BRIQUETTING MECHANISM ANALYSIS FOR SOLID BIOFUEL PRODUCTION

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Abstract. For design of energy efficient compacting mechanisms it is necessary to understand biomass densification behavior. Experimental investigation of common reeds (Phragmites australis) particles compacting in closed die had been realized by laboratory hydraulic press equipment. During compacting the maximum pressure was 212 MPa. Force – displacement characteristics of compacting are nonlinear curves with two quasilinear parts. Similar nonlinear characteristic rhomboid mechanism (Patent LV 14201) calculation and simulation had been realized by MathCAD and Working Model software. The determined inertial forces for mechanism members using Working Model software do not exceed 40 N, therefore these forces can be ignored in designed mechanism calculations.

Keywords: common reeds, briquetting mechanism, rhomboid mechanism.

Introduction

The European Union energy policy determines the aim to increase using of renewable energy resources providing independence from imported energy and reduction of fossil fuel use. Substitution of fossil feedstock for energy by biomass is an important measure also for greenhouse gas (GHG) emission mitigation. Energy crop biomass has the potential to be used as feedstock for solid biomass fuel production in agriculture. Common reeds are important natural biomass resource, because there are more than 2000 lakes with shorelines overgrown by common reeds in Latvia. The common reeds stalk material ultimate tensile strength is 330±29 $N \cdot mm^{-2}$. As common reeds are the strongest stalk material among other energy crops, they can be used as a representative energy crop in investigations of mechanical properties.

Biomass compacting represents the technology for conversion of biomass into a solid biofuel in a shape of briquettes and pellets. The harvested energy crop stalk biomass is a material of low bulk density (60-80 $kg \cdot m^{-3}$), therefore compacting of biomass is one of the important processes for effective handling, transport and storage of this biomass fuel material. The quality and strength of the compacted mass depends on the physical properties of the material, applied force and other process variables. The technologies used for binderless biomass briquetting include machines based on screw and piston-pressed technology. Biomass in screw-pressed technology is extruded continuously by a screw through a taper die, which is externally heated to reduce friction. With piston-press technology, biomass is punched or pushed (corresponding to the impact or hydraulic technology, respectively) into a die by a reciprocating ram or plunger by high pressure [1; 2].

In the paper, attention has been focused on the hydraulic piston press and cold pressing technology. Studying the densification behavior of common reed particles through experiments should help understand the densification mechanisms that could produce high quality compacted products and design energy efficient compacting mechanisms.

Knowledge of the fundamental compaction properties of particles of different biomass species, sizes, shapes, chemical compositions, bulk densities and particle densities is essential to optimize densification processes. It is also important to understand the compaction mechanisms in order to design energy-efficient compaction equipment and to quantify the effects of various process variables on density and durability [3; 4].

The process of biomass compaction can be described with force-displacement characteristics. On the basis of the biomass briquetting investigation results were designed a similar nonlinear characteristic press mechanism in a shape of rhomboid linkage with hydraulic drive (Patent LV 14201).

The aim of the present research is to calculate the rhomboid mechanism force-displacement characteristics and compare with the experimental investigation of common reeds particles compacting characteristics for conformity assessment.

Materials and methods

The main task of this investigation was determination of the compacting force-displacement characteristics from compacting of different size common reeds particles. The compaction experiments had been carried out in a closed die with diameter 35 mm by means of laboratory hydraulic press equipment (Fig. 1). The maximum pressure 212 MPa had been achieved in compacting. The dosage of 35 grams of chopped common reeds particles was used for every briquette pressing.

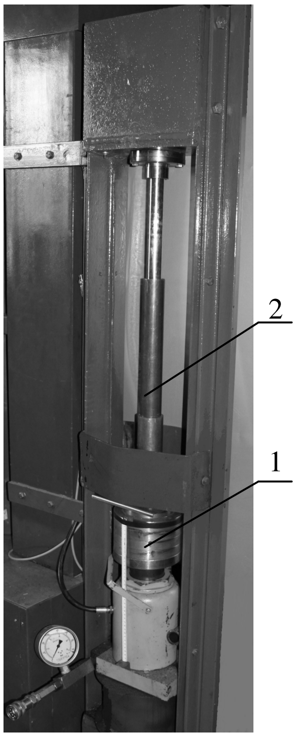

Fig. 1. **Hydraulic press:** 1 – press cylinder; 2 – closed die

Reed stalk material biomass with moisture content of 8 % was chopped to different length and was used for densification. The moisture content was determined using the standard ASAE S358.2 DEC93, where oven drying of the samples was carried out at 103 ºC for 24 h [5]. The particle size of the chopped common reeds was determined from the sieve analysis: <0.5; 1-2; 3-4; 5-6; 7-8; 12-13; 22-23; 32-33 mm.

The use of the rhomboid press mechanism for biomass particle compacting was analyzed. For mechanism (Fig. 2) simulation and determination of inertial forces Working Model software was used [6]. The spring 8 characteristic describes biomass behavior in the pressing cylinder. The mass of the mechanism members 4, 5 and 2, 6 for simulation was assumed 12.8 and 5.3 kg and length – 1.012 and 0.42 m from design. The velocity of the hydraulic cylinder piston 3 was calculated by equation:

$$v = \frac{Q}{A}, \tag{1}$$

where v – velocity of hydraulic cylinder piston, $m \cdot s^{-1}$;
Q – pump flow at rated speed, $m^3 \cdot s^{-1}$;
A – area of cylinder, m^2.

For velocity calculation the hydraulic system parameters of the tractor Claas Ares 557 were used [7] $Q = 60\ l \cdot min^{-1}$ and the rhomboid press mechanism hydraulic cylinder diameter – 60 mm.

The rhomboid press mechanism force-displacement characteristics were obtained with MathCAD software ignoring insignificant inertia and friction forces. The mechanism scheme is shown in Fig. 3.

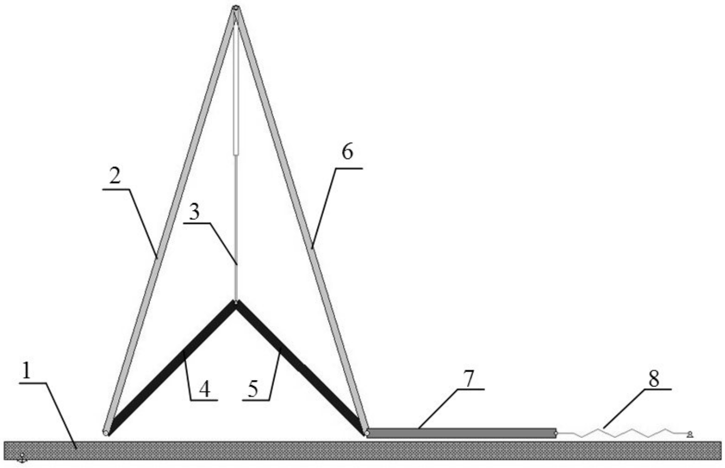

Fig. 2. **Rhomboid mechanism in Working Model software:**
1 – base; 2, 4, 5, 6 – members of mechanism; 3 – actuator (hydraulic cylinder); 7 – piston, 8 – spring (pressing material characteristics)

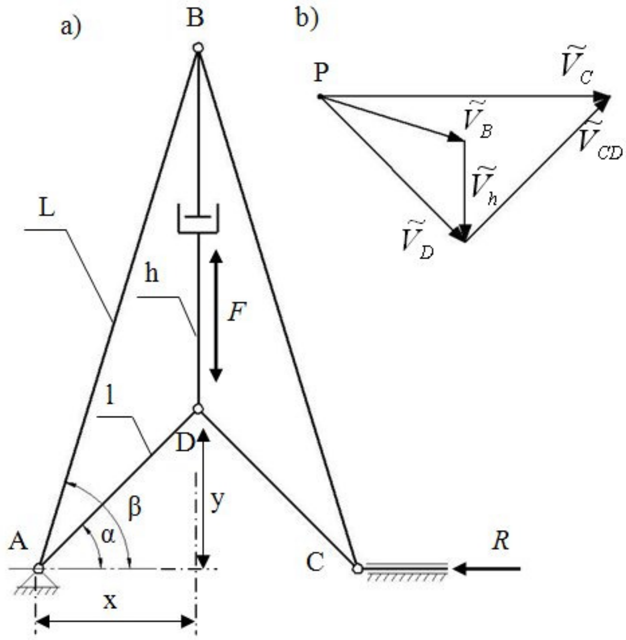

Fig. 3. **Structural scheme:** a – rhomboid mechanism; b – velocity vectors; L, l – length of mechanism members; h – length of hydraulic cylinder

From the velocity vectors scheme (Fig. 3. b):

$$V_h = V_D \cos\alpha - V_B \cos\beta; \quad (2)$$

$$V_C = 2V_D \sin\alpha = 2V_B \sin\beta, \quad (3)$$

where $\cos\alpha = \frac{x}{l}; \cos\beta = \frac{x}{L};$

$\sin\alpha = \frac{y}{l};\ \sin\beta = \frac{h+y}{L};$

V_h – velocity of hydraulic cylinder drive, m·s^{-2};
V_D – velocity of point D;
V_B – velocity of point B;
V_C – velocity of point C;
h – length of hydraulic cylinder;

x, y – position of point D;
l, L – length of mechanism members;
α, β – position angles of mechanism members.

Hence

$$V_h = \frac{V_D x}{l} - \frac{V_B x}{L}. \tag{4}$$

Replace V_D and V_B form equation (3):

$$V_h = \frac{V_C x}{2\sin\alpha l} - \frac{V_C x}{2\sin\beta L}. \tag{5}$$

Hence

$$V_h = \frac{V_C x}{2y} - \frac{V_C x}{2(h+y)}. \tag{6}$$

After mathematical transformation:

$$V_h = \frac{V_C x}{2}\left(\frac{1}{\sqrt{l^2 - x^2}} - \frac{1}{\sqrt{L^2 - x^2}}\right). \tag{7}$$

For unknown force calculation we can use power equation:

$$FV_h = RV_C. \tag{8}$$

Therefore

$$R = \frac{FV_h}{V_C} \tag{9}$$

and

$$R = \frac{x}{2}\left(\frac{1}{\sqrt{l^2 - x^2}} - \frac{1}{\sqrt{L^2 - x^2}}\right)F, \tag{10}$$

where R – biomass reaction in cylinder, N;
F – force from hydraulic drive, N.

Results and discussion

The shapes of the force-displacement characteristics of compacting of different size reed particles in laboratory press equipment were similar – nonlinear curves (Fig. 4) with two quasilinear parts. The maximum piston displacement (750 mm for 32-33 mm particles) required for initial common reed particles compression to 13 MPa. Material final pressing occurs with more rapid increase of the pressing pressure and at a small piston displacement (10-20 mm). These force-displacement characteristics are necessary for design of biomass compacting mechanisms.

Force-displacement characteristics of the designed rhomboid mechanism where calculated with MathCAD software. For calculation equation (10) was used using different drive forces. Fig. 5 shows the calculated pressing force in the pressing cylinder of the rhomboid mechanism.

The designed rhomboid mechanism piston force-displacement characteristics are nonlinear curves with two quasilinear parts like the characteristics of compacting reed particles in the closed die. The piston displacement depends on the mechanism member length and hydraulic cylinder displacement. Therefore, this mechanism is suitable for compacting of smallest particles (including 7-8 mm size), if 35 g briquette is pressed in one stroke (see Fig. 4). For continuous briquetting designed rhomboid mechanism can be used also for all mentioned size particle compacting, because the necessary maximal force has been obtained at the end of the piston displacement. Innovative press mechanism in a shape of rhomboid linkage with hydraulic drive can be developed for mobile briquetting mechanism design on the basis of the tractor hydraulic system.

The determined inertial forces for mechanism members (see Fig. 2) using Working Model software are shown in Fig. 6.

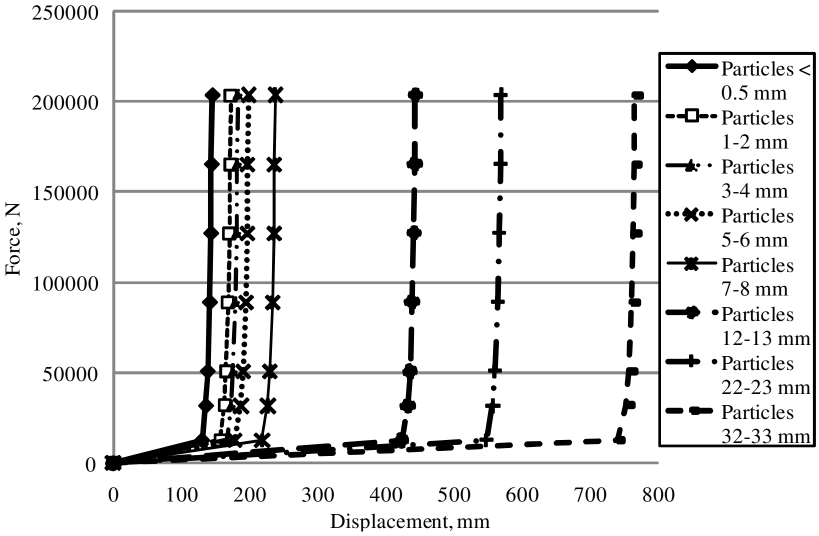

Fig. 4. **Force – displacement characteristics of compacting**

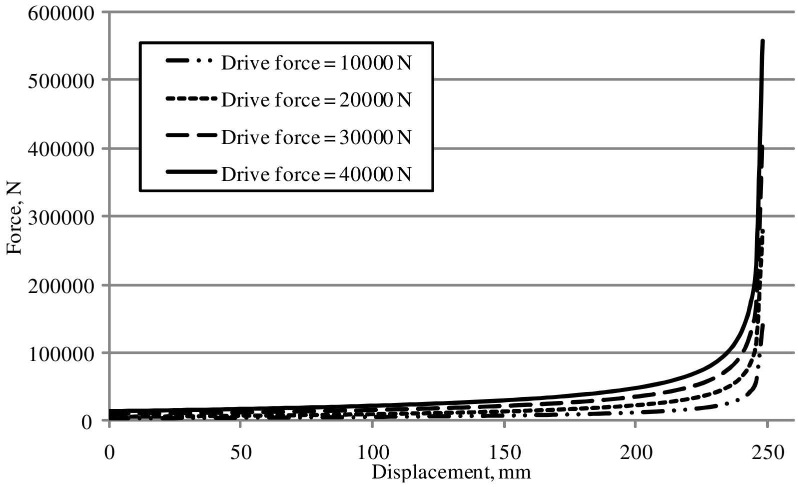

Fig. 5. **Force-displacement characteristics of calculation**

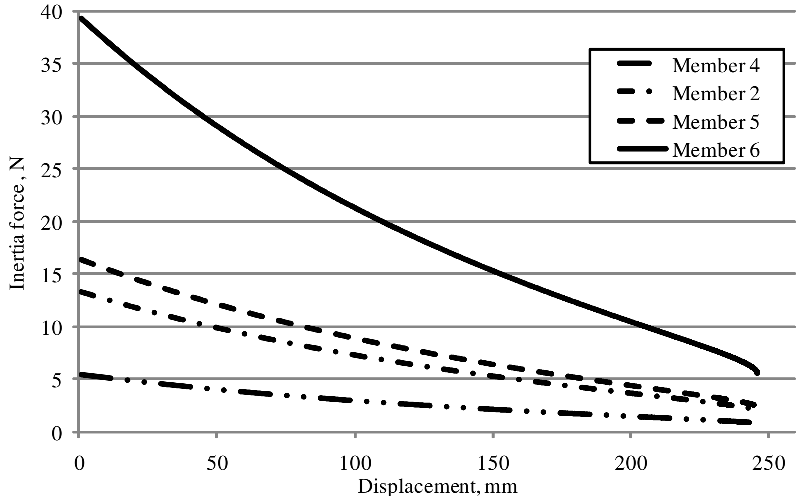

Fig. 6. **Inertia force of mechanism members**

The maximum value of the member 6 inertial force is less than 40 N and does not exceed 17 N for other rhomboid mechanism members, therefore these forces can be ignored in mechanism calculations.

Conclusions

1. The shape of force – displacement characteristics of compacting of different size reed particles were similar – nonlinear curves with two quasilinear parts.
2. The designed rhomboid mechanism (Patent LV 14201) piston force – displacement characteristics are nonlinear curves with two quasilinear parts like characteristics of compacting reed particles in a closed die.
3. The designed rhomboid mechanism with the member size 1.012 and 0.42 m is suitable for compacting of the smallest particles (including 7 – 8 mm size), if 35 g briquette is pressed in one stroke.
4. For continuous briquetting designed the rhomboid mechanism can be used also for all mentioned size particle compacting, because the necessary maximal force has been obtained at the end of the piston displacement.
5. The maximum value of the rhomboid mechanism member inertial forces does not exceed 40 N, therefore these forces can be ignored in designed mechanism calculations.

Acknowledgments

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