

斜齿轮的抗胶合优化修形

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【摘要】 本文作者计算了斜齿轮的载荷分布,并进而计算了齿面的三维闪温分布。以降低齿面最高闪温为优化目标,提出了用数学规划技术对斜齿轮抗胶合修形进行优化设计的方法,考虑了齿轮支承变形对齿面闪温和优化修形的影响,该方法能够显著地提高斜齿轮传动的胶合极限载荷。

关键词: 斜齿轮 胶合 修形

1 前 言

由于硬齿面齿轮的广泛应用,齿轮抗点蚀性能有了很大的提高,对于高速重载齿轮,胶合成为重要的破坏形式。因此,设计具有高抗胶合能力的齿轮传动具有重要的意义。近年来,许多文献已报导了关于胶合强度的计算和实验研究的成果^[1],并正在更进一步研究提高抗胶合能力的设计方法,例如在直齿轮设计中对变位系数进行优化选择^[2]等。

齿廓修形对齿轮的胶合强度有显著改进,许多研究成果已证实了这一方面的作用^[3]。Matsunaga 的实验证明了最合适的修形能够使斜齿轮的胶合极限载荷提高至 2.5 倍^[4]。但是,上述研究均未涉及提高抗胶合能力的专门修形的设计问题。

本文以三维有限元和数学规划方法进行了斜齿轮的齿面接触分析,得到了齿面载荷分布,并进而计算了齿面的接触温度分布。在此基础上,进行了齿轮修形的优化设计,得到的最佳齿面修形,比常用的齿廓修形的效果有了更进一步地提高,无疑为高强度齿轮的设计提供了一条重要途径。

2 斜齿轮面闪温计算

本文的计算对象为一对斜齿轮,其主要参数列于表 1 中。

表 1 被计算的齿轮副参数

齿 数	模 数	压力角	螺旋角	齿 宽	精度等级	法向载荷	转 速
$Z_1=24$ $Z_2=48$	$m_n=4mm$	$\alpha_s=20^\circ$	$\beta=16.26^\circ$	$B=20mm$	JB 5 级	$P=4000N$	$n=10000r/min$

齿面闪温的计算采用 Block 公式^[5],但斜齿轮的载荷分布比直齿轮复杂得多,不能直接使用 ISO 标准中的公式。作者应用三维有限元、数学规划技术来计算齿面的三维接触温度,当齿面摩擦系数 f 与载荷密度的 0.25 次方成比例时^[5],齿面闪温 θ_{fla} 表示如下:

$$\theta_{fla} = x \cdot w_n$$

(1)

式中: w_n 为齿面法向线载荷密度, x 为计算系数。 x 中包括了齿面计算点的综合曲率半径, 两齿面的切向速度、材料特性、粗糙度、润滑油粘度等影响因素, 它的计算可参见文献[5]。修形前后都相同的系数如使用场合系数等均可取 1, 为简化计算, 动载系数也可近似取 1。

如果工作齿面划分有 n 个结点, 一个啮合周期包括 m 个齿轮转角位置, 齿面结点载荷的计算可以表示作:

$$\begin{cases} -[\lambda]\{p\} + [D]\{\alpha\} + [I]_n\{Y_1\}_n = \{\epsilon\} \\ [D]^T\{p\} = P \cdot \{e\}_m \\ \text{或 } P_j = 0 \text{ 或 } Y_{ij} = 0 \quad (j = 1 \cdots n) \end{cases} \quad (2)$$

式中: $[\lambda]$ 为 n 维柔度矩阵, 元素 λ_{ij} 为齿面 i 结点作用一单位载荷时, 同一接触线上 j 结点由于齿轮副和支承系统的变形而产生的齿面结点相对法向位移, 用三维有限元计算得到; $[D]$ 为 $n \times m$ 维矩阵, 由 m 个 n 维列向量组成, 第 i 个列向量为: $\{D\}_i = (0 \cdots 0 \ 1 \cdots 10 \cdots 0)^T$, 即对应于第 i 个转角位置的接触线上的结点元素取 1, 其余为零; $\{p\}$ 为 n 维结点载荷向量; $[I]_n$ 为 n 维单位矩阵; $\{\alpha\}$ 为 m 维向量, α 表示在第 i 个转角位置上齿轮副的相对位移; $\{Y_1\}_n$ 为 n 维结点松弛向量; $\{\epsilon\}$ 为 n 维向量, ϵ 表示 j 结点由于啮合误差而产生的齿面初始分离量; $\{e\}_m$ 为全部元素为 1 的 m 维向量。式(2)中第一式为位移协调条件, 第二式为力平衡条件, 第三式表示可部份结点接触(偏载), 有非线性性质。用数学规划可求得式(2)的载荷向量 $\{p\}$, 齿面闪温计算可表示为:

$$\{\theta\}_{fla} = [T]\{p\} \quad (3)$$

式中: $\{\theta\}_{fla}$ 为 n 维结点闪温向量; $[T]$ 为 n 维对角矩阵, 对角元素 $T_j = x_j / h_j$, x_j 为 j 结点的计算系数(见式(1)), h_j 为 j 结点的接触线长。

3 齿面接触温度分布与二维表示

作者用上节所述公式计算了表 1 所列的齿轮副。计算中未计入齿轮支承的变形, 齿面粗糙度 R_a 取 $0.2 \mu\text{m}$, 动力粘度 η_w 取 5 MPa , 油温取 80°C , 齿轮基体温度取 100°C , 计算得到的齿面接触温度分布绘于图 1 中, 在本文的计算中, 根据 ISO 标准, 均假设齿面各点的基体温度相同。图 1 中坐标 x 为齿宽方向, y 为齿廓方向。沿齿轮副啮合路径(作用线)度量, 图中网格为有限元计算网格的齿面划分。

由图 1 可见, 斜齿轮齿面接触温度的三维分布比直齿轮的二维分布有明显的区别, 最高温度区域分别位于齿面进入啮合和退出啮合的一角(图中分别用 $B \triangleright$ 和 $F \blacktriangleright$ 表示), 在进入啮合角上达到最高接触温度约为 160°C 。Kubo 的斜齿轮胶合试验研究了齿面的接触温度分布^[6], 他的试验结果与图 1 所示的计算结果是相当一致的。

为了表示方便, 并且便于和 ISO 标准对照, 本文定义了斜齿轮齿面接触温度的二维表示方法如图 1 所示, 坐标 s 平行于 y 方向且经过齿宽中点, 啮合路径全长 AE 包括了端面重合度和轴向重合度。 s 坐标轴上坐标点(用 $\bullet$ 表示)代表各接

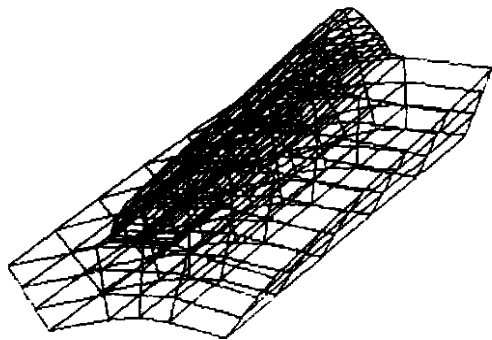


图 1 斜齿轮齿面接触温度分布

触线中点(用×表示)。由图可见,各接触线中点联线经过了最高接触温度区并基本表示了温度梯度的方向。因此,用这样的二维表示方法可以简便地取代齿面三维温度分布,特别是当螺旋角为零时,这一表示方法与 ISO 标准的直齿轮闪温表示方法完全相同。如此表示的图 1 的齿面温度分布如图 2 所示,图中细线为载荷分布。

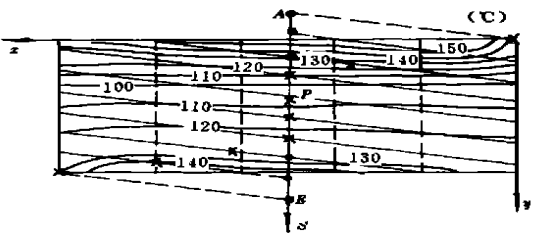


图 2 啮合路径上的齿面接触温度

4 斜齿轮抗胶合修形优化设计

斜齿轮抗胶合修形的优化目标定为降低齿面最高闪温,假定最佳齿廓修形曲线是二次抛物线 $z = ay^2 + by + c$,优化修形可表示如下:

$$\begin{cases} \text{Min}(\theta_{la})_{\max} \\ - [\lambda] \{p\} + [D] \{\alpha\} + [I]_n \{Y_{ij}\}_n = \{\epsilon\} + a\{y^2\} + b\{y\} + c\{e\}_n \\ [D]^T \{p\} = P \cdot \{e\}_m \\ [T] \{p\} - (\theta_{fla})_{\max} \cdot \{e\}_n \leq \{o\}_n \\ \text{或 } p_j = 0 \quad \text{或 } Y_{ij} = 0 \quad (j = 1 \cdots n) \end{cases} \quad (4)$$

式中: $\{y\}$ 为 n 维结点 y 坐标向量; $\{e\}_n$ 为全部元素为1的 n 维向量; $\{o\}_n$ 为 n 维零向量; $(\theta_{la})_{\max}$ 为齿面最高结点闪温。式(4)与式(2)比较,增加了优化目标和选出最高闪温的第四式。作者用式(4)计算了表1所列的齿轮副,计算工况同前。计算得到的最佳齿廓修形和修形效果如图3所示,最高齿面接触温度降至124℃考虑到齿面闪温和载荷密度的线性关系,24℃。闪温和60℃相比较,相当于胶合极限载荷提高到2.5倍,和Mas tunaga 的实验是吻合的。

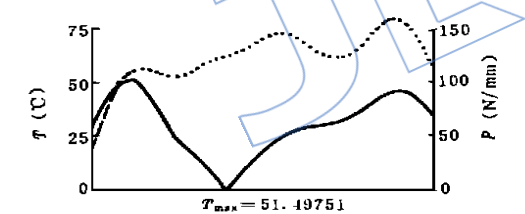


图 3 最佳抗胶合齿廓修形和修形效果

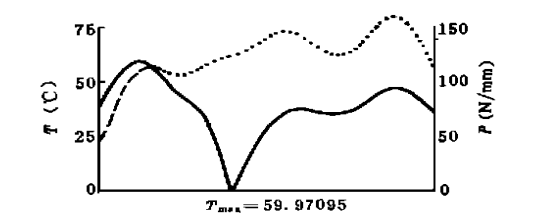


图 4 普通齿廓修形及对齿面闪温的影响

作者进一步与普通改善动态性能的齿廓修形作了比较。图4所示,是常用的修形量对称分布的齿廓修形与该修形对于降低齿面闪温的作用。由图可见,齿面最高接触温度为142℃,比不修形有明显改进,但显然不如按式(4)设计的最佳齿廓修形。

5 齿轮支承变形的影响

上述计算中未计入支承(包括轴、轴承、箱体)变形,适用于支承刚度较高,且布置比较对称的应用场合。为了进一步说明支承变形对胶合的影响及优化修形的效果,作者计算了表1所列的齿轮副,小齿轮悬臂安装时的齿面闪温如图5(a)如示,支承变形引起严重的偏载,使齿轮副进入啮合角上的接触温度升至约234℃,使齿轮很快出现胶合破坏。作者用式(6)的数学规划设计了齿轮副在支承条件下的最佳齿廓修形曲线,修形后最高齿面接触温度降至约191℃(图

5(b)), 且在进入啮合和退出啮合区达到温度平衡, 基本解决了胶合问题。

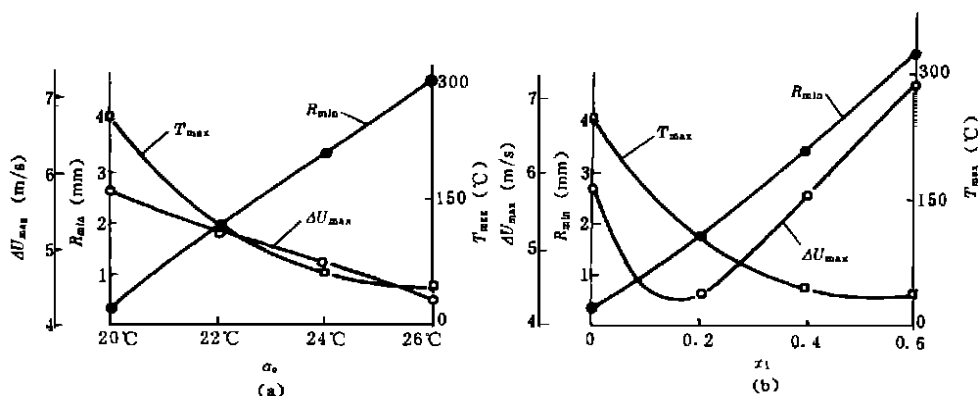


图 5 齿轮支承变形对胶合及修形的影响(a. 齿面闪温; b. 齿廓优化修形)

当然,如果能够通过齿向螺旋角修形先解决齿轮偏载问题,然后再经齿廓优化修形,得到的齿轮抗胶合强度将能接近图 3 所示的水平。

6 结 论

- (1) 本文用数学规划方法求得了斜齿轮齿面载荷分布和齿面接触温度的三维分布。
- (2) 本文提出的总重合度下的斜齿轮啮合路径上的闪温分布表示方法,既能代替斜齿轮齿面三维闪温分布,又与 ISO 标准的表示方法取得了一致。
- (3) 本斜齿轮抗胶合齿廓修形的数学规划设计方法,可使齿面最高闪温大幅度下降。
- (4) 支承变形引起的偏载会加速齿面胶合破坏,故设计修形时应计及支承变形的影响。

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fact, the effects of these coefficients and g expressions on reaction rate and temperature profiles are significant. This paper aims at providing optimal values of these coefficients and rational g expression. Numerical calculations were carried out for recirculating reacting flow behind a bluff-body burner. It is shown that C_R is given by $C_R = (\Delta T^* / 1000)^2 g^{1/2} / g_{\max}^{1/2} \ln(1 + 2g_{\max}^{1/2} / g^{1/2})$, C_{g1} is defined as $C_{g1} = 2 / \sigma_f$, C_{g2} is 2 in this prediction.

The prediction is in favourable agreement with the experimental measurements.

A CALCULATION RESEARCH ON BURNING RATE OF ALUMINIZED COMPOSITE PROPELLANT

Liu Dehui and Peng Peigen

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ABSTRACT

A research has been completed by applying PEM model to combustion simulation of aluminized propellants. The effects of aluminium particles on the surface energy of the propellant are taken into consideration so simply as the heat sink PEM model of J. P. Renie et al, but a new method to determine the pseudopropellant's formulations is presented in this paper, thereby an extended and modified PEM model is developed. According to this model, the burning rates and pressure exponents of aluminized propellants are calculated. The results show that our model makes the calculated results of burning rates and pressure exponents more approach to their experimental data as compared with the heat sink PEM model of J. P. Renie et al.

DESIGN PRINCIPLE OF CHANGE-SPEED INVOLUTE CONICAL GEAR TRAIN

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ABSTRACT

A theory of hobbing involute conical gears on a hobber with a horizontal feed motion is described in the light of the gear engagement principle. The relations among some important parameters of the imaginary rack-shaper cutter and the generated gear are analyzed, and the design method of a change-speed train mainly composed of intersected involute conical gears is considered in detail. It has many special advantages such as many speed degrees only with a few gears, adjustable gear clearance by changing position of the gear along with their axes respectively. Because in designing this kind of train it is very important how to minimize the volume and size and how to maximize the changeable speed degrees and the difference between the highest degree and the lowest degree. A practical method is provided to control some key parameters to reach these goals. The present theory is proved correct and the method is shown practical by tests of a sample change-speed train.

OPTIMAL TOOTH PROFILE MODIFICATION OF HELICAL GEARS FOR IMPROVING RESISTANCE TO SCUFFING

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(Northwestern Polytechnical University)

ABSTRACT

An approach is presented to increase scuffing load capacity of helical gears. Firstly, the flash temperature distribution on tooth is evaluated by using 3-D

finite element method, mathematical programming technique and Block's equation. The calculated results show that the highest flash temperature occurs at the mesh beginning and finishing corners on the tooth flank where scuffing could happen. Further, a tooth profile modification by a parabola is presented. Through the agency of optimization programming with an object function of minimizing the highest flash temperature, the optimal profile modification can be obtained. According to the numerical example, the scuffing limit load could be raised 2.5 times as unmodified helical gears. Finally, the influence of the supporting structure on the distribution of flash temperature is discussed. An optimal profile modification method is developed, which takes the deformation of supports into consideration.

PRIMARY RATED LIFE ESTIMATION FOR TURBINE DISC

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(Guizhou Aeroengine Institute)

ABSTRACT

The estimation of the primary rated life is studied for a aeroengine turbine disc. A method for this purpose is considered and put into practice. The rated life of turbine disc is predicted by local stress-strain approach Larson-Miller curve and Masson Linear rule. And then it is proved by tests. In the life test investigation of the turbine disc, the equivalent accelerated test loading spectrum provided according to equivalent rule (without changing dangerous position and damage characteristics) not only accelerates test, but also satisfies life test specifications. Besides, the turbine disc is enclosed in a case heated up by middle-frequency electro-induction. This method improves hotting characteristics of a turbine disc tester.

RELIABILITY CALCULATION IN CONSIDERATION OF PHYSICAL PARAMETERS OF A MATERIAL AS RANDOM PARAMETERS

Lu Wenlin and Fu Shuang

(Northwestern Polytechnical University)

ABSTRACT

A method of reliability calculation for directionally solidified turbine blade has been provided, which mainly considers physical parameters as random by means of stochastic FEM and Hasofer-Lind method. The method ensures convergence of its calculation, so it is feasible. The calculation results indicate that physical parameters as random ones have less influence on the failure probability than the loading and mechanical parameters.

FUEL CONTROL FAILURE RESEARCH FOR JT8D ENGINE

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ABSTRACT

A failure research of the fuel control in JT8D turbofan engine has been completed, which results in effective reduction of its unscheduled removal rate and sets up the foundation for domestic fuel control repairs. The theoretical analysis, simulation, adjustment tests, establishing and practising the diagram of failure insulation are applied to the failure research. Its economic and social benefits are obvious.