

考虑材料物理参数为随机量时 可靠度的计算

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【摘要】 本文主要考虑了材料物理参数为随机量时, 利用随机有限元及 H-L 方法对定向结晶涡轮叶片进行可靠度计算。计算方法收敛, 说明本方法可行。从计算结果表明, 物理参数为随机量时(相对于外载及材料机械性能为随机量时)对破坏概率影响较小。

关键词: 材料物理参数 随机量 可靠度 计算

本文的可靠度计算, 采用应力—强度干涉理论, 也就是在强度及应力的分布中, 强度大于应力的概率即为可靠度。而影响应力变化的因素, 除了所承受的外载荷、几何尺寸及形状概率分布的影响^[1,2], 还有材料的物理参数分布的影响。本文着重在材料物理参数为随机量时可靠度的计算, 仅考虑了材料正交的两个方向的弹性模量 E_T 、 E_D , 泊松比 ν_1 、 ν_2 和垂直于结晶方向的剪切弹性模量 G_{TD} 等材料的物理参数为随机量的可靠度计算, 以探索计算方法的可行性及其对可靠度的影响。关于定向结晶材料的物理方程、弹性矩阵及刚度矩阵以及叶片的划分网格均在文献[1]中叙述过, 本文着重分析及材料物理量为随机量的随机有限元计算方法。

1 公式的推导

本文仍然以正交材料的 Hill 准则为其失效模式的依据, 现将已推导的结果列在下面。其破坏函数为

$$g = 1 - \frac{(\sigma_x - \sigma_{2y})^2}{\sigma_T^2} - \frac{\sigma_x \sigma_y + \sigma_z^2 - \sigma_x \sigma_z - \sigma_y \sigma_z}{\sigma_D^2} - \frac{\tau_{xy}^2}{\tau_T^2} - \frac{\tau_{yz}^2 + \tau_{xz}^2}{\tau_{TD}^2} \quad (1)$$

将上式对某一随机量 x_i 求偏导, 可得 $\partial g / \partial x_i$ 的表达式, 为各应力分量对随机量的偏导数, 即 $\partial \sigma_x / \partial x_i, \partial \sigma_y / \partial x_i, \dots$ 的函数。按 Taylor 级数在破坏点展开, 并取一次项, 得

$$g = g^*(x) + \sum_{i=1}^k x_i - x_i^* (\partial g / \partial x_i)^* \quad (2)$$

$$E[g] = E[g^*(x)] + \sum_{i=1}^k (\mu_{xi} - x_i^*) (\partial g / \partial x_i)^* \quad (3)$$

$$Var[g] (\partial g / \partial x)^T [c] (\partial g / \partial x)^* \quad (4)$$

式中 $[c]$ 为协方差阵。第 i 个单元可靠性指标

$$\beta_i = E[g_i] / \sqrt{Var[g_i]} \quad (5)$$

其可靠度

$$R = \Phi(\beta) \quad (6)$$

破坏点的选取及逼近迭代及可靠度的计算采用 Hasofer-Lind 方法。计算可靠性指标 β 时需求出应力对随机量的偏导数, 其应力的矩阵式为

$$\{\sigma\} = [D][B]\{U\}$$

上式偏导后为

$$\{\sigma\}'_{x_i} = [D]'_{x_i}[B]\{U\} + [D] + [B]'_{x_i}\{U\} + [D][B]\{U\}'_{x_i}$$

本文所考虑的随机量与几何尺寸无关, 因此几何矩阵的偏导数 $[B]'_{x_i} = [0]$, 得应力的偏导数

$$\{\sigma\}'_{x_i} = [D]'_{x_i}[B]\{U\} + [D][B]\{U\}'_{x_i} \quad (7)$$

上式中较之不计材料物理量为随机量多了含有弹性矩阵 $[D]$ 对随机量 x_i 偏导数 $\{U\}'_{x_i}$, 可从下面推导得出。

$$\begin{aligned} [k]\{U\} &= \{P\} \quad , \quad [k]\{U\}'_{x_i} + [k]'_{x_i}\{U\} = \{P\}'_{x_i} \\ \{U\}'_{x_i} &= [k]^{-1}\{(\{P\}'_{x_i})^* - (\{k\}'_{x_i})^*\{U\}^*\} \end{aligned} \quad (8)$$

下标 “*” 代表各随机量破坏点的数值。

材料物理参数的随机量 E_T, E_D, ν_1, ν_2 和 G_D 等包含在 $[D]$ 矩阵中, 并可求出 $[D]'_{x_i}$ (即 $\partial [D] / \partial E_T, \partial [D] / \partial E_D, \partial [D] / \partial \nu_1, \partial [D] / \partial \nu_2, \partial [D] / \partial G_D \dots$)。将上述的破坏点数值代入 (8) 式中, 即可求出位移的偏导数 $\{U\}'_{x_i}$, 再根据 (7)、(3)、(4)、(5) 式得出可靠度。注意 (8) 式中刚度矩阵 $[k]$ 对随机量 x_i 的偏导数为

$$[k]'_{x_i} = [B]^T [D]'_{x_i} [B] \quad (9)$$

$[D]'_{x_i}$ 矩阵内各元素表达式需事前导出, 并代入破坏点值得出 (9) 式的值 $([k]'_{x_i})^*$ 。

2 算 例

采用 20 节点三维等参元进行有限元及随机有限元计算。叶片材料 DZ-22 的有关物理参数及所需之方差数据选自文献 [3]。有的数据按均值的上下偏差 $\pm \Delta_{x_i}$, 得出标准差

$$[Var(x_i)]^{1/2} = (1/3) \Delta_{x_i}$$

由于物理参数的方差很小, 所得可靠性指标太大, 查不出对应的可靠度, 为检验方法是否可行, 将 E_T 的离差系数放大为 0.05。所有随机量均按正态分布, 如为非正态分布时可按 R-F 或 C-L 方法正态化。本算例经 14 次迭代, 得出 β 值为 2.7245。破坏概率 $P_f = 0.0032214$ 。随机量的均值取为 $E_T = 179340 \text{ MPa}$, $E_D = 125440 \text{ MPa}$, $\nu_1 = 0.331$, $\nu_2 = 0.452$, $G_{TD} = 39494 \text{ MPa}$ 。 ν_1, ν_2 的离差系数^[3]选为 0.0005, E_D 离差系数为 0.005, 而 E_T 及 G_{TD} 均放大为 0.05。

本文建立了航空发动机零件的计及材料物理参数为随机量的随机有限元计算可靠度方法, 并对定向结晶叶片进行了实际计算。计算结果表明逐渐收敛, 所采用的 H-L 及随机有限元对此例是可行的。由于物理量参数离差系数小, 所得之破坏概率值为本项目中载荷阵为随机量计算破坏概率值的 3.7% (本例为验证方法使计算方便, 加重了发动机的工作状态, 计算具体值并非实际工作状况)。从相对数值中看出其影响较载荷列阵的因素为小。

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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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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

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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.