布和轮齿啮合状态。

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TA_5 钛合金低循环疲劳特性试验研究＝An Experimental Study on the High-strain Low-cycle Fatigue Characteristics of a TA_5 Titanium Alloy[刊，中]/Qin Guangyi，Wei Wu，Tan Hong (Harbin 703 Research Institute)//Journal of Engineering for Thermal Energy & Power. -1995，10(5)-310-316

Samples were taken from a ring-shaped special-type TA_5 titanium alloy to perform an experimental study on its high-strain low-cycle fatigue characteristics，and fatigue life characteristic curves and strain-life relation were obtained. After selecting a proper safety factor the authors provide fatigue design curves for the TA_5 titanium alloy and analyse stress cycle hardening/softening characteristics. Finally，by way of a finite element stress analysis it has been proved that the service life of the deep-diving condenser can be significantly enhanced if the main pressure-carrying components are made of single-metal TA_5 titanium alloy instead of the former bi-metallic construction. Key words：titanium alloy，fatigue characteristic curves，stress analysis，condenser

某舰主汽轮机正倒车阀位检测装置的研制及应用＝The Development and Application of an Ahead and Astern Valve Position Moniitoring Device for a Naval Vessel Main Steam Turbine[刊，中]/Sun Shifeng，Li Hui(Harbin 703 Research Institute)//Journal of Engineering for Thermal Energy & Power. 1995，10(5). -317-321

The authors describe the composition of an ahead and astern valve position monitoring device for the main steam turbine of a guided missile destroyer，the selection of its monitoring elements，the working principle of electric circuits，the use of the monitoring device after its installation on a naval vessel. Key words：marine steam turbine，actuator. monitoring device，development and manufacture

新型除氧设备——除氧装置、水箱一体化除氧器＝A New Type of Deaeration Equipment Featuring The Integration of Deaerating Unit and Water Tank[刊，中]/Xiao Futian，Mei Taikang(Harbin 703 Resarch Institute)//Journal of Engineering for Thermal Energy & Power-1995，10(5). -322-326

Deaerators featuring the integration of deaerating umit and water tank pertain to world-class advanced deaeration equipment. With the elimination of deaerating heads widely employed in conventional deaerators they have the merits of small size，low metal consumption and good deaerating efficiency. Described in this paper are the structural design features and working principles of this type of deaerators as well as their comparison with conventional deaerators. In addition，some key technical issues concerning their design and development are also dealt with. Key words：integrated deaerators，feedwater atomizing device

径向销钉式隔板找中方法＝A Method for the Alignment of Radial Pin Type Turbine Diaphragms [刊，中]/Guo Qingwen，Li Jianzhao，Dai Zhenyong，Lan Ruji，Song Chunsheng(Harbin 703 Research Institute)//Journal of Engineering for Thermal Energy & Power. 1995，10(5). -327-329

The proposed method for aligning radial pin type turbine diaphragms has the merit of significantly enhancing alignment efficiency and alleviating labor intensity. Key words：turbine diaphragm，alignment，method

重载齿轮的最佳轮齿修形＝Optimum Tooth Profile Correction of Heavy-Duty Gears[刊，中]/Chang Shan，Xu Zhenzhong(Harbin 703 Research Institute) Li Wei，Chen Chenwen (Harbin Institute of Thchnology//Journal of Engineering for Thermal Energy & Power. -1995，10(5). -330-333

Described in this paper is a method for the accurate calculation of load distribution along the contact line of the simultaneousy engaged teeth of heavy-duty gears. On the basis of the gear tooth mesh condition the opimum tooth profile correction parameters can be determined. By use of a computer program developed by the authors a study has been conducted of the influence of the optimum tooth profile correction parameter on the load distribution coefficient Key words：tooth profile

〔封面说明〕照片(下)

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correction, heavy-duty gear, tooth load distribution

降低斜齿轮噪声的齿轮修形优化设计＝Optimized Desgin of Tooth Profile Correction to Reduce Helical Gear Noise [刊,中]/Huo Zhaobo, Xu Zhenzhong, Chang Shan (Harbin 703 Research Institute); Yan Tonghai (Harbin Engineering University) // Journal of Engineering for Thermal Energy & Power. 1995, 10(5). -334-337

This paper discusses the vibration model and tooth profile correction model of an involute helico-cylindrical gear, presenting a method of tooth profile correction to reduce helical gear noise and an optimized program for effecting such a correction. Also given is a specific example of helical gear pair calculation. The results of calculation show that the correct and rational selection of a helical tooth profile correction amount can lead to a significant reduction of helical gear noise, but an excessively large correction amount may cause an increase in gear noise. Key words: involute gear, noise, gear tooth correction, optimized design.

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