

Research on Identification of the Crack on Rotor Shaft

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Abstract: In the present research the crack identification in rotor systems is proposed based on Holospectrum. The purpose of the research is to detect not only the crack location on a rotor shaft, but also the crack type and the angle between two cracks on a rotor shaft. 3D Holospectrum is introduced to detect crack location on the shaft, and the 2D Holospectrum to detect the crack type and angle between two cracks. The proposed technique was validated through numerical simulations on the rotor system with a two cracks.

1. Introduction

Fatigue cracks are a potential source of catastrophic failures in rotor systems. The research works on identification of crack in past few decades were reviewed by Sabnavis[1], Stoisser[2], and Sekhar[3]. However, the identification of crack type and the angle between two cracks were not attract enough attention until now. The types of crack on a rotating shaft reported in literatures were usually transverse, slant[4][5] and helicoidal[6]. Occasionally, there are multiple cracks [7][8] exist on a rotating shaft, moreover, various combinations of crack type, position and depth have the identification decidedly more complex. In brief, the crack type depends on the loads applied on rotors. Thus, the identification of crack type can provide company engineers with more useful information of operating for monitoring conditions and diagnosing faults of rotating machinery.

In order to identify the crack type and the angle between two cracks, Holospectrum put forward by Qu [9][10] is adopted. The main advantage of Holospectrum is that it can provide much more information about rotor vibration behaviour than ordinary spectra. As a result, the crack location can be identified by 3D Holospectrum, and the crack type and the angle between two cracks can be identified by the 2D Holospectrum at the location of the crack.

In the present research, take the advantage of Holospectrum in the ability of information fusion, the 2D and 3D Holospectrum were suggested to analyse the equivalent moments to identify the crack location, crack type and the angle between cracks. Finally, numerical verifications have been done to identify the two cracks in rotor systems.

2. Holospectrum

In this section, the principle of holospectral techniques, put forward by Qu, is introduced and the 2D and 3D Holospectrum calculated by equivalent moments in order to identify cracks on the rotor.

2.1 2D Holospectrum

The i^{th} frequency component of equivalent moments $M_{xi}^{(k)}$, $M_{yi}^{(k)}$ are as following:

$$\begin{aligned} M_{xi}^{(k)}(t) &= A_{xi}^{(k)} \sin(i\omega_1 t + \varphi_{xi}) \\ M_{yi}^{(k)}(t) &= A_{yi}^{(k)} \sin(i\omega_1 t + \varphi_{yi}) \end{aligned} \quad (1)$$

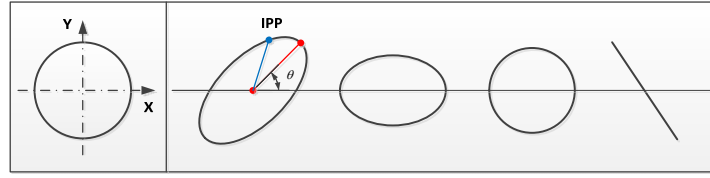


Fig. 1 The principle of 2D Holospectrum

The 2D Holospectrum combines the ordinary spectra of rotor vibration both in horizontal and in vertical direction on rotor measuring section as shown in

Fig. 1. In the paper, the equivalent moments in Equation (1) are used to combine the 2D Holospectrum in order to exhibit the behaviour of cracked rotor.

The IPP is defined as the point on the rotating frequency orbit at $t=0$, and the IPV corresponding to the moment when the mark groove (cut into the rotor shaft for phase measurement) is aligned to opposite the phase detector. As shown in

Fig. 1, the IPV is the vector pointing from the centre of the orbit to the IPP. The IPP of the i th frequency component is

$$IPP_i^{(k)} = \left(A_{xi}^{(k)} \sin(\varphi_{xi}), A_{yi}^{(k)} \sin(\varphi_{yi}) \right) \quad (2)$$

The inclination angle of the major axis of i th ellipse $\theta_i^{(k)}$ is as following. It can be seen from Equation (3) that $\theta_i^{(k)}$ depends on the phase lag of x, y signals.

$$\theta_i^{(k)} = \frac{1}{2} \arctan \left(\frac{2A_{xi}^{(k)} A_{yi}^{(k)} \cos(\varphi_{xi} - \varphi_{yi})}{(A_{xi}^{(k)})^2 - (A_{yi}^{(k)})^2} \right) \quad (i = 1, 2, \dots, n) \quad (3)$$

In the paper, the 1X ellipse in 2D Holospectrum are used to identify the crack type. As listed in Table 1, the 1X orbit can be a series of ellipse, circles or simply straight lines, so the $IPP_i^{(k)}$ and $\theta_i^{(k)}$ can demonstrate much more behaviour of cracked rotors.

Table 1 The type of 1X orbit

Type of orbits/ X, Y directions		Phase lag	Amplitude
Line		0° or 180°	Equal or not
Circle		90° or 270°	Equal
Ellipse	$\theta_1^{(k)} = 0$	90° or 270°	Not equal
	$\theta_1^{(k)} \neq 0$	Others	Equal or not equal

2.2 3D Holospectrum

The 3D Holospectrum is composed of i^{th} ellipses along all nodes of the shaft of rotor as shown in Fig. 2. 3D Holospectrum provide us the rotor vibration behaviour in all nodes as a whole, and the generating lines indicates the relative position of the rotor.

In the paper, the 1X 3D Holospectrum of equivalent bending moments is used, and the cross of the generating lines can identify the location of cracks.

As discussed above, the 1X 2D Holospectrum of equivalent bending moments present the information of the crack type. Also, 1X 3D Holospectrum composed by all 2D Holospectrum on all nodes of rotors can identify the location of cracks. The process of crack identification is shown in Fig. 3. The vibration signals on the rotors bearings are input at the beginning of the algorithm, and the location of crack and the information of crack are obtained from the algorithm.

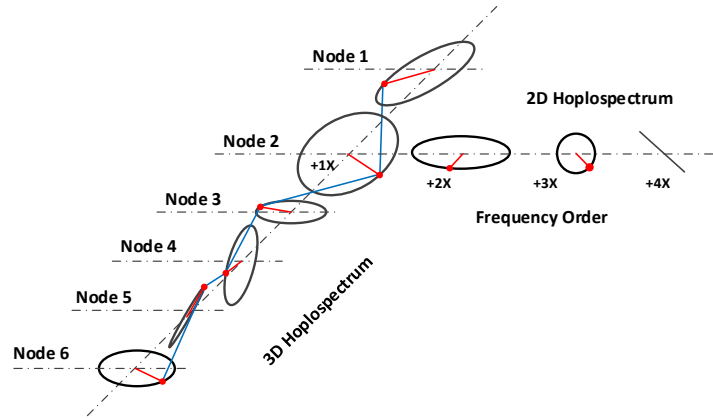


Fig. 2 Holospectrum of the first order component of the vibration (Six sections)

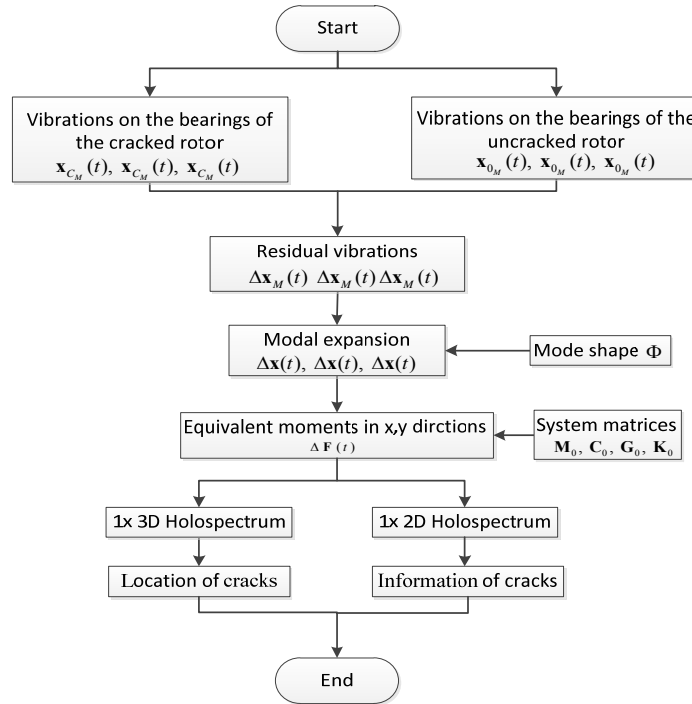


Fig. 3 Flowchart of the crack identification method based on Holospectrum

3. Results and Discussion

The proposed technique was validated through numerical simulations on the rotor system with a two cracks. The finite element model is used here as shown in Fig. 4. The rotor is divided into 14 elements. The disk is situated at the centre of the rotor. The values of the physical parameters are given in table2.

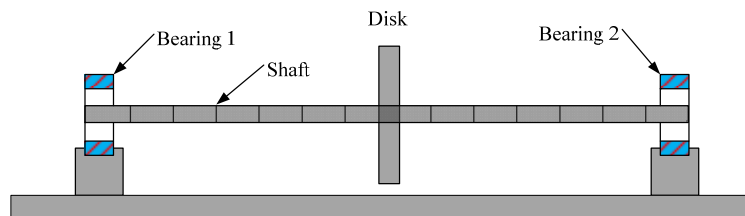


Fig. 4 The finite element model of a rotor bearing system

Table 2 Physical parameters of the cracked rotor system

Description	Value	Description	Value
Length of shaft	560mm	Disk radius	37mm
Radius of shaft	10mm	Disk width	25mm
Density of rotor	$7.85 \times 10^3 \text{ kg/m}^3$	Unbalance eccentricity	$1.65 \times 10^{-2} \text{ mm}$
Modulus of elasticity	$2.11 \times 10^5 \text{ MPa}$	Mass of disk	1kg
Poisson Ratio	0.3	Speed of the rotor	16Hz

Two cases are simulated to demonstrate the capability of the algorithm to identify crack locations, crack types, and the angle between cracks. In the beginning, the vibrations are considered at all the 90 DOF of the model, and this is considered as a reference case.

Case 1: One transverse crack in element 4 and one 45° slant crack in element 12.

Case 2: Two transverse cracks in element 4 and in element 12.

3.1 A transverse and a slant crack

We also can identify the crack locations from the 1X Holospectrum shown as Fig. 5. In Fig. 5, the equivalent moments are observed dominantly at element 4 and 12, and the generating lines of node 4, 5 (element 4) and node 12, 13 (element 12) cross and form intersections. That means the crack location can be identified by 3D Holospectrum. Furthermore, the cracks on the element 4 are be transverse according to the inclination angle of the major axis of 1X ellipse in 2D Holospectrum is zero degree, however, the cracks on the element 12 are be slant due to the he inclination angle of the major axis of 1X ellipse in 2D Holospectrum is not zero degree.

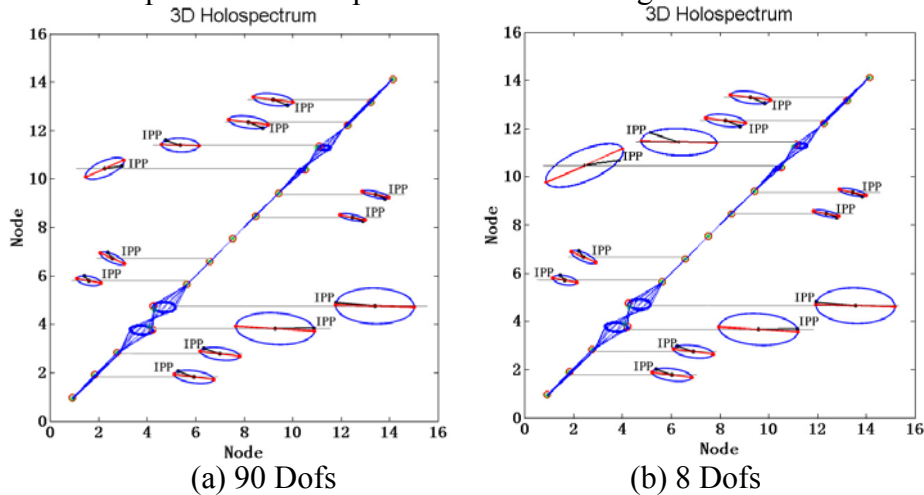


Fig. 5 1X Holospectrum of a transverse crack and a slant crack

3.2 Two transverse cracks

Next, simulations of a rotor with two transverse cracks have been done to validate the capability of identifying the crack type and the angle between two cracks on rotor shafts. The angle of one crack with respect to the other is 90° .

Fig. 6 illustrates the 1X Holospectrum of two transverse cracks. From the 3D Holospectrum, the cracks locate at element 4 and 12 by the amplitude of equivalent moments and the generating lines on cracked element. Simultaneously, from the 2D Holospectrum, the crack type are transverse for the inclination angle of the major axis of 1X ellipse of node 4,5 and 8,9 are zero degree. Furthermore, the angle of IPV of the node 4, 5 are zero but the angle of IPV of the node 12, 13 are nearly 90° , so the angle different of the IPV means the angle between two cracks.

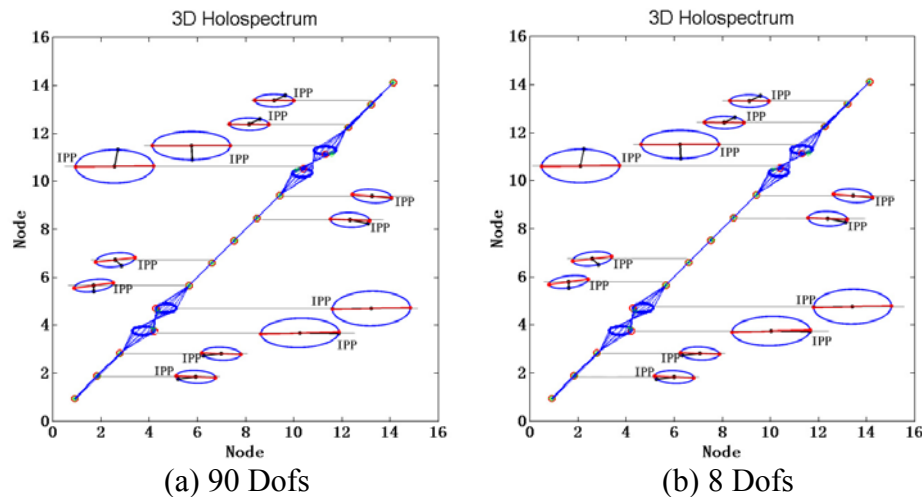


Fig. 6 1X Holospectrum of two transverse cracks

4. Conclusion

The crack identification approach based on Holospectrum is proposed to identify the crack in rotor systems. According to the approach, the identification of crack location depends on the amplitude of 3D Holospectrum and the crack type depends on the inclination angle of the major axis of 1X ellipse on the cracked element, and the angle between cracks depends on the different of IPV angle. Thus, the Holospectrum method can obtain more information about the crack, the present approach would allow for on-line crack identification effectively.

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