Dynamic Balance Test of Elastic Support Rotor System Considering the Influence of Bolt Connection

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Abstract: Due to the influence of manufacturing error and assembly error and other factors, there will be some unbalance on the rotor, which will cause greater vibration at critical speed or higher speed, thus affecting the service life of the rotor, and even endangering the safety of human lives. Therefore, it is necessary to balance the action to reduce the vibration. In this paper, the basic principle of the commonly used dynamic balance method is described firstly. Then, based on the self-built elastic support rotor system test-rig, the response coefficient method and the three circle balance method are used to carry out the dynamic balance test of the rotor. Test results show that both of the two methods can play a good role in vibration reduction. Finally, based on the existing test data, the advantages and disadvantages of the two dynamic balancing methods are compared and analyzed.

Keywords: Elastic support rotor system; Dynamic balance; Response coefficient method; Three circle balance method

1 Introduction

Due to the factors such as material unevenness, process error, uneven deformation of rotor blade, uneven wear or partial block falling, there is always unbalance on the rotor. The unbalance of rotor is the main exciting source of engine. In the process of engine manufacturing or maintenance, even in the process of operation, the rotor needs to be dynamically balanced. At present, the methods of dynamic balance mainly include the influence coefficient method and the three circle balance method.

Goodman TP [1] used the influence coefficient method to carry out the dynamic balance test of the rotor assembly. Thompson et al. [2-4] conducted multi-plane and

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 ISSN 2572-4975 (Print), 2572-4991 (Online)

multi-speed on-site dynamic balancing tests on the rotor of a marine gas turbine using the influence coefficient method, and the vibration damping effect is obvious. However, in the field dynamic balance test, because the vibration phase is more sensitive to the change of rotor speed (especially in the resonance region), and the sensor will also be affected by external factors, which makes the test results bit of uncertain, so it is difficult to obtain the accurate measurement value of vibration phase for general rotor components. Therefore, scholars propose a method that does not need phase measurement to balance the rotor.

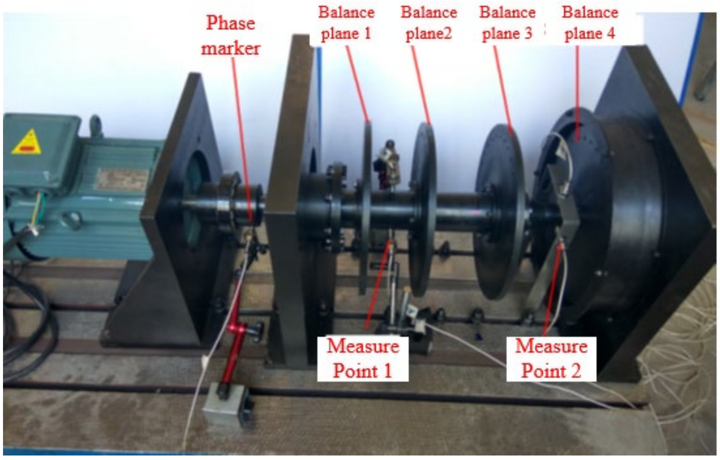
Hartog [5] firstly proposed a single-plane balancing method that does not require phase measurement. Blake et al. [6-7] did a deeper study to make this method perfect, which is now called the three circle balance method. Gunter et al. [8] combined the three circle balance method and the modal information of the rotor to successfully achieve the balance of the flexible rotor.

In this paper, based on a rotor test-rig with four disks and two fulcrums, two methods are adopted to carry out the dynamic balance test, and the advantages and disadvantages of the two methods are explained through the comparison of results.

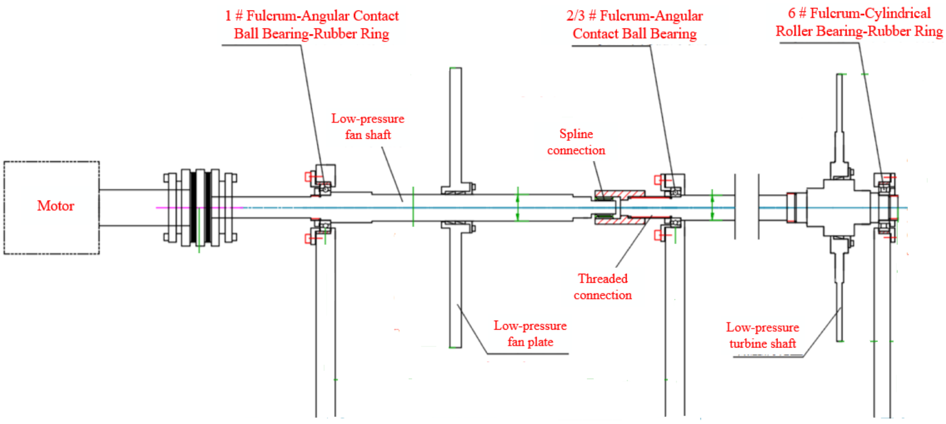
2 Test content and purpose

The rotor test-rig is simplified by the aero-engine rotor-support system, and its structure is shown in Fig.1. The test system is self-built, which is composed of cDAQ 9188 chassis, NI 9229 acquisition card and acquisition software based on LabVIEW. The eddy current displacement sensor is Lianneng CWY-DO-502, and its sensitivity is 4mV/um. Through software programming, a lot of signal processing that originally needed to build complex circuits was realized. The hardware system was softwareized, and the test accuracy and efficiency were greatly improved.

The influence coefficient method and three circle balance method are used to balance the rotor. In the case of one balance speed and two balance measuring points, two balance planes are selected for dynamic balance. The influence coefficients of two balance planes at different measuring points of balance speed are tested respectively, and the dynamic balance is realized by adding bolts in the balance plane. The balance plane is the outermost two of the four turntables, and the balance speed is 2400r/min. The two balance measuring points are shown in Fig.1(a), and loosening the spline coupling is conducted to simulate influence of bolt connection on rotor dynamic balance, spline connection is as shown in Fig.1(b).



(a) Layout of measuring points



(b) Spline connection of rotor test rig

Fig. 1. Balance test points and balance plane layout of the rotor test rig

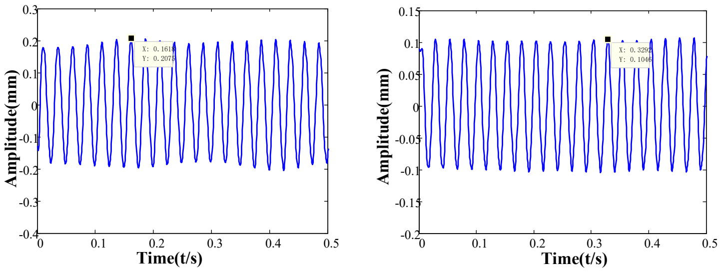
3 Influence coefficient method

The gap on the right side of the coupling is used as a phase marker, and an eddy current displacement sensor is arranged. Three eddy current displacement sensors are selected, which are respectively arranged in the vertical direction of measuring point 1 and measuring point 2 to measure the vibration signal. The sensor arrangement is shown in Fig.1. Set the sampling frequency to 1000Hz, and test the vibration response of the rotor system at 100-3000 r/min under the initial unbalanced state. Then add test weights at the balance plane 1 and 2 ,respectively, and the test weight is $53.44g\angle 180°$,

 ISSN 2572-4975 (Print), 2572-4991 (Online)

respectively measure the vibration response of the rotor system at 2400r /min after adding the test weight.

Calculate the influence coefficient and counterweight, balance the original unbalance by adding test weight, measure the vibration response after dynamic balance, and compare with the vibration response before dynamic balance. At the speed of 2400 r/min, the original vibration of measuring points 1 and 2 is shown in Fig. 2.



(1) Measuring point 1 (2) Measuring point 2

Fig. 2. Vibration signal before dynamic balance of measuring points 1 and 2

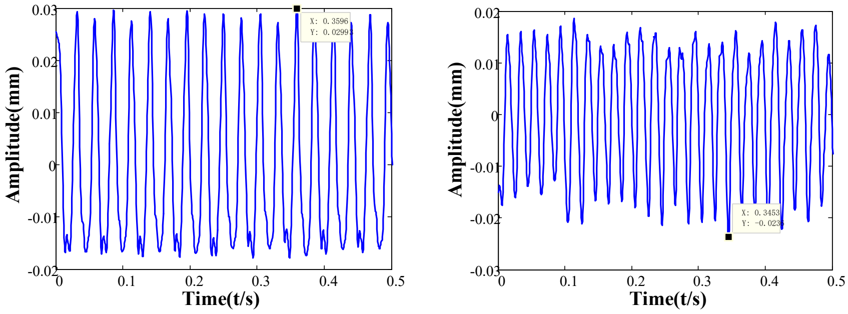
At the speed of 2400 r/min, the vibration response of the test-rig after adding test weight at balance plane 1 and balance plane 2 is shown in Table 1.

According to the vibration signals in Table 1, the balance correction amount to be added at the two correction planes is:

Correction plane 1: $35.9g \cdot mm\angle 318°$,correction plane 2: $43.2g \cdot mm\angle 38°$ .The vibration response of the two measuring points at the speed of 2400r / min measured after dynamic balancing is shown in Fig.3, and the comparison results before and after balancing are shown in Fig. 4.

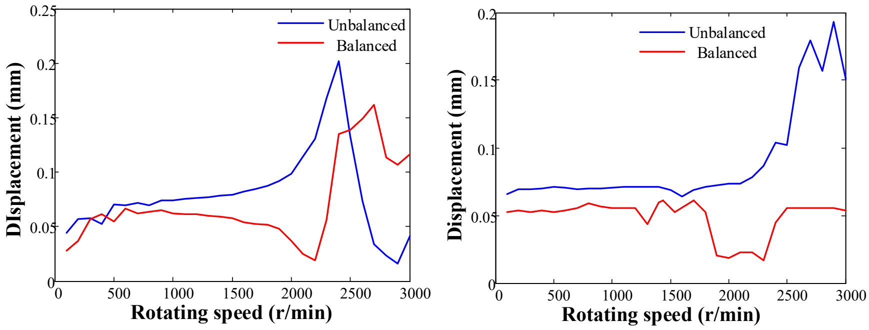
Table 1. Vibration signals of different measuring points after adding test weight

Measuring point	Without test weight	Test weight on plane 1	Test weight on plane 2
1	0.2075mm∠137.79°	0.1881mm∠44.91°	0.2056mm∠85.26°
2	0.1046mm∠35.49°	0.1438mm∠350.92°	0.1001mm∠358.46°



(1) Measuring point 1 (2) Measuring point 2

Fig. 3. Vibration signal after dynamic balance of measuring points 1 and 2



(1) Measuring point 1 (2) Measuring point 2

Fig. 4. Comparison of vibration amplitude before and after dynamic balance of measuring points 1 and 2

Comparing the vibration response of the two measuring points before and after the dynamic balance, it can be found that the dynamic balance has a certain effect, the maximum damping ratio is 85.53%, which proves the effectiveness of the dynamic balance test.

4 Three circle balance method

In the balance test, the three circle balance method is to make three circles according to the size of the unbalance of the rotor and merge them at one point to determine the orientation and size of the light spot of the rotor, so it is called the three circle balance method. Firstly, the vibration of rotor is measured as A0 on the test surface. Then, 68.3g counterweight was added in the phase of 0°, 120°, 240°, direction three times in succession, and the vibration amount was A1, A2, A3. Then take any point O as the center of the circle, A0 as the radius to make a circle, take the points a, b, c on the circle of 0°, 120°, 240° as the center, use the corresponding vibration quantities A1, A2, A3 as the radius to make arcs respectively, the three arcs

 ISSN 2572-4975 (Print), 2572-4991 (Online)

theoretically intersect at a point x. Connect Ox, then Ox represents the vibration vector caused by unbalance.

First, the three circle balance method is used to dynamically balance the measuring point 1, and the test is performed according to the unbalanced mass and phase shown in Table 2. The vibration response of the measuring point 1 is obtained as shown in Fig. 5, and the vibration amplitude is shown in Table 2.

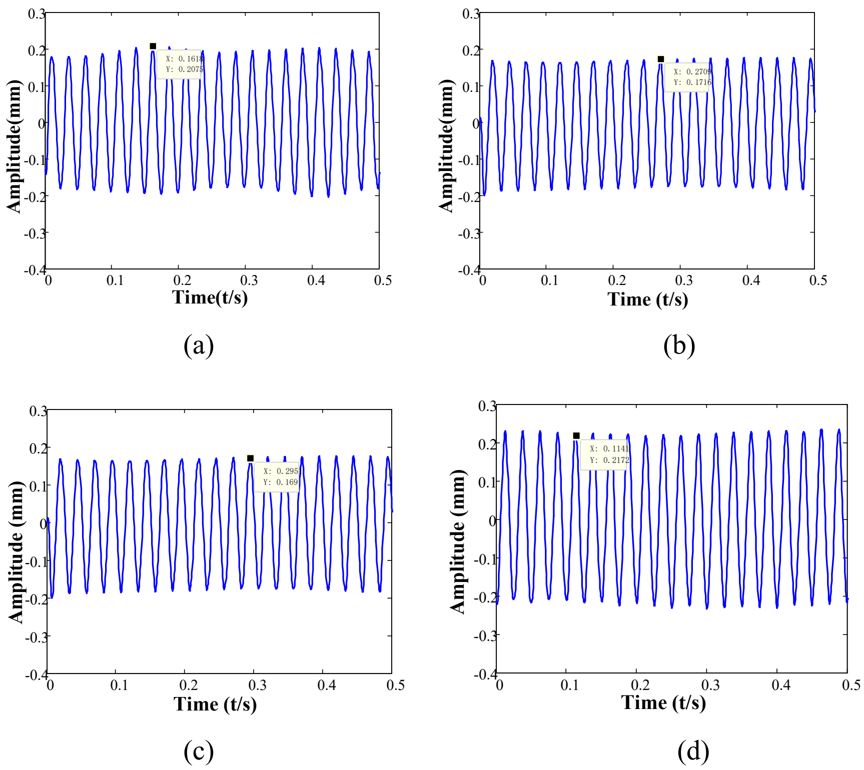


Fig. 5. Vibration response of test point 1 of rotor test bench at 2400 r/min
(a) ~ (d) is the vibration response of balance plate without test weight and with test weight at the phase of 0°, 120°and 240°

Table 2. Vibration amplitude of rotor after adding test weight

Test weight/g	0∠0°	68.3∠0°	68.3∠120°	68.3∠240°
Vibration amplitude /mm	0.2075	0.1716	0.169	0.2172

According to the balance principle of three circle balance method, it is calculated that the weight of the balance weight is 44.2g and the phase is 14°. After adding the balance weight, the vibration response of the rotor at the measuring point 1 of 2400r /

min is 0.02565mm. The speed of the rotor rises to 3000 r/min and the spectrum characteristics before and after the dynamic balance are shown in Fig. 6 and Fig. 7.

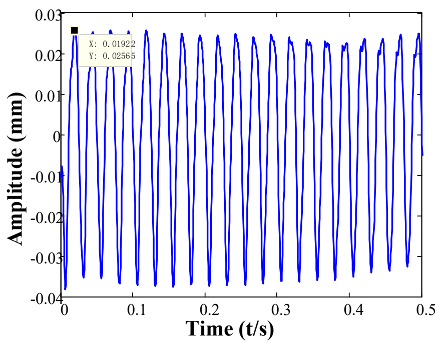


Fig. 6. Vibration response of measuring point 1 at 2400r / min

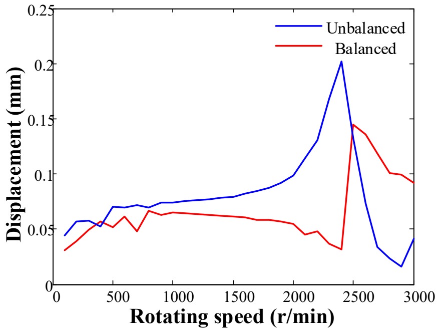
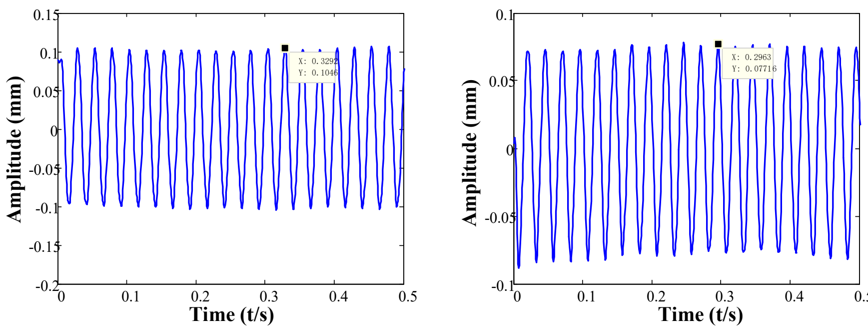


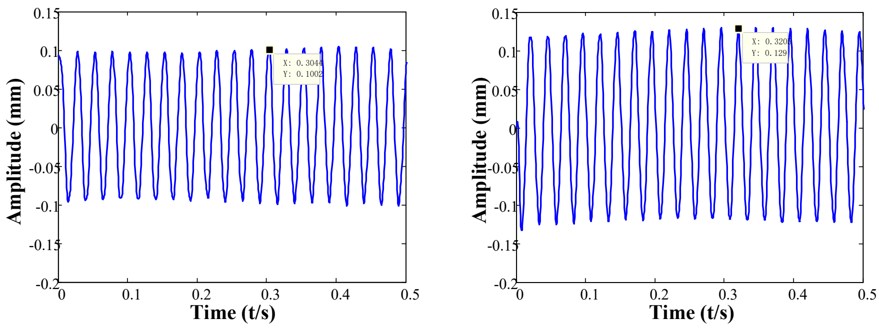
Fig. 7. Comparison of vibration amplitude before and after dynamic balance of measuring point 1

Comparing the vibration response diagram and spectrum diagram of measuring point 1 before and after dynamic balance, the vibration response of measuring point 1 at the first critical speed decreased from 0.2075mm before balance to 0.02565mm after balance, and the proportion of vibration reduction was 87.64%. The effect of vibration reduction was obvious. At the same time, the vibration response at the measuring point 1 at each speed less than the first critical speed also decreased significantly. In the same way, use the three circle balance method to conduct the action balance test on measuring point 2, add the test weight according to table 3, and get the vibration response of measuring point 2 as shown in Fig. 8, and the vibration amplitude is shown in Table 3.



(a) (b)

 ISSN 2572-4975 (Print), 2572-4991 (Online)



(c) (d)

Fig. 8. Vibration response of test point 2 of rotor test bench at 2400 r/min
(a) ~ (d) is the vibration response of balance plate without test weight and with test weight at the phase of 0°, 120°and 240°

Table 3 Vibration amplitude of rotor after adding test weight

Test weight/g	0∠0°	33.1∠0°	33.1∠120°	33.1∠240°
Vibration amplitude /mm	0.1046	0.0772	0.1002	0.129

According to the balance principle of three circle balance method, it is calculated that the mass of the balance weight is 12.4g and the phase is 45°. After adding the balance weight, the vibration response of the rotor at 2400 r/min measuring point 1 is 0.02615mm. The spectrum characteristics before and after the dynamic balance and the vibration response of the rotor when the rotor speed rises to 3000 r/min are shown in Fig. 9 and Fig.10.

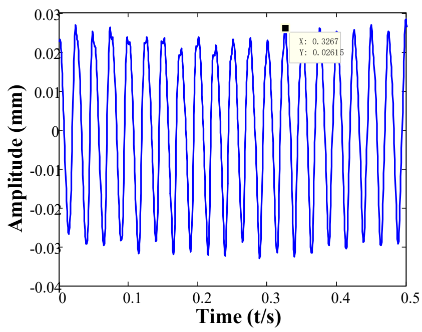


Fig. 9. Vibration response of measuring point 2 at 2400 r/min

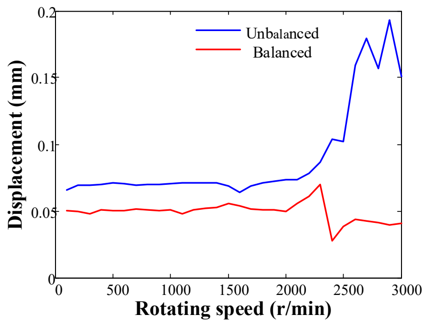


Fig. 10. Comparison of vibration amplitude before and after dynamic balance of measuring point 2

Comparing the vibration response diagram and spectrum diagram of measurement point 2 before and after dynamic balance, the vibration response of measurement point 2 at the first critical speed is reduced from 0.1046mm before balance to

0.02565mm after balance, and the proportion of vibration reduction is 75.48%. The vibration reduction effect is obvious. At the same time, the vibration response of the two measuring points at each speed less than the first critical speed also decreased significantly.

5 Conclusions

(1) Due to the large radius of the turntable, the installation accuracy has a very obvious impact on the vibration amplitude of the rotor. Because of the installation structure of the adjusted turntable on the shaft and the frequent removal of the counterweight during the experiment, the original uneven measurement of the adjusted turntable increases during the experiment.

(2) The three circle balance method is very sensitive to the choice of test weight. Too large or too small test weight is not conducive to data processing, so it can not achieve good balance effect. In the process of test, it is often necessary to select the counterweight quality many times to improve the balance effect, resulting in the actual driving times more than the theoretical four driving times.

(3) It can be seen from the vibration amplitude curve of the rotor in the range of 100 r/min–2400 r/min measured by the two balance methods that the change rule of the vibration amplitude curve of test point 1 is similar, while the change rule of the vibration amplitude curve of test point 2 is poor. The reason may be related to the measurement error of test point 2.

(4) The influence coefficient method and the three circle balance method have little difference in the vibration reduction effect after the dynamic balance of the rotor. The maximum vibration reduction amplitude of the influence coefficient method appears before the balance speed, and the maximum vibration reduction amplitude of the three circle balance method appears at the balance speed. In the actual experiment process, the three circle balance method is relatively simple to operate and easy to process the data, but it requires high experience in the experiment operation. The data processing of the influence coefficient method is more complex and requires accurate measurement of the vibration phase, but the number of starts is less, so it is suitable for field dynamic balance.

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