

扰动波对轴流压气机旋转失速的影响

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【摘要】 提出了考虑轴流压气机进出口气流角和非定常损失变化的二维旋转失速稳定性模型,进行了数值分析和讨论。计算结果表明压气机前方的扰动波对压气机旋转失速稳定性有一定的影响,压气机本身的结构形式以及压气机上、下游结构对扰动波的传播速率有重要影响。

主题词: 轴流式压气机 旋转失速 扰动波

分类号: V231.3

1 轴流压气机二维旋转失速稳定性模型

试验研究表明^[1,2],在压气机失速之前,压气机的前方存在一定幅值的旋转波,即失速前兆波。本文在文献[3]的基础上给出了考虑轴流压气机进出口气流角和非定常损失的二维旋转失速稳定性模型,并进行了数值分析和讨论。

压气机流动可以简化为 3 部分:进口管道流动、内部流动和出口管道流动。

基本假设: (1) 用压气机叶片排进出口总、静压升关系和损失关系来模拟压气机的压升特性; (2) 进口流场均匀、出口管道流场有旋; (3) 高轮毂比压气机,内部流动可以看成二维流动; (4) 考虑压气机叶片槽道内流体惯性产生的滞后,气流的粘性效应以惯性参数对压气机准稳态的一阶动态修正来描述; (5) 考虑压气机进出口气流角和非定常损失的变化。据此可得描述轴流压气机二维气动稳定性的数学模型。其压气机级压升特性、压气机进出口管道压力扰动的解析表达式和压气机静子及转子非定常损失分别为(1-3)式:

$$\frac{\delta P_2}{\rho U^2} - \frac{\delta P_{t1}}{\rho U^2} = \frac{\partial \Psi_{isen}}{\partial \varphi} \delta \varphi + \frac{\partial \Psi_{isen}}{\partial \alpha_1} \delta \alpha_1 - \delta L_s - \delta L_r - \lambda \frac{\partial}{\partial \theta} \delta \varphi - \mu \frac{\partial}{\partial \tau} \delta \varphi \quad (1)$$

$$\frac{\delta P_{t1}}{\rho U^2} = - \left| \frac{1}{n} \right| \frac{\partial}{\partial \tau} \delta \varphi, \quad \frac{\delta P_2}{\rho U^2} = \left| \frac{1}{n} \right| \frac{\partial}{\partial \tau} \delta \varphi - \left| \frac{\varphi}{n} \right| \sec^2 \alpha_2 \frac{\partial}{\partial \theta} \delta \alpha_2 \quad (2)$$

$$\bar{\tau} \frac{\partial \delta L_s}{\partial \tau} = \frac{\partial L_s}{\partial \varphi} \delta \varphi + \frac{\partial L_s}{\partial \alpha_1} \delta \alpha_1 - \delta L_s, \quad \bar{\tau} \left(\frac{\partial \delta L_r}{\partial \tau} + \frac{\partial \delta L_r}{\partial \theta} \right) = \frac{\partial L_r}{\partial \varphi} \delta \varphi + \frac{\partial L_r}{\partial \alpha_1} \delta \alpha_1 - \delta L_r \quad (3)$$

轴流压气机二维气动稳定性模型的特征方程为: $(A - s_n B) \delta \bar{x} = 0$

$$A = \begin{bmatrix} \frac{1}{\xi} (\chi_1 - in \chi_2) & -\frac{1}{\xi} & -\frac{1}{\xi} \\ \frac{1}{\bar{\tau}_s} \chi_3 & -\frac{1}{\bar{\tau}_s} & 0 \\ \frac{1}{\bar{\tau}} \chi_4 & 0 & -(in + \frac{1}{\bar{\tau}}) \end{bmatrix}, \quad B = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}, \quad \delta \bar{x} = \begin{bmatrix} \delta \varphi \\ \delta L_s \\ \delta L_r \end{bmatrix} \quad (4)$$

n 为扰动波的波数, α 为压气机气流角, φ 为无量纲轴向速度, L 为压气机损失的大小, λ 为压气机转子的惯性参数, μ 为压气机级的惯性参数, Ψ 表示压气机的总、静压升系数。下标“1”和“2”表示压气机进、出口参数, 上标“-”表示准稳态参数, χ 、 χ 和 ζ 是参数组合量。

2 计算结果与分析

文献[3]定义了描述轴流压气机扰动传播特性的参数 R , 本文将旋转失速团的传播参数定义为 $\chi = R / (2|n| + \mu)$, 对于本模型来说, χ 的大小反映了扰动传播的快慢。

考虑了 4 种压气机模型在不稳定边界对应的扰动波数与传播参数的相互关系。模型 1: 理想的 IGV 进口导叶, 气流流过 IGV 时不存在损失, 经过 IGV 后气流角不改变, 即 $\partial\alpha_1 / \partial\varphi = 0$; 模型 2: 压气机出口高稠度, 压气机出口气流角不随压气机进口气流角改变, 即 $\partial\alpha_2 / \partial\alpha_1 = 0$; 模型 3: 理想的 IGV 进口导叶和压气机出口叶片高稠度, 即 $\partial\alpha_1 / \partial\varphi = 0$ 和 $\partial\alpha_2 / \partial\alpha_1 = 0$; 模型 4: 压气机进口气流角的变化完全与轴向扰动的发展相联系。

图 1 为上述 4 种压气机模型 4 对应的扰动波的波数与扰动传播参数的相互关系。从图中可以看出, 随着扰动波数的增加, 扰动的传播参数越大, 这说明压气机的旋转失速波的周向传播速率越快, 这与文献[1, 2]的试验结果一致。在同一扰动波数情况下, 第 4 种情况的传播参数最大, 即压气机失速波的周向传播速率最快。其次为第 2 种情况, 即压气机高的出口稠度使得压气机出口气流角几乎不随进口气流角改变, 这相当于保留压气机进口气流角随时间的改变, 而保持压气机出口的约束条件, 传播参数最小的压气机模型为理想的 IGV 情况。这说明压气机本身的结构形式以及压气机上、下游结构对扰动波的传播速率有重要影响。压气机上游 IGV 对扰动波的传播以及对后排叶片的激振力影响最为明显。

压气机前方的扰动波对压气机旋转失速稳定性有一定的影响, 扰动波数越大则传播参数越大; 压气机本身的结构形式以及压气机上、下游结构对扰动波的传播速率有重要影响。

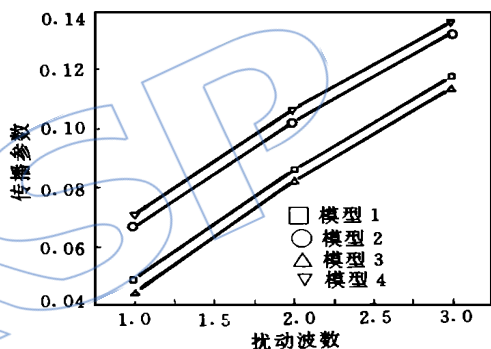


图 1 扰动波数对传播参数的影响

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EFFECTS OF DISTURBANCE WAVES ON ROTATING STALL STABILITY OF AXIAL COMPRESSOR

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ABSTRACT

A 2-D rotating stall stability model considering the inlet and outlet flow angles and unsteady loss of axial flow compressor was proposed, for which numerical analysis has been conducted. The calculated results show that the disturbance waves at the upstream of compressor have influence on the rotating stall stability. The configuration of the compressor produces a strong impact on the propagation speed of the disturbance waves.

Key Words Axial flow compressors Rotating stall Disturbances

AN INVESTIGATION ON FLOW BEHAVIOUR IN AN S- SHAPED DUCT

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ABSTRACT

A new efficient finite-difference scheme for solving turbulence $K-\epsilon$ equations-Turbulence U -scheme has been developed. This method was combined with the solver of Navier-Stokes discretized by a modified Beam-Warming scheme to investigate three-dimensional turbulent internal flow in S-shaped duct. Many numerical experiments and practical applications show that this method provides detailed flow field and parameters for engineering design. As a special example, a numerical simulation has been completed for an S-shaped duct including separation, secondary flow, vortices etc. The comparison of its results with the flow patterns in the circular section s-shaped duct shows a good agreement in essence.

Key Words Numerical simulation Air inlets Flow characteristics

IDENTIFICATION OF GEAR TRANSMISSION SYSTEM WITH A ROTOR ON DYNAMIC NATURAL CHARACTERISTIC

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ABSTRACT

A gear transmission system with a helicopter rotor was experimentally investigated and on-line identified during its operation, and the results were compared with its theoretical analysis. It is found that the gear transmission system with a rotor differs from other gear transmission system by such natural characteristics, that its dynamic characteristics change with its rotational speed. Its changing law has also been obtained, which provides basis for the dynamic modeling analysis and the dynamic design of the system and an effective analytical approach of the gear transmission system.

Key Words Gears Rotor wings Dynamic properties