Critical Speed Analysis of Sliding Bearing Rotor System Based On ANSYS

Cheng Ming¹, Teng Xianbin¹*, Yang Qijiang¹, Pu songcheng¹, Wang yupeng¹, Lin yaodi¹, Zhou yachunyue¹

¹School of Marine Engineering, Guangzhou University of Navigation, Guangzhou 510725, China

*Corresponding author’s e-mail.tengxbin@gzmtu.edu.cn

Abstract: Sliding bearing rotor system plays an important role in rotating machinery, and its critical speed is a key index. In this paper, a sliding bearing rotor system is established, and the critical speed range is obtained by ANSYS Workbench software under different oil film stiffness, which provides guidance and basis for maintaining the stability of sliding bearing rotor system and avoiding resonance.

1. Introduction

In engineering, the rotating machinery can be simplified to the bearing rotor system, so the bearing rotor system is a crucial part of the mechanical system, has been widely concerned by the relevant experts and scholars. Rotating machinery is developing to high speed, and the critical speed greatly affects the stability of the rotating machinery. The sliding bearing studio will produce a fluid film on the surface, so as to avoid the direct contact between the bearing and the journal, avoid the friction heat generation and journal wear, and the oil film can also take away the heat generated.

The oil film can bear the pressure load, reduce the friction of machinery and reduce the vibration of machinery. Therefore, sliding bearings are generally used to support the rotating machinery in life and production. The dynamic performance of the rotating machinery supported by sliding bearings is affected by the non-linearity of bearing oil film and rotor system. When calculating, the sliding bearing is generally simplified as an isotropic spring [1]. Because the dynamic performance index of bearing and rotor is mutually restricted, so in the design of high-speed rotating machinery, bearing and rotor must be designed synchronously, which can not ignore the dynamic characteristics of bearing oil film [2]. Rotating machinery is usually close to or more than the first order critical speed range, the rotor system will appear nonlinear phenomenon, the rotor bearing system is affected by the unbalanced excitation force, near its critical speed will appear large vibration amplitude [3], and the bending degree of the shaft will significantly increase, if a long time in this working condition, the shaft will be seriously bent and deformed, or even broken.

The rotating machinery system is simplified to a software can be used for analysis of the 3D model of the rotor system in order to obtain a reasonable and effective critical speed of rotating machinery, became a research hotspot now, research on the basis of the critical speed, we need to make sure the system in the process of running properly deviate from the critical speed, so as to avoid damage to the equipment system resonance. Whether the rotor system can maintain stable operation under the required working conditions depends largely on the value and range of the critical speed of the nonlinear sliding bearing rotor system, so it is very important to accurately judge the critical speed of the nonlinear rotor system [4].
There are many factors affecting the size of the critical speed of the rotor bearing system, but because of its operation is very complicated, there are many factors are not taken into account, the movement of the calculation results are often not precise enough, therefore, how to make the calculated results and the practical operation of bearing rotor system closer and get more real operation is one of the key problems of current research. In this paper, the ANSYS finite element method is used to build the model which is closer to the actual model, and the calculation accuracy is higher, which is suitable for the calculation of dynamic characteristics of complex rotor system.

2. The establishment of finite element model
The finite element model of sliding bearing rotor is established by SolidWorks, as shown in Figure 1 below. The shaft material is structural steel with Young's modulus of 200GPa, Poisson's ratio $\mu = 0.3$, and density $\rho = 7850$ kg/m$^3$.

![Fig. 1 Finite element model of sliding bearing rotor](image)

3. Working principle of sliding bearing - rotor system
In the sliding bearing - rotor system, when the rotor just begins to rotate, the lower end of the journal and the bearing bush contact directly, there will be direct friction, but with the increase of the speed of the journal, because the lubricating oil has a certain viscosity, and attached to the surface of the shaft, with the journal to do circular motion.

With the circular motion of the journal, the lubricating oil moves circumferentially along the journal under the action of centrifugal force, so some lubricating oil will be thrown between the journal and the lower end face of the bearing bush. As the rotational speed of the journal increases, the centrifugal force on the oil becomes larger and larger, so that more oil is thrown between the journal and the lower end face of the bearing bush. Because of journal and bearing limit of end face is a wedge, so with the increase of oil, the gap between the oil pressure, thus supporting shaft neck, with direct friction between bearing separation to avoid the parts into the liquid friction, the friction between the two mechanical parts at this time quantity is almost zero, greatly reduce the wear between the journal and the bearing bush, prolong its working life.

The working principle of the sliding bearing-rotor system is shown in the following figure, where $n$ is the speed.

![Fig. 2 Working principle diagram of sliding bearing rotor system](image)

4. Dynamic calculation method of sliding bearing - rotor system
In the traditional rotor dynamics, the critical speed is mainly obtained by calculating the rotor bending
vibration. However, with the continuous improvement of mechanical accuracy, the accuracy of the critical speed is also improved correspondingly. The influence of bearings and oil film on the critical speed cannot be ignored. Therefore, it is necessary to take bearing and oil film into consideration to calculate the critical speed of the sliding bearing-rotor system.

In the classical calculation method of dynamics, the differential equation of dynamics is commonly used as follows:

\[
[M]\ddot{U} + [C]\dot{U} + [K]U = \{F\}
\]

(1)

Where \([M]\), \([C]\) and \([K]\) are mass, damping and stiffness matrices respectively, \(\{U\}\) and \(\{F\}\) are displacement vectors and power vectors. The mode shape of the system can be obtained by solving it. The dynamic characteristics of the sliding bearing-rotor system are analyzed by considering the rotating damping and gyro effect of the rotor, and the motion differential equation is obtained as follows:

\[
[M]\ddot{U} + ([C] + [G])\dot{U} + ([K] + [B])U = \{F\}
\]

(2)

The gyroscopic matrix \([G]\) and the rotational damping matrix \([B]\) are related to the rotation speed. When analyzing the unbalance response, the unbalance excitation can be substituted and the response value \(\{F\}\) can be obtained by solving the equation.

In the actual calculation process, the solution of the above equation is often very difficult and the amount of calculation is often very large due to the numerous factors considered. Therefore, in this paper, Solid Works software was used to create a three-dimensional model of the rotor, and then ANSYS Workbench finite element analysis software was imported to conduct modal analysis of the rotor, generate Campbell diagram, and obtain the critical rotor speed.

5. Critical speed analysis of sliding bearing - rotor system

5.1. Introduction and meshing of rotor 3D model

After the completion of SolidWorks modeling, the power shaft file was exported in the format of ".IGS". The power shaft file was imported into the Modal module of ANSYS Workbench, and body sizing was used to divide the grid with the minimum size of 10mm. The finite element model is shown in Figure 3 below.

![Fig. 3 Spindle meshing results](image)

5.2. Finite element software analysis of critical speed

After the grid is drawn, Add constraint "Fixed Support" on two sides of the bearing, and add constraint "Remote Displacement" at two places in contact with the bearing and constraint the Displacement in XYZ direction. KBXX = KBYY = 1 ×10^5, 2 ×10^5, 3 ×10^5 N/m, Set the damping to 0, open "Coriolis Effect" (gyro Effect)\(^{(5)}\) in "Analysis Settings", add the speed range of 2000-15000rad/s, insert "Campbell Diagrams" and handle it. The gyro effect will cause the vortex angular velocity of the rotor system to change as the rotation angular velocity changes, so that the rotor bending vibration is split into positive and negative precession modes. By using the Campbell diagram of the vortex angular velocity changing with the rotation velocity, the critical speed of the system is obtained \(^{(6)}\), and the Campbell diagram of the system is obtained and solved.

5.3. The solution results of the critical speed

The calculation results at different stiffness are shown in the figure below.
Tab. 1 The critical speed when the stiffness is $1 \times 10^5$

| Mode | Whirl Direction | Mode stability | Critical speed  |
|------|-----------------|----------------|----------------|
| 1.   | FW              | STABLE         | 4572.1 rad/s   |
| 2.   | BW              | STABLE         | 10525 rad/s    |
| 3.   | FW              | STABLE         | 11113 rad/s    |
| 4.   | FW              | STABLE         | NONE           |
| 5.   | BW              | STABLE         | NONE           |
| 6.   | FW              | STABLE         | NONE           |

Tab. 2 The critical speed when the stiffness is $2 \times 10^5$

| Mode | Whirl Direction | Mode stability | Critical speed  |
|------|-----------------|----------------|----------------|
| 1.   | FW              | STABLE         | 4740.7 rad/s   |
| 2.   | BW              | STABLE         | 10589 rad/s    |
| 3.   | FW              | STABLE         | 11193 rad/s    |
| 4.   | FW              | STABLE         | NONE           |
| 5.   | BW              | STABLE         | NONE           |
| 6.   | FW              | STABLE         | NONE           |

Tab. 2 Critical speed when rigidity is $3 \times 10^5$

| Mode | Whirl Direction | Mode stability | Critical speed  |
|------|-----------------|----------------|----------------|
| 1.   | FW              | STABLE         | 4883.4 rad/s   |
| 2.   | BW              | STABLE         | 10614 rad/s    |
| 3.   | FW              | STABLE         | 11225 rad/s    |
| 4.   | FW              | STABLE         | NONE           |
| 5.   | BW              | STABLE         | NONE           |
| 6.   | FW              | STABLE         | NONE           |
According to the above data, with the increase of oil film stiffness, the critical speed also increases. When the oil film stiffness is at the order of $10^5$, the first-order critical speed of the bearing rotor system is about 4500-5000rad/s, and there is little difference between the second-order critical speed and the third-order speed, which is about 10000rad/s/11500rpm. With the increase of oil film stiffness, the critical speed also increases gradually. The results of finite element calculation and high speed dynamic balance experiment meet the needs of practical engineering[7].

6. conclusion
In this paper, ANSYS Workbench software was used to analyze the critical speed of rotating machinery. Through analysis and calculation, the Campbell diagram of the rotor system and its critical speed were obtained, and it was verified that the oil film stiffness had a linear relationship with the critical speed within a certain range. The results of this paper can avoid the unnecessary resonance caused by the rotor system working at the critical speed, and a sliding bearing-rotor system is established. On this basis, the solution process of the critical speed of the sliding bearing-rotor system is described in detail, and the corresponding critical speed is obtained. When the oil film stiffness increases in a certain range, the corresponding critical speed also increases. Based on the design, calculation and simulation of a sliding bearing rotor test bed, the above results are obtained, which provide guidance and basis for the design of rotating machinery.

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