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Design of Mistuning Patterns to Control the Vibration Amplitude of Unstable Rotor Blades

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Abstract

Flutter onset is one of the major causes for increased vibration levels in low pressure turbine (LPT) rotor blades. This paper describes the design process and the experimental testing of intentional mistuning patterns specifically chosen to show the possibility to control the flutter characteristics of an LPT rotor. The Asymptotic Mistuning Model (AMM) methodology is used to select the intentional mistuning patterns. The AMM formulation incorporates elastic and aerodynamic data from detailed FEM and CFD computations, and measured values of the rotor blades intrinsic mistuning. The intentional mistuning patterns are implemented in the rotor by mounting small masses at the tip-shroud of the blades, and the effect of these small masses is also introduced in the AMM description. Two intentional mistuning patterns are selected. The classical alternate mistuning pattern, designed to fully suppress flutter, and a second intentional mistuning pattern that is designed with the idea of halving the vibration amplitude of the tuned unstable rotor. This second mistuning pattern demonstrates that, through the implementation of the appropriate intentional mistuning pattern, flutter cannot only be suppressed but also modulated. The two mistuned LPT rotors were tested in a free flutter experiment at a high speed rotating wind-tunnel, and the experimental results showed a good agreement with the AMM stability predictions. This is the first time, to our knowledge, that the possibility to control flutter through intentional mistuning has been experimentally validated in a rotating rig. The AMM is also applied to evaluate the effect of the aerodynamic coupling in the stability calculations of the mistuned rotors, and the AMM results are compared with high fidelity numerical calculations. It is shown that, despite its very reduced formulation, the AMM produces quite accurate stability predictions, and that it is essential to take into account the aerodynamic coupling; if it is not considered then the instability level of the mistuned rotors can be substantially underestimated.

Keywords: Aeroengine aeroelasticity, Bladed disk vibration, Flutter, Intentional mistuning

1. Introduction

Fuel consumption and weight reduction are two very strong requirements on every new generation of modern aircraft engines. These demands drive substantial changes in the development and configuration of the engine components. Compressors and turbines are designed with fewer stages and higher pressure ratio per stage, which leads to higher stress levels on the blades. In addition, to reduce weight, Low-Pressure Turbine (LPT) rotor blades are also becoming more slender and with higher aspect ratio than their predecessors, making them more prone to aeroelastic instabilities.

Flutter is one of these instabilities. It occurs without any external forcing, and is triggered when the unsteady distortion produced in the gas flow by the elastic vibration of the blades has a net effect on the blades that tends to increase their vibration amplitude. Once flutter starts on an unstable rotor, the oscillating amplitude of the blades increases, provoking higher stresses with each vibration cycle. Depending on the magnitude of the friction damping effects, these stresses can become high enough to cause the sudden destruction of the blades; or they can be allowable, if the vibration ends up stabilized below a certain amplitude. Even if this is the case, these alternating stresses need to be superimposed with other sources of excitation, severely constraining the design space of the rotor blade.

On the other hand, bladed disks are manufactured to be cyclic symmetric, with a sector repeating itself around the structure. But the sectors of a realistic bladed disk cannot be perfectly similar; they have small geometric and structural differences (usually called mistuning) that are typically caused by manufacturing processes and wear. In the case of forced response, these imperfections are known to produce the localization of the vibration to a few blades, which exhibit a much higher vibration amplitude than that predicted for the rotor assuming all sectors are identical (tuned configuration), see, e.g, the review in [1].

However, many studies [2–5] show that the effect of

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