

燃气轮机过渡过程中叶尖间隙估算 及间隙变化对加速过程的影响

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【摘要】给出了一种估算燃气轮机加、减速过程中叶尖间隙及效率随时间变化的简化方法。算例结果与国外文献的对比表明该方法是可行的且有一定的准确度。

主题词: 燃气轮机 动态过程 叶尖 间隙

分类号: U 263. 11

1 叶尖间隙估算模型

为了使燃气轮机过渡过程性能模型更准确地反映真实的物理过程, 本文给出了一种估算燃气轮机在加、减速过程中压气机和涡轮叶片叶尖间隙变化及其对效率影响的方法。叶尖间隙的精确计算模型应当建立在多维换热热伸长分析以及弹性力学的基础之上, 但对于燃气轮机过渡过程性能计算是, 需发展一种简化估算方法。叶轮机机械的实际工作过程, 叶尖间隙变化应主要由热效应和机械效应两方面引起。为计算方便起见本叶尖间隙估算模型将一台多级压气机或涡轮简化为一个当量级, 再将当量级每个子部分近似的地简化为规则的几何形状。当量级采用全台的平均气流参数和材料的平均物性。叶尖间隙变化可描述如下^[1]:

$$\Delta C_L = \Delta R_c - \Delta R_b - \Delta R_d \quad (1)$$

式中各 ΔR 分别表示机匣、叶片和盘的径向尺寸瞬时变化。它们的瞬时热伸长用下式估算:

$$\Delta R_h = C_x \cdot \Delta T_m \cdot L, \quad \Delta T_m = [\alpha(T_g - T_m) \cdot A \cdot \Delta t] / (M e \cdot C_m) \quad (2)$$

其中, 机匣、叶片和盘的换热系数将用相应的在相似理论基础上建立的实验关联式估算^[2]。

盘和叶片的离心伸长可分别按下两式进行估算^[2]:

$$\Delta R_{dc} = \frac{1}{E_d} \cdot \frac{3R_o \omega^2}{2\pi\delta} \left\{ \sum M_b \left(\frac{R_o^2 + R_i^2}{R_o^2 - R_i^2} \right) + \rho_d [R_i^2 (3 + \sigma) + R_o^2 (1 - \sigma)] \right\} \quad (3)$$

$$\Delta R_{bc} = \left[\left(\frac{R_i^3}{3} + \frac{R_b^3}{6} + \frac{R_i^2 \cdot R_b}{2} \right) \rho_b \omega^2 \right] / E_b \quad (4)$$

2 效率变化的估算

因叶尖间隙变化对效率的影响可按下式估计^[3]:

$$\Delta \eta = 0.7 \frac{\Delta C_L \cdot \psi}{h_b \cdot \cos \beta_o} \left[1 + 10 \left(\frac{\varphi \cdot \Delta C_L \cdot b}{h_b^2 \cdot \psi \cdot \cos \beta_o} \right)^{0.5} \right] \quad (5)$$

将上述叶尖间隙模型加入燃气轮机过渡过程模拟计算程序, 计算了某双轴涡扇发动机的加速过程, 时间步长 Δt 取为 0.05 秒。在模拟的加速过程中考虑了转子转速、气流参数和换热

系数等随时间的变化。计算获得了在加速过程中高压压气机和高压涡轮叶尖间隙的变化(见图 1), 估算了由于叶尖间隙变化对压气机效率的影响(见图 2)。

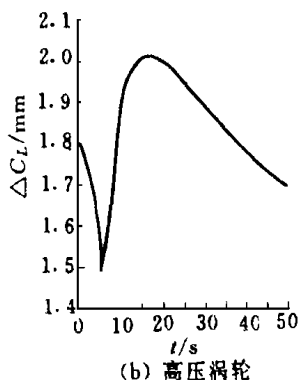
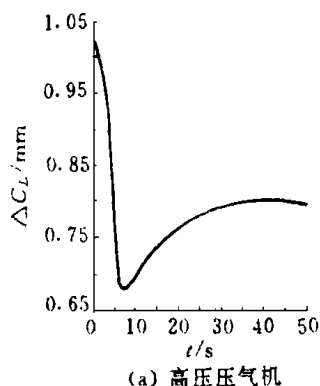


图 1 叶尖间隙随加速时间的变化

图 2 叶尖间隙变化引起的部件效率的变化

由图 1 得知, 叶尖间隙随时间的变化规律以及间隙变化的量级均与参考文献[1]和[2]提供的图线相吻合。从图 1 中可看出, 在加速开始的 5 秒钟左右时间内, 由于转子部分的受热膨胀较机匣快, 加上转速迅速增加产生较大离心弹性变形, 使压气机和涡轮的叶尖间隙变小; 当转子达最大转速时由于机匣热变形加大导致间隙增大。以后机匣热伸长达到极限, 但转子部件继续膨胀, 结果叶尖间隙又转而减小, 这一效果涡轮较压气机更加明显。

由于二次流损失与叶尖间隙成正比变化, 因而图 2 得到的压气机效率随时间变化与间隙变化规律相反。由图 3 中可看出叶尖间隙变化对加速过程的影响并不十分明显, 其影响程度相对零部件与气流间热交换影响^[4]要小得多,

只是在转子加速到最大转速后因叶尖间隙变大使高压转子转速稍有回落。

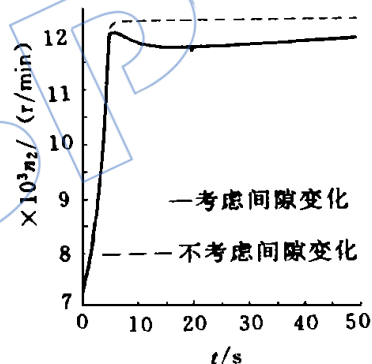
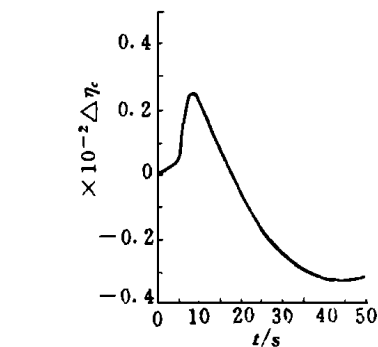


图 3 叶尖间隙变化对加速响应曲线的影响

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TECHNICAL NOTES

A MULTIGRID SCHEME FOR CALCULATING THREE-DIMENSIONAL FLOWS THROUGH COMPRESSOR BLADE ROW

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ABSTRACT Based on the MacCormack explicit difference Scheme, a multigrid scheme has been developed to solve the three-dimensional Euler equations expressed by weak conservation law in cylindrical coordinate system. The distribution and interpolation formulas of corrections for the presented multigrid scheme have been derived. The present Euler solver was used to calculate the flows of two sets of transonic compressor rotor blade rows, and proven to be a valid and useful design tool. The computed results indicate that this scheme is enable to accelerate the computation convergence greatly, and the method is accurate and reliable.

Key words Compressors Three-dimensional flow Finite difference methods

DESIGN AND EXPERIMENT OF CENTRIFUGAL COMPRESSOR 3-D IMPELLERS FOR HEAVY GASES

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ABSTRACT An inverse problem method based on s_2 flow surface theory of 3-D flow field has been developed to design centrifugal compressor impellers for heavy gases and some techniques to improve the performance of high pressure ratio impellers have been presented too. Two impellers with Mach number $M_{u_2} = 1.26, 1.06$ and relative width $b_2/D_2 = 0.054, 0.036$ respectively have been designed by use of this method. Experiments of the impellers have been performed in a closed-loop test rig with Freon gases (R11) to verify the design method. The dynamic pressures distribution from shroud to hub at the exits of impellers and the losses of vaneless diffusers and volutes have been measured and analyzed under different work points. Their good performance obtained from tests shows the design method and techniques presented in this paper is feasible and favourable.

Key words Centrifugal compressor 3-D impeller Design and experiment

A MODEL FOR ESTIMATING TIP CLEARANCES IN GAS TURBINE ENGINE TRANSIENTS

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ABSTRACT During the gas turbine engine transient, the clearances of the compressor and turbine blade tips differ from those in stable operation because the heat change between gas and components causes the different radial movements of the rotor and case. In order to simulate the real thermodynamics process in the gas turbine engine transient as possible, a model for estimating the variations of the tip clearance and efficiency with time is given. In this model, the typical stage chosen from a multi-stage turbomachinery will be decomposed into three components (case, blade and disc), the instantaneous heat growth of each component is calculated individually by means of the different heat transfer model, and the instantaneous centrifugal growths of blade and disc are also estimated, therefore the instantaneous tip clearance are obtained by summing the heat and centrifugal growths of all compo-

nents. The shifts in efficiency resulted from the change of tip clearance will be predicted by semi-empirical formula, with the aid of the tip clearance model of the variations of the tip clearance, efficiency and thrust with transient time have been estimated. The results prove the effectiveness and accuracy of the model.

Key words Gas turbines Transient process Blade tip Clearance

EFFECT OF CURVING OF HEAVY-DUTY BLADES ON WALL FLOW

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ABSTRACT Static pressures on endwalls and blade surfaces and growth of the losses along flow direction were measured, and the flow visualizations of the endwall and blade suction surface with ink traces were also made. The experimental results show that the positive curving of the blade increases the streamwise adverse pressure gradient in the cascade inlet and makes isobars on the front part of the blade suction surface into opposed "C" shape, thereby the saddle point separation near the blade leading edges and convergence of separation lines on the suction surface to the cascade middle are intensified. The negative curving of the blade reduces the adverse pressure gradient in the cascade inlet and makes isobars perpendicular to the endwall on the front part of the blade suction surface. As a result not only the separation flow near saddle point weakens, but also the separation flow on the suction surface turns into free vortex laminar separation so as to avoid interception of the upper and lower separation lines. In consequence, the secondary vortex losses are decreased greatly.

Key words Turbines Curving Blades Wall flow

CHARACTERISTICS OF INTERNAL FLOW PERFORMANCE OF AN STF FAN PROPULSION SYSTEM

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ABSTRACT The total characteristics of a Supersonic Through Flow (STF) fan propulsion system of unconventional configuration have been studied. Therefrom some conclusions are obtained as: 1. The system's bypass ratio must be actively controlled by adjusting both core and bypass engine's through flow areas. 2. A general propulsion system with a bypass ratio variable cycle is able to hold a higher fan compression ratio or a stronger fan power in supersonic flight, when it is coupled with a variable core nozzle critical section area. 3. For this new concept propulsion system, the specific thrust per unit of the total air mass flow does not vary with altitude up to the stratosphere. Some calculational results are presented briefly to support the above-mentioned conclusions.

Key words Supersonic flight Supersonic through flow Turbofan Propulsions characteristics

EVALUATION OF SAFETY LIVES OF AEROENGINE PARTS

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ABSTRACT The safety lives of parts in an aeroengine are determined by use of the confidence limits of three-parameter Weibull distribution. The safety lives obtained by the point estimation of three-parameter Weibull distribution have been compared with those of two-parameter Weibull distribution. It is shown that this method is convenient in engineering application.

Key words Aircraft engines Confidence limit Safety Life