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# Design and test for hob-type chopped roller of green fed harvester

**Ge Yiyuan, Jiang Yongcheng, Li Yaqin, Liang Qiuyan, Wang Junfa, Du Shuang, Wen Xiaoxin, Zhang Jinbo**

([1]Heilongjiang jiamusi, College of mechanical engineering jiamusi university, 154007; [2]Heilongjiang jiamusi, jiamusi Bofa agricultural machinery research limited company, 154007)

*Corresponding author: Wang Junfa(1958-), doctor, professor, doctoral supervisor, e-mail: wangjunf2934@sina.com

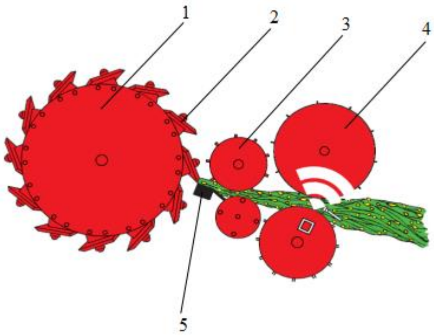
**Abstract:** The chopped roller is the main working part of green fed harvester, of which performance directly affects the cutting effect and power consumption of the machine. A new type hob-type closed chopped roller is designed because of the large cutting resistance of the harvester, and the blade on the roller is arranged in a double row herringbone. It does dynamics analysis for chopped roller and gets three affect parameters, they are cutting speed, sliding cutting angle and grinding blade angle. Under the condition that the blade sharp degree is consistent, take the cutting resistance torque as test aim, the influence of cutting speed, sliding cutting angle and grinding blade angle to cutting resistance torque was studied by using orthogonal test of secondary rotation,the main order of the influence of each factor on the index is cutting speed > grinding blade angle > sliding cutting angle. When the cutting speed is 1200 r/min, sliding cutting angle is 25°, grinding blade angle is 25° which is the best parameter combination for the cutting resistance torque. The experimental results provide data support for further optimization of the chopped roller.

## 1. Introduction

Heilongjiang province is China’s largest production base of commodity grain, the production of straw is at the first place in domestic, but the straw storage and transportation chain is not perfect, lead to straw burning is serious[1-2]. In 2016, our province issued a subsidy policy for the production of corn silage, which required to ensure the area of grain change and the amount of feed. The chopping of silage is the most important part of the harvest scheme. The cutting resistance of the chopped roller is large, and the large power consumption is an urgent problem to be solved. At present, the chopped roller mainly includes flail type, disk type and drum type. The drum chopper has the merits that structure is compact, cutting length is uniform, it easy to be cut, easy to install and used widely. John Deer, New Holland, Keith Company, and Germany KAMPER Company product of the green fed harvesters have a high efficiency of harvest and intelligent detection system. The development of domestic green fed harvester is fast, and the representative models include the animal husbandry 9QSZ3000 of xinjiang machinery research institute Self-propelled silage harvester. 4QX series corn silage harvester of agricultural machinery engineering science research institute of Heilongjiang province; The FL3000A green fed harvester produced by Zoomlion; Modern agricultural machinery co., LTD. (Beijing) agricultural machinery co., LTD. production of the 9080 type hanging type green fed harvester[3-4]. The high price and power consumption of the overseas green fed harvester, and the key components are expensive, the machine supply cycle is long[5-9]. Domestic green fed harvester has some problems such as low life of key components and easy blocking of key parts. In view of the present research situation, this paper take green harvest components as the research object, it set up a test bed to solve the cutting resistance problem of chopped roller , it will provide theory support for further optimization of chopped components.

## 2. The structure and working principle of the chopped roller

The structure of the cutter is shown in Figure 1, including the chopped roller, cutter blade (moving blade), fixed blade and clamping compression mechanism. Among them, the clamping compression mechanism adopts the segmented progressive compression structure, including the first level clamping compression mechanism and the secondary clamping compression mechanism. The hob-type chopped roller is a closed structure, and the outer wall of the roller is fixed on the middle shaft through the inner side plates. A number of tool holder arranged in a herringbone are welded around the outer wall of the roller, and the cutting blades are bolted to the tool holder.




1-Chopped roller; 2-Cutter blade (moving blade); 3-The secondary level clamping compression mechanism; 4-The first level clamping compression mechanism; 5-Shear blade

Figure 1. Schematic diagram of cutter structure.

The cutting edge of cutting blade adopts wear-resisting treatment to improve the life of the cutter. The parameters and installation parameters of the cutting blade are determined by dynamic analysis and test of the blade cutting process.

## 3. Dynamic analysis of cutter blades

For research on the chopped roller moving blade of cutting resistance, first to move for the process of cutting blade dynamics analysis, find the factors that influence the cutting resistance and through the test study on the cutting resistance factor parameter combination of the minimum.

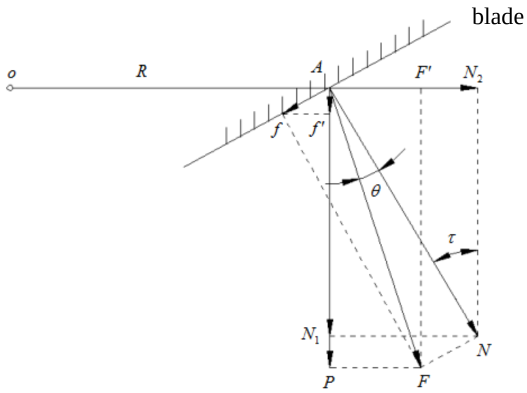



Figure 2. Dynamic analysis for blade cutting process.

As shown in Figure 2, the rotary radius of the roller is $R$, the sliding cutting angle $\tau$. $N$ is the vertical reaction on the blade, divide $N$ into $N_1$ and $N_2$, and $N_1$ to overcome the cutting resistance. $N$ the force on the friction angle of deflection a theta for $F$, $F$ along the edge direction projection for the frictional resistance of the blade material $f$, $f'$ to overcome the frictional resistance. Cutting resistance $P$ perpendicular to the radius of rotation of the roller, the force to make the blade pressure was cut materials, and $P=N_1+f'$.

$$N_1 = N\cos\tau \qquad f' = f\sin\tau \tag{1}$$

Because

$$N = pL \qquad f = \mu N \tag{2}$$

$p$——The vertical reaction force on the unit length of the blade, N/mm;
$L$——The practical work length of the blade, mm;
$\mu$——Friction coefficient between blade and material.
So

$$\begin{aligned} P &= N_1 + f' = pL\cos\tau + \mu pL\sin\tau \\ &= pL\cos\tau(1+\mu\tan\tau) \\ &= \frac{h}{\sin\tau}p\cos\tau(1+\mu\tan\tau) \\ &= hp\cot\tau(1+\mu\tan\tau) \end{aligned} \tag{3}$$

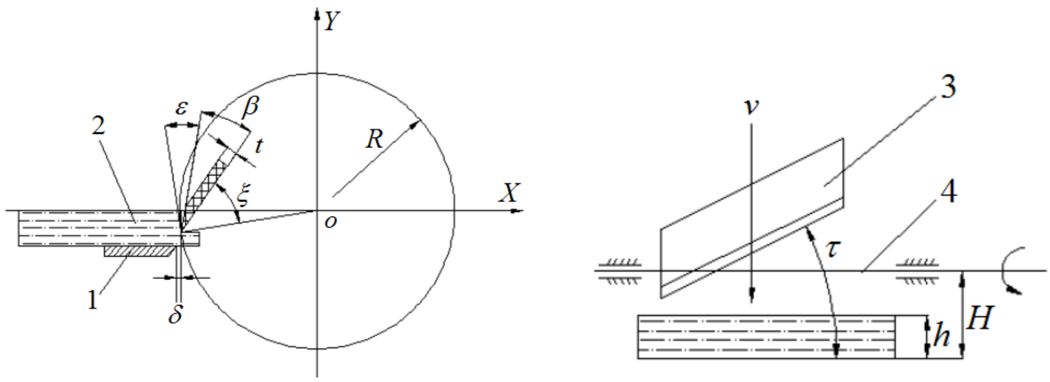
$h$——The thickness of the cut material, mm.

It can be seen from formula (3), the cutting resistance P is related to $h$, $P$ and $\tau$. The literature can be seen (the theoretical analysis and experimental study of the drum type slot grass machine slasher), the vertical reaction force on the unit length of the blade $p$ is related to the thickness of the blade $t$ (mm) and the yield strength $\sigma_c$ (N/mm$^2$) of the material[9].

$$p = t\sigma_c + Eh'^2\left[\tan\beta' + \mu\sin^2\beta' + \mu'\left(\mu + \cos^2\beta'\right)\right]/2h \tag{4}$$

$E$——The elastic modulus of straw, N/mm$^2$;
$h'$ ——The compression depth of straw layer before cutting, mm;
$\beta'$——Corner cut, $\beta'=\beta+\varepsilon$, (°);
$\mu'$ ——Friction coefficient inside straw.

The sliding cutting angle is the angle between the motion direction of the moving blade and the moving blade edge line normal. $v$ is the linear velocity of a point on the moving blade, it can be divided into the slid cutting speed along the direction of the blade $v_\tau$ and the cutting speed perpendicular to the blade direction $v_n$, and the angle $v_n$ of the angle $v$ is the sliding cutting angle $\tau$, $\tan\tau=v_\tau/v_n$ which is the slid coefficient. When $\tau=0$, the moving blade was in cutting state; when, $0<\tau<\delta_1$ it was sliding cutting $\delta_1$ is the friction angle between the moving blade and the material[10]. When sliding cutting, the velocity direction of the blade and the not perpendicular actual of the blade angle will become smaller and the cutting resistance will be reduced. The cutting roller has a certain sliding cutting effect.




1-Fixed blade; 2-Straw layer; 3-Moving blade; 4-Roller rotation axis
Figure 3. Geometric parameter analysis diagram of chopped roller.

To sum up, the main parameters influencing the performances of chopped roller including cutting speed $v$, sliding cutting angle $\tau$, angle of grinding blade $\beta$ sharpness angle and cutting anterior angle $\xi$, installation angle $\varepsilon$, cutting clearance $\delta$, material thickness $h$, moving blade thickness $t$ Etc, the geometric parameters of the chopped roller as shown in Figure 3.

## 4 Cutting resistance test

Figure 4. Test bench.

The optimum cutting resistance is the key to design of high efficiency green fed harvester. In this paper, the cutting resistance test of knife roller was carried out on the self-developed feeding test bench. The test bench structure is shown in Figure 4.

### *4.1 Test conditions*

The factors that affect the cutting resistance include two kinds, the physical mechanical characteristics of the material and the parameters of the roller. Due to the large influence factors, this test only investigated the influence of the parameters of the roller on the cutting resistance, and the physical mechanical properties of the materials were maintained in constant state[11-12].

The parameters of chopping blade and straw are shown in table 1. In the same situation of the physical mechanical properties of the straw and the parameters such as the anterior angle of cutting. The chopped roller speed $n$, sliding cutting angle $\tau$ and grinding blade angle $\beta$, the influence of three factors on the cutting resistance torque $M$ was investigated[13-14].

The cutting resistance torque is measured by the torque sensor installed between the adjustable-speed motors and the cutting roller. The rotational speed of the cutter is changed by the frequency converter to control the motor.

Table 1. Parameters of cutter blade and straw.

| Parameters | Numerical |
|---|---|
| Roller rotary diameter $R$ | 600mm |
| Cutting edge length $L$ | 350mm |
| Cutting edge thickness $t$ | 8mm |
| Blade number | 2×16 |
| Straw average diameter $d$ | 19.21mm |
| Water content of maize straw | 64.26% |
| Straw yield strength $\sigma_c$ | 7MPa |

The factor level coding table is shown in table 2, and the level values are appropriately rounded.

Table 2. Factor level coding table.

| Levels \ Factors | A:Roller speed $x_1$ r/min | B:Sliding cutting angle $x_2$ ° | C:Grinding blade angle $x_3$ ° |
|---|---|---|---|
| -1.682 | 600 | 5 | 15 |
| -1 | 720 | 9 | 19 |
| 0 | 900 | 15 | 25 |
| 1 | 1080 | 21 | 31 |
| +1.682 | 1200 | 25 | 35 |

| | | | |
|---|---|---|---|
| $\Delta_i$ | 180 | 6 | 6 |

*4.2 Test scheme and results*

This article uses orthogonal test of secondary rotation[15]. The test scheme and results are shown in table 3.

Table 3. Test scheme and results.

| Serial number | Test number | Roller speed /r·min$^{-1}$ | Sliding cutting angle /° | Grinding blade angle /° | Cutting resistance torque /N·m |
|---|---|---|---|---|---|
| 1 | 22 | -1 | -1 | -1 | 150 |
| 2 | 11 | 1 | -1 | -1 | 107 |
| 3 | 8 | -1 | 1 | -1 | 33 |
| 4 | 18 | 1 | 1 | -1 | 80 |
| 5 | 12 | -1 | -1 | 1 | 197 |
| 6 | 17 | 1 | -1 | 1 | 50 |
| 7 | 2 | -1 | 1 | 1 | 300 |
| 8 | 15 | 1 | 1 | 1 | 83 |
| 9 | 23 | -1.682 | 0 | 0 | 400 |
| 10 | 10 | 1.682 | 0 | 0 | 60 |
| 11 | 13 | 0 | -1.682 | 0 | 283 |
| 12 | 6 | 0 | 1.682 | 0 | 67 |
| 13 | 19 | 0 | 0 | -1.682 | 77 |
| 14 | 7 | 0 | 0 | 1.682 | 283 |
| 15 | 1 | 0 | 0 | 0 | 150 |
| 16 | 5 | 0 | 0 | 0 | 152 |
| 17 | 20 | 0 | 0 | 0 | 153 |
| 18 | 3 | 0 | 0 | 0 | 151 |
| 19 | 16 | 0 | 0 | 0 | 150 |
| 20 | 21 | 0 | 0 | 0 | 150 |
| 21 | 14 | 0 | 0 | 0 | 153 |
| 22 | 9 | 0 | 0 | 0 | 152 |
| 23 | 4 | 0 | 0 | 0 | 155 |

*4.3 Analysis of the test results*

The variance analysis table for test data is shown in table 4.

Table 4. Analysis of variance table.

| Source | Sum of squares | Degree of freedom | Mean square | F-value | Significance |
|---|---|---|---|---|---|
| Model | 1.274E+005 | 6 | 21229.78 | 6.77 | 0.001 |
| A | 63577.53 | 1 | 63577.53 | 20.27 | 0.0004 |
| B | 10093.05 | 1 | 10093.05 | 3.22 | 0.0918 |
| C | 26930.12 | 1 | 26930.12 | 8.59 | 0.0098 |
| AB | 50 | 1 | 50 | 0.016 | 0.9011 |
| AC | 16928 | 1 | 16928 | 5.40 | 0.0337 |
| BC | 9800 | 1 | 9800 | 3.12 | 0.0962 |
| Error | 50183.73 | 16 | 3136.48 | | |
| Sum | 1.776E+005 | 22 | | | |

It can be seen from table 4 that all factors are significant in different degrees except A, B, C, AC and BC. After being processed by design-expert software, the regression equation between the cutting resistance torque $y$ and the factors is:

$$y = 153.7 - 68.2x_1 - 27.2x_2 + 44.4x_3 + 2.5x_1x_2 - 46x_1x_3 + 35x_2x_3 \tag{5}$$

The relationship between *y* and the three factors of A, B and C is:

$$\begin{aligned} y &= 153.7 - 68.2x_1 \\ y &= 153.7 - 27.2x_2 \\ y &= 153.7 + 44.4x_3 \end{aligned} \tag{6}$$

It can be seen from equation (6) that the speed of roller, sliding cutting angle and cutting resistance torque are proportional, that is, the cutting resistance torque decreases when the knife roller speed and sliding cutting angle increase. This is because that when the cutting speed increases, the forage deformation time is short, the required power consumption is reduced, and the total power consumption of cutting is reduced accordingly, so the cutting resistance torque is reduced greatly.

The grinding blade angle is inversely proportional to the cutting resistance torque, that is, when the grinding blade angle increases, the cutting resistance torque increases. This is because that $\beta+\varepsilon+\xi=90^{o}$ , when the cutting anterior angle is constant, the grinding blade angle is larger, and the installation angle is smaller. The volume of material is reduced after it passes the clamping compress mechanism, when the blade is cut, the cut grass and uncut grass will rebound and expand. When the installation angle $\varepsilon$ is smaller, the rebound resistance will increase, and the friction area between the material and blade will also increase, it can prevent the cutter roll, reduce the speed of cutter and increase the power consumption.

In addition, there is an interaction between AC and BC. The regression equation of the interaction between the roller speed A and the grinding blade angle C to the cutting resistance torque is:

$$y = 153.7 - 68.2x_1 + 44.4x_3 - 46x_1x_3 \tag{7}$$

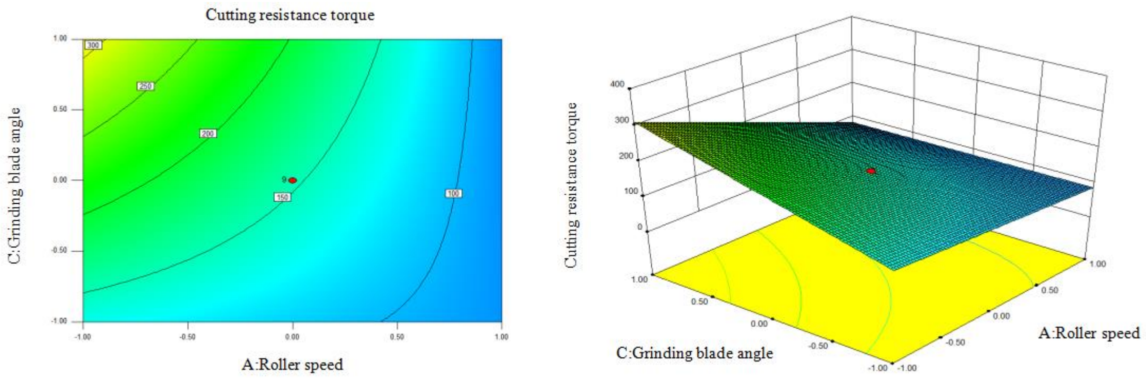



Figure 5. Contouring and response surface under the interaction of A and C.

Figure 5 is the contour map and response surface diagram of the influence that interaction between A and C to the cutting resistance torque. The figure 5 shows that when the speed of roller increases, the cutting resistance torque will reduce, and when the grinding blade angle increases, the cutting resistance torque is also increase, but the test proved that if the grinding blade angle is too small, it can make the life of blade down, so it is more appropriate that the grinding blade angle is 25°.

The regression equation of the interaction between the sliding cutting angle B and the grinding blade angle C to the cutting resistance torque is:

$$y = 153.7 - 27.2x_2 + 44.4x_3 + 35x_2x_3 \tag{8}$$

Figure 6 is the contour map and response surface diagram of the influence that interaction between B and C to the cutting resistance torque. The figure 6 shows that the larger the sliding cutting angle, the smaller the cutting resistance torque, but when the grinding blade angle increases, the cutting resistance torque has no significant change.So it is more appropriate that the sliding cutting angle is 25°.

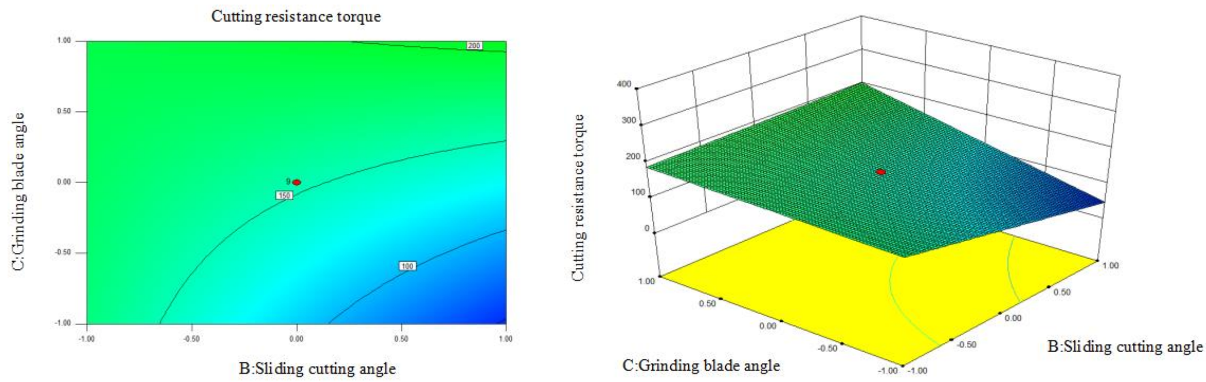



Figure 6. Contouring and response surface under the interaction of B and C.

## 5. Conclusion

(1) It does kinetic analysis for chopped roller which is the key components of green fed harvester, and gets the parameters that affect cutting resistance torque.

(2) It researches three test factors include cutting speed, sliding cutting angle and grinding blade angle which affect the cutting resistance torque of chopped roller, establishes a model of each factor impact on the index, and analyzes the influence of the interaction on the index.The result shows that the optimal operation parameters of the chopped roller are cutting speed is 1200m/s, sliding cutting angle is 25° and grinding blade angle is 25°.

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