



Simulation of casing vibration resulting from blade–casing rubbing and its verifications



G. Chen

College of Civil Aviation, Nanjing University of Aeronautics and Astronautics, Nanjing 211106, PR China

ARTICLE INFO

Article history:

Received 5 January 2015

Received in revised form

18 June 2015

Accepted 23 September 2015

Handling Editor: L.N. Virgin

Available online 23 October 2015

ABSTRACT

In order to diagnose effectively the blade–casing rubbing fault, it is very much necessary to simulate the casing vibration correctively and study the casing signals' characteristics under blade–casing rubbing. In this paper, the casing vibrations in aero-engine resulting from the blade–casing rubbing are simulated. Firstly, an improved aero-engine blade–casing rubbing model is introduced, in which, the effects of the number of blades and changes in the rotor–stator clearance on rubbing forces are considered, the improved rubbing model can simulate rubbing faults for various rubbing conditions, including single-point, multi-point, local-part, and complete-cycle rubbing on the casing and rotor. Secondly, the rubbing model was applied to the rotor–support–casing coupling model, and the casing acceleration responses under rubbing faults are obtained using the time integration approach, which combines the Newmark- β method and an improved Newmark- β method that is a new explicit integral method named the Zhai method. Thirdly, an aero-engine rotor tester with the casings was used to carry out rubbing experiments for single-point rubbing on the casing and complete-cycle rubbing on the rotor, the simulation result was found to agree well with the experimental values, and the improved blade–casing rubbing model was fully verified. Finally, other rubbing faults were simulated for various rubbing conditions and their rubbing characteristics were analyzed.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

The existing rubbing models are mainly divided into elastic models [1] and rigid models [2,3]. In an elastic model, the stator is assumed to be completely elastic, and the collision effect is not considered, whereas in a rigid model, the stator is assumed to be completely rigid, and deformation of the stator in the rubbing process is not considered. Because a thin-walled structure is adopted in an aero-engine stator casing, the mass of the stator that contacts the rotor in the rubbing process is far less than that of the rotor [4], and the elastic models are widely used in aero-engine rubbing fault modeling and analysis [5,6].

Recently, research on rubbing faults has focused on the structural features of the blades. Liu et al. [7] conducted numerical simulation of the dynamic process of aero-engine blade-to-case rub-pact by explicit–implicit integration scheme, the low-frequency linear steady-state response and high-frequency nonlinear transient response due to the rub-impact. By taking the structure of a certain high-pressure turbine as example, the process of blade to case rub-impact was simulated,

E-mail address: cgyzx@263.net

and the dynamic response characteristic of the blade during the process was analyzed. The result shows that, the stress wave, which affects the stress distribution of blade, will be generated and propagated on the body blade during the process of rub-impact; after the process of rub-impact, the dynamic response of blade is a decaying harmonic motion at the damped low-order natural frequency. Williams [8] developed a new modeling technique for modeling blade-casing rubs, which includes a detailed model of the interaction with liner wear. The new method is time based, but is very efficient, enabling a wide range of initiating conditions to be explored, and a series of examples had been developed to verify the method, and investigate potential interaction phenomena under representative simulated conditions. In addition, the method can predict that instability may occur above a threshold level of tip rub severity, and demonstrates the improvement in an alternative blade design for which rub tolerance is known to be superior.

Some scholars have proposed simulation methods for rubbing fault based on the pulse force model for this rubbing condition [9–12]. Sinha et al. [9] simulated the dynamic response of a Timoshenko beam under repeated pulse loading. The tip of the rotating beam was subjected to a periodic pulse load due to local rubbing against the outer case introducing Coulomb friction in the system. Transient response of the beam with the tip deforming due to rub was discussed. Numerical results were presented for this vibro-impact problem of hard rub with varying coefficients of friction and the contact-load time. The effects of beam tip rub forces transmitted through the system are considered to analyze the conditions for dynamic stability of a rotating blade with intermittent rub. Turner et al. [10] simulated the time-transient vibratory motion of a general configuration engine turbomachinery free-standing blade when subjected to in-service blade-on-casing tip-rub events. Correct characterization of the blade tip-surface rub mechanics tribology models necessitates using empirical information that is currently being acquired from single-blade spin-pit tests now in progress in a parallel companion phase of this research. Output results for validation cases are presented. The analysis efficiently simulates complete transients involving multiple successive incursions (blade on casing hits), tracking the blade tip contact force distribution and blade motion throughout the simulated time frame including blade motion during, between and after successive casing hits. Turner et al. [11] established experimental and analytical capabilities through an alliance between GE Aviation and The Ohio State University Gas Turbine Laboratory. One of the early findings of the program is the influence of blade flexibility on the physics of rub events. The focus of this paper is to quantify the influence of airfoil flexibility through a novel modeling approach that is based on the relationship between the applied force duration and maximum tip deflection. Results from the model are compared with experimental results, providing sound verification. Tai et al. [12] established the dynamical equation of blade with impulse loading on the Timoshenko beam element considering the effect of Coriolis and centrifugal forces. The dynamic characteristics of the blade at different rotating speeds were analyzed. The results show that synchronization is produced between blade displacement and impulse loading under low speed, and the blade is in high-frequency vibration when the force is removed. Non-synchronization is observed under high engine speed because of inertia and the blade is in low-frequency due to the shorter vibration. Moreover, the displacement of blade in high speed is less than that in low speed for the effect of centrifugal rigidization.

Légrand et al. [13] introduced a very simple two-dimensional model of outer casing and bladed disk in order to predict the occurrence of such phenomenon in terms of rotational velocity. In order to consider traveling wave motions, each structure is represented by its two n_d -nodal diameter standing modes. Equations of motion are solved first using an explicit time integration scheme in conjunction with the Lagrange multiplier method which accounts for the contact constraints, and then by the Harmonic Balance Method. Both methods yield identical results that exhibit two distinct zones of completely different behaviors of the system. Batailly et al. [14] introduced a combination of component mode synthesis methods with a contact algorithm based on the Lagrange multiplier technique. The use of three types of reduction methods – modal projection over the two first k -nodal diameter free vibration modes and two component mode synthesis methods namely the Craig-Bampton and the Craig-Martinez methods – emphasized the consistency of interaction detection. It was also pointed out that displacements obtained for each DoF of the reduced order models are extremely sensitive to the modal reduction basis considered due to the highly nonlinear contact case. Consequently, the notion of motion convergence was introduced in addition to the well-known notion of asymptotic convergence in terms of displacements. Légrand et al. [15] studied the contact characteristics between a blade tip and casing with an abrasion coating inside, based on the piecewise linear plastic constitutive relation. The results showed that the frequency component of the blade response is affected by an abrasion coating and that the initial clearance between the blade tip and the coating in the wearing process has a great effect on the blade's vibration amplitude. Padovan et al. [16] assumed that the casing is rigid, simplified the blade as a cantilever, derived a normal rubbing force expression for a compressor blade, and discussed the effect of each system parameter on single-blade and multiple-blade rubbing dynamics characteristics. Sinha et al. [17] established a blade-rotor model, in which, all the dynamical equations include the effect of the rotary inertia and gyroscopic moments because of both shaft bending as well as staggered blades flexing in-and-out of the plane of the disk. The governing equations also account for internal material damping in the shaft and the external damping in the support bearing system. The effect of blade tip rub forces being transmitted to the shaft is analyzed in terms of the dynamic stability of the rotor, especially during wind milling.

However, there are several inevitable problems associated with current rubbing fault research. First, the models do not fully consider various rubbing types, which include single-point, multi-point, local-part, or complete-cycle rubbing of the casing or local-part or complete-cycle rubbing of the rotor. As a result, the simulated and actual features of rubbing faults are very different. Second, the currently available rubbing models are not used directly in rotor-support-casing coupling models, and thus the simulation of rubbing faults does not reflect the whole aero-engine vibration fault characteristics.

Download English Version:

<https://daneshyari.com/en/article/287163>

Download Persian Version:

<https://daneshyari.com/article/287163>

[Daneshyari.com](https://daneshyari.com)