

# A Dynamic Analysis of the Rotary Cutting System of King Grass Shredder

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**Abstract:** With the rotary cutting system of king grass shredder as the research object, this paper established finite element models for rotating shaft, rotating shaft-belt pulley, rotating shaft-rotary cutting part and rotary cutting system and analyzed the influences of belt pulley and rotary cutting part on the dynamic characteristics of rotary cutting system. The results showed that the belt pulley and rotary cutting part had a great influence on the second order critical speed of rotary cutting system, and the rotary cutting part had a greater influence on the critical speed of first order forward precession than the belt pulley. Meanwhile, the critical speed of rotary cutting system that conformed to facts was calculated. There was a big difference between its first order and second order critical speeds, but the critical speed of first order backward precession was lower. Finally, it was found after analysis that the natural frequency of rotary cutting system was lower than the vibration frequency induced by belt drive, so the shredder can run safely.

## 1 Introduction

The speed of shredder, as a widely-used material shredding machine, directly influences its shredding efficiency, and the rotating speed is exactly an important indicator of the efficiency of shredder [1-2]. Generally speaking, the higher rotating speed, the better working state a shredder has. If the rotating speed exceeds the critical speed, the machine will vibrate and make noise. In severe cases, the safe operation of the equipment will be affected [3-4]. This shows that critical speed is a very important parameter in the design process of rotary machinery. The rotary cutting system is a key working part of shredder, and its critical speed plays an important role in the operating performance of shredder [5-6]. In this paper, the dynamic characteristics of rotary cutting system of king grass shredder were analyzed, and the calculation and analysis results were of great reference value for the dynamic design of the king grass shredder.

## 2 Establishing a Finite Element Motion Equation for the Rotary Cutting System

With nodal displacement as the unknown quantity, an ordinary differential equation for rotor system was established. The motion differential equation was as follows:

$$[M]\{\ddot{U}\} \pm \omega[J]\{\dot{U}\} + [K][U] = \{Q\} \quad (1)$$

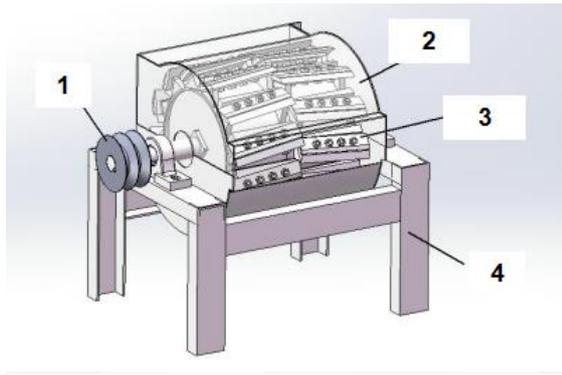
Where  $[M]$  was the mass matrix that took movement inertia and rotational inertia into account,  $\omega[J]$  was the

rotational inertia matrix,  $\omega$  was the angular velocity of rotation,  $[K]$  was the stiffness matrix, and  $\{Q\}$  was the generalized force.

## 3 Establishing a Finite Element Model for the Rotary Cutting System

In this paper, the rotary cutting system of king grass shredder was modeled using SolidWorks software and the following assumptions were made: 1) the contact between various parts was binding contact; 2) the effect of damping when the bearing supported was ignored; 3) the motion of the rotary cutting part relative to the rotary shaft was not considered. The rotary cutting system was simplified as follows: 1) the thread, chamfer, fillet and keyway in the model were removed; 2) the parts contained in the rotary cutting system were divided into three entities: rotating shaft, rotary cutting part and belt pulley; 3) it was assumed that the support stiffness of the bearings of rotating shaft part was all  $1 \times 10^7 \text{N/m}$ . The parameters of rotary cutting part material were elastic modulus  $E=2.06 \times 10^{11} \text{N/m}^2$ , the Poisson's ratio  $\nu=0.304$ , and the density  $\rho=7850 \text{kg/m}^3$ . Based on the above data, finite element models were established for rotary cutting system, rotating shaft, rotating shaft-belt pulley, rotating shaft-rotary cutting part and rotary cutting system, in order to lay a foundation for the subsequent analysis of dynamic characteristics.

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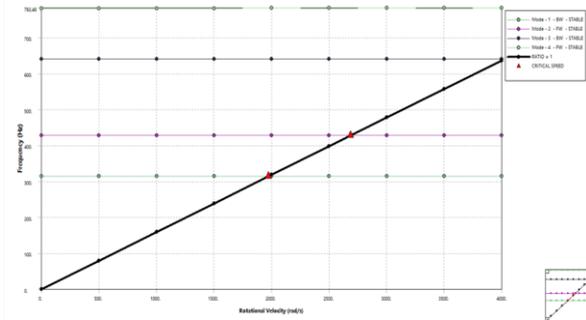


**Fig. 1:** Schematic of Shredder Assembly

Note: 1. Belt pulley; 2. protective cover; 3. rotary cutting part; 4. Stand

#### 4 Calculating the Critical Speed of the Rotating Shaft

Fig.2 is the Campbell chart of the rotating shaft. The critical speeds and natural frequencies calculated are shown in Tab. 1. The first order and second order critical speeds were high. The gyroscopic effect had little influence on the critical speed and can be ignored.

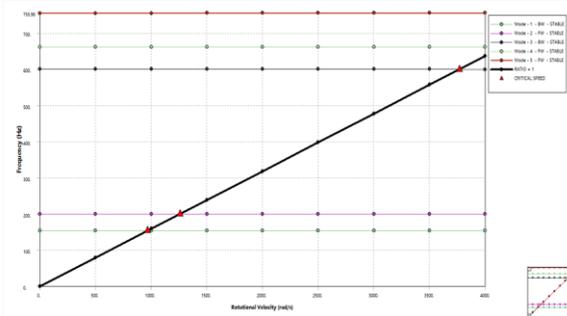


**Fig. 2** Campbell Chart of the Rotor System of the Rotating Shaft

**Tab. 1** Analysis Results of Four Models

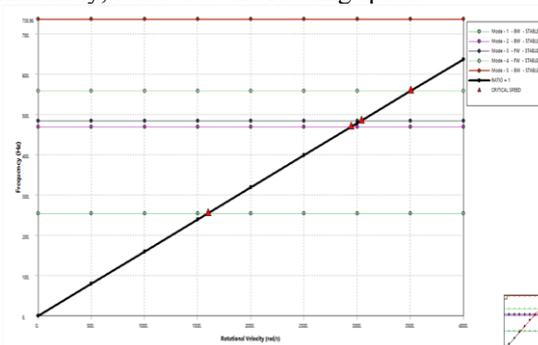
Model	Natural Frequency/Hz		Critical Speed/rad/s			
	First Order	Second Order	First Order Backward Precession	First Order Forward Precession	Second Order Backward Precession	Second Order Forward Precession
Rotating Shaft	316.67	430.3	1985.35	1999.83	2716.3	2721.8
Rotating Shaft-Belt Pulley	165.4	203.8	989.4	998.6	1249.5	1253.5
Rotating Shaft-Rotary Cutting Part	258.3	462.7	1623.1	1625.3	2903.8	2915.6
Rotary Cutting System	246.1	276.4	1553.6	1558.5	1683.8	1672.5

The critical speeds and natural frequencies calculated are shown in Tab. 1. The belt pulley had a great influence on the critical speed of rotor system, the critical speed of first order backward precession dropped to 989.4r/min, the critical speed of first order forward precession dropped to 998.6r/min, and the changes in the critical speeds of second order forward and backward precessions didn't differ a lot from the changes in the critical speeds of first order forward and backward precessions.



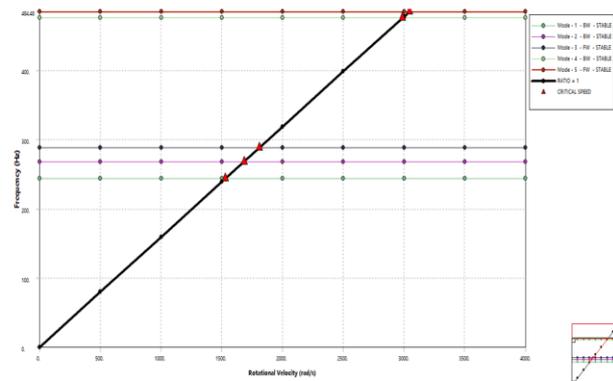
**Fig. 3** Campbell Chart of the Rotor System of the Rotating Shaft-Belt Pulley

Fig. 4 is the Campbell chart used to calculate the critical speed of the belt pulley-rotating shaft rotor system. The critical speeds and natural frequencies calculated are shown in Tab. 1. From Tab. 1 and Fig. 7, it can be seen that the rotary cutting part also had a great influence on the critical speed of the rotating shaft. It had a relatively great impact on the critical speeds of first order forward and backward precessions, but an even greater impact on second order critical speed. The second order critical speed of rotor system dropped very significantly, relative to the rotating speed.



**Fig. 4** Campbell Chart of the Rotor System of the Rotating Shaft-Belt Pulley

It can be seen from Fig. 5 and Tab. 1 that there was a big difference between the critical speeds of first and second order forward precessions of the rotary cutting system. And the critical speed of first order backward precession was lower, at 1553.6r/min.



**Fig. 5** Campbell Chart of the Rotor System of the Rotating Shaft-Belt Pulley

The design working speed of the rotating shaft part was 1800r/min, and the vibration frequency induced by belt drive can be calculated by the following formula:

$$f = n \times \frac{\pi d n r}{60L} \quad (2)$$

Where  $f$  was the vibration frequency (Hz) induced by belt drive;  $n$  was the multiple of belt drive frequency, which was an integer;  $d$  was the diameter (m) of the belt pulley;  $n r$  was the rotating speed of the belt pulley (r/min) and  $L$  was the perimeter (m) of the belt. Generally speaking, the value of  $n$  was the number of belts. For v-belt drive, the number of belts normally wouldn't be greater than 8. Here, it was assumed that  $n=3$ ,  $n r=2830$ r/min,  $d=0.273$ m,  $L=1.954$ m. They were substituted into the equation and it was found though calculation that  $f=62.08$ Hz, which was far lower than the natural frequency of the lowest order in the above two cases, so there was no resonance.

## 5 Conclusion

Both belt pulley and rotary cutting part have an influence on the critical speeds of all orders of the rotor, and with the increase of the number of parts and components, the overall stiffness of structure decreases and the critical speed drops. The influence of the belt pulley on the critical speeds of first order forward and backward precessions of the rotor system is slightly greater than that of rotary cutting part. And the influence of the rotary cutting part on the critical speeds of second order forward and backward precessions of the rotor system is greater than that of belt pulley.

In these four cases, the natural frequency the rotating shaft is the highest, while the natural frequency of rotary cutting system is the lowest, which indicates that the stiffness of rotating shaft is greater than that of the other three cases. In these four cases, the natural frequency of

the rotor system of rotating shaft is the highest, while the natural frequency of rotating shaft-belt pulley is the lowest.

The vibration frequency induced by belt pulley is far away from the first order critical speed in these four cases, so no resonance will be produced, and the shredder can run safely.

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