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Engineering Consultants

Methods for blade flutter prediction

Advanced design techniques avoid flutter

- Flutter in turbomachine blades has been a serious cause of failure, difficult to predict and expensive to correct.
- Flutter is an aeromechanical phenomenon that usually occurs at a blade natural frequency and involves sustained blade vibration resulting from the changing pressure field around an aerofoil as the blade oscillates.
- For the process to occur it is necessary that over one cycle there is an input of energy from the gas stream to the blade of a sufficient magnitude to overcome the mechanical damping.
- Empirical design techniques that have been used for many years are giving way to advanced methods in which unsteady finite element analysis and unsteady Computational Fluid Dynamics are united to form a powerful, more precise, modelling tool.
- ANSYS® and PCA Engineers are now applying the advanced technology to a wide range of applications from large steam turbines to automotive turbochargers.

Background

Flutter is dependent on both the aerodynamic and structural characteristics of a turbine or compressor blade, and until recently it has not been possible to design for avoidance of this phenomenon with total confidence. Historically, empirical design criteria have been used, based on parameters involving blade natural frequencies and flow transit times, but these methods fail to take into account generally-found vibrational modes or the influence of adjacent blades.

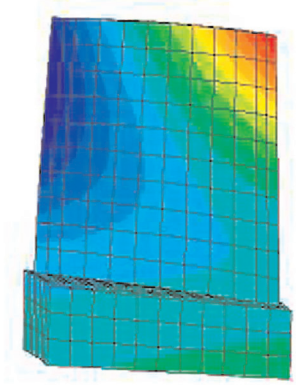

Fig. 1 Typical mode of blade excitation

Recent Advances

Advances in unsteady computational fluid dynamics combined with developments of loosely-coupled CFD and FE codes now permit the transfer, at the fluid-structure interface, of variables which govern these forced vibration processes.

A particularly useful development by ANSYS® has been the facility to deform the CFD computational grid in response to deformations at the fluid-structure interface and integrate this with unsteady flow computations. PCA has utilized this capability by mapping time-dependent deformations computed from an FE analysis to the CFD computational grid.

Application to flutter assessment

Usually blade flutter occurs at a blade natural frequency that is determined, together with its corresponding mode of vibration, by traditional finite element techniques. Figure 1 illustrates a typical torsional blade mode, where for each node point on the blade gas-swept surface the relative amplitude is known as a function of time.

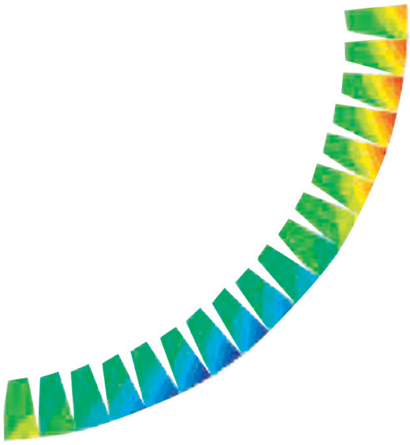

Fig. 2 Nodal diameter pattern (4 ND)

A bladed-disc assembly can be classified as a rotationally periodic structure and therefore the mode shapes of adjacent blades within a row are fully defined by a phase difference. This phase difference (the inter-blade phase angle or IBPA) depends on the number of blades in the row and the number of patterns repeating around the annulus. This latter parameter is often called the Nodal Diameter and can move either with or against the direction of rotation. A typical nodal displacement pattern is shown in Figure 2. The modal displacement information can now be applied to the computational grid to compute both the time-varying flow through a blade-row and the dynamic pressure field over each defined blade.

The computed dynamic pressure distribution and the corresponding modal displacements are then used to compute the work done on the blade over one complete cycle. If the net work done on the blade is positive then work is being imparted to the blade thus creating negative damping, a potentially unstable situation leading to a self-sustained vibration (flutter) likely to cause a material fatigue failure. On the other hand, if the aerodynamic work done on the blade is negative, the blade motion is doing work on the fluid and leads to a stable or damped vibration. The results of such a calculation are shown in Figure 3. In this case the blade is stable (no flutter) because the damping is always positive. This

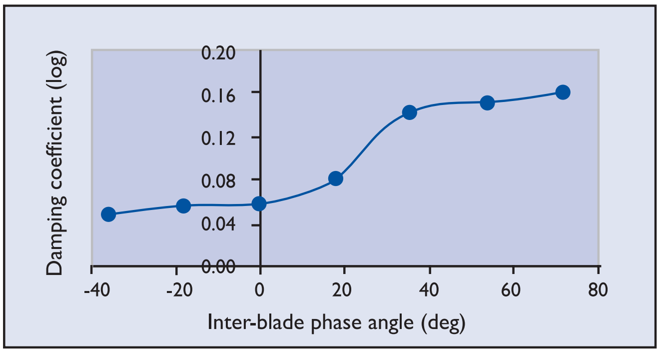

Fig. 3 Aerodynamic damping

information is critical to the design; blades are relatively easy to modify before manufacture but extremely costly to rectify on operational plant.

ANSYS® and PCA Engineers are now applying such technology to a wide range of applications extending from large steam turbines to small turbochargers. These techniques are assisting engineers to design compressor and turbine blading where both aerodynamic efficiency and structural integrity is paramount over the operational range of the machine.

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