An extensive test campaign of a turbine bladed disk in the presence of mistuning and underplatform dampers, and numerical validation

Giuseppe Battiato*, Christian M. Firrone*, Valeria Pinto* and Antonio Giuseppe D'Ettole**

Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Torino, Italy

**AvioAero, Rivalta di Torino, Torino, Italy*

Abstract. The design of lighter and highly loaded aircraft turbo-engines is driven by the need of improving their efficiency for a sustainable air propulsion. In this context, forced and self-excited vibrations in bladed disks must be mitigated to avoid HCF damage that jeopardizes the structural integrity of the whole engine. Current vibration prediction methods are not fully reliable due to complexities of the bladed disks design and nature of excitations. To improve the reliability of such methods, it is necessary to (i) investigate key problems like mistuning and nonlinear friction damping, and (ii) to validate design methodologies. In this paper, the results of a test campaign to study the effect of mistuning and of underplatform dampers are presented and discussed. The data collected have been used to validate an in-house numerical code. The code exploits an efficient reduction method for large finite element (FE) models of mistuned bladed disks.

Introduction

The design of aircraft turbo-engines is driven by the need of improving their efficiency for a sustainable air propulsion. This leads to a lighter design of blades, vanes and seals, that are usually prone to vibrations. In working conditions, both forced and self-excited vibrations must be mitigated to avoid high cycle fatigue (HCF) failure. To improve the reliability of the current vibration prediction methods, several European projects have been launched (i) to investigate the effects of mistuning and nonlinear friction damping, and (ii) to improve the design practices. Several efforts in the testing and numerical prediction of mechanical vibrations in turbine bladed disks have been made in the ARIAS European project [1]. In this paper, the test campaign performed at the GE Avio testing laboratory, on the ARIAS bladed disk test case are presented and discussed. The bladed disk has been tested in the tuned and the intentionally mistuned configurations, either in the presence or not of underplatform dampers (UD). The blades response has been measured and processed by Blade Tip-Timing system. The data collected in the test campaign have been used to validate a numerical code developed for the prediction on the nonlinear forced response (FR) of mistuned bladed disks in the presence of UD. To avoid the high computational costs associated to the solution of nonlinear FR, the code exploits the reduction method for large finite element (FE) models of mistuned bladed disks presented in [2].

Results and discussion

The test campaign has been performed on a turbine bladed disk having 144 blades. Each blade has a real aerodynamic airfoil with a tip able to accommodate the permanent magnets for the mechanical excitation, a balancing mass and a mistuning mass. The latter is installed depending on the disk configuration to test, i.e either mistuned or tuned, with or without mistuning masses respectively. The tested mistuned configuration follows the alternate pattern 0-1, where the 0 and 1 denote the blades without and with mistuning mass. The bladed disk has been tested in vacuum conditions for the excitation of either synchronous or asynchronous vibrations. The numerical validation has been performed on the reduced order models (ROM) of the tuned and mistuned bladed disk, that have been created by using the reduction method presented in [2]. The reduction process has led to two ROMs having approximatively the 0.007% of the degrees-of-freedom (dofs) of the full FE model. For both ROMs the same set of master dofs have been retained: the accessory dofs for the force application and the response monitoring, and the dofs at the blades' platform for the contact forces prediction due to the relative motion between the blades and the UDs. The force amplitude used in the numerical simulation has been tuned using as a reference the averaged experimental data obtained in the absence of UD. The modal damping has been set equal to the one identified from the experimental FR. As expected, the numerical FR for the modes of interest (i.e. flap and torsional) show good agreement with the experimental ones, in terms of vibration amplitude and Q-factor, while a deviation less of the 10% has been found for natural frequency. This is due to uncertainty associated to the contact areas and stiffness associated to the actual coupling between blades and disk, that has not been deeply investigated. The same excitations have been used to excite the ROMs in the presence of UDs. In most of the examined cases, the numerical vibration amplitude at resonance as well as the Q-factor fall in the range of uncertainty resulting from the analysis of the experimental data, denoted by a mean value and a standard deviation.

References

[1] https://www.arias-project.eu/

[2] Pinto, V., Battiato, G. and Firrone, C.M., 2022. A Reduction Technique for the Calculation of the Forced Response of Bladed Disks in Presence of Contact Mistuning At Blade Root Joints. Journal of Engineering for Gas Turbines and Power. ttps://doi.org/10.1115/1.4055722