

载荷与响应耦合下叶片鸟撞击响应分析

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【摘要】 分析飞鸟与航空发动机叶片的撞击损伤时,需要准确预估叶片的瞬态响应。其中叶片的变形会影响到撞击载荷的大小与分布,从而影响到叶片的响应。本文提出一种简单有效的计算方法,考虑了上述耦合效应,并以模型叶片为例,分析了它对叶片响应的影响程度,为工程实际应用积累了经验。

主题词: 叶片 鸟撞击 耦合 响应分析

分类号: O313.4

1 引言

由于在实际叶片的鸟撞击过程中,叶片是可变形靶体,其变形会影响撞击载荷的大小与分布。在以往的工作中^[1-4],分别采用固-固耦合及流-固非耦合算法计算了鸟撞击叶片的瞬态响应,没有考虑载荷与响应之间耦合对叶片响应的影响。为准确预估叶片鸟撞击响应,分析上述耦合效应的影响,本文提出一种简单有效的计算方法,以模型叶片为例,分析了它对叶片响应的影响程度,为工程实际应用积累了经验。

2 载荷与响应耦合下的载荷模型

如图 1 所示,在鸟撞击载荷作用期间,在 t_i 时刻,设鸟以相对速度 V_i 、入射角 θ ($\theta_0 = 90^\circ$ 为正撞击) 撞击叶片,而到 $t_{i+1} = t_i + \Delta t$ 时刻,叶片发生变形,使其入射角变为 θ_{+1} ,同时使叶片具有法向速度 V_{pi} ,则在时间 Δt 内应用动量定理:

$$F \Delta t = m(V_i \sin \theta_{+1} - V_{pi}) \quad (1)$$

可得出 $t_i + \Delta t$ 时刻的撞击力 F 为:

$$F = \frac{\rho A [(V_i \sin \theta_{+1} - V_{pi})]^2}{\sin \theta_{+1}} \quad (2)$$

式中, ρ 和 A 分别为模拟鸟的密度和横截面积。

撞击载荷的作用时间由撞击时鸟体在撞击过程中消耗的长度 S 来决定:

$$S = \int \left[V_i - \frac{V_{pi}}{\sin \theta_{+1}} \right] dt \quad (3)$$

当 S 等于鸟体的长度 L 时,撞击过程结束。

撞击载荷的力-时间函数形式通常为三角形形式。为模拟这种三角形形式的力-时间函数,可令面积 A 按图 2 所设的三角形形式变化,这样由 (2) 式确定的 F 也按图 2 所设的三角形

形式变化,图中纵坐标中 a, b 分别为椭圆形撞击区域的长轴与短轴,当正撞击时, $a = b = R$, R 为鸟体的初始半径。

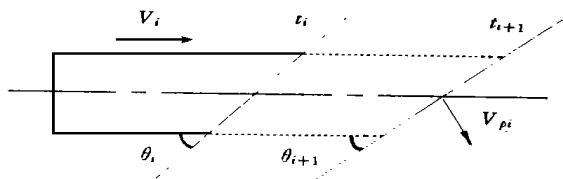


图1 鸟撞击叶片示意图

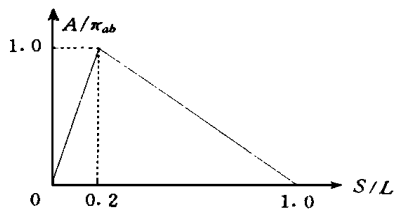


图2 面积 A 的变化方式

在程序实现时,按照计算时间步,先得到叶片撞击载荷作用区域内节点的位移及速度,求出其转角及法向速度,然后由(2)及(3)式计算撞击载荷值和作用时间,再将计算结果返回程序进行下一个时间步的计算。如此反复,直到撞击载荷作用结束为止。

3 算例

为分析考虑载荷与响应之间耦合效应对叶片响应的影响程度,本文计算了不考虑耦合效应与考虑耦合效应时的两个算例,分别用算例1及2表示。计算中,所用悬臂固支模型叶片为钢质平板,长0.2 m,宽0.12 m,厚度为0.05 m,其材料性能参数为:弹性模量 $E = 200 \text{ MPa}$,屈服极限 $\sigma_s = 240 \text{ MPa}$,泊松比 $\mu = 0.3$,材料密度 $\rho = 7.81 \times 10^3 \text{ kg/m}^3$ 。模拟鸟质量 $m = 0.17 \text{ kg}$,直 $D = 0.05 \text{ m}$,长度 $L = 0.1 \text{ m}$,以 $V = 152.5 \text{ m/s}$ 的相对速度正撞击在距叶根0.11 m处的中心线上。叶片的有限元网格采用8节点超参壳元划分,总计131个节点,36个单元。计算的时间域 $t = 15 \text{ ms}$,时间步长为 $20 \mu\text{s}$ 。

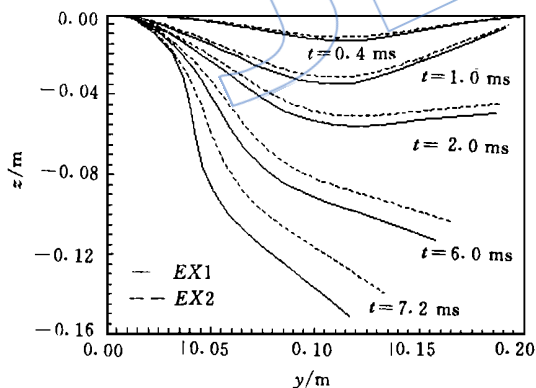


图3 叶尖中心点挠度随时间变化曲线

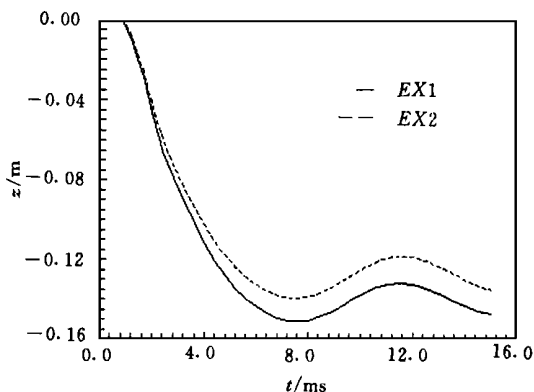


图4 叶片径向中心线的挠度

图3和图4分别给出了算例1和2叶尖中心点 A 点挠度随时间变化曲线、不同时刻下叶片径向中心线的挠度。图3中,算例1和2两者同时到达最大挠度点,其回弹到最小挠度点的时间也相同,两者的差别仅在于 A 点的挠度值不同。到达最大挠度点时,两者相差8.3%。此后,两者的振动形式相同,挠度值不同。到 $t = 15.0 \text{ ms}$ 时,两者相差8.4%。两者的残余变形相差也在8.4%左右。图4中,当 $t = 0.4 \text{ ms}$ 时两者差别仅在于考虑耦合效应时(算例2),其撞击

载荷作用区域的局部变形要稍小于不考虑耦合效应的局部变形。此后,到 $t = 7.2 \text{ ms}$ 时,两者弯曲变形的差别逐渐加大,除挠度值不同外,其形状特征基本相同。

此外,在算例 1 和 2 的应力计算结果中,两者在撞击载荷中心点 A 处的最大等效应力分别为 375.25 MPa 和 350.6 MPa ($t = 1.20 \text{ ms}$),相差 7.03% ;两者在叶片根部中心点处的最大等效应力分别为 315.40 MPa 和 304.5 MPa ($t = 1.60 \text{ ms}$),相差 3.58% 。

应该说明的是,在考虑载荷与响应之间耦合效应时,载荷的作用时间虽然延长,在本文中算例 2 比算例 1 大约延长了 12% ,但由于叶片变形的卸载作用,两者综合作用的结果仍使叶片的整体变形要小于不考虑耦合效应时的结果。

4 结 论

通过上述算例可知:载荷与响应之间耦合对叶片响应的整体变形影响与不考虑耦合时相差 8.4% 左右,而对叶片到达最大变形的时间,以及叶片的振动形式等均影响不大;在撞击过程中,叶片上产生的最大等效应力相差也约为 7.03% 。由此可见,当考虑叶片与载荷之间的耦合效应时,相当于减小了载荷作用的冲量值,整体变形及等效应力均要小一些。此外,从计算用时上比较,算例 2 与算例 1 分别为 278.05 和 234.34 分钟,相差 18.7% 。因此,要求准确计算叶片鸟撞击响应时,应该考虑这一因素的影响。但从简化问题、减少机时的角度考虑,若只要求一般地了解叶片鸟撞击响应的特征时,则可不考虑这一因素,此时计算得出的结果偏于安全,这为工程应用提供了非常有价值的经验。

参 考 文 献

- 1 高德平,李清红. 叶片鸟撞击的理论和试验研究. 航空动力学报, 1990, 5(4): 335- 338
- 2 李勇. 结构软体冲击数值分析与试验研究: [学位论文]. 南京航空学院, 1989
- 3 范尔宁. 发动机叶片鸟撞击载荷和瞬态响应研究: [学位论文]. 南京航空学院, 1990
- 4 陈伟,尹晶,高德平. 平板叶片斜撞击瞬态响应的计算分析. 南京航空航天大学学报, 1996: 25(4): 854- 857

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tion rate was given by Arrhenius model. The results show that the numerical method and physical models are proper for simulation of spray combustion processes.

Key Words Spray combustion flow Calculation Algorithm

AN EXPERIMENTAL STUDY ON PRIMARY NOZZLE TYPES OF EXHAUST EJECTOR SYSTEMS

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ABSTRACT

Optimum distances between primary nozzle exit and mixing tube inlet, static pressure recovery of the mixing flow in mixing tube, total pressure distributions at the exit of mixing tube, pumping coefficients and total pressure losses of the exhaust ejector systems with four different types of primary nozzles have been measured in the experiments. The results have an important reference value for selecting primary nozzle types of exhaust ejector systems.

Key Words Nozzle with injector Aerodynamic tests Experiments

TECHNICAL NOTES

NONLINEAR PERTURBATION METHOD FOR ANALYSIS OF MODAL SENSITIVITIES WITH REPEATED EIGENVALUES

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ABSTRACT

An algorithm was made out for analyzing the modal sensitivities with repeated eigenvalues of real symmetric matrices by means of nonlinear perturbation equation. It has advantage in retaining the symmetry and band structure of the original eigen-system matrices. A numerical example shows that the method has high accuracy and can be easily implemented on computer.

Key Words Modal analysis Eigenvalues Perturbation method

TRANSIENT RESPONSES OF BLADES TO BIRD IMPACT COUPLED WITH DEFORMATIONS OF BLADE

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ABSTRACT

It is necessary to calculate the transient responses of blades precisely in analysis of blade damage due to bird impact. Because the deformations of blade can

influence the distribution and magnitudes of bird impact loads, the coupling of the bird impact with blade deformation has a remarkable influence on the transient responses of the blade. A simple and effective method is provided to analyze the responses of blades with consideration of this coupling. Taking a model blade as an example, its influence extent is also sized up.

Key Words Blade Bird impact Coupling Response analysis

A DOUBLE- CHAMBER VAPORIZING COMBUSTOR WITH HIGH TEMPERATURE RISE AND UNIFORM EXIT TEMPERATURE FIELD

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ABSTRACT A new type of combustor, a double- chamber vaporizing combustor has been developed for heating apparatus of heating calibration tunnel. Its average exit temperature can reach 1850°C, the highest temperature rise from inlet to exit can reach 1600°C. In addition, this combustor has many other excellent characteristics, such as constant exit temperature field. Some experiences and keys to its development are described herein.

Key Words Combustion chambers Flame tubes Temperature field

3- D NUMERICAL SIMULATION OF BLADE- ANGLE SLOTTED HUB TREATMENT

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ABSTRACT Three- dimensional incompressible steady time- averaged N- S equation, continuity equation and $k- \epsilon$ turbulence model equations are applied to calculation of the flowfield in the cascade passage with blade- angle slotted hub treatment. The mechanism of extending stability by blade- angle slotted hub treatment is elaborated by means of a three- dimensional viscous numerical simulation. It is revealed that a pressure difference between suction and pressure sides induces a strong flow which enters in the rear of the slot and pours out from the front of the slot. This flow blows off the low energy boundary layer and retards stall emergence. The SIMPLE algorithm with non- stagger grid is employed to solve the problem of the pressure oscillation.

Key Words Compressor Wheel hub Treatment Nonsteady flow
Numerical simulation