Original Research Article

Design Optimization of Hammer Blade Crusher to Improve the Crushing Performance

ABSTRACT

China is a large agricultural country, each year will produce a large number of straw. The recycling of straw to China's agricultural development and environmental protection are very helpful, the recycling of straw is mainly energy, fertilizer, feed several uses, different uses need different crushing fineness, so adjust the crushing fineness can improve the recycling rate of straw. This paper mainly on the impact of straw crushing fineness factors for This paper focuses on the theoretical analysis and study of the factors affecting the fineness of straw crushing, and provides a general design plan for the crushing chamber.Firstly, the effect of different hammer and sieve gaps on the pulverisation fineness is studied and the straw pulverisation fineness is changed by changing the hammer and sieve gaps. The effect of hammer blade material, structure, arrangement, distribution density and hammer blade speed on the fineness of the straw is studied. Study the effect of the aperture size and arrangement of the sieve on the fineness of the crushing, and adjust the fineness of the crushing by changing the aperture size of the sieve. The study of the material in the crushing process generated by the "ring flow layer" mechanism, and by changing the shape of the crushing chamber structure to destroy the "ring flow layer" on the impact of the crushing performance of the crusher.Secondly, according to the production requirements of the hammer mill, the structure and material of the hammer blade and screen plate are designed and selected, and the hammer blade is analysed statically using Ansys, the rotor is analysed modally, a complete model of the crushing chamber is designed, and a three-dimensional model of the crushing chamber is built using SolidWorks.Finally, after simulation calculations, the design of the rotor headquarters structure is reasonable. An adjustable hammer and sieve clearance was achieved, reducing costs and improving the efficiency of the pulveriser crushing.

Keywords: Hammer Blade Pulverizer, Crushing fineness, Sieve plate, Hammer piece.

1. INTRODUCTION

China is a large agricultural country, straw resources are very rich, but a large number of straw resources recovery, storage, transportation is very inconvenient, so the utilization rate is very low, and a large number of farmers use open burning, not only to cause great pollution to the environment, and the chemical substances produced after burning will cause harm to the soil. But straw stays on the farm and will bring inconvenience to farming, so the study of straw crusher can not only help farmers convenient and efficient to complete the straw crushing, but also improve environmental pollution, while can greatly improve the recycling rate, the development of China's agriculture has a very important role to play.

The treatment and recycling of straw is an important factor affecting the development of society. China now has the following main areas for the recycling of straw, straw feed, energy, fertilizer, etc. Most of the fields need to crush and treat the straw before it can be used. Different fields need different straw-crushing fineness[1], but China's existing straw-crushing devices and technology can not meet the needs of each field, so the study of corn straw-crushing fineness can improve the recycling rate of straw, to meet the needs of different fields of straw recycling, and then promote the rapid development of China's agriculture.

The study of straw crushing fineness can improve the economic and social benefits of our country, improve the recycling rate of straw, meet the requirements of different areas of straw fineness, after crushing, can be widely used as livestock feed, pellet feed, silage, paper making, etc. It reduces the pollution caused by straw burning and promotes the rapid development of our agriculture.

2. FACTORS INFLUENCING THE FINENESS OF CRUSHING

There are four ways of hammer blade distribution, spiral, symmetrical, staggered balance, and staggered symmetry, of which the symmetrical arrangement is the most widely used, he is characterized by repeated motion trajectory, symmetrical pin centrifugal force, combined force line of action coincides and equal size, mutual balance, better crushing effect [2]. Check the relevant experiments that can be obtained [3], the more the number of hammers crush the finer the particle size. However, if the number of hammer blades is too much, the unevenness of the crushed particle size increases, so we need to choose the right number of hammer blades to crush. The greater the speed of the hammer blade, the greater the striking effect on the corn stover, and the smaller the size of the crushed straw. However, as the hammer blade speed increases, it will reduce the efficiency of the material out of the screen. Therefore, choose the appropriate hammer speed, and change the material crushing fineness while reducing the impact on the sieving efficiency. Checking the relevant literature, it can be seen that for corn straw, the best crushing fineness of the hammer blade is 52m/s [4].

According to Qin Yonglin [5], related research experiments show that the diameter of the sieve hole determines the fineness of the material, the diameter of the sieve hole is large, the size of the crushed finished product is larger, the diameter of the sieve hole is small, the size of the crushed finished product is small, the relationship between the diameter of the sieve hole and the size of the crushed finished product is roughly the average size of the finished product (mm) = (1/4 to 1/3) the diameter of the sieve hole (mm).

The hammer sieve gap is the distance between the hammer head and the sieve plate. The optimal hammer sieve gap is different for different materials, and it is usually recommended that the straw particle size is 10-14 mm [6]. The smaller the hammer sieve gap, the greater the extrusion friction between the hammer blade and the material, the smaller the particle size of the material, the larger the hammer sieve gap, the smaller the extrusion friction of the material, the larger the particle size of the material. Therefore, you can adjust the crushing fineness of the material by adjusting the hammer and sieve gap.

3. CRUSHING FINENESS ADJUSTMENT

From the above analysis, it can be seen that the key to adjust the fineness of crushing is the speed of the hammer blade, the size of the screen aperture and the size of the hammer and screen gap. From the above data, we know that the best crushing speed of corn straw is 52m/s. The size of the screen aperture can be changed by changing the sieve of different apertures to change the fineness of the material. The size of the screen aperture is divided into four levels, fine hole diameter 1-2mm; coarse hole diameter 5-6mm; large hole diameter 8mm or more [7]. When the coarse crushing, change to a larger aperture screen, the same fine crushing, change to a smaller aperture sieve plate. The following focus on how to easily and quickly adjust the hammer screen gap.

3.1 Hmmer and sieve gap adjustment

Changing the hammer screen gap is to change the distance from the end of the hammer blade to the screen, and one can choose to change the hammer screen gap by replacing the length of the hammer blade, but this way is troublesome to operate, less efficient, and more costly to replace the hammer blade. According to [3], there is a better and more convenient way to adjust the hammer screen gap, as shown in Figure 1 below, which consists of hammer blade, curved liner plate, adjusting screw, screen, and housing. The screen is held tightly to the adjusting screw 2 by the screen pressure frame. If a smaller hammer sieve gap is required, the adjusting screw is adjusted inward by a wrench, and if a larger hammer sieve gap is required, the adjusting screw is adjusted outward by a wrench. The size of different hammer sieve gap is applicable to different fineness of crushing. This method is simple and convenient, saving the time and cost of replacing hammer blades and improving production efficiency.

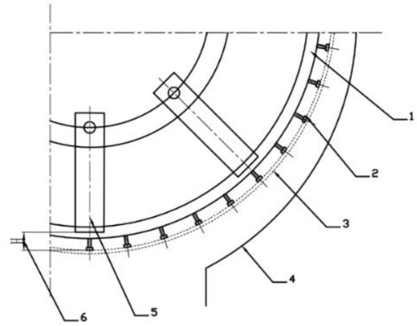


Fig.1. Structure diagram of adjustable hammer and sieve gap 1 curved liner, 2 adjusting screws, 3 screens, 4 housing, 5 hammer blade, 6 hammers and sieve gap

4.HAMMER BLADE CRUSHER CRUSHING CHAMBER DESIGN

4.1 Crushing chamber structure design

In the crushing process, the material is pushed by the high-speed rotor, which generates an annular flow layer. This leads to uneven crushing, low crushing efficiency and other problems. In order to break the annular flow layer, relevant researchers improve this problem by changing the shape of the crushing chamber, of which the teardrop type is the crushing chamber structure into the shape of a water drop [8], which improves the productivity of the crusher and is most widely used.

4.2 Design of the sieves

Hammer mill sieve shape mainly has fish scale sieve and perforated sieve, fish scale sieve can improve production efficiency, but processing difficulties, wear resistance is poor, higher prices, shorter life [9]. In contrast, the cylindrical perforated sieve has greater advantages and is more widely used at a higher cost [10]. The arrangement of the sieve holes also has a great impact on the efficiency of the crusher, the most widely used is the equilateral triangular arrangement, so the design of the cylindrical shape and equilateral triangular arrangement of the sieve. The structure of the sieve blade is shown in Figure 2.

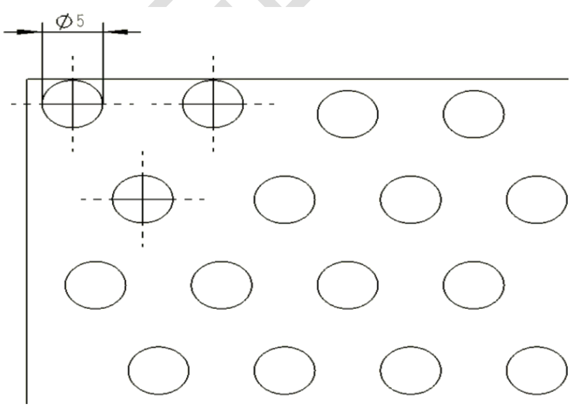


Fig.2. Shape and arrangement of sieve holes

4.3 Rotor headquarters design

The rotor headquarters of the hammer blade crusher consists of a main shaft, hammer blade, pin, hammer plate frame and sleeve, etc. The use of 4 pins 16 hammer blade symmetrical arrangement, effective symmetry of the centrifugal force of the pin, the combined force line of action coincides and the size of equal direction opposite, the crushing effect is better. Select the appropriate rotor diameter D and width B is important for the productivity of the crusher. Check the relevant information on the width of the crushing chamber B and rotor diameter D to determine the variety of crushed materials, and to meet the D/B = 1.1-3.5 [11], for crushing corn particles to choose a larger D and smaller B [12]. Therefore, the machine rotor diameter according to the design requirements and previous experience design selection D = 300mm, B = 100mm, in line with the design requirements. By checking the table, it is known that the best line speed suitable for corn crushing is 52m/s.

According to

$V = \frac{n\pi D}{60} n = \frac{60\times52\times1000}{300\times3.14}$=3312r/min (1)

Take the rotor speed of 3600r/min, where V is the linear speed of the hammer blade m/s; n is the rotor speed r/min;D is the diameter of the rotor mm.

4.4 Selection of hammer blades

There are currently many different types of hammer blades for hammer blade crushers. Because rectangular hammer blades are simple to manufacture, low cost and have been standardized. According to the design requirements, the rectangular hammer blade is selected. The hammer blade material is 65Mn steel with carburizing treatment. According to the national standard LST-3605-1992 hammer blade specifications are shown in Figure 3.

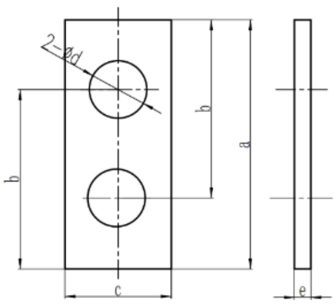


Fig.3. Schematic diagram of the size specification of the hammer blade

Determine the specific parameters according to the empirical formula:

$a = \beta \times D$=0.25×300=75mm (2)

Where is the hammer length coefficient, according to the design requirements to take 0.25; D is the rotor diameter, 300mm

$c = 0.1 \times D = 0.1 \times 300 = 30mm$(3)

b is the distance from the pin hole to the top, considering the size of the rotor diameter, in order to avoid interference caused by the movement of the hammer blade in the rotor, after comprehensive consideration, take b = 50 mm. d is the diameter of the pin hole, e is the thickness of the hammer blade, the hammer blade thickness range of 2-10 mm, to ensure the life of the case, the thin hammer blade can improve the crusher's power output, take e = 2 mm, take d = 8 mm.

4.5 Number of hammer blades

The number of hammer blades is mainly based on the density of the hammer blades, the effective width of the crushing chamber, and the thickness of the hammer blades to decide, the calculation formula into the following:

$z = \frac{K_1\times B_1}{e}$=$\frac{0.35\times90}{2}$=15.75 z=16 (4)

Where k_1 is the hammer density coefficient, k_1 = 0.27-0.47, according to the design requirements, the design takes 0.35; B_1 is the effective width of the crushing chamber, the design takes 90mm.

4.6 Turntable design

The diameter of the rotor is 300mm, the total length of the hammer blade is 75mm, the turntable should not be too big, take the diameter of the turntable is 160mm, the turntable and the shaft are connected by key, 4 pin holes connect the hammer blade and the turntable. The structure of the turntable is shown in Figure 4.

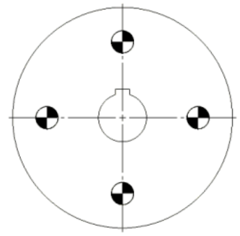


Fig.4. Schematic diagram of turntable structure

4.7 Design of hammer blade holder

By the above design, the hammer frame includes two turntables, 4 pins, 16 sleeves and 16 hammer blades. The hammer blade holder structure is that 16 hammer blades are distributed on 4 pins and each hammer blade is axially positioned between them through the sleeve, 4 pins are connected to two turntables, and the turntables are keyed to the spindle and axially positioned through the sleeve. The specific structure is shown in Figure 5.

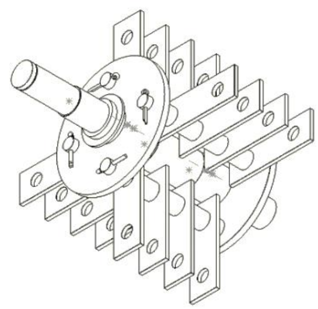


Fig.5. Overall structure of the hammer blade holder

5.DESIGN CALCULATION OF DRIVE SHAFT

5.1 Selection of electric motors

Most the hammer mill transmission mode using a belt drive, the choice of motor power P (KW) to determine the production capacity of the crusher Q (t / h), can not be too large or too small, generally calculated by the following formula: P = (6.4-10.5) Q, Q = 0.3t / h, the maximum power P = 10.5 × 300 × 10^3 = 3.15KW.

Check the relevant information [13], the hammer mill spindle speed is generally 1400-3000r/min, the design takes 2200r/min, check the relevant information, and choose Y112M-2 type motor, the main parameters are shown in Table 1

Table 1. Motor parameters

Power Rating	Rotational Speed	Quality	Dimension
4KW	2890r/min	17kg	400×245×265

5.2 Shaft material and power

The input power of the shaft is equal to the rated power of the motor multiplied by the transmission efficiency between the motor and the spindle, which is 0.94 for the belt drive, and the calculated input power of the shaft is 3.76KW.

5.3 Shaft torque and diameter

Torque of the motor : T_1=9550 P_1/n_1 =9550×1000×4/2200=117363.63N.mm

Rotor spindle torque : T_2=9550 P_1/n_1 =9550×1000×3.76/3600=9974.4N.mm

Check "Mechanical Design", the formula of the minimum diameter of the shaft is $d \geq C\sqrt[3]{(P/n)}$, get $d \geq 11.36$mm, so take the minimum diameter of the shaft is 32mm. the structure design of the shaft is shown in Figure 6.

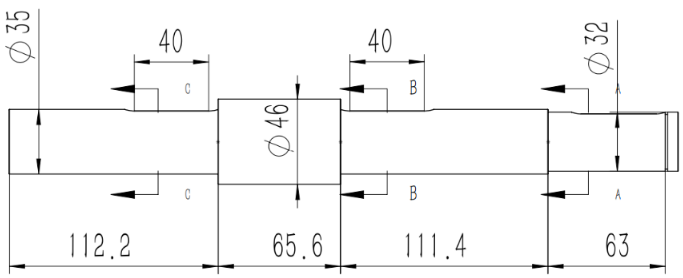


Fig.6 Structure design of the shaft

5.4 Design of the pin

The pin is used to connect the hammer blade and the hammer plate frame, the diameter of the pin is the same as the diameter of the hole on the hammer plate frame is 16mm, and the length of the pin is determined by the width of the crushing chamber, the thickness of the hammer plate frame and the margin together, it is known that the effective width of the crushing chamber B is 90mm, the thickness of the hammer plate frame is 8mm, the pin leaves a margin of 2mm, so the length of the pin L=90+2×8+2=118mm.

5.5 Key design calculation

The connection between the rotor spindle and the hammer plate frame is connected by a round head flat key. According to the size of the shaft at the connection with reference to the standard specification of the key, the size of the key is chosen as key width × key height × key length = 6mm × 6mm × 40mm, and the key is calibrated.

Assuming that the load is uniformly distributed on the working surface of the key, the strength condition of an ordinary flat key is $\sigma_p = \frac{2T\times10^3}{kld}$ substituted into the above equation: $\sigma_p=\frac{2\times9.974\times1000}{3\times34\times35}$=5.6Mpa≤ $[\sigma_p]$. Therefore, the strength of the key meets the requirements.

6.SIMULATION ANALYSIS OF HAMMER BLADE AND ROTOR
6.1 Static analysis of hammer blades

According to the specification GB/T150, the parameters of the material at room temperature are shown in Table 2.

Table 2. Material parameters of the equipment

Materials	Temperature（℃）	Permissible stress(MPa)	Young's modulus(MPa)	Poisson's ratio	Density(Kg/m3)
65MN	room temperature	430	1.97E5	0.282	7802

A fixed constraint is applied at the connecting pin, and a concentrated force is applied on one side of the hammer blade in the direction of the tangent to the rotor. The obtained calculation results are shown in Figures 7, 8 and 9.

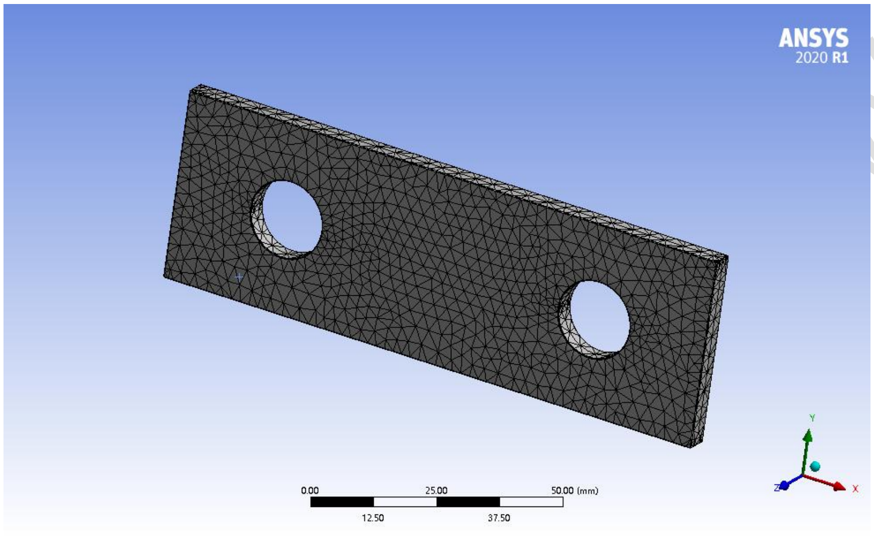


Fig.7. Finite element calculation model

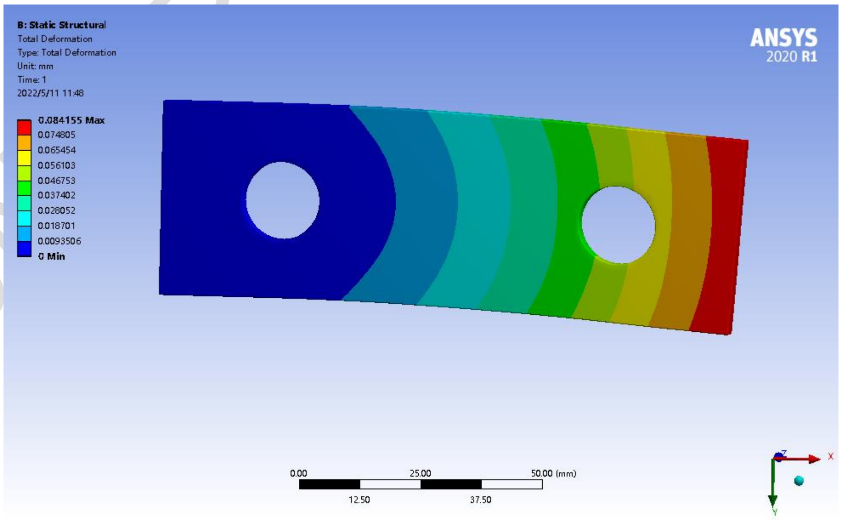


Fig.8. Structure deformation cloud

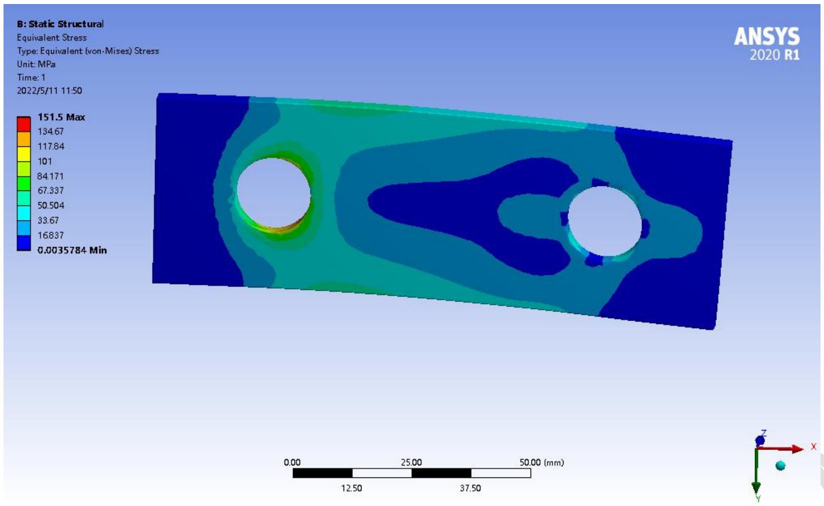


Fig.9. Equivalent effect force cloud

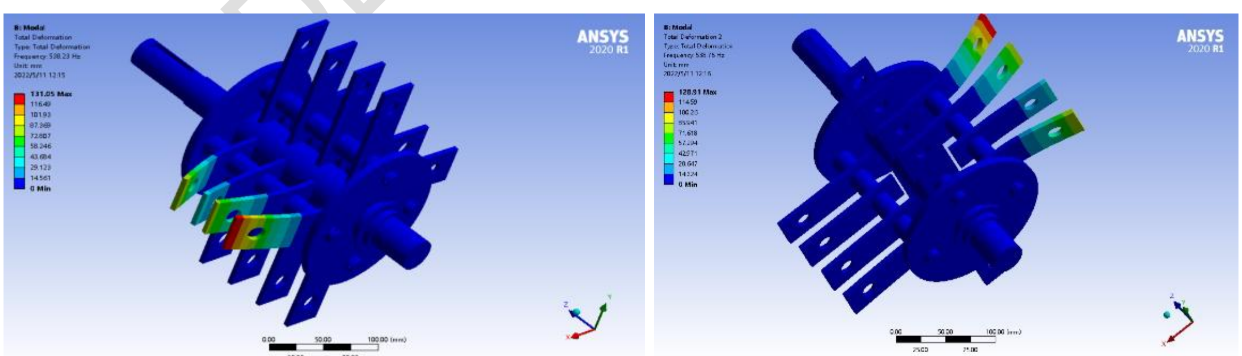
As can be seen from Figure 8, the maximum deformation of the hammer blade is 0.084155mm, which is a very small deformation. As can be seen from Figure 9, the maximum stress on the hammer blade is 151.5Mpa, while the permissible stress on the hammer blade is 430Mpa, the maximum stress is much less than the permissible stress. Therefore, the design of the hammer blade is reasonable and meets the working requirements.

6.2 Rotor headquarters structure and modal analysis

The rotor headquarters structure is shown in Fig. Modal analysis is performed on the rotor. In order to avoid or utilize resonance to ensure the structural stability of the rotor, the intrinsic frequency of the part must be determined, and the calculation results are shown in Table 3. The first 6 orders of vibration are shown in Figure 10.

Table 3: First six orders of inherent frequency of the rotor

Order	First order	Second order	Third order	Fourth Order	Fifth Order	Sixth Order
Inherent frequency/Hz	538.23	538.76	540.07	540.25	547.52	548.09



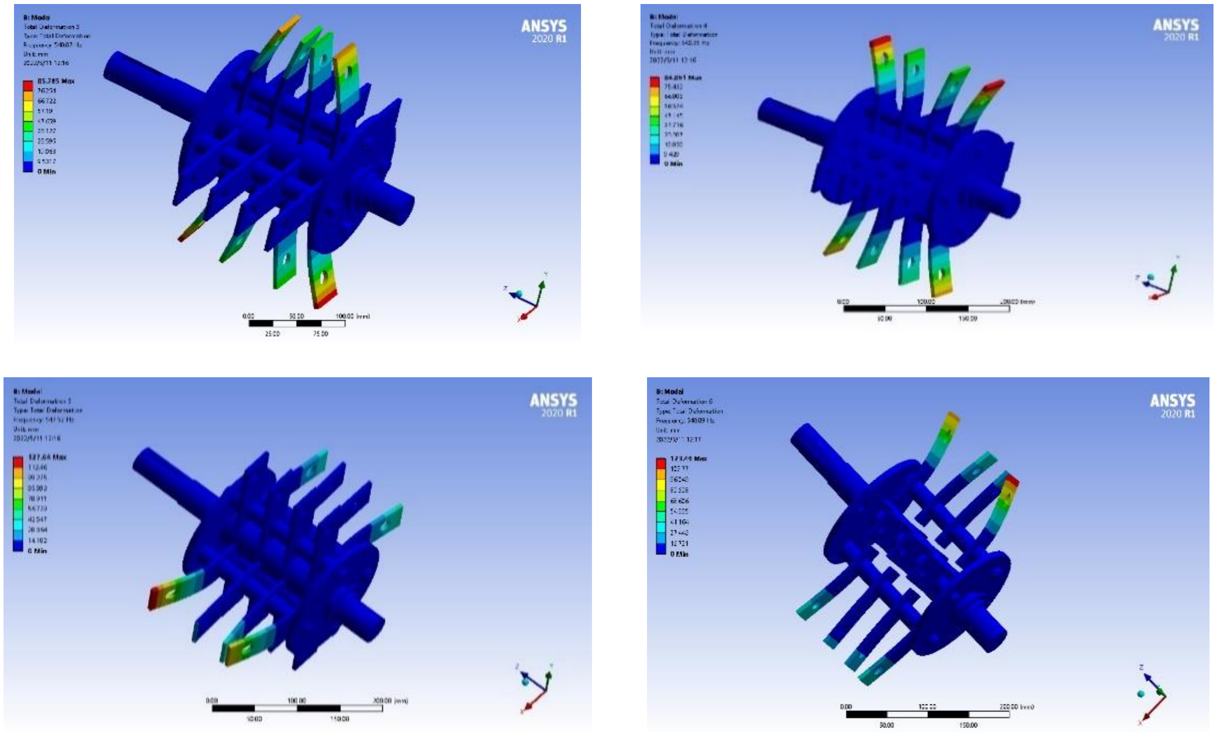


Fig.10. The first 6 orders of vibration

Checking the relevant information [14,15], it can be seen that the critical speed of the shaft system is calculated by the formula 88888 according to the formula will be the first six orders of the rotor's intrinsic frequency into the critical speed, the specific data as shown in Table 4.

Table 4: Rotor intrinsic frequency and critical speed

Number of steps	1	2	3	4	5	6
Inherent frequency/Hz	538.23	538.76	540.07	540.25	547.52	548.09
Critical speed/r/min	32293.8	32325.6	32404.2	32415	32851.2	32885.4

To ensure the normal operation of the rotor, the working speed should leave a certain range of critical speed of each order[16], the dangerous working speed of this design is 32,293.8×0.7=22,605.66, while the speed of the hammer-blade crusher studied in this design is 3600r/min. far below the dangerous working speed, so the speed and structure of the designed rotor is reasonable.

7. CONCLUSION

From the above data analysis, the factors affecting the fineness of the crushing are the influence of the material circulation layer, the arrangement and density of the hammer blade, the shape and aperture size of the sieve, and the size of the hammer and sieve gap.

Firstly, the teardrop type crushing chamber is used as the structure of the crushing chamber of the hammer mill. The teardrop type crushing chamber can effectively improve the influence of the material circulation layer and make the fineness of the crushed material more uniform.

In order to balance the centrifugal force of the pins and improve the influence of the material circulation layer, the hammer blades are arranged in a symmetrical arrangement with 4 pins and 16 hammer blades. The hammer blade material is 65Mn steel, carburized, rectangular hammer blade. The hammer blades were analysed statically and the overall rotor structure was analysed modally. According to the calculation results, the design of the hammer blades can meet the requirements and the overall rotor structure and speed design are reasonable.

Finally, the size of the sieve holes was changed by changing the sieves with different aperture sizes, the sieves were changed manually, the sieve holes were cylindrical and the arrangement was made in an equilateral triangular arrangement. The impact of the hammer and sieve gap on the fineness and uniformity of the crushed material is very important, the adjustment of the hammer and sieve gap is changed by installing adjusting screws, changing the pitch of the screws and thus adjusting the distance between the hammer and the sieve plate, the suitable hammer and sieve gap for straw is 10-14 mm. this adjustment method saves the cost of replacing different lengths of hammer blades and improves production efficiency.

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