ISSN: 2637-6067
DOI: 10.6918/IJOSSER.202004_3(4).0012

Critical Speed Analysis of the Outer Rotor of WL-500 Centrifuge

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Abstract

The rotor system is an important structure of a centrifuge. The critical speed of the rotor is directly related to the balance of the rotor. In order to study the law of the critical speed of the rotor, a model of the external rotor of the WL-500 centrifuge was established, and the rotor structure was analyzed modally using ansys software to obtain the natural frequency and mode shape to avoid the working speed reaching the critical speed Resonance occurs. By changing the parameters of the rotor system, the influence of the parameters on the critical speed of the centrifuge rotor is studied, and the first and second order speeds of the centrifuge rotor are obtained under different parameters. Based on the obtained critical speed, the influence of external rotor parameters on its critical speed is analyzed. From the analysis data, it can be concluded that the critical speed of the first two stages of the outer rotor of the rotating drum has little effect. The increase of the support span will reduce the critical speed of the rotor. The increase of the aspect ratio will increase the first-order speed and then decrease The second-order critical speed decreases first and then changes little; the increase of the support stiffness will increase the first two-stage speed of the rotor, and the second-order critical speed will change significantly.

Keywords

Rotor; finite element; critical speed; parameters; modal analysis.

1. Introduction

In recent years, in order to improve the separation efficiency and throughput of decanter centrifuges more effectively, decanter centrifuges have become more and more trendy towards large-scale, high parameters, and large aspect ratios [1-2], but decanters Once the speed of the centrifuge is increased and the aspect ratio is also increased, the dynamic characteristics of its rotor will change greatly. The difficulties brought by these aspects make the design and manufacture of the centrifuge quite difficult. As the length-to-diameter ratio of the decanter centrifuge drum increases, the bending stiffness of the decanter drum and the spiral will be significantly reduced, so its critical speed may be very low, even lower than Its working speed, then at this time it is not appropriate to treat the drum and spiral of the decanter as a rigid rotor [3]. In the process of researching and manufacturing such large and high-speed centrifuges, they need to be modeled and calculated to understand the dynamic characteristics of their rotors.

2. Modeling of the Rotor System

The structure of the centrifuge is shown in Figure 1, and the separated centrifuge rotor system is shown in Figure 2. According to the research purpose and the criteria for establishing the rotor model, the outer rotor model is separated separately. In order to study the dynamic characteristics of the outer rotor, it is simplified.

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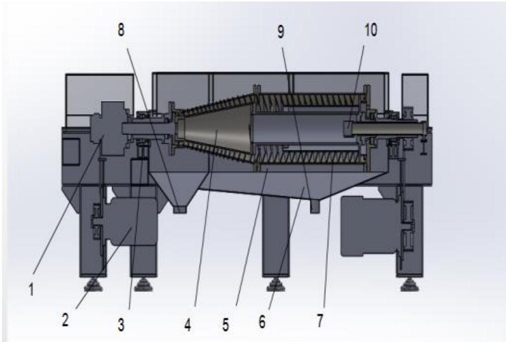

1 Differential 2 Speed governing motor
3 Bearing block 4 Cone rotor 5 Drum
6 Housing 7 Column rotor 8 Drain outlet
9 Drain outlet 10 Drain outlet

Figure 1. Schematic diagram of the centrifuge

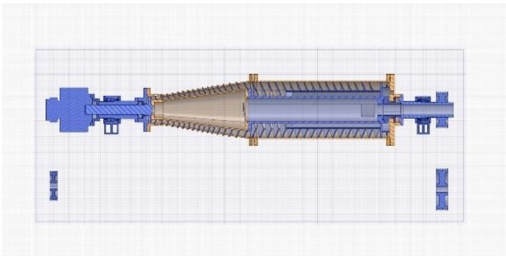

Figure 2. Schematic diagram of the rotor structure of the centrifuge

The first thing to ignore is the bolted connections between the parts. Think of these parts as a whole connected by bolts. Due to the complexity of the rotor system, when studying the outer rotor, the rotor system must be divided into three parts: shaft, disc and support [4-5]. In this paper, the bearing is simplified into a support, and the components supporting the conveying pipe in the blade and the screw conveyor are simplified into a disk. The model established is shown in Figure 3.

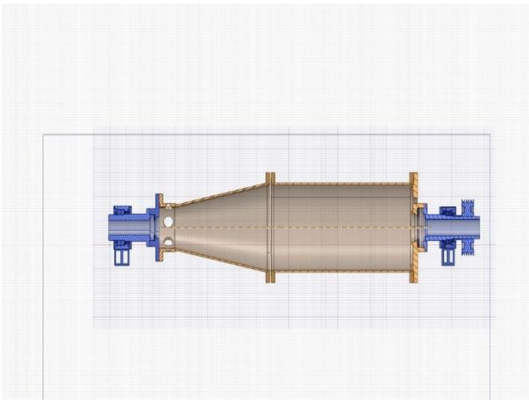

Figure 3. Simplified schematic diagram of the outer rotor structure

Pipe16 is a single-axis straight pipe unit. The advantage of this unit is that it has the functions of twisting, bending and tensioning. The Pipe16 element structure

is composed of two nodes, and the nodes are composed of 6 degrees of freedom, translation degrees of freedom along the X, Y, and Z directions of the nodes and rotation degrees of freedom

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around the node. The element is based on a three-dimensional beam element (BEAM4). There are many options for the element's real constant input, including the outer diameter and thickness of the tube. When performing rotor dynamics analysis, you only need to enter the external diameter (OD) of the section, the thickness of the tube (TKWALL), and the rotation speed (SPIN). Since only the lateral vibration of the rotor system needs to be considered in this paper, only the rotational freedom in the X direction and its displacement freedom are constrained [6]. For the main bearing, the conbin214 spring element is composed of two nodes, in which the degrees of freedom at one end must be constrained, and the node at the other end must be established on the shaft. The established finite element model is shown in Figure 4.

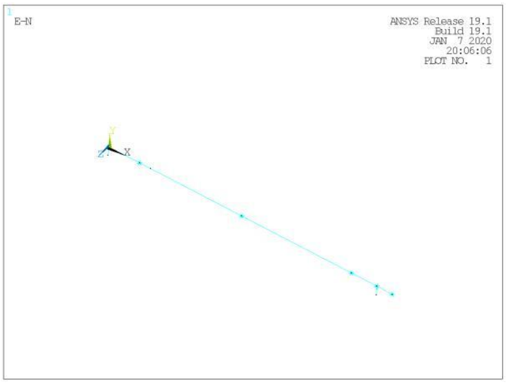

Figure 4. Finite element calculation model

3. Establishment of Boundary Conditions

3.1. Selection of Real Constants

3.1.1. Establishment of Material Parameters

Elastic Modulus $E = 2.06\times10^{11}\, N/m^3$

Poisson's ratio $\mu = 0.3$

Density $\rho = 7800\, kg/m^3$

3.1.2. Bearing Stiffness

Because the rigidity of the ball bearing itself is relatively large, and the damping is very small, when we input the real constant, we only need to consider the stiffness of the bearing, and we can ignore its damping. With reference to literature [7], we can get the formula for calculating the radial stiffness of ball bearings:

$$K = 32375\times0.00044^{1/2} Z D_b^{1/3} Q_\theta^{1/3} \cos^2\alpha$$

K is the radial stiffness of the ball bearing, N/mm; Z is the number of rolling individuals; D_b is the rolling element diameter, mm; α is the contact angle; Q_θ is the maximum load on the rolling element, N.

By calculation, the stiffness of the left and right bearings connecting the inner and outer rotors is:

$$K_{11} = 2.4\times10^8 (N/m)\ K_{12} = 2.9\times10^8 (N/m)$$

The stiffness of the bearing supporting the outer rotor is:

$$K_{21} = 3.5\times10^8 (N/m)$$

$$K_{22} = 4.7\times10^8 (N/m)$$

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3.2. Method for Extracting Modalities

In ansys, the modal analysis module can calculate the natural frequency and mode shape of a system. The gyro moment factor is involved. There are two methods for extracting the modal: one is the damping method, and the other is the QR damping method [8]. Because QR damping method is relatively simple to use and has high calculation accuracy, this method is used in this paper for calculation.

4. Results and Discussion

4.1. Critical Speed Analysis

The centrifuge is a large instrument with a dual rotor structure, and there is a certain differential speed between the inner and outer rotors, so the effect of the differential speed should be considered in the calculation. It is assumed that the rotation speed of the outer rotor is W1 and the rotation speed of the inner rotor is W2. The differential speed of the inner and outer rotor of the centrifuge is about 0.2 ~ 3%, so it is assumed that the relationship between the speed of the inner and outer rotor is W2 = W1 (1 + 1%). After calculation, the Campbel of the system is shown in Figure 5:

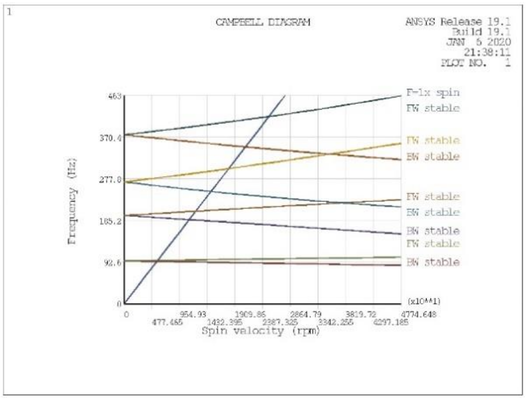

Figure 5. Campbel

It can be known from Figure 5 that the first and second-order speeds of the system are 5793 r/min and 12367 r/min, respectively. The operating speed of this type of centrifuge is 4000 r/min, which is much lower than its first-order speed, so it will not happen that resonance occurs. The first two modes of the system are shown in Figure 6 and Figure 7:

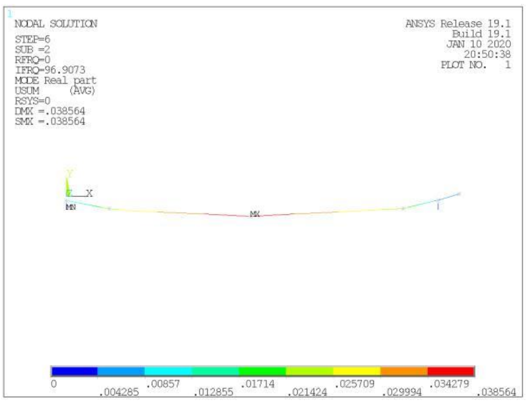

Fig 6. First-order mode shape diagram

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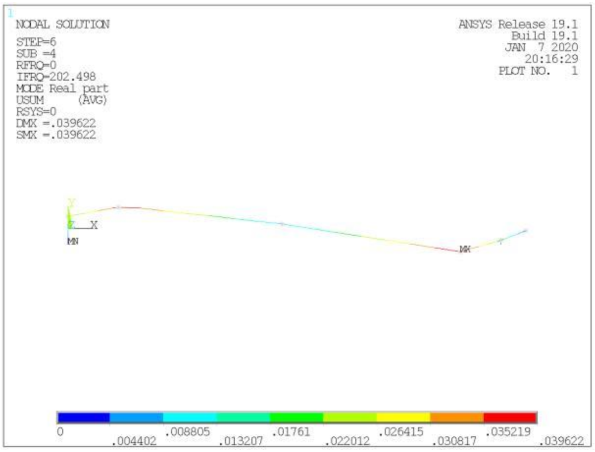

Fig 7. Second-order mode shapes

It can be seen from Fig. 6 that the first-order mode of the outer rotor is mainly manifested by the bending of the right end drum, and there is not much change in the rest. It can be seen from Fig. 7 that the second-order mode is mainly manifested by the left differential up, and the right end drum is bent to a certain extent. With reference to Fig. 5, it can be seen that, at the first-order critical speed, the influence of the rotor gyro torque is relatively obvious, and at the second-order critical speed, the influence of the differential gyro torque is relatively obvious.

4.2. Analysis of Critical Speed of External Rotor with Parameters

There are many influencing factors on the critical speed of the rotor, including the gyro torque of the rotor [9]; in addition, the critical speed of the rotor also has a certain effect on the rotor structure. This paper establishes the model through parameterization, because parametric modeling has parameters that are convenient to change the structure, which makes the research easier. The outer rotor model and its corresponding parameterized model are shown in Figure 8. This article mainly analyzes the influence of the following factors on its critical speed.

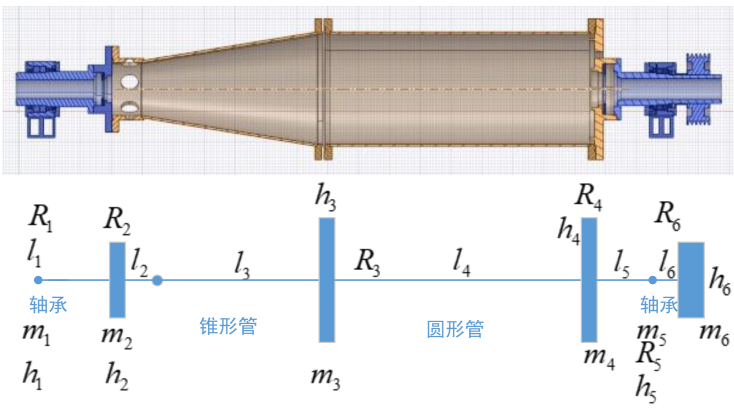

Figure 8. Parametric model of the outer rotor

4.2.1. Effect of Support Span on Critical Speed

The critical speed of the rotor has a certain relationship with the support span. This paper changes the distance between the two supports by changing the parameter of the distance between the two bearings in the parameterized model, and then keeps the other parameters unchanged. The effect of the first two critical speeds of the rotor. The influence of its supporting span on the critical speed of the rotor is shown in Figure 9:

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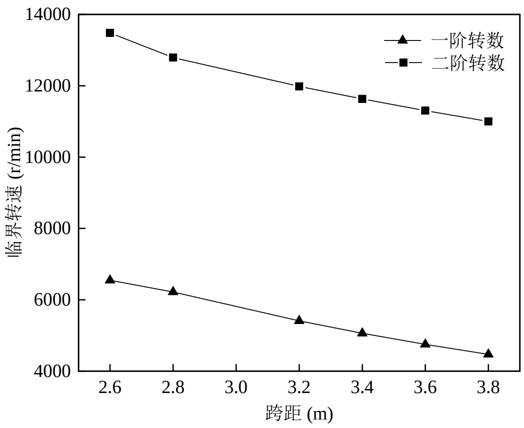

Figure 9. Effect of support span on the critical speed of the rotor

It can be seen from Fig. 9 that the first-order and second-order critical speeds of the rotor decrease as the support span increases. However, it can be seen from the data analysis that whether the first-order critical speed or the second-order critical speed decreases with the increase of the support span, it can be concluded that the effect of the support span on the critical speed of the rotor larger.

4.2.2. Effect of Drum Wall Thickness on Critical Speed

The critical speed of the rotor also has a certain relationship with the drum wall thickness [10]. Firstly, a parametric model of the rotor is established. In the established parametric model, the wall thickness of the model is changed by changing the wall thickness parameters in it, and other parameters are maintained. The effect of the critical speed is shown in Figure 10:

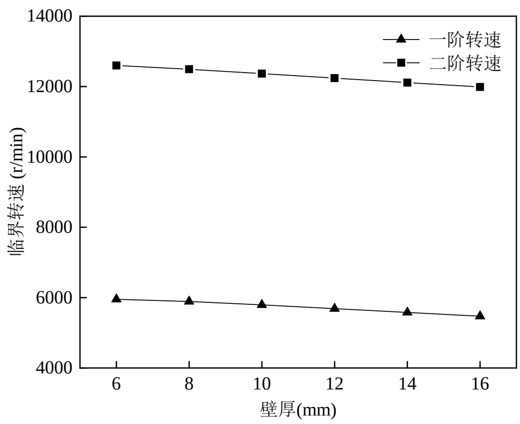

Figure 10. Effect of wall thickness on critical speed

It can be seen from Fig. 10 that as the drum wall thickness increases, the first-order and second-order critical speeds thereof gradually decrease. However, it can be seen from the data analysis that the first- and second-order critical speeds do not decrease significantly with increasing wall thickness. From this, it can be concluded that the wall thickness of the rotating drum does not greatly affect the critical speed.

4.2.3. Effect of Aspect Ratio on Critical Speed

With the increase of the aspect ratio, without changing other parameters, the effect of the first two critical speeds of the outer rotor is shown in Figure 11:

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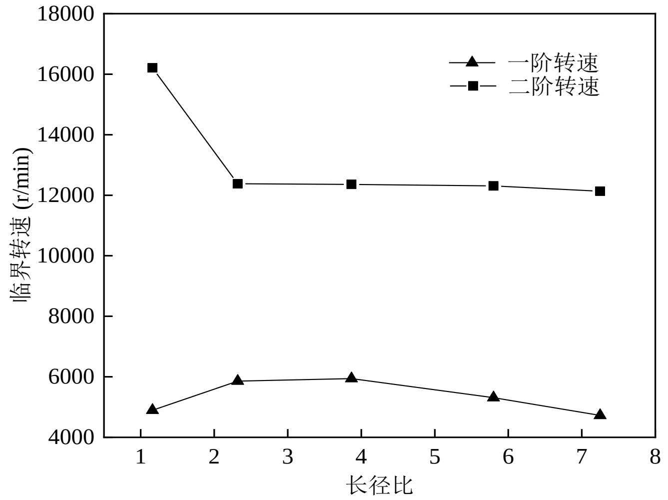

Figure 11. Effect of aspect ratio on critical speed

As can be seen from Figure 11, with the increase of the aspect ratio, the first-order critical speed of the first-order critical speed increases first and then decreases, mainly realized as the aspect ratio of about 1 to 3, the critical speed appears to increase, when After the aspect ratio is greater than 3, the first-order critical speed will slowly decrease. For the second-order critical speed, the trend decreases first and then does not change. It is mainly realized that the aspect ratio is between 1 and 2.5. The second-order critical speed shows a rapid decline. As the aspect ratio increases, its The second-order critical speed does not change much.

4.2.4. Effect of Support Stiffness on Critical Speed

It can be known from [11] that bearing stiffness has a significant effect on the critical speed of the rotor system. This article establishes a model through parameterization. By changing the parameters in the model, the left bearing stiffness, the right bearing stiffness, and both bearing stiffness are changed to analyze the influence of the support stiffness on the first two-stage critical speed of the outer rotor. As shown in Figures 13 and 14:

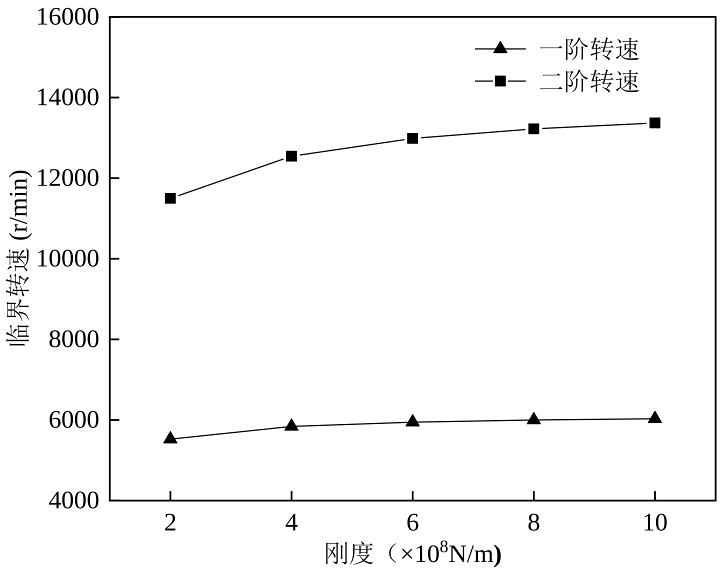

Fig 12. Effect of stiffness of left bearing on critical speed

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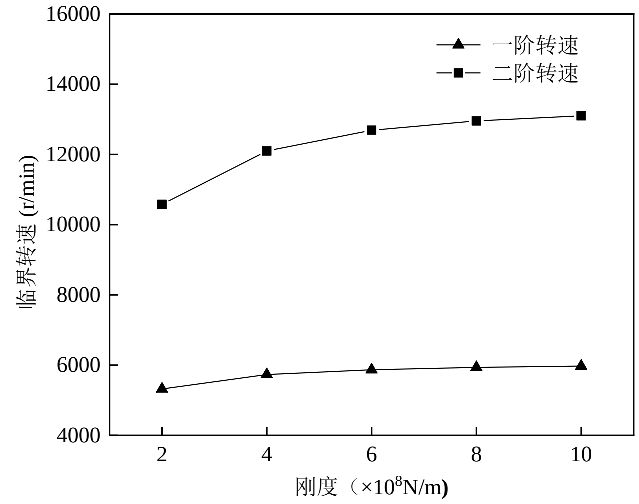

Figure 13. Effect of stiffness of right bearing on critical speed

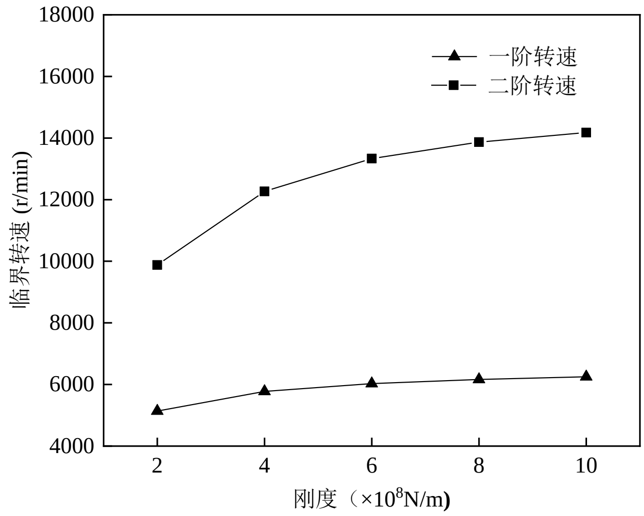

Figure 14. Effect of stiffness of left and right bearings on critical speed

As can be seen from Fig. 12, when the stiffness of the left bearing is changed and the stiffness of the right bearing is maintained, the first-order critical speed and second-order critical speed of the outer rotor both increase with the increase of the left bearing stiffness. Small, while the increase of the second-order critical speed is relatively obvious. It can be seen from Fig. 3 that when the stiffness of the right bearing is changed and the stiffness of the left bearing is maintained, the first and second critical speeds of the outer rotor both increase with the increase of the stiffness of the right bearing. The relative increase in first-order critical speed is relatively large. As can be seen from Figure 14, when the stiffness of the left and right bearings is changed at the same time, the first and second critical speeds of the outer rotor also increase with the increase of the bearing stiffness. The increase in the first critical speed is relatively small and the second critical The speed increase is large. From the above three figures, it can be seen that whether the stiffness of the left bearing, the stiffness of the right bearing, or the stiffness of both bearings is changed at the same time, the first and second critical speeds of the rotor will increase as the stiffness increases. Among them, the increase of bearing stiffness has a greater impact on the second-order critical speed.

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5. Conclusion

In this paper, the external rotor of WL-500 centrifuge is parametrically modeled, and its first two-stage critical speeds are calculated and analyzed. By changing the structural parameters, the influence of the first two-stage critical speed of the outer rotor is analyzed, and the conclusion is as follows:

(1) The first-order mode shape of the outer rotor is mainly the bending of the drum, while the second-order mode is mainly the uplift of the left differential.

(2) The effect of the wall thickness of the rotating drum on the critical speed of the rotor is not significant; as the support span increases, the critical speed of the rotor will decrease significantly; and for the effect of the aspect ratio, the first-order speed will increase first. It decreases after large, but the second-order speed appears to decrease first and then changes little; as the support stiffness increases, the second-order speed of the rotor increases more significantly, while the first-order critical speed increases only slightly.

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