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Nonlinear Dynamic Behavior of Double-Disk Isotropic Rotor System with Axial Rub-Impact

Y. Zhang, W.M. Wang, J.F. Yao*

School of Mechanical and Electrical Engineering, Beijing University of Chemical Technology, Beijing 100029, P.R. China

yjf9818@126.com

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Abstract. In the case of considering the shear effect and gyroscopic effect, a finite element model is developed to study the nonlinear dynamic behavior of a double-disk isotropic rotor- bearing system with axial rub-impact in this paper. The influences of rotational speed and initial phase difference on the operation stability of the rotor-bearing system are discussed. It transpires that the response of the rotor system with axial rub- impact is mainly synchronous periodic motion. The vibration signals of axial rub-impact include such as the synchronous signal and the multiple frequencies, in which the synchronous signal is dominating signal. There is no weakening wave phenomenon in time wave plot. All the results are in reasonable good agreement with those observed in engineering. The results of this paper could provide certain reference for fault diagnosis and self-healing of large high-speed rotating machinery system, thus ensuring the safe operation of the system.

Introduction

With the development of the science and technology, rotating machinery is developing in the direction of high speed, overloading and complexity, which results in more and more questions. Rotor physical contact with stationary elements and the subsequent rubbing at the contact area is a serious malfunction in rotating machinery that may lead to the machine's catastrophic failure. Generally, there are two types of rubs, i.e., radial rub and axial rub. Up to now large amount of research work [1-4] about the dynamic behavior of rotor system with radial rub-impact has been done and great progresses have been made. But axial rub-impact problem scarcely investigated in the literature. In a few papers [5-8] on axial rub-impact problem spring-mass system and transverse freedoms are mainly considered.

Based on the finite element method and considering the shear effect and gyroscopic effect, the nonlinear dynamic behavior of a double-disk isotropic rotor-bearing system with axial rub-impact is discussed in this paper. The influences of rotational speed and initial phase difference on the dynamic response of rotor system are analyzed in detail. And the dynamic behaviors of the rotor system are represented in bifurcation diagrams, time wave plots, amplitude spectrums, shaft-center trajectories and Poincare section maps.

The dynamic model of rotor system with local axial rub impact

Consider a double-disk isotropic rotor-bearing system with only local axial rub-impact taking place only on the left disk as shown in Fig.1. The two disks have the same eccentric magnitude, *b*, diameter *D* and thickness *t*. The length and diameter of the shaft are l and D_z respectively. The rotational speed is denoted by w and δ_z is the axial clearance between rotor and stator. The action of the supporting bearing to rotor is simplified by means of stiffness and damping coefficients as a function of rotating speed, which obtained from numerical simulation by DyRoBeS BePerf®.

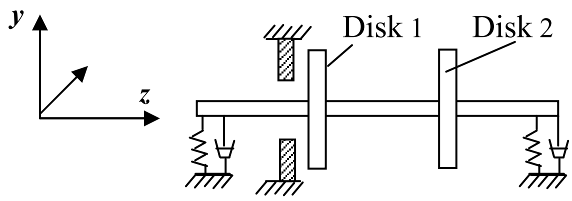


Fig. 1. The mechanic model of rotor system with axial rub-impact

Assuming that the disk1 has a pitching angle θ and axial displacement z_1 , the corresponding axial clearance between rotor and stator is $\delta_\theta = (\delta_z + z_1) - D\theta / 2$. The axial rub-impact between rotor and stator would take place when the δ_θ gets a negative value. The mechanic model of axial rub-impact is indicated in Fig.2, and the F_{zx}, F_{zy}, F_{zz}, M_{zx}, M_{zy} and M_{zz} are rub-impact caused forces and moments, respectively. According to the theoretical mechanics, the velocity components at rub position in x- and y- directions, v_x and v_y, are as Eq. (1).

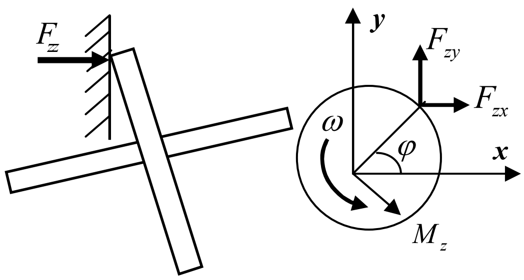


Fig. 2. The mechanic model of axial rub-impact

$$\begin{cases} v_x = \dot{x}_{o1} + D(\omega + \theta_z)\theta_x / 2\theta \\ v_y = \dot{y}_{o1} + D(\omega + \theta_z)\theta_y / 2\theta \end{cases} \tag{1}$$

where, θ_x, θ_y and θ_z denote the rotation angles of the cross-section around axis x ,y and z, respectively. Thus the forces and moments caused by axial rub-impact are stated as follows

$$\begin{cases} F_{zx} = fk_z\delta_\theta sign(v_x)\left|v_x / \sqrt{v_x^{\ 2} + v_y^{\ 2}}\right| \\ F_{zy} = fk_z\delta_\theta sign(v_y)\left|v_y / \sqrt{v_x^{\ 2} + v_y^{\ 2}}\right| \\ F_{zz} = k_z\delta_\theta \\ M_{zx} = -k_z\delta_\theta D\theta_x / 2\theta \\ M_{zy} = -k_z\delta_\theta D\theta_y / 2\theta \\ M_{zz} = F_{zx}D\theta_x / 2\theta + F_{zy}D\theta_y / 2\theta \end{cases} \tag{2}$$

where k_z the axial stiffness of stator and f is is the axial friction coefficient.

The FEM model of rotor system with axial rub-impact

By use of a beam element considering the shear effect and gyroscopic effect, the finite element model of a double-disk rotor-bearing system with axial rub-impact has been made, as shown in

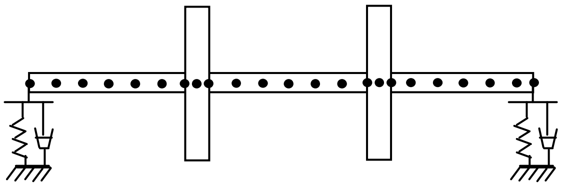


Fig. 3. The finite element model of rotor system

Fig.3. The model is composed of 22 elements and 23 nodes. Every node has 6 degrees of freedom-three translational and three rotational: x, y and z are the translation freedoms in x-, y- and z- directions, and θ_x, θ_y and θ_z denote the rotation angles of the cross-section around axes x-, y- and z-, respectively. The corresponding non-linear equations of this system are integrated in the time domain using the Newmark's implicit method. The equation of motion of the rotor system can be expressed as

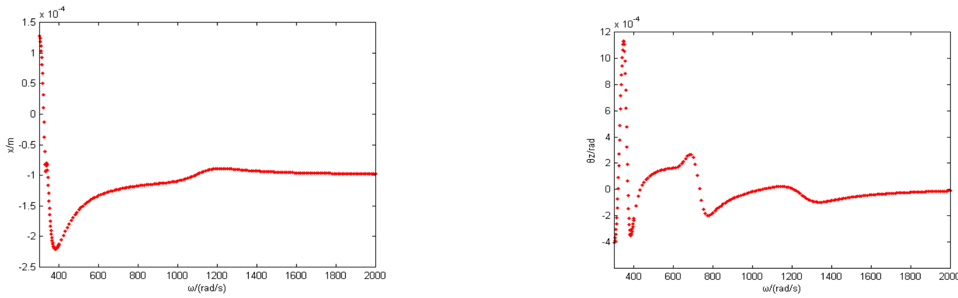
$$M\ddot{a}(t)+C\dot{a}(t)+Ka(t)=F(t) \tag{3}$$

where M, C, and K are the mass matrix, damping matrix and stiffness matrix, respectively. The damping matrix includes Rayleigh damping matrix and gyroscopic matrix. The load vector contains unbalanced forces, rub forces and gravity.

Numerical Calculation and Discussion of dynamic behavior of rotor system

There are b=0.1mm, D=300mm, t=50 mm, f=0.1, $k_z=45e6$ N/m and $\delta_z=1\mu m$. The length and diameter of the axial are 1000mm and 50mm, respectively.

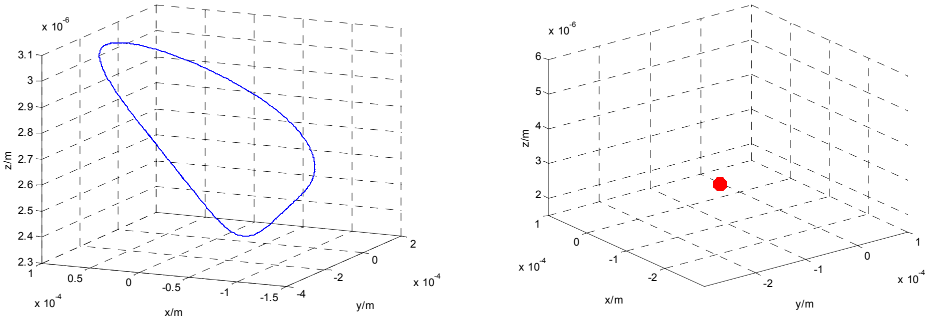
The influence of rotational speed. The numerical solutions for several different rotation speeds are shown in Figs 4-8 graphically when initial phase difference between two disks $\Delta\phi=0$ and. Figure 4 is the bifurcation diagrams of x-displacement and the rotation θ_z of the left disk. It can be seen that the response of the rotor system with axial rub-impact is mainly synchronous periodic motion,



(a) Bifurcation diagram of x-displacement (b) Bifurcation diagram of θ_z rotation angle

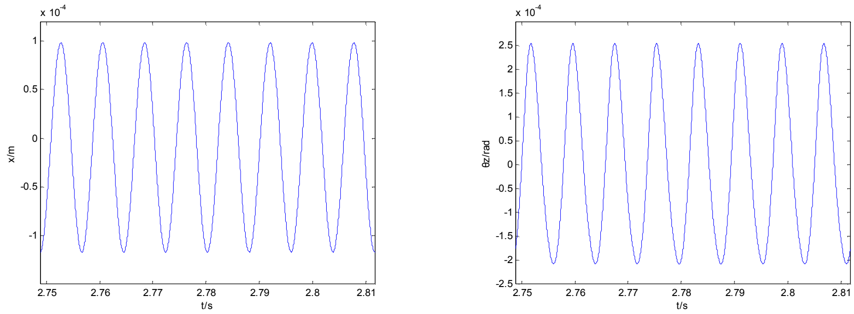
Fig. 4. Bifurcation diagrams versus rotational speed

which is distinctively different from that of rotor system with radial rub-impact. The results transpire that the response of the rotor system with axial rub- impact has better stability. For $w=800$ rad/s, Figs.5-6 show that the shaft-center trajectory at the left disk, Poincare section map, time wave plots and amplitude spectrums of the rotor system. There are the synchronous signal and the multiple frequencies in the amplitude spectrums of θ_z rotation angle, but only synchronous signal for x-displacement. There is no weakening wave phenomenon in time wave plot and the non-linear character of the rotor system with axial rub-impact is not distinctive. Fig.7 is the amplitude-speed curve which shows there exits a resonance peak value corresponding to first critical rotation speed 3247rpm. Fig.8 compares the x displacements of the system with and without considering axial rub-impact. It transpires that the amplitude of x displacement with axial rub-impact is a little bigger.

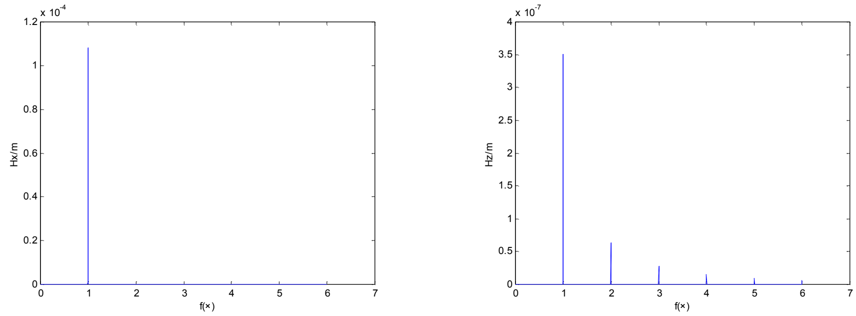


(a) Axle-center trajectory (b) Poincare section map

Fig. 5. Shaft-center trajectory and Poincare section map

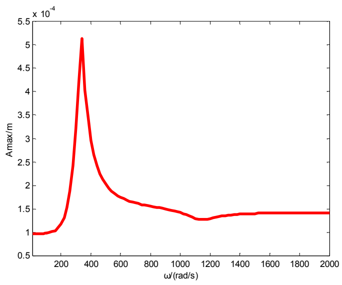


(a) Time wave plot of x-displacement (b) Time wave plot of θ_z rotation angle



(c) Amplitude spectrum of x-displacement (d) Amplitude spectrum of θ_z rotation angle

Fig. 6. Time wave plots and Amplitude spectrums



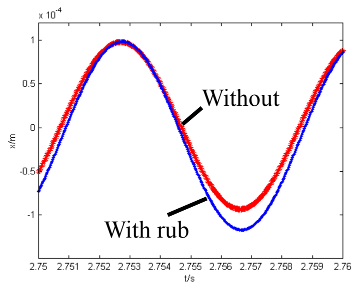


Fig. 7. Amplitude-speed curve Fig. 8. Comparison of x displacements

The influence of initial phase difference. The bifurcation diagram of the x-displacement for $w = 2000\text{rad/s}$ is shown in Fig.9 graphically. It is known that the system still keeps better stability for different initial phase difference.

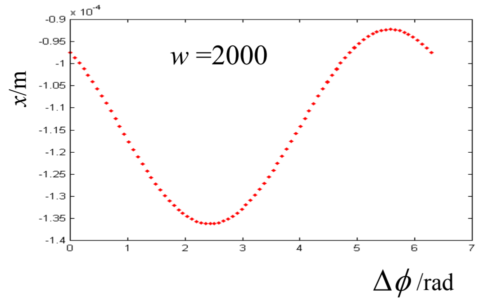


Fig. 9. Bifurcation diagram of x versus initial phase difference

Conclusions

Based on the finite element method and considering the shear effect and gyroscopic effect, the nonlinear dynamic behavior of a double-disk isotropic rotor-bearing system with axial rub-impact is investigated numerically in this paper. The effects of rotational speed and initial phase difference on the stability of rotor system are mainly discussed. It is indicated that vibration characteristics are similar with those of unbalance if only axial rub-impacting has been taken place. For Given parameters, the response of the rotor system with axial rub- impact is mainly synchronous periodic motion with the synchronous signal and the multiple frequencies, in which the synchronous signal is dominating signal. There is no weakening wave phenomenon in time wave plot. All the results transpire that the rotor system with axial rub-impact has better stability, which is in reasonable good agreement with those observed in engineering. Based on the mechanism study of rotor system with axial rub-impact, the fault type of rub-impact could be identified and controlled according to vibration characteristics of rotor system

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References

[1] Wen Bangchun，Wu Xinhua, Ding Qian etc. The theory and experiment of the nonlinear dynamic mechanics of rotating machinery, Beijing: Science press, 2004。

[2] Huang Wenhu, Xia Songbo, Jiao Yinghou etc.. The basic theory and method of the nonlinear dynamic mechanics design of rotating machinery, Beijing: Science press, 2004.

[3] Yu Lie, Liu Heng, Dynamic mechanics of rotor-bearing system, Xian: Xian Jiaotong University press, 2001.

[4] Li Chaofeng, Li XiaoFeng, Ma Hui etc., The nonlinear dynamic behavior of a rotor-bearing system with rub-impact by a continuous model,Journal of Vibration Engineering. 22(2009) 395-399.

[5] Ding Qian, Lateral Vibration of a Rotor/Bearing System with Axial Rubs,Journal of Mechanical Strength. 26(2004) 132-137.

[6] Zhenwei Yuan, Fulei Chu, Rujiang Hao, Simulation of rotor's axial rub-impact in full degrees of freedom, Mechanism and Machine Theory.42(2007)763-775.

[7] Xu Kejun, Qin Haiqin, Numerical Simulation Analysis For Rubbing Model of A Two-Disk Rotor-Stator System, Journal of Vibration and Shock. 26（2007）74-79.

[8] Xu Kejun, Qin Haiqin, Dynamic Model of Two Disk Rotor-Stator Rubbing Action, Journal of Vibration and Shock. 26（2007）17-21.