Accepted Manuscript

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Mohammad Shadmani, Reza Tikani, Saeed Ziaei-Rad

PII: S0022-460X(18)30538-8

DOI: 10.1016/j.jsv.2018.08.061

Reference: YJSVI 14390

To appear in: *Journal of Sound and Vibration*

Received Date: 17 March 2018

Revised Date: 11 August 2018

Accepted Date: 16 August 2018

Please cite this article as: M. Shadmani, R. Tikani, S. Ziaei-Rad, On using a distributed-parameter model for modal analysis of a mistuned bladed disk rotor and extracting the statistical properties of its in-plane natural frequencies, *Journal of Sound and Vibration* (2018), doi: https://doi.org/10.1016/j.jsv.2018.08.061.

On using a distributed-parameter model for modal analysis of a mistuned bladed disk rotor and extracting the statistical properties of its in-plane natural frequencies

Mohammad Shadmani[a], Reza Tikani[a,*], Saeed Ziaei-Rad[a]

[a]*Department of Mechanical Engineering, Isfahan University of Technology, Isfahan 84156-83111, Iran*

Abstract

In this paper, mistuning of bladed-disk systems is investigated. The blades are considered as continuous Euler-Bernoulli beams with transverse and longitudinal degrees of freedom. The governing equations of motion for the tuned and mistuned bladed disk systems are derived and discretized by use of Galerkin method. The obtained equations have time-varying coefficients and cannot directly be used for calculating the system critical speeds and Campbell diagram. For the tuned case, by use of Coleman and complex transformations one can transform the time varying system to a time-invariant system. Further transformations are required for the mistuned system to change into a time-invariant system. Next, a four-bladed disk system supported by bearings was considered. The modal analysis was performed and the critical speeds and the Campbell diagram were calculated. The results indicate that both coupled modes and conjugate modes appear in the Campbell diagram which are changing with the rotating speed. Finally, a probabilistic analysis was performed on the mistuned parameters by use of Monte Carlo method. It was found that the disk dominant modes are insensitive to the various mistuning realizations. However, the blade dominant modes are sensitive to the mistuning parameters and have a coefficient of variation one order of magnitude less than the mistuning coefficient of variation. It was also seen that the probability density functions of whirl speeds for different mistuned properties are able to be considered Gaussian.

Keywords: Bladed disk, Mistuning, Distributed-parameter model, Whirl speed, Monte Carlo method

1. Introduction

Nowadays, bladed disk rotors have many applications. They are used wherever turbines, compressors, aircraft engines, fans, etc. are in service. A large number of researches have been widely performed over the past decades to understand the dynamics of bladed arrays in order to reduce the level of vibrations in these systems. Bladed disks are originally designed to have identical blades, but there are always random deviations from the nominal blade properties as a result of manufacturing tolerances, material non-homogeneity, assembly method, wear, etc. Typically, the cyclic symmetry assumption is used to analyze the bladed disks, but when the blades possess a slight dissimilarity in physical or structural properties, this assumption is not valid and the system dynamics undergoes a dramatic change. In this case, the bladed disk is said to be mistuned. Various models are adopted for studying the bladed disks. Lumped parameter models are simple and do not mainly give accurate results, while finite element models impose a computational burden so that chiefly need to be reduced in order to lessen the computation time. On the contrary, non-FEM distributed-parameter models are important because they give relatively accurate results and solving their resultant equations is not computationally cumbersome. Among the different studies, a minority of them used a non-FEM distributed-parameter model. Yigit et al. [1] derived fully coupled nonlinear equations of

*Corresponding author
Email address: r_tikani@cc.iut.ac.ir (Reza Tikani)