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Redesigning a Stalk Chopper Mechanism for Reducing Cutting Energy and Optimizing Its Bite Length

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INFO

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ABSTRACT

Considering the increasing population of the world and the lack of human food sources, it is very important to pay more attention to fodder plants that can indirectly supply human food. By using choppers, a large amount of fodder can be transported and prepared for anaerobic fermentation of fodder. In this research, a control mechanism has been proposed to change the angle of the knives on the cutting drum with a tangent plane on the circumference of the drum in order to change the distance between the knives and the fixed knife and change the length of the pieces. The mechanism was analyzed in SAM software, and then the three-dimensional model of different blade angle states was designed and analyzed in CATIA V5 R21 software. According to the obtained data, although the Von Mises stresses occur at the minimum angle of 22 degrees and the maximum Von Mises stress occurs at an angle of 16.5 degrees, there is no significant difference in the amount of stresses. Therefore, this mechanism can be recommended for all the mentioned situations (angles). For 1600rpm rotational speed and 6083 N/m line force density the occurred Von Mises stress in 22 degree angle is lower than zero degree angle.

INTRODUCTION

Despite the increasing population of the world and the lack of human food sources, it is very important to pay more attention to fodder plants that can indirectly supply human food. Fodder can be provided from different plant sources. Corn is one of the common fodder products that is used as fodder for feeding livestock. Silo corn is one of the main sources of livestock feed and indirectly plays a role in providing human food resource. By using choppers, which are in three modes: trailed, semi-mounted or self-propelled, it is possible to carry and chop a large amount of fodder and in addition to uniformity to facilitate the mechanized movement of fodder from harvesting to animal feeding, it was prepared for ensiling in order to expel air, which is essential for anaerobic fermentation of fodder. For the high quality of the parts obtained, the parts length should be variable according to the type of livestock. In addition, for the rotating speed of 950 rpm of the cutting cylinder, by doubling the speed of the feeding roller from 10 rpm to 20 rpm, the parts length increased 1.66 times (Borotov, 2020). A cutting cylinder (Fig. 1), which usually has six or eight diagonally mounted blades on it and is placed in front of a fixed knife (Behrozilar and Aqbaei, 2019).

The length of the cut pieces, which is usually between 3 and 90 mm, is done by changing the speed of the feeding rollers, which is done in some cases with the help of a gear box and sometimes with wheels and chains, by changing the number of knives on the cutting cylinder or the change in the circumference of the cutting cylinder changes (Aygun and CAkIr, 2014).

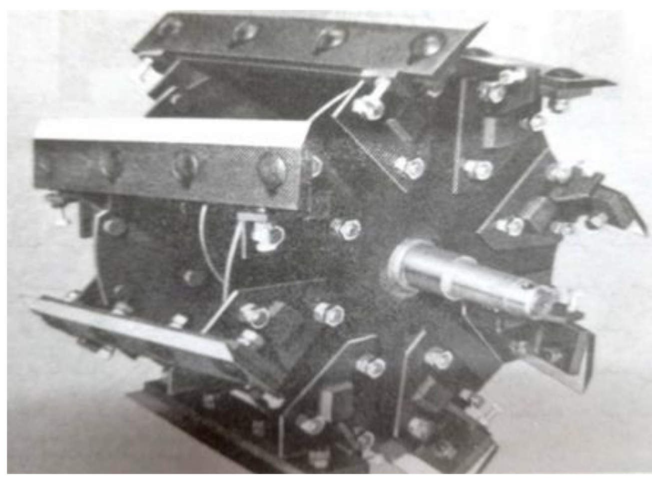

Fig 1. Cutting cylinder in the chopper (Behrozilar and Aqbaei, 2019).

Also, in a research to evaluate the device, the impact of the rotating speed of the shredder blade (400, 550 and 700 rpm) and the rotational speed of the feeding rollers (350, 400 and 450 rpm) on the shredder performance including energy consumption For the chopper blade, the

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energy consumption for the feeding rollers, the length of the chopped corn has been checked (Xie et al., 2018). The appropriate length of the pieces, which is 20 to 30 mm, was obtained for the speed of 550 rpm of the cutting cylinder and the speed of 400 rpm of the feeding roller. The theoretical length of the parts will be less than the length of the parts when the input stem is not perpendicular to the cutting cylinder. To increase the length of the parts, to increase the feed rollers speed, or to decrease the speed of the cutting cylinder, the blades on the cutting cylinder can be removed one by one. Depending on the blade condition, several different types of stem cutting can occur. Usually, first a compression stage and then cutting happens. If there is a counter blade and the distance between the counter blade and the small blade, there will be no need for high blade speed and consequently high cutting energy. The higher cutting time and more less energy will be required for diagonal cutting (Srivastava et al., 1993). The machines optimization is very important until the tools that used to cut and crush agricultural products require a lot of energy and high cost (Guo et al., 2009).

In order to optimize the agricultural machinery by 3D modeling, using ANSYS software and the static stress of Von Mises, the stress level of 168 MPa was obtained (Suleimanzadeh and Heydarbeigi, 2018). The blades used in the current choppers in the market have high cutting resistance, high-energy consumption and low quality. In the past, a double-edged blade was designed to cut fodder corn stalks by modeling the teeth shape. Based on the data obtained from the statistical analysis, the average force on the blade and cutting energy decreased with 71.07 N and 0.47 J, respectively (Tian et al., 2017). In this research, a control mechanism has been used to change the angle of the knives on the cutting cylinder with a tangent plane on the circumference of the circle in order to change the distance between the knives and the fixed knife and change the length of the pieces.

MATERIALS AND METHODS

Part design environment of 21 CATIA V5 R software was used to draw the parts. SAM software was used to analyze the parts, and CATIA V5 R21 was used in the Generative Structural Analysis section of the Analysis and Simulation environment.

The length of the cut parts of the plant is obtained from the equation (1) (Srivastava et al., 1993):

$$L_s = \frac{6000 \times V_f}{n_c \times \lambda_k} \tag{1}$$

Where, L_s is the theoretical length of the cut pieces in millimeters, V_f is feeding speed in meters per second, n_c is rotational speed of the cutting cylinder and λ_k is the number of knives on the cutting cylinder.

As can be seen, in relation (1), the effect of the angle of the blade with the tangent plane on the peripheral plane of the cutting cylinder is not considered. This effect is calculated from equation (2).

$$L_{s1} = l_s + W_{bl} \times sin\, sin\, \alpha \tag{2}$$

Where, L_{s1} is Length of the cut parts, including the angle of the blade with the tangent plane on the circumference of the cutting cylinder, W_{bl} is blade width, α is angle of the blade with the tangent plane on the circumference of the cutting cylinder.

In the above relationship, the threshold of changing the angle of the blade with the tangent plane on the circumference of the cutting cylinder was considered in the range of 0 to 22 degrees. In the idea presented in this research, a temporary mechanism has been proposed to change the angle of the blades with the tangential plane on the circumference of the cutting cylinder, so that its effect on the quality of cutting and the reduction of the energy required for cutting is investigated. This temporary mechanism enables the ability to change the angle at the operator's choice. Six blades are normally installed on the cutting cylinder by screws. Here, the blades are articulated to the beginning and end of the cutting cylinder with the help of pins that allow them to move rotationally relative to the cutting cylinder. There is also a concentric hexagon with a cutting cylinder to which 12 cranks are attached. Each blade is connected to the central hexagon by 2 cranks in an articulated manner and with the help of a pin. Fig. 3 shows the parts and design of the intended mechanism.

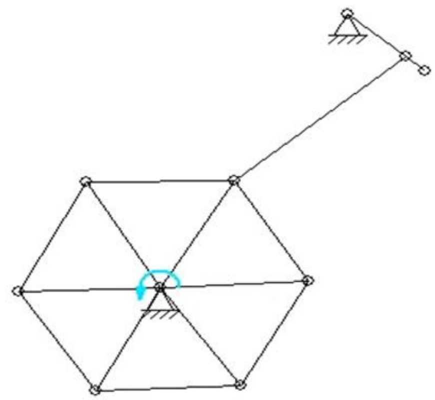

Fig 2. Mechanism modeled in SAM software

In addition, to reduce the pressure and stress, two cranks have been used and the material of the cranks is assumed to be steel (Tarighi et al., 2011). The equivalent mechanism used in SAM software is shown in Fig. 3.

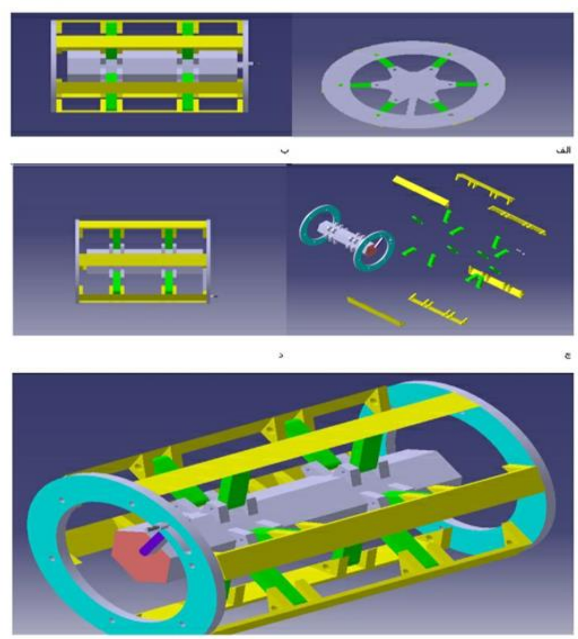

Fig 3. Image of the proposed mechanism to change the length of parts and reduce cutting energy: a- left view, b- opposite view, c- exploded view, d- general view

In the cutting cylinder used in the chopper, there are no hexagons, cranks, and retaining bolts, and they have been added for design purposes (Rains and Cundiff, 1993). In the case where the blade has rotational motion and operates with rotational radius r and speed v and variable angle τ. The speed component is divided into two parts, Vn and Vt, which are the shape change speed and sliding cutting speed, respectively. N is the resistance force of the plant against Vn and T is the friction force against Vt. The result of N and T is the force R, which is under the angle φ from N. If the intensity of the vertical forces of resistance of the plant in front of the blade (the pressure exerted on one centimeter length of the blade) is p, then T and N are obtained from Equeations (3) and (4).

$$N=pl \quad (3)$$
$$T=\mu N \quad (4)$$

Where, μ is coefficient of friction between plant and blade, l is blade length (cm).

If we consider the speed v alone, the resistance of the plant against this speed is the force p, which is the result of two forces p1, p2 that are calculated through Equation 5 and 6.

$$P_1 = N\cos\tau \quad (5)$$
$$P_2 = T\sin\tau \quad (6)$$

By adding Equation (5) and (6), we have:

$$P = P_1 + P_2 = N\cos\tau + T\sin\tau \quad (7)$$

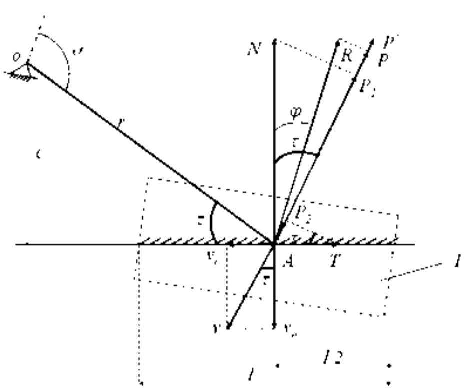

Fig 4. Information about the blade with rotational movement

From Fig. 2 we get:

$$N = R\cos\varphi \quad (8)$$

Substituting in Equation (7), we have:

$$P = R\cos\varphi\,(\cos\tau + \mu\sin\tau) \quad (9)$$

By placing μ=tan φ and with the help of addition to multiplication relations, we have:

$$P = R\cos(\tau - \varphi) \quad (10)$$

In cutting plants, unlike metals, the amount of work done is not proportional to the cross-sectional area, and due to the fibrous structure, it depends on the cutting direction of the blade and stem. According to Kramarenko's theory, in the oblique cut of the stem, despite the increase of the cut surface, a significant reduction in the cutting energy and the work done is achieved compared to the vertical cut and in the case of 45 degrees, we see a reduction of about 30-40%.

The specific pressure of the blade on the plant is obtained from Equation (11):

$$P = C\frac{1}{\tan\tau} \quad (11)$$

Where, P is specific pressure of the blade on the plant (kg/cm), C is shear resistance coefficient of the blade (kg/cm), and T is cutting angle.

Choppers work with different rotational speeds, but here the speed of 1600 rpm is considered (Behrozilar and Aqbaei, 2019) and the maximum force on the blade in this case is caused by the reaction of the maximum force that the blade can apply to the fodder and is caused by the torque transferred from the power axis in this round. The applied torque is obtained through equation 12 (Suleimanzadeh and Heydarbeigi, 2018).

$$P = \frac{2\pi NT}{60} \quad (12)$$

Where, P is power take-off (W), N is rotational speed (rpm) and T is torque (Nm).

According to the tractor we use to pull the chopper, the maximum torque is different (Yilmaz et al., 2011). Here the ITM800 tractor is assumed. In this tractor model, the maximum power is 82 hp equal to 61147 W.

$$61147 = \frac{2\times3.14\times1600\times T}{60} \qquad T=365.12\ \text{N.m}$$

In addition, to increase the accuracy of the calculations in the analysis using the Katia software, instead of the force, a wide linear load has been used. The length of the blade in the chopper is assumed to be 30 cm and the radius of the base of the cutting cylinder is 20 cm. To calculate the concentrated force, from the Equation 13 (Meriam and Kraige, 2011):

$$\frac{T}{R} = \frac{365}{0.2} = 1825N \quad (13)$$

Where, F is concentrated force applied by the blade (N), R is radius of the base of the chopper cylinder (m).

Also, the extended linear load is obtained by dividing the concentrated force on the length of the blade, which is shown in equation 14 (Meriam and Kraige, 2011).

$$F_W = \frac{F}{L_{Blade}} = \frac{1825}{0.3} = 6083\frac{N}{m} \quad (14)$$

Where, F_W is linear extended load applied by the blade (N/m) and L_{Blade} is blade length (m).
The maximum force applied at this rotational speed is caused by the reaction of the force obtained in relation 14 from the side of the feed on the blade. Then, by using the Line force density option and entering the number obtained in Equation 14 and clicking on the compute option, the value of the Von Mises stress can be seen in the results (Azadbakht et al., 2013).

RESULTS AND DISCUSSION

By using the proposed mechanism, while reducing the cutting energy and increasing the pressure exerted by the blade on the plant, the length of the cut piece can also be slightly changed by changing the angle of the blade. Also, due to the use of bolts and nuts as the holder of the mechanism, the length of the pieces is the same and there is no vibration, and in principle there is no difference between the sizes. The operator can easily change the angle by opening the nut and moving the bolt inside the curved sector. In addition, if desired, the motor server can be used to move the off-center arm. In the analysis with SAM software, a cut view of the blade was analyzed. According to the data obtained from the Katia software, despite the fact that the lowest Von Mises stress (according to the results mentioned in Table 1 occurs at an angle of 22 degrees and the highest at an angle of 16.5 degrees, there is no significant difference in the amount of tensions. Therefore, this mechanism can be recommended for all the mentioned situations (angles). Considering that the cutting force required for plants is different according to their rheological properties, the ideal cutting angle will be different for different plants.

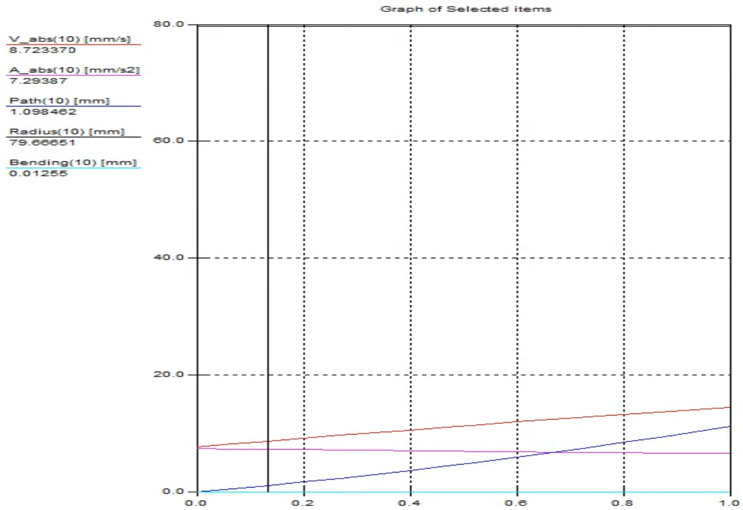

Fig 5. Results of equivalent mechanism analysis with SAM software

So, we can set the angle of the cutting blades according to the type of plant in each of the mentioned situations according to the inherent properties of the desired plant. Also, the maximum force on the blade was calculated at the rotational speed of 1600 rpm

Table 1. Maximum Von Mises stress for different angles

Blade angle	Von Mises stress
Zero degree angle	4.67e-006 $\frac{N}{m^2}$
5.5 degree angle	1.25e-006$\frac{N}{m^2}$
11 degree angle	3.55e-006$\frac{N}{m^2}$
16.5 degree angle	1.3e-005$\frac{N}{m^2}$
22 degree angle	2.29e-007$\frac{N}{m^2}$

Fig. 7 shows the maximum changes in von Mises stress with angle change. The maximum Von Mises stress was 186 and 192 MPa for using 22 and 0 degree angles, respectively. As can be seen, at a rotational speed of 1600 rpm and a linear load of 6083 N/m, a lower Von Mises stress is applied to the blade at an angle of 22 degrees. Therefore, based on the rheological properties of plants, the right angle can be chosen.

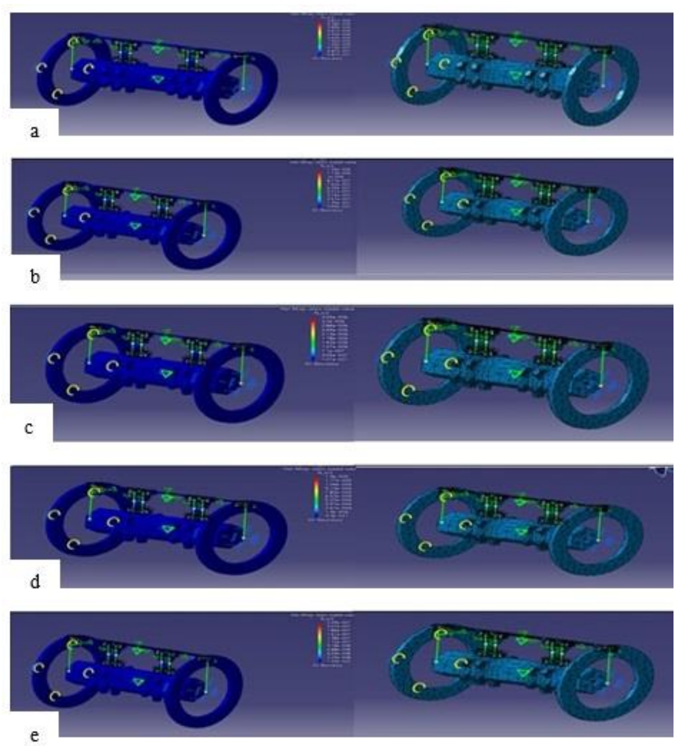

Fig 6- Von Mises stress and mesh occurring at, a:0˚, b: 5.5˚, c: 11˚, d: 16.5, e: 22˚in CATIA V5 R21 software

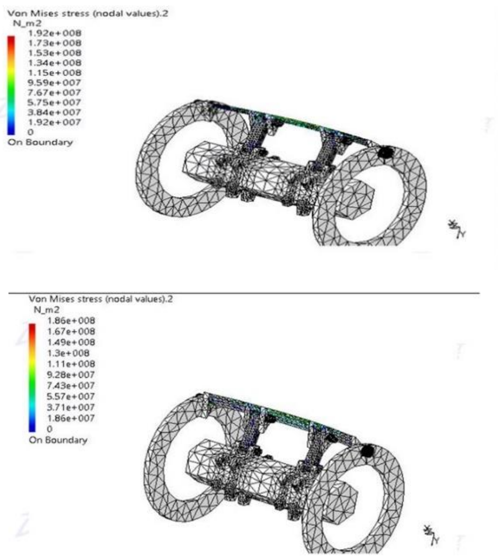

Fig. 7. Von Mises stress for the maximum linear force on the edge of the blade at a rotational speed of 1600 rpm, 0 and 22 degree, respectively

CONCLUSIONS

In a chopper with a blade length of 30 cm and a cutting cylinder with a based radius of 20 cm, the linear extended load force was calculated to be 6083 N/m. According to the data obtained from Katia software, the value of Von Mises stresses was the minimum at the angle of 22 degrees and the maximum at the angle of 16.5 degrees. There was no significant difference in the amount of stress. Therefore, this mechanism can be recommended for all the mentioned situations (angles) and based on the rheological properties of the plants, the right angle can be chosen. At a rotational speed of 1600 rpm and a linear load of 6083 N/m, at an angle of 22 degrees, a lower Von Mises stress is applied to the blade than at an angle of 0 degrees.

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