KINEMATIC ANALYSIS OF RHOMBOID PRESSING MECHANISM

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Abstract. The development of energy crops and agricultural residue utilization for energy are important goals of the rural area. Compacting represents a technology for conversation of biomass into a solid biofuel. Biomass of energy crops and agricultural residues is a material of low density (80-150 kg·m^{-3}), therefore, compacting of biomass is one of the important processes for effective handling, transport and storage of this herbaceous biomass material. The purpose of the work is innovative rhomboid pressing mechanism kinematic analysis using Working Model 2D program. Previously simple rhomboid (Galloway) mechanism kinematic parameters with Mathcad program were obtained. The kinematic of the same mechanism was modelled with Working Model 2D program. Comparing the values of the kinematic parameters from Mathcad and Working Model 2D program modelling good compliance (5.2 %) of the results was obtained. This justifies that the Working Model 2D program can be used for successful kinematic modelling of planar mechanisms. Using the Working Model 2D program addition options (variety of joints and constraints) the kinematic model of the hydraulically operated rhomboid pressing mechanism was obtained. Velocity and acceleration values for links and points during the working cycle were determined. Kinematic analysis would be a basis for further mechanism design optimization.

Keywords: rhomboid pressing mechanism, kinematic analysis.

Introduction

In Latvia, 2 million ha agricultural land is recognized by the EU, 0.65 million hectares used for grain and rape cultivation, 0.65 million hectares used as pasture. Some 700 000 hectares are not used for the traditional agricultural production, whereof 250 000 are not used [1] at all! Bergvik Skog SIA in Latvia recommends developing the plantation of forests on these not used agricultural lands. Herbaceous energy crops for solid biofuel production can also be cultivated on these agricultural lands. This plant breeding has the advantage that it does not damage the drainage systems of land. Beside the mentioned bioenergy resources, some part (20 %) of cereal crop residues and common reeds can be used for solid biofuel production. In the technology chain after shredding of the mentioned dry biomass the densification operation occurs. The rhomboid pressing mechanism (patent LV 14201 B) was invented as a briquetting press design prototype. It is intended to power the mechanism from the tractor hydraulic systems in the countryside. As the pressure of the tractor systems is not exceeding 20 MPa, it is an important rhomboid mechanism property to serve as a force converter. The aim of this research is previously to determine the kinematic relationship between the rhomboid pressing mechanism input and output links for further dynamic parameter calculation. Systems of equations, geometric relations between the links of the manipulator rhomboid mechanism were analysed [2] in literature, but the kinematic parameters were not obtained. It is only claimed [3] that in these crank-crank types of planar linkage mechanisms, two turns of the input link results in one full turn of the output link when the input drive has the shortest link. On the other hand, it is claimed that rhomboid linkage (Galloway mechanism) is used for non-uniform [4] velocity transformation with average relationship 1:2. This statement is correct when the input drive has the longest link. With the aim to perform the rhomboid mechanism force calculations for the biomass press precise relationship between the mechanism input and output link speed is necessary to find out.

The rhomboid mechanism modelling with Working Model 2D [5] program lets to obtain both kinematic and dynamic parameters of mechanism. Using Mathcad program for simple rhomboid (Galloway) mechanism kinematic modelling allows to find the relationship between the rhomboid (Galloway) mechanism input and output link angular displacement, speed and acceleration. Working Model program is a tool for motion simulation and analysis of mechanical systems. Kinematic simulation of the rhomboid (Galloway) mechanism with Working Model 2D allows to find the relationship between the input and output link angular displacement, speed and acceleration. Comparing the modelling results of Mathcad and Working Model softwares for determination of the rhomboid (Galloway) mechanism kinematic parameters allows to verify the reliability of the Working Model 2D program modelling results. Using the Working Model 2D program addition options (variety of joints and constraints) the kinematic model of the hydraulically operated rhomboid pressing mechanism (patent LV 14201 B) is obtained. The acceleration values of the rhomboid pressing mechanism links are valid for the calculation of the forces in the mechanism.

Materials and methods

The Galloway mechanism is a plane linkage with one pair of equal length shorter links, and one pair of equal length twice longer links, forming a rhomboid [6] geometry. Fig.1 shows the rhomboid mechanism with proportions of links, recommended by Galloway. In a Galloway crank – crank type mechanism single rotation of the input longer link results in two full rotations of the output link. Dependence of the output shorter link turning angle $\Psi(\Phi)$ or $\varphi(\Phi)$ on the turning angle of the input longer link Φ is expressed by equation (1) and conditions (2):

$$\Psi(\Phi) := 2\arcsin\left(\frac{a\sin(\pi-\Phi)}{\sqrt{c^2+a^2+2ac\cos(2\pi-\Phi)}}\right), \tag{1}$$

$$\varphi(\Phi) := \begin{vmatrix} \Psi(\Phi) \text{ if } \Phi < \dfrac{2\pi}{3} \\ (2\pi - \Psi(\Phi)) \text{ otherwise} \end{vmatrix}, \tag{2}$$

where a – linkage BC = DC (see Fig.1);
c – linkage AB = AD (see Fig.1).

The turning angle $\Psi(\Phi)$ of the shortest link is used as auxiliary variable and conditions (2) let obtain the simple rhomboid (Galloway) mechanism kinematic parameters with Mathcad program.

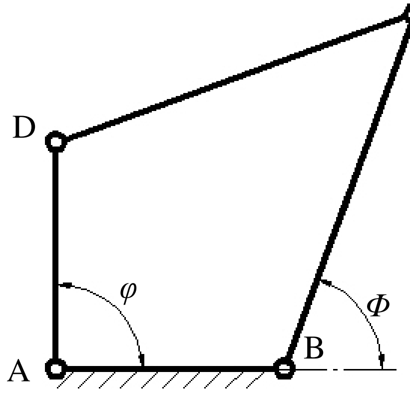

Fig. 1. **Rhomboid mechanism with Galloway proportions of links**

The kinematic of the same mechanism was modeled with Working Model 2D program.

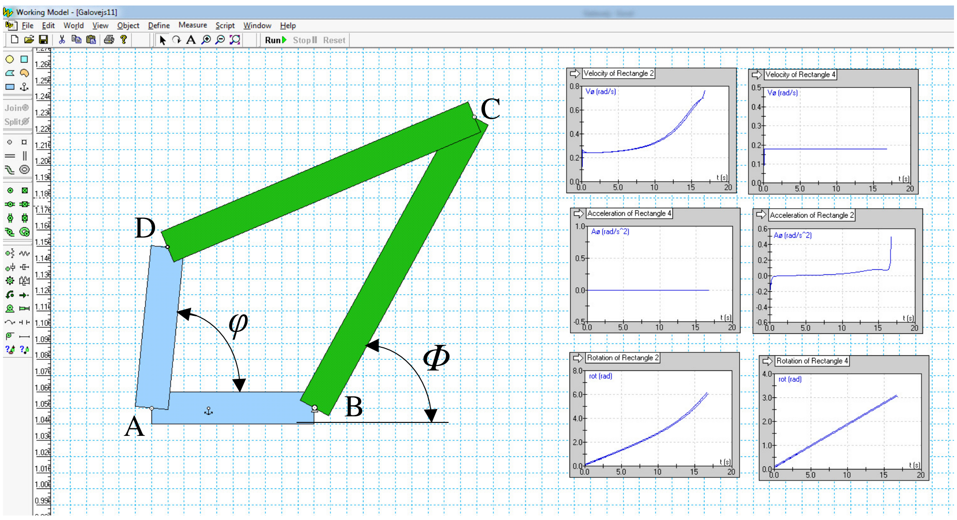

Fig. 2. **Galloway mechanism simulation in Working Model software**

The Working Model program peculiarity is that it allows during simulation to get graphs of kinematic parameters as functions of time. With a view to get the output link angle, velocity and acceleration as functions depending on the input link angle, velocity and acceleration were used in the Microsoft Excel program.

Using the Working Model 2D program addition options (variety of joints and constraints) the kinematic model of the hydraulically operated rhomboid pressing mechanism according to the patent LV 14201 B in Fig. 3 was obtained. The rhomboid mechanism pressing link (4 and 5, in Fig. 3) size is 500 mm and the supporting link (2 and 6, in Fig. 3) sizes are 1100 mm. In Working Model program the hydraulic cylinder was replaced by the linear actuator element 3.

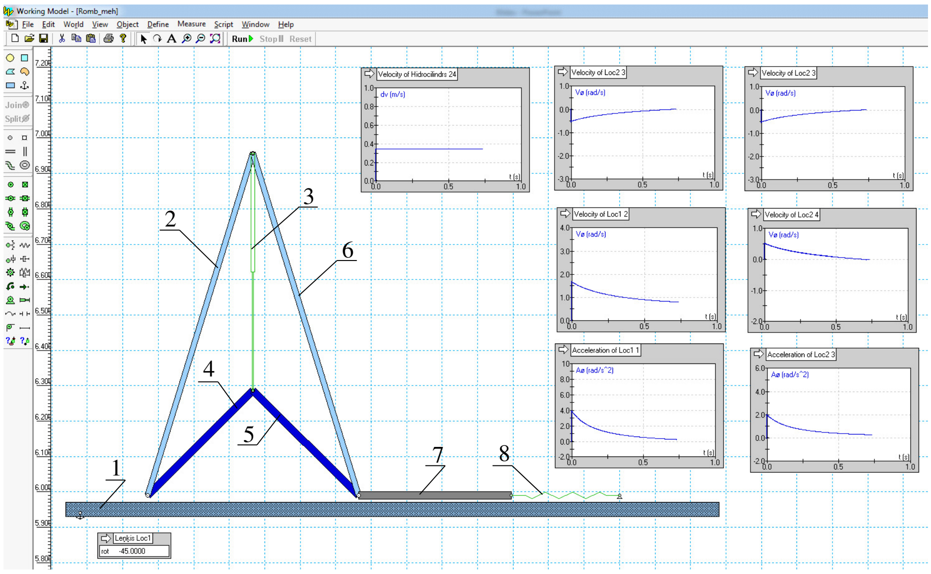

Fig. 3. **Rhomboid pressing mechanism in Working Model software:** 1 – base; 2, 4, 5, 6 – links of mechanism; 3 – actuator (hydraulic cylinder); 7 – piston; 8 – spring (pressing material characteristics)

During simulation for the actuator 3 constant drive speed 0.3 m s^{-1} was used. It corresponds to the normal hydraulic cylinder rod speed. Resistance in the pressing die was provided with the spring element 8.

Results and discussion

Fig. 4 shows the results of the shorter link turning angle $\varphi(\Phi)$ depending on the turning angle of the input longer link Φ. Comparing the calculation results of Mathcad and Working Model softwares the maximal difference between the results is 2.5 %.

Up to 180º of $\varphi(\Phi)$ the relationship between the input and output angles is linear. In the range of 180º to 360º of $\varphi(\Phi)$ there is a slight non-linearity in the relationship.

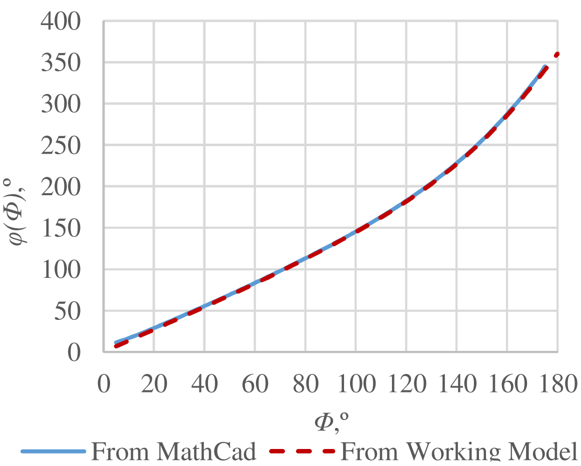

Fig. 4. **Angular displacement results**

There is a zone of uncertainty for the rhomboid (Galloway) mechanism movement at $\varphi(\Phi) \rightarrow 0^o$ and $\varphi(\Phi) \rightarrow 360^o$.

In Fig. 5 the results of the Galloway mechanism angular velocity modelling are shown. Comparing the calculation results of Mathcad and Working Model softwares the maximal difference between the results is 3.8 %. The largest deviations are observed for the input link values $\Phi \rightarrow 0^o$ and $\Phi \rightarrow 180^o$. The relationship between the input and output link speeds is non-linear in diapason of $\Phi = 0^o \ldots 180^o$.

In Fig. 6 the results of the Galloway mechanism angular acceleration are shown. Comparing the calculation results of Mathcad and Working Model softwares the maximal difference between the acceleration results is 5.2 %. Non-linearity of the angular acceleration curves is even more pronounced compared to the angular speed curves.

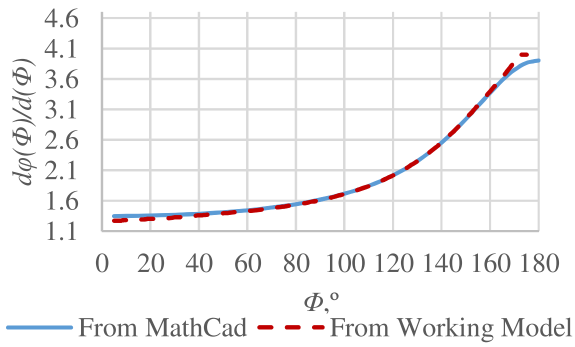

Fig. 5. **Angular velocity results**

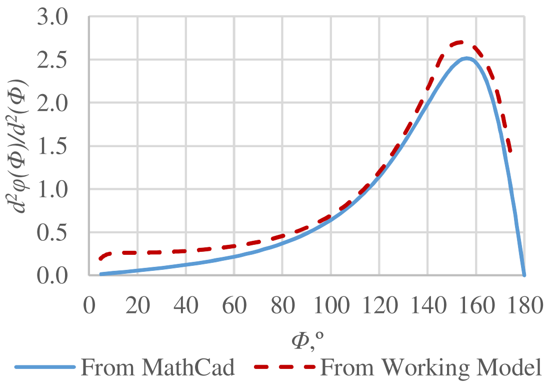

Fig. 6. **Angular acceleration results**

Comparing the modelling results of Mathcad and Working Model softwares for determination of the rhomboid (Galloway) mechanism kinematic parameters close coincidence of the results is obtained. Maximal uncertainty of the results is 5.2 % for angular acceleration and less for angular velocity and angular displacement. This is a proof that Working Model program provides equally accurate kinematic parameters of the rhomboid (Galloway) mechanism as Mathcad.

The rhomboid pressing mechanism link velocity and acceleration values during the working cycle were determined. Fig. 6 shows the results of the rhomboid pressing mechanism link angular velocity and Fig. 7 presents the rhomboid pressing mechanism link angular acceleration. During modelling for the actuator 3 constant drive speed 0.3 m s^{-1} was used.

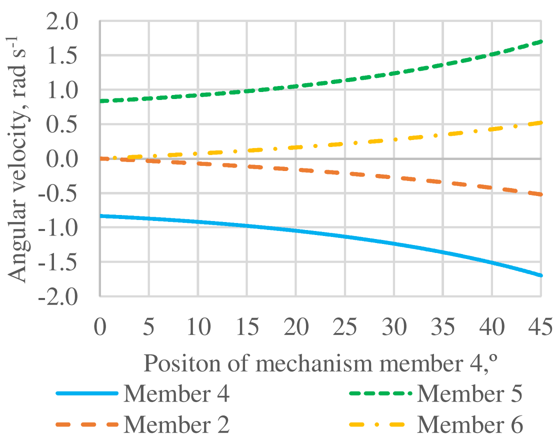

Fig. 6. **Angular velocity of rhomboid mechanism links**

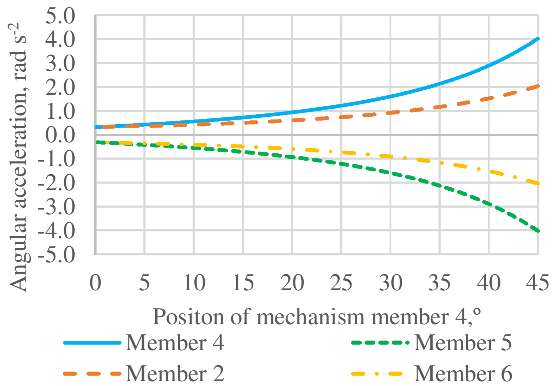

Fig. 7. **Angular acceleration of rhomboid mechanism links**

The angular displacement of the pressing links (4 and 5, in Fig. 3) of the pressing mechanism varies from 45º to 0º relative to horizontal baseline. Accordingly, the angular speed of the pressing links (4 and 5) changes from 1.61 to 0.82 $rad \cdot s^{-1}$ and the angular speed of the supporting links (2 and 6 in Fig. 3) changes from 0.52 to 0 $rad \cdot s^{-1}$. During pressing angular acceleration of the pressing links (4 and 5) changes from 4.02 to 0.31 $rad \cdot s^{-2}$ and angular acceleration of the supporting links (2 and 6) changes from 2.03 to 0.31 $rad \cdot s^{-2}$. The angular speed and acceleration during pressing decreases both for pressing and supporting links. The acceleration values of the pressing mechanism links are valid for calculation of the forces in the mechanism.

Conclusions

1. Comparing the modelling results of Mathcad and Working Model softwares for determination of the rhomboid (Galloway) mechanism kinematic parameters close coincidence of the results is obtained.
2. Maximal rhomboid modeling uncertainty of the results is 5.2 % for angular acceleration, 3.8 % for angular velocity and 2.5 % for angular displacement.
3. The angular displacement of the rhomboid pressing mechanism pressing links varies from 45º to 0º relative to horizontal baseline. Accordingly, the angular speed of the pressing links changes from 1.61 to 0.82 $rad \cdot s^{-1}$ and the angular speed of the supporting links changes from 0.52 to 0 $rad \cdot s^{-1}$.
4. During pressing angular acceleration of the pressing links changes from 4.02 to 0.31 $rad \cdot s^{-2}$ and angular acceleration of the supporting links changes from 2.03 to 0.31 $rad \cdot s^{-2}$.
5. The acceleration values of the rhomboid pressing mechanism links are valid for calculation of the forces in the mechanism.

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