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Literature Survey of the Research of Blade-Casing Rub-Impact Characteristics on High Speed Rotating Machinery

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ABSTRACT

Complicated rubbing issues are often occurred on rotating machinery. Combining with mechanism of transient rub-impact effects of the rotating blade-casing, the development about rubbing problem of rotor dynamics, vibration characteristics of constraints blade and rub-impact problem of the rotating blade-casing were summarized. And it analyzed deficiencies and significance of numerical simulation in the research of blade-casing structure thermal coupling characteristics on rotating machinery.

INTRODUCTION

Blades are the key components of aero-engine. Because of the smaller gap, the tip and the casing were prone to rub on high speed operation. The serious rub-impact will cause the blade rupture, rotor instability, leading to a major operation accident [1]. Scholars have done considerable research and have achieved fruitful results over the complex processes.

In this paper, the transient rub-impact characteristics of blade-casing structure are summarized. The article is organized as follows: First, it introduces the development about rubbing problem of rotor dynamics; Second, the vibration characteristics of constraints blade are summarized; Third, a brief review of the research on rub-impact problem of blade-casing is carried out; Finally, it analyzed deficiencies and significance of numerical simulation in the research of blade-casing structure thermal coupling characteristics on rotating machinery.

DEVELOPMENT ABOUT RUBBING PROBLEM OF ROTOR DYNAMICS

Rotor dynamics is an important part of the rotating machinery, which is used to study the dynamic characteristics of rotor and its components. So far, researchers have made a detailed study on rotor dynamics in theory and experiment.

With the rapid development of industry, rotary speed rises may increase the possibilities for vibration of rotor system, which could cause serious instability of rotor. G. Ferraris proposed dynamic model of double rotor system with reverse rotation derived from Rayleigh-Ritz method. Then the critical speed of rotation and unbalance response with asymmetric supporting stiffness were calculated by using the finite element method and the modal truncation method, and some of the results were verified by tests [2].

Domestic scholars also have made a lot of research on rotor dynamics. For dual rotor system of aero-engine, Keming WANG got the vibration characteristics of whole machine by using sub-structure transfer matrix method [3]. Through theoretical and experimental, steady response of the reverse rotation double rotor was researched by Guihuo LUO, and then it was pointed out that reverse rotation of double rotor system was helpful to reduce the influence of whole gyro torque on the aircraft [4]. Aiming at rub-impact in rotor system, Shunming LI proposed the nonlinear differential equations of bending and torsional coupled vibrations of rotor. And then the rub-impact response characteristic was studied by using DT CWT [5]. In literature, the effect of thermal bending on rotor vibration and fault was studied through the experiment [6].

At present, the main emphasis of our research are condition monitoring and fault diagnosis, unbalanced responses, vibration and stability control of rotor system, etc. The nonlinear dynamic analysis of rotor system with rub-impact is gradually becoming a hot topic, but now little research is focused on the thermal coupling for rotor system.

DEVELOPMENT ABOUT VIBRATION CHARACTERISTICS OF CONSTRAINTS BLADE

Blades are the key components of aero-engine. In order to avoid the damage by nonlinear vibration, researchers have made a detailed study on simplified blade model in theory and experiment.

Cantilever Beam Model

As early as 1850s, scholars had considered blade as cantilever beam model. For natural vibration characteristics of blades, Saravia took the rotating blades as thin-walled structure, and applied finite element method to analyze its free vibration and dynamic stability in recent years[7].In domestic, Xingyu TAI established the blade kinetic equation under impulse to simulate the dynamic characteristic[8]. For nonlinear dynamic response of high speed rotating blades, Yanping CHEN proposed the model of Euler-Bernoulli with rotating thin walled beam (Figure 1)[9].

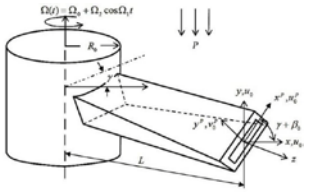

Figure 1. The model of Euler-Bernoulli with rotating thin walled beam

Thin-walled Model

For thin-walled model, Goley made research on center change of the resonance frequency in nonlinear response to get influences from various factors on pneumatic, noise, harmonic and random load [10].In domestic, Jiyong LI and Shunming LI analyzed the modal shapes and frequency variation of thin-wall structure under the variable temperature and noise. And then they proposed a method for analyzing the vibration response of random mass plate [11].

Entity Model

In order to reduce the error, many scholars used entity model to simulate the real blade. For certain aero-engine turbine blades, Chunwang LI made research on the vibration modal analysis to get influences

from various factors on blades including centrifugal force field, aerodynamic field, temperature field and thermal field etc [12]. In literature, natural frequency and vibration response of rotating blade were simulated by cyclic symmetry algorithm, contact analysis and pre-stress modal analysis [13]. These obtained conclusions could provide technical guidance for fault research and optimization design of high speed rotating blades.

Shell Structure Model with Variable Thickness

In order to save computing time, scholars began to use shell structure model with variable thickness for the simulation, and the model can analyze the variable cross-section blade effectively. By comparing the calculated results between variable thickness shell structure model and entity model, the accuracy and efficiency of the shell structure model with variable thickness was verified by Hui MA [14]. Some scholars have also studied the difference between these two models in the numerical calculation of blade, such as Didi ZHONG.

Therefore, it can be concluded that the key to the study of vibration characteristics was how to simplify the blade in previous research, but now little research was focused on the thermal effects for blades.

DEVELOPMENT ABOUT RUB-IMPACT PROBLEM OF THE ROTATING BLADE-CASING

Owing to raise the thrust weight ratio of modern aero-engine, it is very important to optimize the structures of the components. Narrowing the gap between rotor and stator is one of the important mean, but which could increase the possibilities for rub-impact between the tip and the casing. Rotor/stator rubbing problem has always been concerned, and scholars have done some research on the rub-impact of blade-casing structure.

For the nonlinear dynamic response of rub-impact effect, Jiang deduced the equations of normal rub-impact force between blade and casing in consideration of centrifugal force [15]. Haijiang KOU proposed dynamic modal of hub-plate system with rubbing (Figure 2) and deduced the approximate mathematical expressions of rub-impact based on the results of experiment and finite element analysis. And then it discussed the application of beam model and thin plate model at different points and lines touch [16].

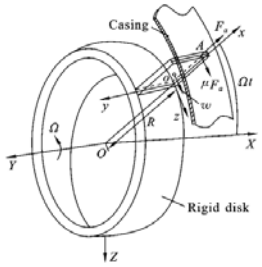

Figure 2. Dynamic modal of hub-plate system with rubbing

Guo CHEN and Haifei WANG proposed a new rub-impact model of blade-casing on the basis of general elastic rub-impact model. And then the rules of rub-impact between casing and single point, multi-point, local and complete revolution of rotor was simulated, at the same time, the experiment results have verified the feasibility and correctness of the model[17]. For rub-impact experiment, Hui MA simulated the rubbing between blade and casing by using the finite element modal of rotor-blade-casing system (Figure 3). And strengths and weaknesses of the 5 blade-casing modal was summarized in great detail [18].

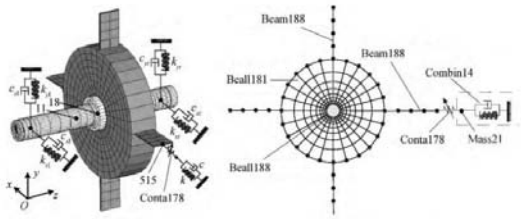

Figure 3. Finite element modal of rotor-blade-casing system

From the literature, the main emphases of our research are nonlinear dynamic response and rub-impact fault between blade and casing. But there is little research focusing on the effect of rub-impact considering transient temperature. There will be the focus for our study.

SUMMARY

In summary, the rub-impact fault between blade and casing is the main type of aero-engine fault. Until now, there is an emphasis for research about dynamic response of the process between blade and casing. However, the study on transient thermal coupling effect of blade-casing structure is ignored by researchers. So it will be the focus to study the vibration characteristics of thin wall structure and the thermal-structure coupling characteristics of blade-casing structure.

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