RESEARCH ON OPTIMIZATION OF KNIFE APPROACH ANGLE FOR CUTTING MAIZE AND SORGHUM STALKS

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Abstract. Nowadays choppers are equipped with knives that are inclined toward the drum generator for progressive cutting. Optimal inclination depends on the nature of the chopping material. This paper presents a method to determine the optimum values of the knife approach angle for cutting maize and sorghum stalks. A pendulum type apparatus was used to determine the displacement in the knife and cutting energy requirements for cutting the stalk. The cutting energy and knife velocity in its lowest position were determined using theoretical equations. The pendulum was raised to 110º meaning a knife velocity of 5.32 $m \cdot s^{-1}$. To determine the displacement in the knife and cutting force, strain gauges were connected to the knife and linked to an HBM acquisition equipment. For straight cuttingthe necessary cutting energy was determined at a value of 28.5 J in case of maize stalks, and 32 J in case of sorghum stalks. For inclined cutting four different approach angles, 0º, 12º, 24º and 36º were selected to study the influences on displacements and cutting energy. To obtain the different knife approach angles, the knife was fixed in different holes drilled in the pendulum head support. As expected, inclined cutting showed improvements for both displacement and cutting energy. For both maize and sorghum stalks the lowest displacement was observed at a 36º inclination of the knife with values of 3.55 µm and 5.32 µm. The cutting energy was observed to be minimum at 24º for maize stalks and 36º for sorghum stalks with a value of 22 J in both cases.

Keywords: knife approach angle, cutting energy.

Introduction

In the technological process of the forage harvester, the most important working tool is thechopper, which performs the fragmentation of the feed to the required size and throws it to the exhaust system of the combine. Nowadays choppers are equipped with knives that are inclined toward the drum generator for progressive cutting [1].

The energy consumed by chopping is one of the most important parameters in the construction of harvesting equipment.

The cutting forces and cutting speed required for cutting forage play an important role in designing energy efficient equipment. The initial penetration of the knife results in localized plastic deformation, followed by buckling and deformation as the knife advances [2].

The energy required for a chopper of a forage harvester can be classified into: friction between the moving parts of the machine and friction with air; the kinetic energy needed to accelerate the chopped material; the energy required to overcome the friction of the chopped material with the stationary parts of the machine and the energy required to cut the stalk [3].

A method to improve the cutting process is to optimize the knife parameters.

A number of studies have been carried out to improve the cutting process of chopping equipment.

J. Prasad determined the optimum values of bevel angle, knife approach angle, shear angle and knife velocity for cutting maize stalks. The knife bevel angle of 23º, knife approach angle of 32º, shear angle of about 55º and the knife velocity of about 2.65 $m \cdot s^{-1}$ were shown to be optimum [4]

The bevel angle influence on cutting was also studied by B. Hoseinzadeh et al. Minimum shearing energy was obtained at knife bevel angles of 25º and 30º [5].

Sunil K. Mathanker et al. studied the effect of the blade oblique angle and cutting speed on cutting energy for energycane stems. The lowest average specific energy was 0.26 $J.mm^{-1}$ for a 60º oblique cut at an average cutting speed of 7.9 $m \cdot s^{-1}$, whereas the highest average specific cutting energy was 1.24 $J \cdot mm^{-1}$ for a straight cut at an average cutting speed of 16.4 $m \cdot s^{-1}$ [6].

This work was carried out to determine the optimum value of the knife approach angle for cutting maize and sorgum stalk. For this, the displacements in the knife and cutting energy were studied.

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Materials and methods

A pendulum type apparatus was used to determine the displacement in the knife and cutting energy requirements for cutting the stalk. It consists of a frame, swing arm, knife support, support for fixing the plant and the angle indicator.

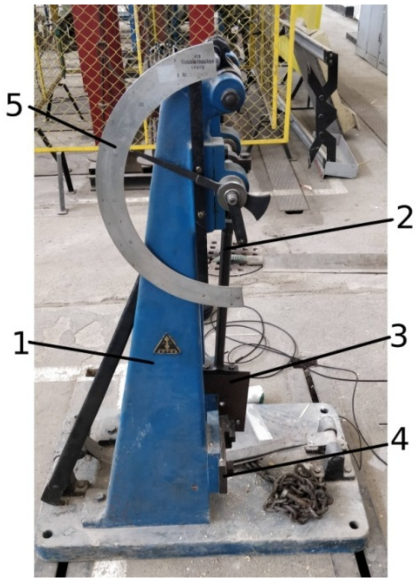

Fig. 1. **Pendulum apparatus:** 1 – frame; 2 – swing arm; 3 – knife support; 4 – plant fixing support; 5 – angle indicator

The device operates on the principle of a compound pendulum, in which a long arm suspended at one end with a knife fixed at the opposite end is made to oscillate in the vertical plane. During the experiment, stalk was mounted at the lowest oscillating point, where the balance line is located. The arm is then offered an angular displacement. When it is released, it gains speed, as it moves downwards until it reaches maximum speed.

The following formula was used to determine the energy required for cutting: [4]

$$E = W_t \cdot R(\cos\theta_c - \cos\theta_0) \quad (1)$$

where E – energy required for cutting, J;
Θ_c – maximum angular displacement of the pendulum arm after cutting, degrees;
Θ_0 – maximum angular displacement in the absence of cutting, degrees;
W_t – total weight of the pendulum (swing arm), N;
R – distance between the center of gravity of the swing arm and the axis of rotation, m.

The speed of the knife in the lowest position of the pendulum arm can be obtained with the following formula: [4]

$$v = \omega \cdot L = \sqrt{\frac{2 \cdot W_t \cdot R(1-\cos\theta)}{l}} \cdot L \quad (2)$$

where v – speed of the knife in its lowest position, $m \cdot s^{-1}$;
ω – angular velocity of the swing arm at its lowest position, rad/s;
L – length of the swing arm, m;
W_t – total weight of the pendulum (swing arm), N;
R – distance between the center of gravity of the swing arm and the axis of rotation, m;
Θ – maximum initial angle at which the pendulum arm is raised, degrees;
I – mass of moment of inertia of the components of the pendulum around the axis of rotation, $kg \cdot m^2$.

The knife approach angle is the angle that the cutting edge of the knife makes with the normal tothe knife direction of movement.

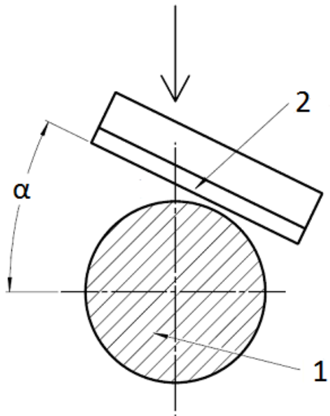

Fig. 2. **Knife approach angle:** 1 – plant; 2 – knife; *α* – knife approach angle

Four different approach angles, 0º, 12º, 24º and 36º, were selected to study its influences on displacements and cutting energy. To obtain the different knife approach angles, the knife was fixed in different holes drilled in the pendulum head support.

The pendulum was raised to 110º meaning a knife velocity of 5.32 $m \cdot s^{-1}$. To determine the displacement in the knife and cutting force, strain gauges were connected to the knife and linked to HBM acquisition equipment.The stain gauge was placed near the tip of the knife and as close as possible to the cutting area without the plant damaging the gauge.

Fig. 3. **Strain gauge**

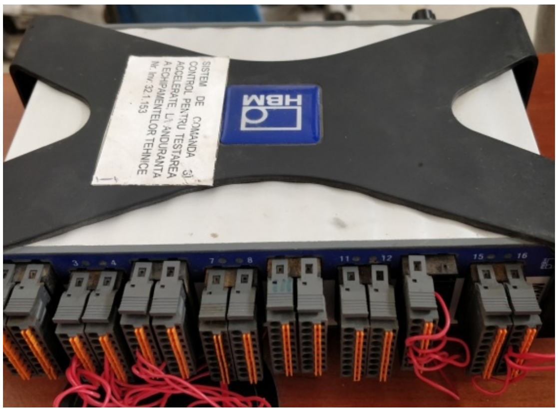

Fig. 4. **HBM acquisition equipment**

Results and discussion

Figure 5 shows the displacements obtained in the knife, when the knife is placed at an approach angle of 0º, meaningstraight cutting. Figure 6 shows the forces obtained during straight cutting.

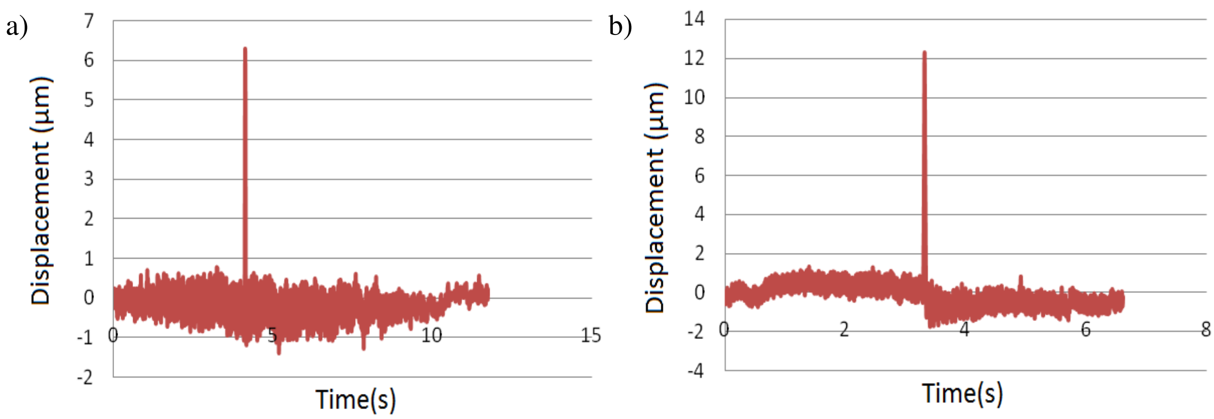

Fig. 5. **Knife displacements:** a – maize; b – sorghum

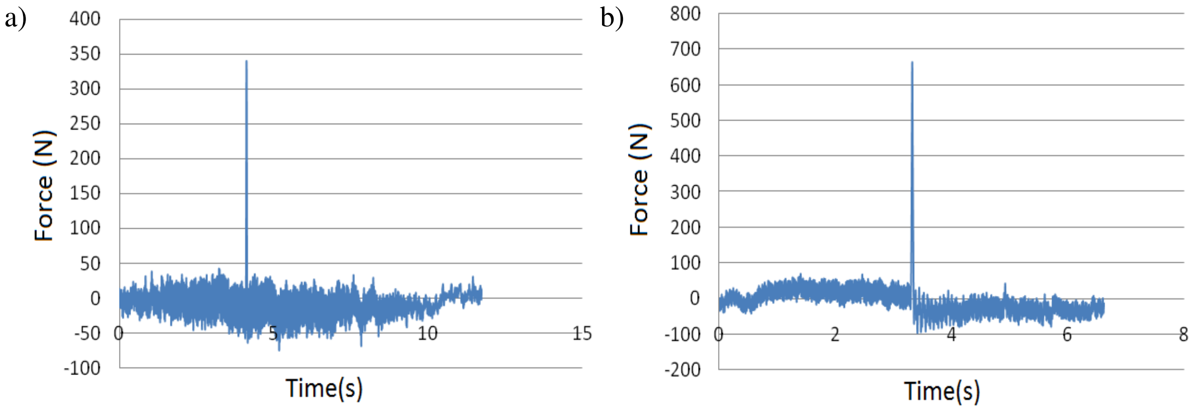

Fig. 6. **Cutting forces:** a – maize; b – sorghum

It is observed that for sorghum the values are higher, almost double. This is because sorghum has higher mechanical properties.

The energy required for the straight cutting in the case of maize stalk was determined at the value of 28.5 J, and in the case of sorghum stalk at 32 J.

Figure 7a shows the influence of the knife approach angle on the displacements of the knife for maize stalk. The graph shows a decrease of the displacements of the knife with the increase of the inclination, with a minimum value of 3.55 µm corresponding to the inclination at 36°. For this value the obtained force was 191 N.

Figure 7b shows the influence of the knife approach angle on the displacements of the knife for sorghum stalk. The minimum displacement was also obtained at the inclination of 36° with a value of 5.23 µm. For this value the obtained force was 283 N.

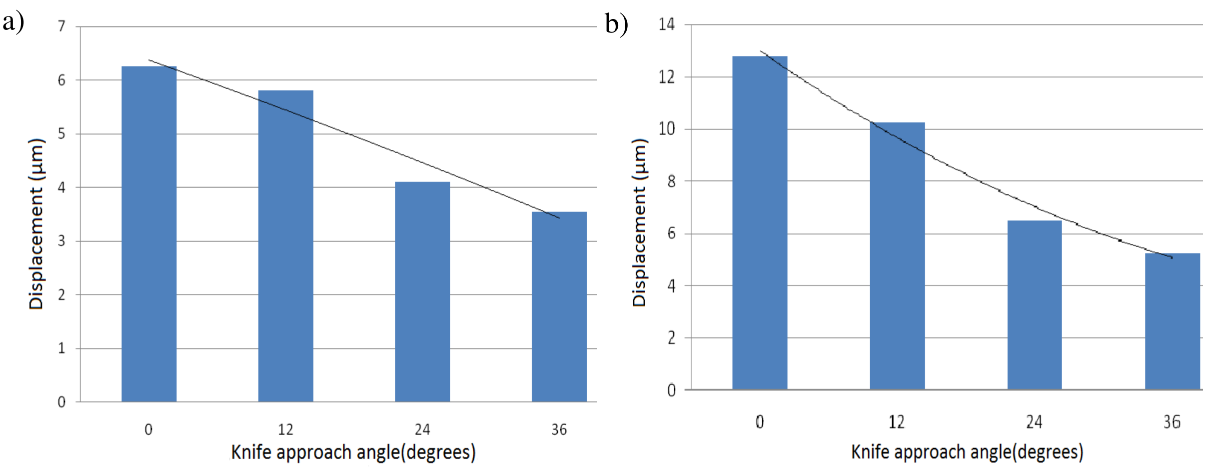

Fig. 7. **Knife approach angle influence on displacements:** a – maize;b – sorghum

Figure 8a shows the influence of the knife approach angle on the cutting energy for maize stalk. It is noticed that the cutting energy has decreased with the increase of the inclination and is minimum at 24° having the value of 22 J.

Figure 8b shows the influence of the knife approach angle on the cutting energy for sorghum stalk. The minimum cutting energy was obtained at the inclination of 36°with a value of 22J.

The high cutting energy for small knife approach angles is due to the high impact of the knife on the stalk. When the knife approach angle is higher, sliding occurs, which diminishes the impact effect of the knife and therefore decreases the energy requirement.

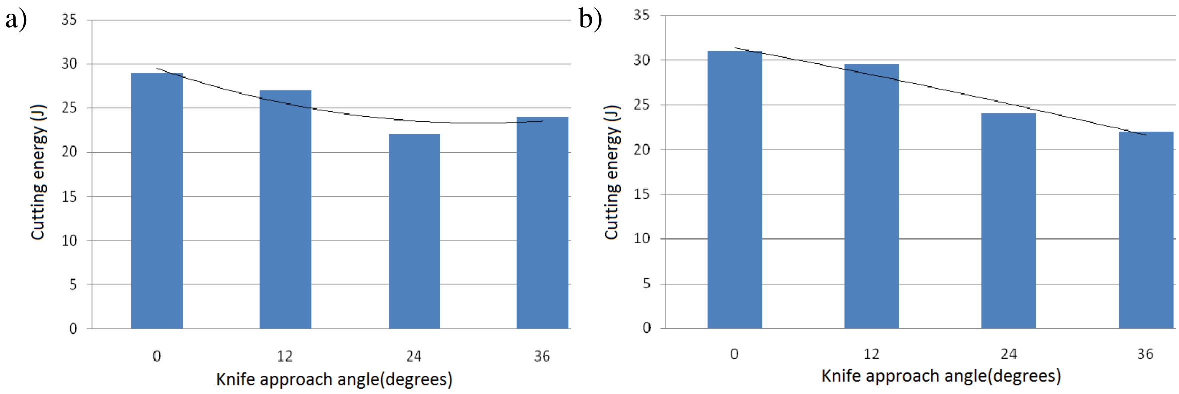

Fig. 8. **Knife approach angle influence on cutting energy:** a – maize; b – sorghum

Conclusions

This work used a pendulum type apparatus to determine the optimum value of the knife approach angle for cutting maize and sorghum stalks.The values of the displacement in the knife and of the energy required for cutting for several inclinations of the knife were measured.

Inclined cutting showed a lower displacement than the straight cutting. For both maize and sorghum the lowest displacement was observed at a knife approach angle of 36º.

Increased inclination of the knife showed improvements for the cutting energy also. The cutting energy was observed to be minimum at 24º for maize and 36º for sorghum.

Acknowledgements

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