Rub-impact and Misalignment induced Vibration of HP Rotor System in Aero-Engine

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ABSTRACT

The numerical simulations of vibration induced by rub-impact and misalignment happening on the high pressure (HP) rotor system of an aero-engine are achieved, and also confirmed by experimental measurements on a special designed test-rig. The simulation model of the rotor dynamics is set up by using of ADAMS, composes of both effective stiffness elements of two different elastic supporting and s rigid shaft. The local rub-impact happening between one disc and the casing shell, the front supporting misalignment are involved in the model. In the model, the rub-impact mechanism is expressed by the parameters of its stiffness and damping and friction, and the misalignment is simulated by changing the position of the front supporting. To change the running speed and the rub-impact or misalignment levels, the transverse vibrations of the discs and shaft of the HP rotor are calculated. The numerically simulated time-domain responses, the frequency spectra and the shaft-center trajectories are plotted and compared on the above different operating conditions. These simulation results are compared to explore the efforts on rotor vibrations of the rotating speed, rubbing stiffness or friction, and the misalignment displacement or angle. Finally, the simulation results are also consistent with the measured vibrations on the HP rotor test-rig, which confirms that the established model and simulation method and typical results are acceptable.

1. INTRODUCTION

Nowadays, safety and stability of aero-engine are put forward higher requirements. As an important part of aero-engine, the vibration fault of the rotor system, such as unbalance, misalignment, rub-impact and etc., directly determines the vibration level of the whole system[1]. As an important part of the aero-engine rotor system, the high-pressure rotor plays an important role in the vibration of the rotor system.

Due to the complex of the aero-engine, it is difficult to reproduce the unbalance and misalignment fault in the prototypes. Therefore, different simulation technology is widely used in rotor fault simulation. Among which, ADAMS is based on computational multi-body dynamics, including many professional modules, and can be used to establish the kinematics and dynamics of mechanical systems. So ADAMS can implement the simulation of dynamics of the system in actual condition [2].

Based on the theories of dynamics of rotor system, together with the rub-impact and misalignment mechanism involving its stiffness and damping and friction, a multi-body dynamic model of the aero-engine high-pressure rotor system is built on the software platform of ADMAS. The numerical simulations of ADAMS model includes both unbalances of discs and local rub-impact between discs and casing shells, and the time-domain responses, frequency spectra and shaft-center trajectories of the high-pressure rotor system vibration with rotor unbalance, rub-impact and bearing misalignment are analyzed. This study provides a verification method for studying the rub impact and misalignment of aero-engine rotor.

2. SIMPLIFICATION OF HP ROTOR

A typical aero-engine HP rotor system are composed of nine compressor discs and a high-pressure turbine, which is supported by bearings of an elastic support and a rigid support. According to the principle of dynamic similarity, the HP rotor system is simplified as an annular hollow beam with equivalent cross section. The discs of the compressor and the turbine are considered as rigid bodies with rotating effect shown in figure 1 [3].

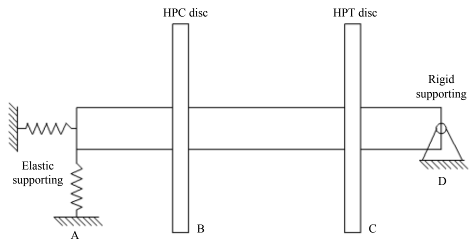


Fig. 1 The structure schematic diagram of HP rotor system

3. DYNAMIC MODEL OF HP ROTOR BASED ON ADAMS

The basic parameters of the HP rotor structure are shown in Table 1. H_{1d} and H_{2d} are the inner and outer diameter of shaft respectively; d is the diameter of the disc; h is the thickness of the turntable disc.

Table 1 The basic parameters of HP rotor system

parameters	numerical value（mm）
L_{AB}	185
L_{AC}	515
L_{AD}	700
H_{1d}	80
H_{2d}	90
d	200
h	30

In ADAMS, the impact function is used to calculate the contact force between two objects. The contact force is composed of two parts, where the first part is the elastic force due to the mutual penetration between the two objects, and the other part is the damping force produced by relative speed. Rub-impact mechanics expression can be expressed as

$$F = \begin{cases} 0 & x>\delta_0 \\ k(\delta_0 - x)^e - N \cdot C_{max} \cdot \mathrm{step}(x, \delta_0 - d, 1, \delta_0, 0) & x \ll \delta_0 \end{cases} \tag{1}$$

where, k is the stiffness coefficient; δ_0 is the initial distance between the two contact objects; x is the actual distance the two contact objects in the rubbing process; C_{max} is the maximum damping coefficient is used to characterize the collision energy loss; N is the rotating shaft speed; e is rub-impact index which used to represent the nonlinear degree of material; d is the penetration depth.

When use ADMAS to build the model of the HP rotor system, the 'Bushing' and 'Spherical joint' are used to simulate the elastic and rigid supporting respectively, and the parameter setting of stiffness are shown in table 2. The HP rotor unbalance is simulated by adding a mass block on the high-pressure compressor disc. A rubbing block is arranged at a certain distance from the high-pressure rotary disc and the different rubbing conditions are simulated by adjusting the clearance and rubbing parameters. The dynamic friction between the turbine disc and the rubbing block is 0.1. The multi-body dynamic model of HP rotor rub-impact based on ADAMS is illustrated in figure 2.

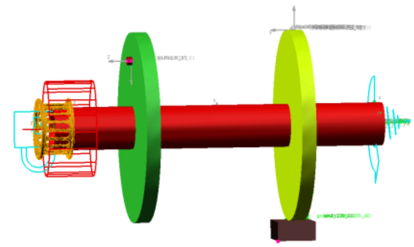


Fig. 2 The HP rotor system model based on ADAMS

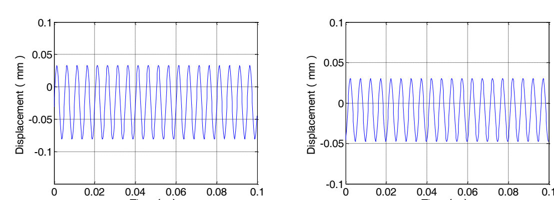
ADAMS provides a variety of integrators. This paper selects the GSTIFF integrator with high speed and high solve precision. There are three kinds of GSTIFF integrator integral format including I3, SI2 and SI1, where the speed of solving I3 format is faster, but error will be generated when it comes to speed. Especially at acceleration stage, the SI1 format is not suitable for processing contact problems with friction [4], while SI2 integral method is optional, and the integral error is set to 0.001.

Tab. 2 Parameter setting of the simulation model

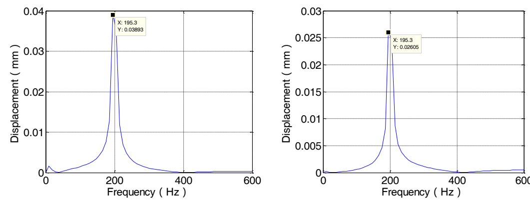
Parameter	Data
Rub-impact stiffness	1e6N/m
Rub-impact damping	100Ns/m
Force Exponent	1.5
Penetration Depth	0.1mm
Rubbing clearance	0.1mm
HPC unbalance quality m_{e3}	20g
High-rotor motion N	12000r/min
The stiffness of Bushing	1e8
The damping of Bushing	1e5

4. NUMERICAL SIMULATIONS OF VIBRATION INDUCED BY RUB-IMPACT ON THE HP ROTOR SYSTEM

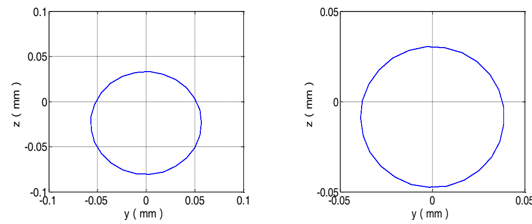
In this paper, time-domain responses, frequency spectra and shaft-center trajectories of the HP rotor system are obtained via simulation analysis. The vibration characteristics of high-pressure compressor disc (HPC) and turbine disc (HPT) under different operating conditions are shown in figure 3-4.



(a)HPC time-domain (b) HPT time-domain



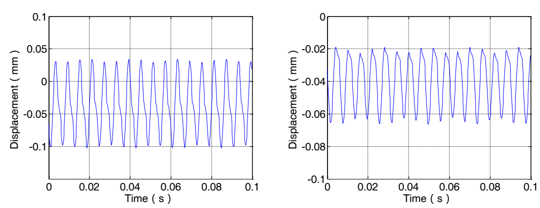
(c)HPC frequency spectra (d)HPT frequency spectra



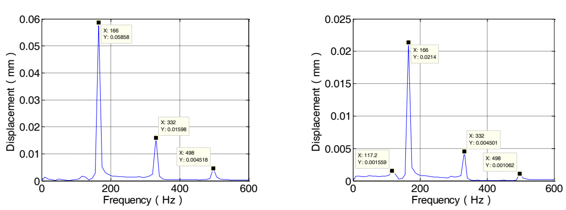
(e)HPC trajectories (f)HPT trajectories

Fig.3 Analysis results without impact

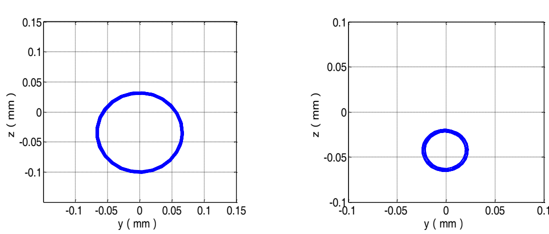
According to Figure 3, Owing to the existence of the rotor system unbalance, the system is in certain vibration. The discs are in a certain range of periodic reciprocating vibration and the other frequency components basically cannot be seen, where the trajectory line is in round shape.



(a)HPC time-domain (b) HPT time-domain



(c)HPC frequency spectra (d)HPT frequency spectra



(e)HPC trajectories (f)HPT trajectories

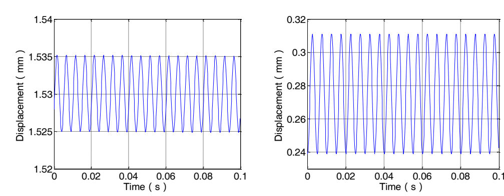
Fig.4 Analysis results with impact

From Figure 4, we can find that the frequency spectrum of the high-pressure compressor disc is dominated by the frequency 166Hz, 332Hz, 400Hz and the frequency 166Hz occupies the absolute priority, while the trajectory line appears some confusion within a certain range. The time domain diagram of high-pressure turbine disc are under zero, and the frequency spectrum is dominated by the frequency 166Hz, 332Hz, 400Hz and the frequency 166Hz occupies the absolute priority, the trajectory line appears more confusion within a certain range.

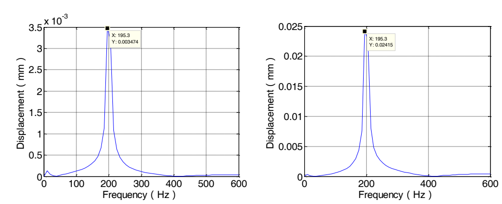
It can be seen from the figure that the frequency spectrum of each disc mainly falls to 166Hz and there is a combination of frequency components such as 332Hz and 400Hz. The spectrum amplitude of the high-pressure turbine disc increased.

5. NUMERICAL SIMULATIONS OF VIBRATION INDUCED BY MISALIGNMENT ON HP ROTOR SYSTEM

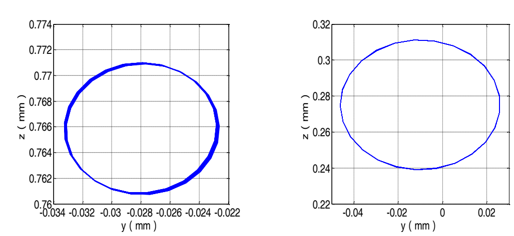
The misalignment of the rotor system affects the stability of the whole rotor system. In this paper, we simulate the motion of the rigid rotor system under the condition that the support is not concentric by moving the cage along the Z direction. The vibration response, frequency spectrum and trajectories of the high pressure compressor disc (HPC) and the turbine disc (HPT) are obtained with misalignment 1mm and 2mm respectively, which is shown in figure 5 and 6.



(a)HPC time-domain (b) HPT time-domain

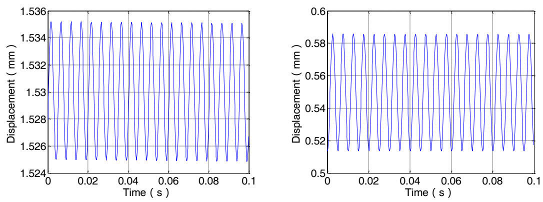


(c)HPC frequency spectra (d)HPT frequency spectra

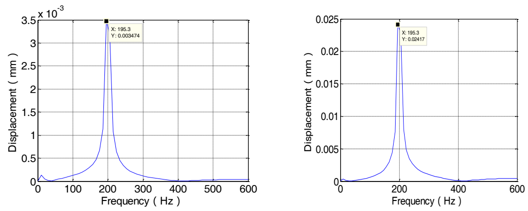


(e)HPC trajectories (f)HPT trajectories

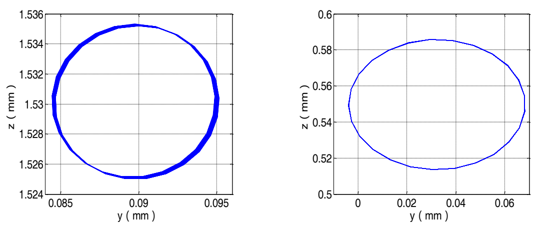
Fig 5 Vibration response of HP rotor with 1mm misalignment



(a)HPC time-domain (b) HPT time-domain



(c)HPC frequency spectra (d)HPT frequency spectra



(e)HPC trajectories (f)HPT trajectories

Fig 6 Vibration response of HP rotor with 2 mm misalignment

Compared figure 5-6 with figure 3, it can be seen that the mean value of time domain diagram of two discs is increased obviously, and the trajectories of high-pressure compressor disc appears some confusion within a certain range. Compared figure 5 with figure 6, it can be seen that the change of vibration amplitude of high-pressure compressor disc is not obvious. The mean value of the high-pressure turbine disc is increased obviously.

6. CONCLUSIONS

This paper elaborates brief research on the unbalance, misalignment and rub-impact of HP rotor system of an aero-engine, which has presents the analysis methods of the dynamic balance of the rotor and is helpful to monitor and diagnosis of the rub-impact fault. I

In the unbalance response of the high-pressure rotor, the rotating frequency take the absolute advantage with other frequency, and the trajectory line is in a round shape. In addition to the rotation frequency, the combined frequency of the rotor system is also found when high-pressure turbine disc under rubbing. Misalignment has a great influence on the response of the HP rotor system, it changes the stable position of rotor system directly.

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