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Study on the recognition of aero-engine blade-casing rubbing fault based on the casing vibration acceleration

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ABSTRACT

By mean of the aero-engine rotor experiment rig with casings, the blade-casing rubbing experiments, which include the single-point rubbing and the partial rubbing, are carried out. The casing vibration acceleration signals are analyzed in order to extract the rubbing faults' characteristics. The results show that: the casing signals under rubbing have obvious impact characteristics; the impact frequency is the frequency of blades passing the casing, and it equals the product of rotating frequency and the number of blades; in the frequency spectrum, there is the blades-passing frequency and its multiple-frequencies; the strength of impact is modulated by rotating frequency, so that there are families of side bands on both sides of the blades-passing frequency and its multiple frequencies, and the side bands' interval equals the rotating frequency. There are obvious quefrency components of the rotating frequency and its multiple frequencies in the cepstrum. Finally, the rubbing characteristics found out in this paper are verified by using an actual aero-engines' test data.

1. Introduction

In order to improve thrust weight ratio and structure efficiency of aero-engine, its clearance between rotor and stator need be narrowed; however, the possibility of the rotor–stator rubbing, especially the blade-casing rubbing, will greatly increase. Rubbing between rotor and stator can cause many serious consequences, such as rotor–stator clearance's enlargement, bearings' wear, blades' break, even mechanical failure [1,2].

At present, a lot of scholars had studied the rubbing dynamics mechanism and rubbing experiments, had found out some characteristics and phenomena caused by rubbing, such as waveform cutting, the frequency doubling, frequency division and chaos, and theoretical analysis had been verified by experiments in many literatures [3–10].

However, for the aero-engine, the main distinctions of rubbing faults have as follows: (1) the casing is typical thin-walled structure; (2) the rubbing fault mainly appears between the blade and the casing; (3) generally, only vibration acceleration on casing can be measured, it is very difficult to obtain the vibration displacement.

The existing theoretical and experimental researches did not consider all of the above-mentioned characteristics, so they can not be directly applied to aero-engine rubbing fault diagnosis. Therefore, it is very important and necessary to study the characteristics and laws of casing vibration acceleration signals for effectively identifying the rubbing faults of aero-engine.

In view of this, in this paper, a rotor experiment rig of aero-engine is used to carry out the single-point rubbing and partial rubbing experiments; the casing vibration acceleration signals are measured, by means of the casing acceleration signals' analysis, the characteristics and laws of blade-casing rubbing faults are found out. Finally, the characteristics are verified by using a real aero-engines' test data.

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2. Analysis of rubbing faults' characteristics based on the rubbing experiments

2.1. Introduction to the aero-engine rotor experiment rig

Traditional rubbing experiments do not consider the thin-walled structure of the aero-engine and the rotor disk-blade structure, therefore, the rubbing characteristics are not close to those of a practical aero-engine. In this study, a rotor experiment rig of the aero-engine, which is designed by the Shenyang Aero-engine Design Institute of China, is used to carry out the rubbing experiments. The structural design of this experimental rig is greatly improved. First, its shape is made consistent with that of the core-engine casing, and its size is treble reduced. Second, the internal structure is simplified, that is, the core-engine is simplified to 0-2-0 support structure form and an adjustable stiffness support structure is designed to adjust the system' dynamic characteristics. Third, the multistage compressor is simplified to a single-stage disk structure. Finally, the experimental rig of the aero-engine forms the rotor-support-blade disk-casing system. The experimental rig is shown in Fig. 1. In the experiments, rubbing bolts are screwed by a spanner to make the rubbing loop out of shape, so that single-point rubbing appears between the rubbing loop and rotating turbine blades. The position of bearing housing can be adjusted by a turbine screw mechanism so that the whole rotor move to the casing and the blade-casing partial rubbing appears. Rubbing sparks occurs when rubbing is very serious.

The rotor experimental rig of the aero-engine is shown in Fig. 1. The rubbing positions and the installation positions of accelerometers are shown in Figs. 2 and 3, the directions in Figs. 2 and 3 are defined facing the turbine casing; The partial rubbing adjusting mechanism and the accelerometer on the top of the compressor casing are shown in Fig. 4, as shown in Fig. 4 the blade-casing partial rubbing is carried out through moving the shaft-disc-blades in the left or right direction after screwing the adjusting mechanism of partial rubbing.

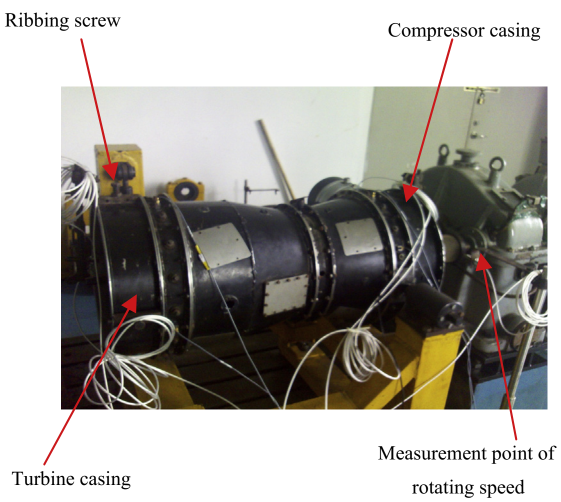

Fig. 1. Aero-engine rotor experimental rig.

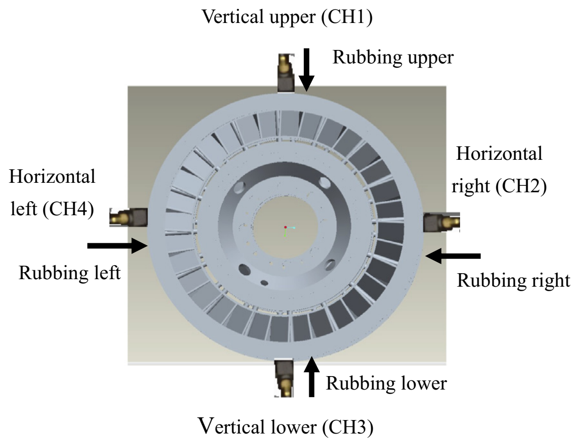

Fig. 2. Radial measurement points and rubbing points on turbine casing.

Four experiments data on May 12, 2012 and April 29, 2013 are selected for analysis, as shown in Table 1. The experiments on May 12, 2012 are single-point rubbing on the turbine casing. The measurement points are the upper, the right, the lower, and the left on the turbine casing; the rubbing intensity is moderate at the rotating speed of 1500 rpm. The experiments on April 29, 2013 are single-point rubbing and partial rubbing on the turbine casing. The measurement points are the upper, the right, the lower, and the left on the turbine casing and the upper on the compressor casing; the rubbing intensity is moderate at the rotating speed of 1200 rpm.

2.2. Characteristics analysis of casing acceleration signals under single-point rubbing

The testing data of channel 1 (CH1) obtained from the experiments conducted on May 12, 2012, is selected; the corresponding rubbing position is the vertical upper; and the experimental rotating speed is 1489 rpm = 24.8 Hz. Figs. 5 and 6 are the time domain waveforms, and Fig. 6 is the enlargement of Fig. 5. The frequency spectrum plots are Figs. 7–9, Fig. 9 is enlargement 1 of Figs. 7 and 8 is enlargement 2 of Fig. 7. Fig. 10 shows the cepstrum of the signal.

Because the rotor experiment rig is the shaft-disk-blade structure, when the rubbing occurs, every blade hits the rubbing point in turn; this impact action circulates once when the rotor rotates a circle. Therefore, the impact frequency caused by rubbing is the frequency of blades passing the casing, and it equals the product of rotating frequency and the number of blades, therefore, in the frequency spectrum, there is the impact frequency and its multiple frequencies. In addition, under the excitation of unbalance force, the rotor produces the whirling motion whose frequency equals the rotating frequency, so that the strength of impact action of rubbing is modulated by rotating frequency. Therefore, there is the obvious amplitude modulation characteristics in the frequency spectrum, namely there are many side bands on both sides of the rubbing frequency and its multiple frequencies. In the