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STUDY ON THE UNBALANCE OF MAGNETIC SUSPENDED ROTOR BASED ON HOLOSPECTRUM

Yefa HU, Huachun WU, Li WEI, Xiaoguang WANG
School of Mechanical Engineering, Wuhan Univ. of Technology, Wuhan, Hubei 430070 China
whcwhut@whut.edu.cn

ABSTRACT
Without extra equipment, the application of holospectrum technology in the control of magnetic suspended rotor can fully utilize vibration information of rotor system in all measuring sections, get the component of force imbalance and torque imbalance based on the theory of holospectrum decomposition, convert the compensation amount of imbalance to corresponding current and add to control current, finally solve the dynamic balance problem of high speed rotating of flexible magnetic suspended rotor, give an method of rotor imbalance compensation. Thus, the method is a promising technology in balancing practice in situ of rotating machinery.
KEY WORDS: Holospectrum, Flexible Magnetic Suspended Rotor, Unbalance.

INTRODUCTION

Magnetic suspended rotor (MSR) is a new, high technology advanced field product. With the advantages of frictionless, no wear, without lubricating, no pollution, low consuming and long life, it suits high and super high speed, vacuum condition and some of the special conditions. Presently it has been used in military, space stations, nuclear industry, energy, chemicals, transportation and other fields. As material uneven, machining precision, assembly error, and other aspects of factors exist in magnetic suspended rotor, the mass unbalance is always exist. Even in a very high precision machining rotor, the mass unbalance is unavoidable. The amplitude of the unbalanced exciting force is proportional to the square of the velocity, when the velocity is up to a certain extent, the amplitude of the unbalanced vibration would exceed the protection gap, rubbing will occur between the magnetic bearing's stator and rotor, making the system out of control. So, the unbalance research of the MSR appears to be especially important [1].

With the carrying out of deeper research on the MSR technology, its application is more and more extensive, the speed is much higher, and is generally flexible rotor. The pros and cons of the rotor's balance status is often the fatal factor that determines its use life and efficient operation. In many cases, the existence of unbalance is the factor that induces other failures, and once the ubalance is improved, some other fault will also disappear; this makes people improve the balance of the rotor system, seeking a better balance and a way to suppress the unbalanced vibration.

In the MSR system, there are generally two types of way to suppress the vibration imbalance: One is auto balance, this way makes the rotor revolve around the inertia spindle, and thus no reaction force of the same frequency with the rotate speed is passed to the foundation through the radial magnetic bearings. The other is imbalance compensation; this method makes the rotor revolve around the geometric axis, which can greatly improve the rotor's rotation accuracy. The adopted methods are mostly notch filters, adaptive forced balancing, gain scheduled H infinity robust control, sliding mode [2][3][4].

The above methods compensate for the MSR imbalance to a certain extent, and have achieved some results. But they did not use the magnetic suspended rotor's vibration information. Once the machining of the MSR is completed, uneven distribution is fixed in the corresponding control system, as long as the magnetic suspended rotor's imbalance distribution at this moment can be accurately measured, then impose an imbalance control force in the opposite direction, and achieve the imbalance compensation for the MSR. This paper inherits the original displacement, phase sensors in the MSR system, in the circumstance of no additional equipment, makes full use of the rotor's measured vibration of information in each aspect, get the force imbalance and couple uneven component with the Holospectrum technology, transform the imbalance compensation component into the corresponding current, and add them up to the control current, thereby achieve imbalance compensation for the flexible MSR, finally solve the dynamic balance problem when the flexible MSR rotate at a high speed, and on this basis put forward a way to compensate for the imbalance in the MSR.

PRINCIPLE OF HOLOSPECTRUM

Traditional method of Spectral analysis make the vibration signals separate in the amplitude and phase, but phase information is often overlooked. Secondly, the traditional method of spectrum analysis can not show the interrelationship between the rotor's vertical and horizontal vibration in one support cross-section, nor show the interrelationship among various support cross-sections. Actually the relationship between the rotor's vertical and horizontal vibration in the same support cross-section is close, only the interrelationship among various support cross-sections can reflect the rotor's actual vibration, therefore, by isolation analysis of a certain vibration, can't understand the whole vibration state of the rotor.

To solve the above problem, Prof. Liangsheng QU in Xi'an Jiaotong University firstly set up the Holospectrum in 1988, it fully integrated machinery vibration amplitude, frequency, and phase information, significantly increased the recognition rate of failure[5]. Holospectrum technology is the embodiment of multi sensor data fusion used in rotating machinery monitoring and diagnosis; it fuses the information provided by the sensors in the bearing's various cross-sections, on the basis of FFT algorithm, with a certain revise method, accurately obtain the vibration signal amplitude, frequency, phase value gathered by a free style, then integrate the vibration signal's amplitude, frequency, phase information in the rotor cross-section's horizontal and vertical direction, use a series of ellipse to characterize the rotor's vibration action under different frequency components. 2D,3D Holospectrum decomposition principle as shown in Figure 1.

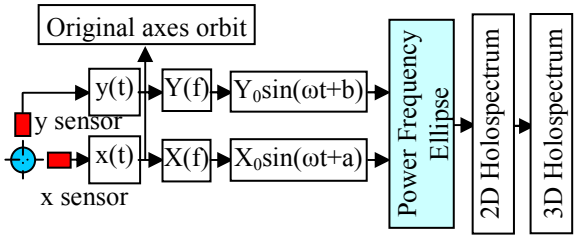


FIGURE 1: Holospectrum decomposition principl of single cross section

2D Holospectrum is the combination of axes orbit analysis and spectral analysis, namely, after the vibration in the x, y direction is spectrum analyzed respectively, then integrate the vibration in x, y direction under various frequency components. For only contain a single-frequency component, the axes orbit under various frequency components is a series of circle, ellipse, straight line, bias.

3D Holospectrum technology is developed on the basis of 2D Holospectrum technology. While analyzing the vibration of the rotor, hope to inspect the information in all the measurement surface as a whole, therefore, arrange the rotor's frequency ellipse in each measuring surface according to the space relative position, and join the corresponding point on the frequency ellipse according to the time order, then get the 3D Holospectrum, it can reflect the rotor's whole vibration status more profoundly.

Figure 2 is the 3D Holospectrum obtained by composing the data from the rotor's four measurement surface.

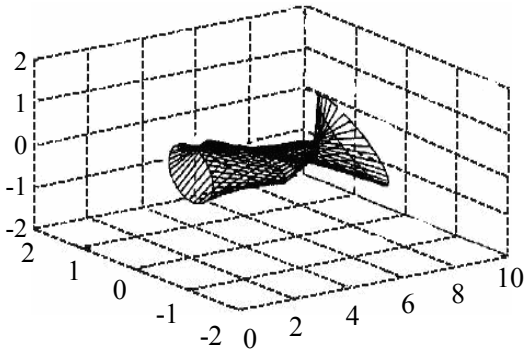


FIGURE 2: 3D Holospectrum with four measurement surface

3D Holospectrum information fuse method is firstly to make the displacement sensor signal transit DC isolation, filter processing, distill working frequency component through the FFT with interpolation revise algorithm, and compound the working frequency ellipse. Then, arrange the frequency ellipse of each section according to the space relative position, and join the corresponding point on the frequency ellipse according to the time order, so 3D Holospectrum is built.

COMPENSATION PRINCIPLE OF MSR UNBALANCE BASED ON HOLOSPECTRUM

Currently, the MSR system is equipped with eddy current displacement sensors to monitor the actual location of the rotor, usually at the front, back magnetic bearings are four radial displacement sensors installed vertical to each other, and an axial displacement sensor, the equipment as shown in Figure 3. Therefore, the MSR system has a precondition for Holospectrum application.

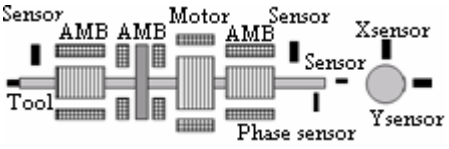


FIGURE 3: The diagram of unbalance compensation based on holospectrum

Known from the rotor dynamics model, the rotor's unbalance vibration is formed by piling up the vibration mould at each rank. As for those rotating machinery whose working speed is between the first and second critical speed, the rotor unbalance vibration is formed by a first rank vibration mould and a second, which the first vibration mould is caused by force unbalance, the second vibration mould is caused by couple unbalance. In order to carry out the rotor dynamic balancing effectively, we should try to separate the first vibration mould from the second vibration mould, and balance them respectively, which is vibration mould decomposition under the working speed. Traditional decomposition is gone with a one-direction (x or y) vibration; whereas with the use of 3D Holospectrum decomposition technology can more effectively separate the force unbalance from the coupling unbalance at the working speed, thereby enhancing the rotor balance accuracy.

3D Holospectrum correspondent to the unbalance is hyperboloid body, it can be decomposed into two separate parts. One is a column, corresponding to the static unbalance; the other is a cone, corresponding to couple unbalance. For the double bearing measuring surface model is shown in Figure 4.

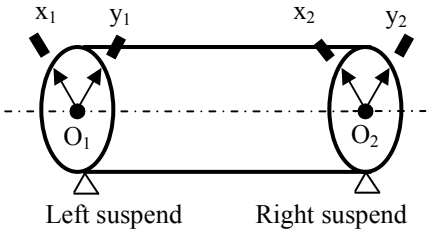


FIGURE 4: Dual support measuring surface model

Suppose the unbalance response at the bearing is caused by the unbalance force and couple, that the rotor frequency vibration's static force and couple component are r11, r12, the static force component and couple component at the right bearing are r21, r22, the specific situation are shown in Figure 5.

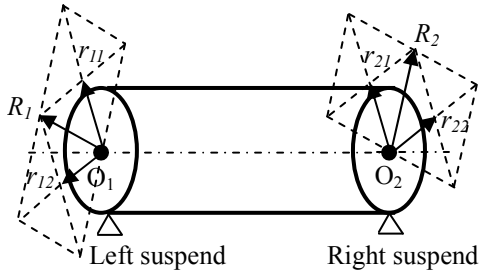


FIGURE 5: Force and couple component schematic diagram of power frequency vibration in rotor

Based on the basic assumptions of the uniform and symmetric MSR system, will get equation:

$$\begin{cases} r_{11} = r_{21} \\ r_{12} = -r_{22} \end{cases} \quad (1)$$

Suppose with the function of the unbalance force at both bearings in the rotor, the frequency vibration's displacements are of the same size and the same direction, according to the geometric principles of decomposition, the following relations can be established:

$$\begin{cases} r_{11} = \dfrac{R_1 + R_2}{2} \\ r_{12} = \dfrac{R_1 - R_2}{2} \\ r_{21} = \dfrac{R_1 + R_2}{2} \\ r_{22} = -\dfrac{R_1 - R_2}{2} \end{cases} \quad (2)$$

In this way, based on Holospectrum decomposition principle, theoretically decomposed the rotor frequency vibration displacement at both ends of the crew into two parts: the vibration displacement caused by force unbalance couple unbalance , and thus has got a new way to recognize the type of imbalance in the rotor.

Therefore, the 3D Holospectrum caused by static unbalance can be set up by r_{11}, r_{21}. The 3D Holospectrum caused by couple imbalance can be set up by r_{21}, r_{22}, so 3D Holospectrum has a unique advantage in distinguishing the imbalance type.

After dealing the vibration signal with amplification, hardware filtering, A/D conversion, it is sent into the computer, get the rotor's unbalance component with Holospectrum technology, thus find out the unbalance in the rotor, and provide guidance for making a scheme to reduce the impact of imbalance.

COMPENSATION METHOD FOR MSR IMBALANCE

Rotor unbalance vibration is of the same frequency as its speed, so, as long as we can accurately measure the unbalance distribution of the rotor, convert it into the corresponding unbalance current compensation, impose the unbalance current compensat ion to the magnetic bearing through the power amplifier, the magnetic bearing produce the corresponding unbalance control force, thereby can achieve flexible MSR unbalance compensation.

Whether the rotor is rigid or flexible, the vibrations caused by the force unbalance at both ends of the rotor

are of the same phase, the expression of the vibration is an oval cylinder; whereas in the case of the couple unbalance are the opposite, and the vibration response is an elliptic cone. According to 3D Holospectrum obtain the force and couple unbalance at the front and back magnetic bearings:

$$\begin{cases} F_{x_i}(\omega) = F_{x_i}\sin(\omega t + \alpha_1) \\ F_{y_i}(\omega) = F_{y_i}\sin(\omega t + \beta_1) \end{cases} ,\mathrm{i} = 1,2 \quad (3)$$

Where $F_{x1}(\omega)$, $F_{y1}(\omega)$ are the force imbalance in x, y direction; F_{x1}, F_{y1} are the amplitude of the force imbalance in in x, y direction; ω is the rotation frequency of the rotor; α1, β1 are the relative phase angle of the force imbalance to the original phase in x, y direction.

Using the advantage of the MSR system, according to formula (3) of the unbalance force, the actual needs of unbalance current compensation can be calculated by the relationship between the magnetic bearings force and the current:

$$\begin{cases} i_{xi} = \dfrac{K_{xi}x_{xi} - F_{xi}}{K_{ii}} \\ i_{yi} = \dfrac{K_{xi}x_{yi} - F_{yi}}{K_{ii}} \end{cases} \quad (4)$$

Where i_{xi}、i_{yi} (i=1,2) are the magnetic bearings' current unbalance compensation in x, y direction ; x_{xi}, y_{yi} are the actual excursion distance of the rotor's center of mass in x, y direction.

According to the above analysis, the MSR's unbalance compensation method based on the Holospectrum is available, as shown in Figure 6.

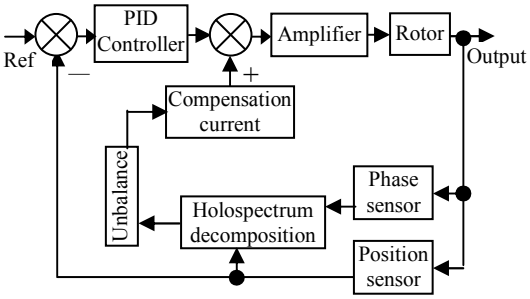


FIGURE 6: Unbalance compensation diagram based on Holospectrum

Seen from Figure 6, MSR imbalance compensation is realized by make the magnetic bearing add an electromagnetic force to the rotor, this forcr is equal to the size of the vibration imbalance but in the opposite direction, forcing it "balanced". Using Holospectrum decomposition technology can effectively decompose the imbalance force and couple in the rotor, in different speed, impose the corresponding imbalance current compensation on the magnet so that the rotor revolves around its geometric center, improve the rotation accuracy. The computer simulation results show that this method can achieve imbalance compensation for flexible MSR.

EXPERIMENT RESEARCH

The method in this paper has been verified by experiment on the constructed MSR system test (as shown in Figure 7). The basic parameters are as follows: Rotor quality of 4.875 kg, single magnetic pole area of front, back bearing respectively are 341mm^2, 286 mm^2, working gap 0.3mm, the protecting bearing clearance 0.15mm, coil turns of 384, bias current 1A . Amplifier is the self-designed half-bridge switching-amplifier, working voltage DC 150V, voltage and current conversion rate of 0.4A/V; displacement sensors are of eddy current type with the sensitivity of 5mV/μ m.

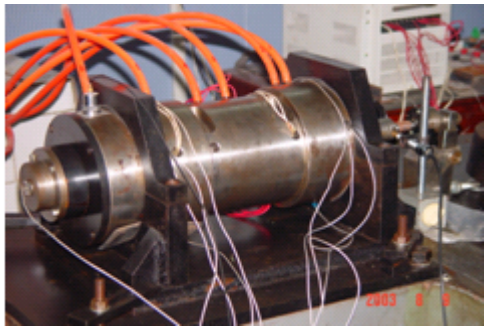
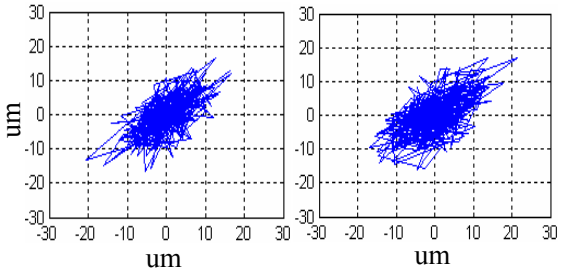


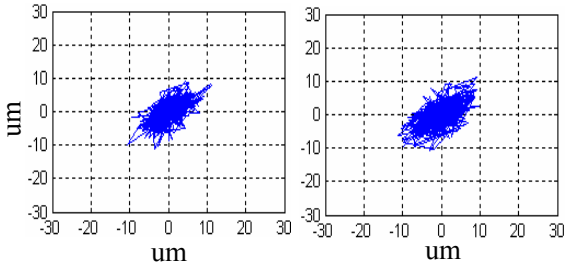
FIGURE 7: The equipment of magnetic suspended rotor

Unbalance response can be inhibited by correction signalwhich is added through power amplifier of front and back AMB. Figure 8 shows the front and back axes orbit of the MSR at the speed of 18000 rpm without imbalance compensation; Figure 9 shows the axes orbit of the front and back magnetic bearings after imbalance compensation, using the Holospectrum technology. Figure 8 (a) and Figure 9 (a) is axis orbit of front AMB, another is axis orbit of back AMB.



(a) Front AMB (b) Back AMB

FIGURE 8: Orbits of the rotor



(a) Front AMB (b) Back AMB

FIGURE 9: Orbits of the rotor

As is shown in Figure 8, 9, after the imbalance compensation is carried out, the axes orbit decreases, the MSR's vibration which is of the same frequency as the speed also has reduced, therefore makes great contribution for improving the rotation accuracy.

CONCLUSION

Apply Holospectrum theory in the study of MSR's imbalance, with no additional equipment, acquire more information about the MSR system, then decompose for the force imbalance and couple imbalance using Holospectrum decomposition technology, calculate the corresponding imbalance current compensation, impose it on the magnet through the amplifier, to make the rotor rotate around its geometric center. The experimentation results show that, this method is easy to be put into practice, can effectively reduce the imbalance vibration; it is of great significance in improving the rotation accuracy of the rotor.

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