

粉末冶金涡轮盘有限元应力分析

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【摘要】 对某型航空发动机粉末冶金涡轮盘进行了有限元应力分析。首先根据转子系统的连接方式确定了涡轮盘应力计算边界条件, 然后对该涡轮盘进行了热弹性、弹性应力和热应力分析。计算结果表明: 该粉末冶金涡轮盘在最大稳定工作状态下处于弹性工作范围; 超转至 122% 时除轮心有微小的塑性变形外, 轮盘基本处于弹性范围; 不均匀温度场对轮盘的应力分布有较大的影响。

主题词: 粉末冶金 涡轮 盘 应力分析

分类号: V232.3

粉末冶金涡轮盘由于具有足够高的低循环疲劳寿命和良好的抗蠕变能力因而在世界先进的航空发动机上广泛采用^[1]。国外的研究和经验表明由于研制初期粉末盘的生产工艺的不完善以及应力分析技术的不成熟, 可能导致粉末冶金涡轮盘的设计计算强度不够而导致破裂等潜在的危^[2]。根据某型粉末冶金涡轮盘设计和寿命估算的需要, 使之可靠地应用于发动机, 本文用有限元方法对该粉末冶金涡轮盘进行了应力分析。

1 计算模型与边界条件的选取

某型粉末冶金(FGH95)涡轮盘与压气机盘之间靠端面套齿传递扭矩, 转子系统采用中心拉杆连接在一起, 为可靠传力, 在装配时施加了 10 吨的预紧力。该轮盘具有高转速、高负荷、高工作温度以及盘型面特殊的设计特点。当轮盘旋转以后, 由于转子的挠度, 会使预紧力变小, 转速不同, 则预紧力不同。严格地说, 该涡轮盘应力分析时的约束边界条件应当根据整个转子系统的分析以后才能确定, 但这样工作量大, 也是没有必要的。根据这种结构特点, 采用了如图 1 所示的轴对称有限元计算模型, 只在端面套齿处给予了 z 方向的约束, 应力计算中预紧力取为 10 吨。这样取值是基于以下分析得到的: 取轴向预紧力为 0, 5 吨和 10 吨分别进行应力分析, 结果表明预紧力只对轴和轮毂有影响, 而在其它部位引起的应力基本为零。预紧力越大则轮盘的应力越大, 但预紧力为 10 吨和零时相差不大, 可见预紧力对轮盘的主体应力分布影响较小。因此

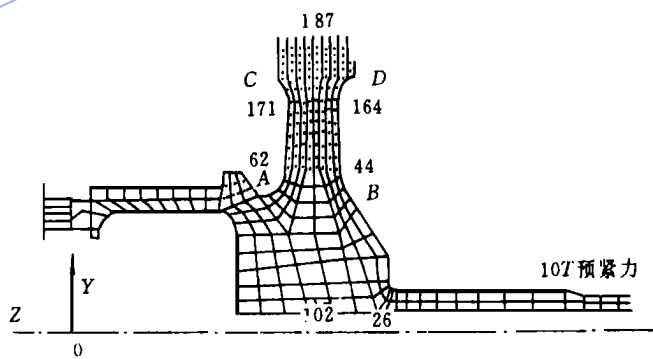


图 1 有限元计算模型

在轮盘主体应力分析中预紧力取 10 吨,可以给出偏于安全的计算结果。计算中叶片和轮缘凸块的离心力,假定为均匀分布在以轮盘的榫槽底为界的外缘。

2 计算结果及应力分析

涡轮盘最大状态时的工作转速为 45000 r/min,轮缘和轮心温度分别为 550℃和 400℃。采用 ADINA 程序^[3],对轮盘进行了热弹性、弹性、热应力以及超转至 122% 下的应力分析。

热弹性应力计算结果表明:在额定工作状态下,轮盘最大等效应力发生在轮心为 1065 MPa,整个轮盘处于弹性范围。这是由于粉末冶金涡轮盘材料具有比常规的涡轮盘材料高得多的屈服极限,如 GH36 在室温下的屈服极限为 500.66 MPa^[4],而 FGH95 此时的屈服极限则大于 1000 MPa,特别是它具有良好的高温性能,650℃下的屈服极限与室温相差不到 10%,而 GH36 则相差达 40%。正因为如此,粉末高温合金材料 FGH95 能满足该发动机的高转速、高负荷及高工作温度的设计要求。

图 2 为等效应力 $\bar{\sigma}$ 的分布,可以看出,轮盘存在 7 个应力集中区,它们是:轮心部分、轮缘、轮辐与轮缘交接处、轮辐与轮毂的交接处以及轴与轮盘主体连接处。表 1 中列出了这些部位在最大转速时的应力、应变值,轮心处应力最大,为 1065 MPa,比 $\sigma_{0.2}$ 小很多。

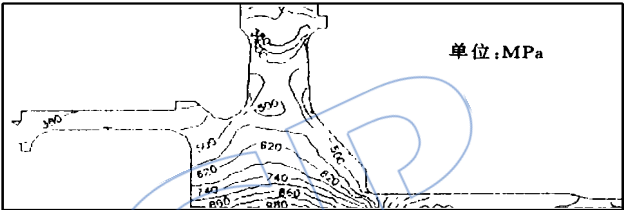


图 2 热弹性计算的等效应力分布

不考虑不均匀温度场引起热应力时,涡轮盘的弹性应力分析结果表明:轮心部分的应力比热弹性分析时要小,而轮缘则相反,见表 1。

表 1 热弹性、弹性分析的等效应力与应变(45000 r/min)

区 域		轮心	轮心与轴连接处	A 区	B 区	C 区	D 区	轮缘
单元与积分点		102, 2	26, 1	62, 2	44, 2	171, 1	164, 3	187, 1
热弹性	等效应力(M Pa)	1065	830	719	763	557	597	326
	等效应变(10 ⁻²)	0.5309	0.4140	0.3583	0.3799	0.2791	0.3000	0.1680
弹 性	等效应力(M Pa)	967	726	672	701	569	605	489
	等效应变(10 ⁻²)	0.5133	0.3852	0.3569	0.2768	0.3037	0.3233	0.2641

不考虑离心载荷及轴向预紧力时,在最大稳定状态的温度场作用下,进行了热应力分析。计算结果表明:轮缘部分具有最大的周向压缩热应力,轮心部分的周向热应力较小,为拉伸应力,而在轮辐与轮毂的交接处基本为零,图 3(a)和(b)为周向热应力和等效热应力分布。

超转至 122% 热弹塑性应力分析结果表明,除轮心部位有微小的塑性变形外,轮盘基本处于弹性范围,最大应力为 1226 MPa,刚好大于该部位的屈服应力 1216 MPa,这充分说明粉末冶金涡轮盘具有良好的高温力学性能。

轮心部位:由于预紧力越大轮盘的应力越大,因此采用图 1 所示的计算模型,在轴向预紧力为 10 吨的情况下,热弹性分析得到的轮心应力是工作过程中最大应力,以此应力来进行疲劳寿命估算是偏于安全的。

轮缘部分: 不均匀温度场引起的热应力在轮缘为负, 它抵消了离心力引起的正应力, 使得轮缘部分的热弹性应力分析的应力小于弹性应力分析时的结果。在实际工作过程中, 轮缘部分的最大应力不一定发生在最大稳定工作状态, 而很可能发生在过渡状态。例如在连续的大功率状态以后变为慢车的瞬间时, 轮缘部分受冷空气冷却, 温度迅速下降, 轮幅和轮心由于热惯性温度仍较高, 这样的温度梯度引起周向拉应力, 而当转速还没下降得很多时, 离心力和热应力的共同作用可能使轮缘的应力达到最大值。因此必须以瞬态温度场和相应的转速谱为基础, 才能准确地确定轮缘部分的应力上限值。

轮幅部分: 不均匀温度场引起的热应力在轮辐的 A、B 区域基本为零, 直径在其之外部分的热应力为负, 直径在其之内的为正, 因此 A、B 区计算出的应力基本反映其工作过程中的最大应力。

3 结 论

(1) 由于采用屈服强度高的新型粉末高温合金材料, 使得涡轮盘的应力状态大大地得到了改善。在额定状态工作时轮盘处于弹性状态, 不均匀温度场对轮盘的应力和变形都有较大的影响。(2) 采用本文所选取的有限元计算模型, 应力分析结果是合理的, 按 10 吨预紧力, 轮心和轮幅与轮毂的交接处热弹性应力分析得到的是稳态工作过程中最大的应力, 以此进行疲劳寿命计算可以给出偏于安全的结果。(3) 超转至 122% 时除轮心有微小的塑性变形外, 其余部分仍然为弹性, 说明粉末冶金涡轮盘具有良好的高温力学性能。

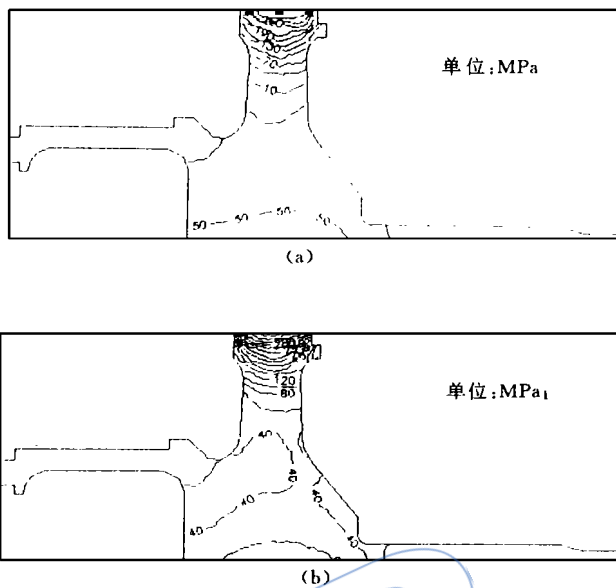


图 3 涡轮盘热应力分布(a)周向热应力(b)等效热应力

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Heat transfer coefficient for the suction side, however, was decreased due to film cooling.

Key Words Numerical computation Bladws Thermo- convection coefficient

TECHNICAL NOTES

DEVELOPMENT OF FAILURE DIAGNOSIS TECHNIQUES IN ENGINE DIGITAL CONTROL SYSTEMS

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ABSTRACT

This paper surveys the development of sensor failure diagnosis in engine digital control systems. First, the early research works on techniques of sensor failure detection and isolation are reviewed. The main disadvantage of model- based methods is high sensitivity to modeling errors which are inevitable because of the complexity of the aircraft engine. Then, the paper considers the necessity of robust failure diagnosis and its development. In view of the fact that the neural networks have been successively applied to control realm and possess themselves of tremendous potentials, the neural- network- based failure diagnosis is recommended as a promising approach in the engine digital control systems.

Key Words Aircraft engines Digital control system Fault diagnosis

INFLUENCE OF TEMPERATURE RATIO ON PENETRATION DEPTH OF 2D CONFINED CROSS FLOW

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ABSTRACT

The influence of temperature ratio on the penetration depth of two- dimensional confined cross flow is investigated numerically. It is found that the temperature ratio of jet to main flow was an important parameter independent of momentum ratio. This phenomena can be explained in terms of the concept of "thermal drag". A cold jet injected perpendicularly into a confined hot air flow is heated and accelerated as the momentum ratio is given. The thermally induced pressure drop is converted into the momentum increase and consequently increases the penetration depth. On the contrary, a hot jet injected perpendicularly into a confined cold air flow for the given mometum ratio decreases its own momentum due to cooling by the mainflow. As a consequence, its penetration depth also is cut down.

Key Words Temperature distribution Jet penetration Numerical computation

FINITE ELEMENT STRESS ANALYSIS OF POWDER METALLURGY TURBINE DISC

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ABSTRACT

A stress analysis of a Powder Metallurgy (PM) turbine disc was accomplished by finite element method. First, the calculation boundary was determined according to the linkage mode of the rotor, then its elastic, thermoelastic and thermal stress analyses were made. The results show that the deformation of the PM disc is elastic at maximum rotational speed. As the rotational speed exceeds the maximum by 22%, the deformation of disc remains elastic except in the core. The inhomogeneous temperature field has a strong effect on the stress distribution of the disc.

Key Words Powder metallurgy Turbines Disks Stress analysis

APPLICATION OF DOMAIN DECOMPOSITION METHOD TO PREDICTION OF TURBULENT FLOW FIELDS

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ABSTRACT

The Domain Decomposition Method (DDM) is applied to calculation of turbulent flow fields. A general DDM-1 scheme $S_{1,\omega}$ is developed for turbulence equations with treatment of variables in overlapped domains. It features that the whole computational domain is decomposed into several subdomains according to the flow properties and the different decomposed domains employ corresponding physical models. A prediction of turbulent flow fields in a sudden pipe expansion was made and compared with the experimental data. It was shown that the scheme can predict the reattachment point, mean axial velocity and turbulence kinetic energy more accurately than the methods using a single model in entire domain.

Key Words Decomposition method Turbulent flow Numerical simulation

THRUST CHARACTERISTICS OF EXHAUST EJECTOR SYSTEMS WITH LOBED NOZZLES TESTED AT COLD HIGH SPEED CONDITIONS

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ABSTRACT

A set of thrust characteristics (thrust with nozzle pressure) of a round convergent nozzle, five lobed nozzles and lobed nozzle-mixing tube combinations with and without diffusers have been obtained from the experimental investigation at cold high speed conditions (nozzle pressure = 0.15~0.5 MPa). Test results show that the lobed nozzles of the exhaust ejector systems at high speed conditions also have superior application prospects, provided their designs consider the impact of high speed flow, in especial, the aerodynamic characteristics of supersonic exhaust flow.

Key Words Nozzles with injector Thrust characteristics High speed