GEOMETRIC AND KINEMATIC PARAMETERS OF BIOMASS CUTTER

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Abstract. In the handling and usage processes, sufficient density and durability of biomass (straw, read) briquettes should be provided. The orientation of straw or reed stalks had to promote binding by the pressing operation. In the previous investigations was stated that the density of the arranged reed and hemp stalk particles exceeds the recommended in standards 1000 $kg \cdot m^{-3}$ and reaches the value 1185 $kg \cdot m^{-3}$ for the arranged hemp stalk particles with the length 150 mm and briquetting pressure 212 MPa. The specific briquetting energy of coarse chopped arranged reed and hemp stalk particles ranges from 51.61 $kJ \cdot kg^{-1}$ to 67.23 $kJ \cdot kg^{-1}$. In comparison the fine chopped reed particle briquetting energy gives the maximum specific energy 40 $kJ \cdot kg^{-1}$. The splitting force of the hemp stalk briquettes ranges from 110 $N \cdot mm^{-1}$ to 122.37 $N \cdot mm^{-1}$, splitting force of the arranged reed particles lies between 65 $N \cdot mm^{-1}$ and 80 $N \cdot mm^{-1}$. The specific splitting force is 2 to 5 times higher than for non arranged stalk briquettes. Arranged structure of biomass particles in briquetting die is recommended for significant increasing durability of stalk material briquettes. New briquetting equipment is necessary to be designed for biomass particle arranging before pressing. The goal of the investigation is to evaluate the geometric and kinematic parameters of the stalk biomass cutter. The article presents the modelling and experimental results of the biomass cutter designed for coarse cutting of arranged biomass stalks.

Keywords: biomass, cutters, cutting energy.

Introduction

In the handling and usage processes, sufficient density and durability of biomass (straw, read) briquettes should be provided. The orientation of straw or reed stalks had to promote binding by the pressing operation. In the previous investigations was stated that the density of the arranged reed and hemp stalk particles exceeds the recommended in standards 1000 $kg \cdot m^{-3}$ and reaches the value 1185 $kg \cdot m^{-3}$ for the arranged hemp stalk particles with the length 150 mm and briquetting pressure 212 MPa. The specific briquetting energy of coarse chopped arranged reed and hemp stalk particles ranges from 51.61 $kJ \cdot kg^{-1}$ to 67.23 $kJ \cdot kg^{-1}$. In comparison the fine chopped reed particle briquetting energy gives the maximum specific energy 40 $kJ \cdot kg^{-1}$. The splitting force of the hemp stalk briquettes ranges from 110 $N \cdot mm^{-1}$ to 122.37 $N \cdot mm^{-1}$, splitting force of the arranged reed particles lies between 65 $N \cdot mm^{-1}$ and 80 $N \cdot mm^{-1}$ [1]. The specific splitting force is 2 to 5 times higher than for non arranged stalk briquettes. The specific cutting energy for 100 mm long stalk particles is more than 7 times lover then for the particle size used in the traditional briquetting process. The theoretically calculated value of the specific cutting energy is below 1 $kJ \cdot kg^{-1}$. The structure of long stalk briquettes provides higher durability because long stalks work like reinforcement bars. Arranged structure of biomass particles in briquetting die is recommended for significant increasing durability of stalk material briquettes. New briquetting equipment is necessary to be designed for biomass particle arranging before pressing. Reeds in several countries are commonly used for roof building. The necessary material for it is collected in bundles. This harvesting technology could be used also for reed material planed for briquetting. Stalks in bundles already are oriented in the direction necessary for it. The topicality of this paper is connected with the bundle cutter which provides stalk orientation after cutting. The goal of the investigation is to evaluate the geometric and kinematic parameters of the stalk biomass cutter. The article presents the modelling and experimental results of the biomass cutter designed for coarse cutting of arranged biomass stalks.

Materials and methods

The study was carried out at the Institute of Mechanics, Faculty of Engineering. There are several methods used in biomass cutting. It has been proved that the lowest energy consumption of stalk shredding provides for shear cutting [2].

In the result of the research a cutting method with two rotating knife rollers was developed, Fig. 1. The experimental model of the cutter was designed end experimentally tested. The cutter consists of two rotors connected with each other with the gears 3. The blades 2 are mounted on the rotor and are powered by an electric motor 4. Biomass (common reed stalks) is fed to the knives on the tray 5.

Angular velocity of the rotor was measured using the tachogenerator 6. To determine the geometric and kinematic parameters of the cutter a mathematical model was worked out. The main geometric parameters are given in Figure 2.

In order to achieve high-quality cutting the blades should contact during rotation. Suppose that the cutting edges, points 1 and 2, Figure 3, are coming close to each other and cut down a reed. To avoid jamming the mechanism, the blade of the knife edge and the plane must have the proper clearance around moving.

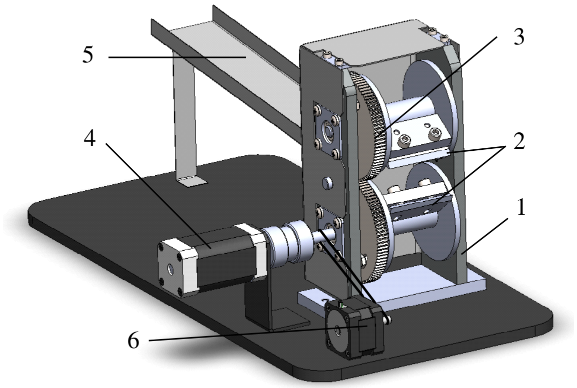


Fig. 1. **Experimental cutter design:** 1 – body; 2 – blades; 3 – gears; 4 – electric drive; 5 – tray; 6 – tachogenerator

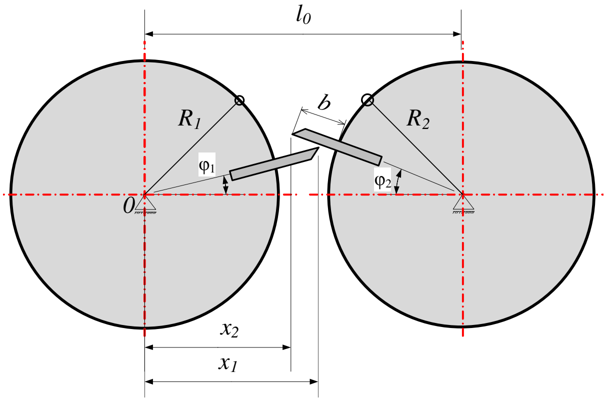


Fig. 2. **Geometric parameters of the cutter:** R_1 and R_2 – radius of the rotors, b – knife edge projection outside the rotor, l_0 – distance between the rotor center, x_1, x_2 – knife blade coordinates

In order to design the proper knife shape, the distances between the knife edges and knife-plane tangent points Δy_1 and Δy_2 and knives overlap Δx, Fig. 3, should be calculated. To create a knife movement kinematics model, assume the following notation, Fig. 3: points 1 and 2 – knife edge points, points n_1 and n_2 – points on the knife planes at the overlap Δx.

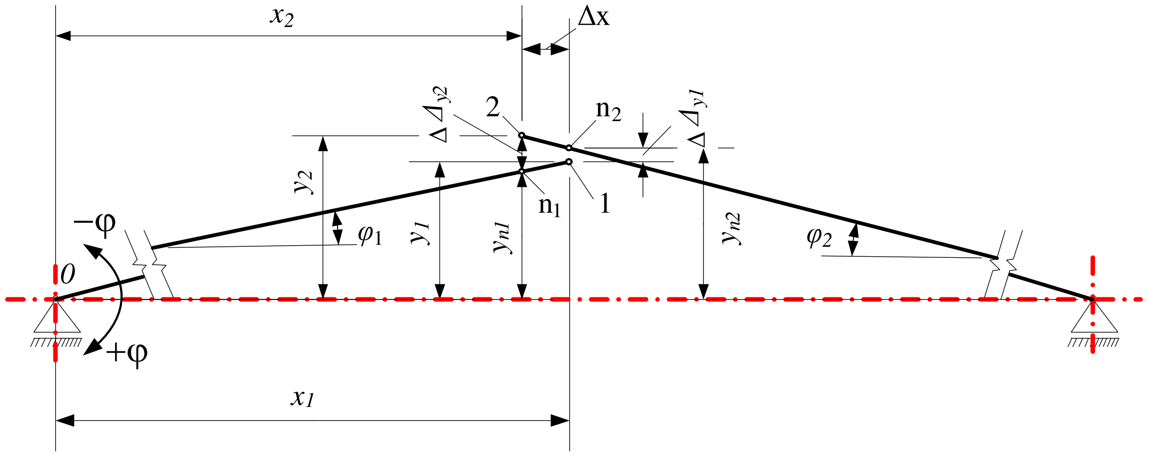


Fig. 3. **Scheme of calculations**

At first, calculate knife edge coordinates x_1 and x_2:

$$x_1 = (R+b)\cdot\cos\varphi_1, \tag{1}$$

$$x_2 = (2R+b)-(R+b)\cdot\cos\varphi_2. \tag{2}$$

Assume that $l_0 = 2R+b$, Fig. 2.

Overlap of the blades:

$$\Delta x = x_1 - x_2 = (R+b)\cdot\cos\varphi_1 - \left(2R+b\right) + (R+b)\cdot\cos\varphi_2, \tag{3}$$

after simplifying:

$$\Delta x = (R+b)\cdot(\cos\varphi_1 + \cos\varphi_2) - \left(2R+b\right). \quad (4)$$

Knife edge coordinates y_1 and y_2 can be calculated according formulas (5) and (6):

$$y_1 = (R+b)\cdot\sin\varphi_1, \quad (5)$$

and

$$y_2 = (R+b)\cdot\sin\varphi_2. \quad (6)$$

Coordinates of the points n_1 and n_2 were calculated according to equations (7) and (8):

$$y_{n1} = y_1 - \Delta x\cdot tg\varphi_1, \quad (7)$$

and

$$y_{n2} = y_2 - \Delta x\cdot tg\varphi_2. \quad (8)$$

The distances between the knife edge and knife-plane tangent points Δy_1 and Δy_2 were calculated according to formulas: $\Delta y_1 = y_1 - y_{n2}$ and $\Delta y_2 = y_2 - y_{n1}$.

Given the equations (5), (6), (7) and (8), the distances Δy_1 and Δy_2 were calculated:

$$\Delta y_1 = (R+b)\cdot(\sin\varphi_1 - \sin\varphi_2) + [(R+b)(\cos\varphi_1 + \cos\varphi_2) - (2R+b)]\cdot tg\varphi_2, \quad (9)$$

and

$$\Delta y_2 = (R+b)\cdot(\sin\varphi_2 - \sin\varphi_1) + [(R+b)(\cos\varphi_1 + \cos\varphi_2) - (2R+b)]\cdot tg\varphi_1. \quad (10)$$

The knife mutual movement speed in the direction of x-axis was determined by differentiating Δx overlap by time. Assume that the rotational speed is constant, and then the angles φ_1 and φ_2 are expressed by formulas (11) and (12);

$$\varphi_1 = \varphi_{01} + \omega\cdot t, \quad (11)$$

$$\varphi_2 = \varphi_{02} + \omega\cdot t, \quad (12)$$

where φ_{01}, φ_{02} – initial angles, rad;
ω – angular velocity, s^{-1};
t – time, s.

Inserting equations (11) and (12) in formula (4), and differentiating, we obtain the velocity change between the knives, equation (13):

$$v_x = -\omega\cdot\left(R+b\right)\cdot\left[\sin\left(\varphi_{01} + \omega\cdot t\right) + \sin\left(\varphi_{02} + \omega\cdot t\right)\right]. \quad (13)$$

The obtained equations 4, 9, 10 and 13 were used to simulate the kinematic parameters of the cutter.

To determine the cutting energy of the reed stalks, the experimental tests were carried out. Energy consumption for reed stalk cutting has been investigated using experimental equipment Fig. 1. To calculate the cutting energy the electric drive voltage and current consumption were measured. The measurement data were recorded with a virtual data logger *Picoscope* and calculated with *Excel* software. The total cutting power for one cut was represented by the area underneath the entire power – time curve, Fig. 4. No-loading energy was recorded and subtracted from the total energy.

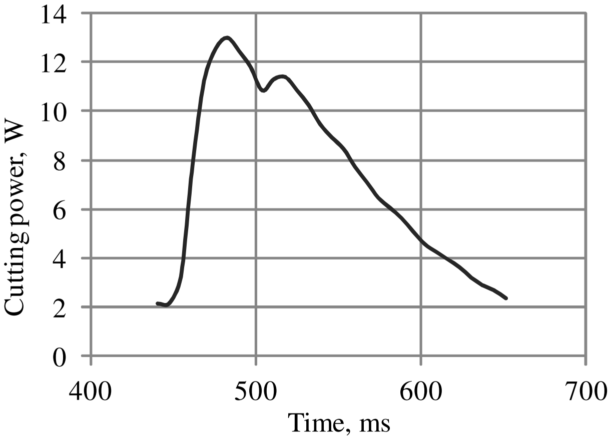


Fig. 4. **Cutting power depending on the cutting time**

The calculation of the energy for one cut E_1 is done according to equation (14):

$$E_1 = \left[\left(\frac{P_2 + P_1}{2} \right) \Delta t + \left(\frac{P_3 + P_2}{2} \right) \Delta t + \ldots + \left(\frac{P_n + P_{n-1}}{2} \right) \Delta t \right], \tag{14}$$

where E_1 – energy for one cut, J;
P_1 – first data point, W;
P_2 – second data point, W;
P_n – n^{th} data point, W;
Δt – time interval between the data points, ms.

The total energy E was the sum of the one cut energy E_1 of the sample. The reed samples were prepared using 3 and 5 reed stalks for one sample. For the experiments air dried reed stalks were used. The samples were weighed with electronic scales.

The specific cutting energy E_s was calculated for every reed stalk by equation (15):

$$E_s = \frac{E}{n_{st} \cdot n_{cut} \cdot m_s}, \tag{15}$$

where E_s is the specific cutting energy, $\text{J} \cdot \text{g}^{-1}$;
n_{st} – quantity of the stalks;
n_{cut} – number of cuttings;
m_s – specific mass of the stalks, g.

The specific mass of the stalk was calculated according to equation (16):

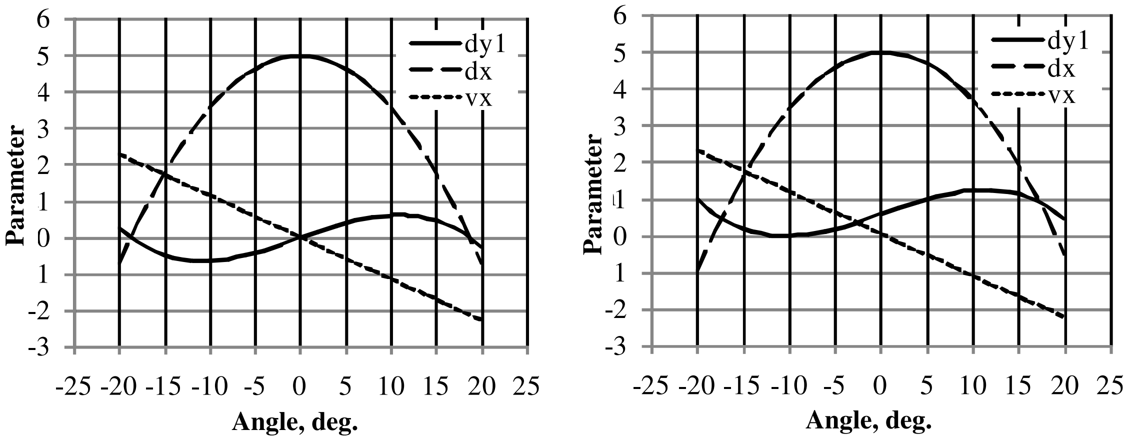
$$m_s = \frac{m}{n_{st}}, \tag{16}$$

where m_s – specific mass of the stalks, g;
n_{st} – quantity of the stalks.

Calculations were performed according to the experimental model size: R = 42.5 mm and b = 5 mm. The specific cutting energy was calculated for three overlaps of the knives: 0.8, 3.0 and 5.2 mm.

Results and discussion

To determine the geometric and kinematical parameters of the cutter suppose that the drive rotor is the left rotor in Fig. 3. Suppose that the rotor rotation is a clockwise direction and the angle is equal to zero if a knife lies on the right of the centre of rotation. The change of the parameters was modelled for the rotation angles -25° < φ < 25°. The distance between the knife edge and knife-plane tangent point Δy_1, and the knife overlap was determined for different rotation angles and the angular differences. It was assumed that at the starting point $|\varphi_{01}| < |\varphi_{02}|$. The angular difference was calculated as $|\varphi_{02}| - |\varphi_{01}|$. Cutting of the biomass occurs when the knives come close each other. If the rotor angular difference $\Delta\varphi$ is equal to zero, the blades are facing directly to the edges when the overlap of the knives is equal to zero (Fig. 5a).



a) $\Delta\varphi = 0$ b) $\Delta\varphi = 0.8$

Fig. 5. **Kinematic and geometrical parameters depending on the rotation angle:** *dy*1 – distance between the knife edge and knife-plane tangent points Δy_1, mm; *dx* – overlap of the blades, mm; *vx* – velocity change between the knives, $m \cdot s^{-1}$

Further rotation of the knife blade crosses the other knife plane and cuts into it. The maximum cut-in depth reaches 0.62 mm (Fig. 6). To avoid jamming of the mechanism, a proper form of the knife surface should be designed.

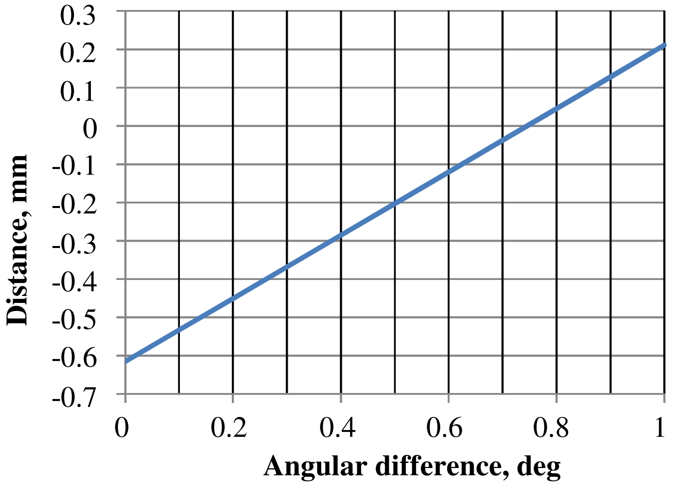


Fig. 6. **Maximum penetration of the knife edge 1 in the knife-plane n_2 depending on the angular difference**

Such location of the blade provides biomass shear cutting. The mutual velocity of the blades exceeds 2 $m \cdot s^{-1}$, Fig. 5a. Increasing of the angular difference $\Delta\varphi$ decreases cut-in depth in the knife plane. If the angular displacement reaches 0.8 degrees, a blade of the knife 1 just touches the other knife plane when the overlap of the knives reaches 3 mm. The mutual movement of the blade speed is 1.2 $m \cdot s^{-1}$, Fig. 5b. As the knife blade is in contact with the plane direct shear cutting does not occur.

Specific cutting energy was stated for three overlays of the knives with different rotation velocity. Samples were formed with three and five stalks, Fig. 7.

As can be seen from Figure 7, the specific cutting energy of the samples with three stalks is less than for samples from five stalks of the knives overlay to 3.0 mm. If the knife overlay is 5.2 mm, the specific cutting energy decreases.

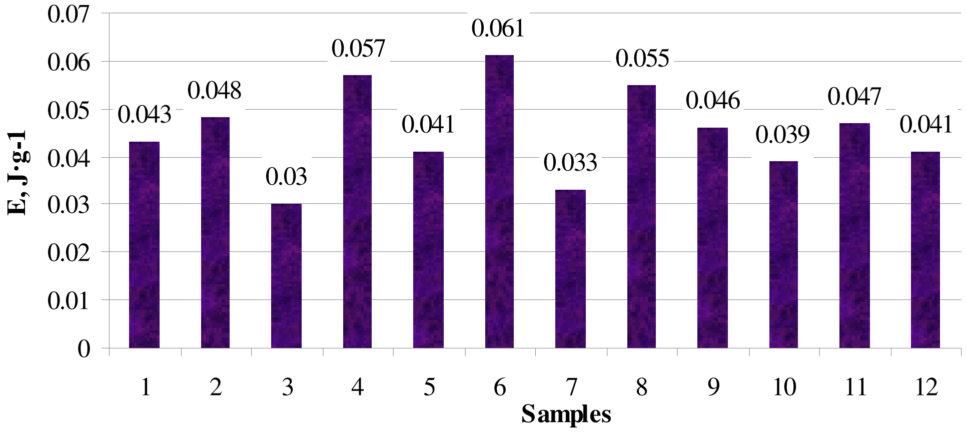


Fig. 7. **Specific cutting energy for different cutter parameters**

Table 3

Explanation for Fig. 7

Number of samples	**Overlay, mm**	**Angular velocity, s^{-1}**	**Number of stalks**	**Number of samples**	**Overlay, mm**	**Angular velocity, s^{-1}**	**Number of stalks**
1	1.3	24	3 stalks	7	3	31.4	3 stalks
2	1.3	24	5 stalks	8	3	31.4	5 stalks
3	1.3	31.4	3 stalks	9	5.2	24	3 stalks
4	1.3	31.4	5 stalks	10	5.2	24	5 stalks
5	3	24	3 stalks	11	5.2	31.4	3 stalks
6	3	24	5 stalks	12	5.2	31.4	5 stalks

Conclusions

1. If the rotor angular difference is equal to zero, the blades are facing directly to the edges and provide biomass shear cutting with the mutual velocity of the blades 2 $m \cdot s^{-1}$. Maximum of the cut-in depth of the blade in the knife plane reaches 0.62 mm.
2. Increasing of the angular displacement of the blades to 0.8 ° decreases the cut-in depth of the blade to zero and decreases the mutual velocity of cutting to 1.2 $m \cdot s^{-1}$.
3. The cutting energy ranges from 0.03 $J \cdot g^{-1}$ to 0.04 $J \cdot g^{-1}$ for the samples of three stalks and from 0.05 $J \cdot g^{-1}$ to 0.06 $J \cdot g^{-1}$ for the samples of 5 stalks when the blade overlap does not exceed 3mm.
4. If the blade ceiling is 5.2 mm, the specific cutting energy of three stalks is rising to 0.05 $J \cdot g^{-1}$, but for five stalks goes down to 0.04 $J \cdot g^{-1}$.
5. The geometric and kinematic model will be used to design the proper blade shape and determine the most appropriate blade speed.

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