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ANALYSIS OF THE KNIFE-BAR DYNAMICS MOVEMENT IN CUTTING UNIT

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Abstract

Presented in this article are the results of the analysis of the movement dynamics of a scissor-fingers cutting unit, propelled by an asymmetric crank unit. The analysis was undertaken in order to create a database for the purpose of building a model of mathematical cutting process and carrying out simulative calculations needed for efficiency optimization of crop harvesting. The analysis of the movement dynamics of a scissor-fingers cutting unit presented in this paper enables to calculate the coefficient of friction in actual machine-working condition.

Keywords: *scissor-fingers cutting unit, dynamics of a knife-bar, friction in the scissor-fingers cutting unit*

1. Introduction

A scissor-fingers cutting unit is the basic working unit in numerous agricultural machinery. It is often used in combine harvesters, forage harvesters and mowers.

The idea behind the design of the scissor-fingers cutting unit is that the unit is comprised of a moving knife-bar and a stationary fingers-bar. Knives riveted to the knife-bar form a trapeze. Blades of the knife are smooth or nicked.

Fingers attached to the fingers-bar are used for separating sheared material into portions.

The fingers are incisioned, what enables the knives' reciprocating movement and they are anteriorly narrowed – allowing easier material separation. In some designs stalks are clinched to fingers forming counter-cutting edges. However in other designs the side edges of fingers serve this function. Appropriate adhesion between knives and a stalk is provided by stresses bolted to the fingers-bar. Moreover, knife-bar rests upon a slide. The design of a scissor-fingers cutting unit is presented in Fig 1.

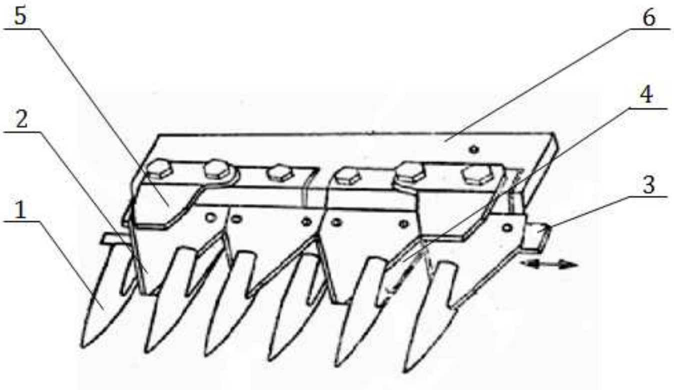

Fig. 1. An example design of a scissor-fingers cutting unit [3]:
1-finger, 2-knife, 3-knife bar, 4-counter-cutting edge, 5-knife-bar stress, 6-fingers-bar

Presented in Fig. 2, on the other hand, is a cross-sectional example of a scissor-fingers cutting unit.

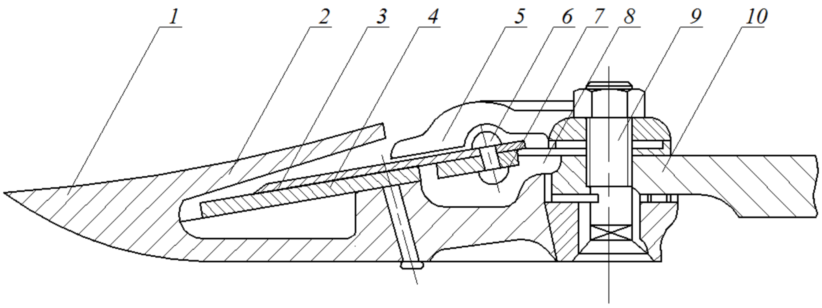

Fig.2. A cross-sectional example of a scissor-fingers cutting unit [3]:
1 – finger, 2 – fingers blade, 3 – knife, 4 – stalk, 5 – stress, 6 – rivet, 7 – moving knife-bar, 8 – slide,
9 – screw, 10 – stationary fingers-bar

The operating principle of a scissor-fingers cutting unit is that fingers separate sheared plants and divide them into portions. Subsequently every knife squeeze stalks of plants into the side edges of fingers so-called stalks (counter-cutting edges) and perform the shearing.

The most often used form of propulsion for a knife-bar's reciprocating movement are asymmetric crank mechanisms, which provide the lowest abrasion.

Shearing of plant material by the use of a scissor-fingers cutting unit is the basic technological process under crop harvesting.

The existing design solutions for cutting units are characterized by significant energy consumption of the cutting process, what consequently leads to equipping their propulsion units with high output engines. This points out the fact that known design solutions were created based mostly on constructor's intuition. It is related to the lack of mathematical models describing the cutting process by the use of a scissor-fingers cutting unit, upon which simulative calculations could be carried out that are the basis for optimization of the design of cutting units and a possible increase in the effectiveness of the cutting process ex. crop shearing.

Construction of such models is not possible without a detailed analysis of the movement of a scissor-fingers cutting unit.

2. Analysis of the movement of a knife-bar of a scissor-finger cutting unit

The work analysis of a scissor-fingers cutting unit in a dynamic aspect is somewhat troublesome because of the complexity of the whole system and the imperfection of the dynamic dependences describing it. In a scissor-fingers cutting unit we can distinguish the following parts:

- spinning wheel with a crank,
- rod,
- knife-bar,
- fingers-bar with a slide.

Experimental research of a scissor-fingers cutting unit in a dynamic aspect carried out by the authors does not provide a sufficient answer due to the fact, that it is referring to the sum of pressures inflicted on each element and does not isolate the causes of their occurrence. Additionally, the research indicates significant drag of the knife-bar's idle movement.

Therefore, the authors of this paper carried out the analysis of the dynamics of a scissor-fingers cutting unit. The model of the dynamics was compiled based on the following assumptions:

- the eccentric disc is spinning with a constant angular velocity ω,
- coulomb friction is present between the knife-bar and the slide,
- frictional resistance between a knife-bar and a rod, and between a rod and a crank are omitted.

Presented in Fig. 3 is the schematic of an asymmetric crank mechanism.

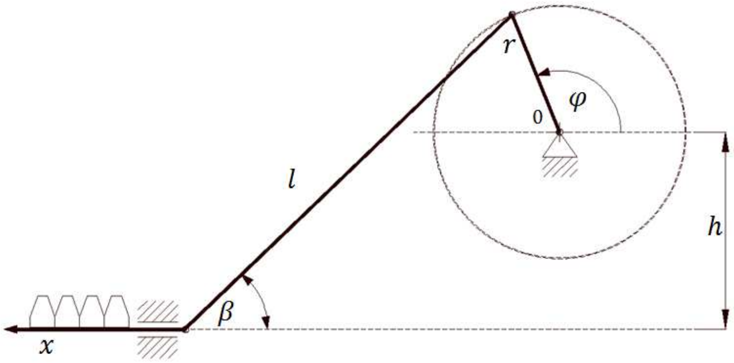

Fig 3. Schematic of an asymmetric crank mechanism:
r – crank's radius, l – rod's length, φ - crank's rotation angle, x – Knife-bar's displacement (the knife-bar in the figure has been rotated by 90° in relation to the real plain of movement), β-rod's angle against knife-bar's plain of movement, h – distance between crank's rotation axis and knife-bar's plane of movement

In order to determine knife-bar's inertia forces B_n and rod's inertia forces B_k their masses have been designated. For the design of a scissor-finger-cutting unit propelled by asymmetric crank unit the rod's mass has been designated to equate $m_k = 2{,}60$ kg and the knife-bar's mass to equate $m_n = 4{,}12$ kg.

Knife-bar's inertia force B_n is described by the equation:

$$B_n = m_n |a_n|, \quad (1)$$

where:

m_n – knife-bar's mass,
a_n – knife-bar's acceleration.

Whereas rod's inertia force B_k is described by the equation:

$$B_k = m_k\sqrt{a_x^2 + a_y^2}, \qquad (2)$$

where:

m_k – rod's mass,
a_x – ingredient along the x axis of rod's acceleration,
a_y – ingredient along the y axis of rod's acceleration.

The diagram of inertia forces described by equations (1) and (2) is presented in Fig. 4.

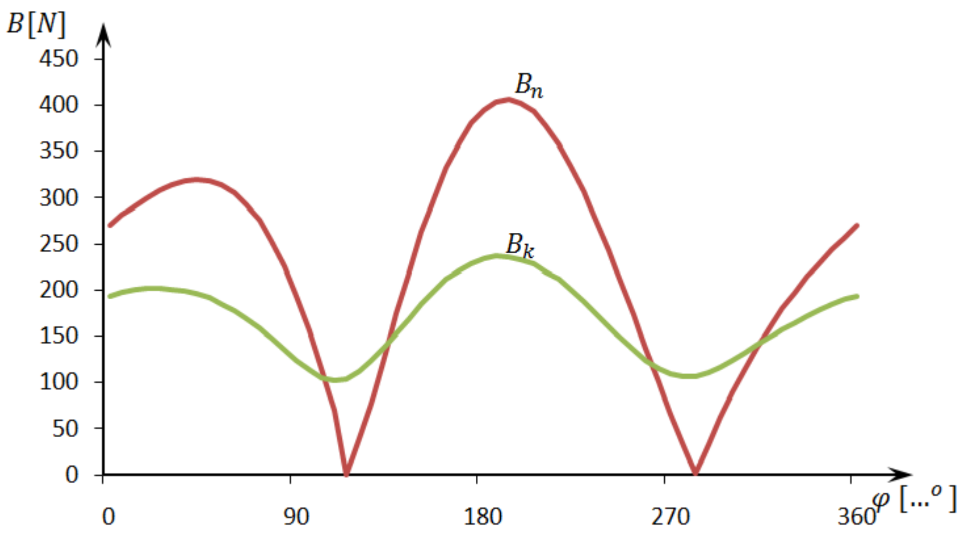

Fig. 4. The diagram of rod's inertia force B_k and the diagram of knife-bar's inertia force B_n

It is derived from Fig. 4 that rod's inertia force B_k reaches values approximately similar to knife-bar's inertia force B_n. This is the reason why during the analysis of a cutting unit's dynamics the rod's inertia forces B_k are omitted, what is a common practice in recognized publications [2, 3] and being unfounded can lead to faulty results.

That is why the disposition of forces working on a rod in a scissor-fingers cutting unit has been evaluated, what is presented in Fig. 5. Forces working on the rod R and P, can be described by ingredients $R = (R_x, R_y)$ and $P = (P_x, P_y)$.

Force R originates from the crank working on the rod in the point of their kinematic linkage. Force P is connected with the crank working on the rod also in the point of their kinematic linkage.

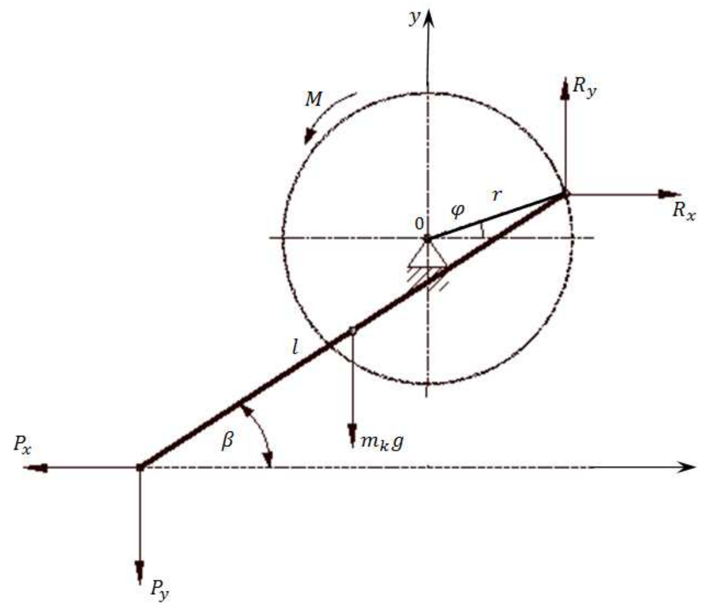

Fig. 5. The division of forces working on the rod in idle movement in a scissor-fingers cutting unit

Crank's action against the rod is described by the dependence:

$$-R_x\ r\ sin(\pi-\varphi)+R_y\ r\ sin\left(\frac{\pi}{2}+\varphi\right)=M, \tag{3}$$

where:

M − instantaneous torque.

Fig. 6 presents the division of forces working on a knife-bar.

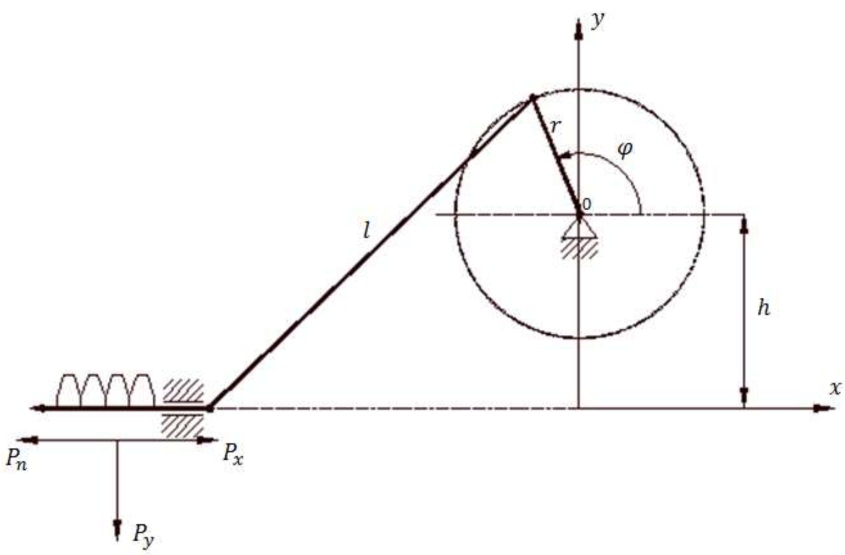

Fig. 6. Forces working on the knife-bar in idle movement

Equation of knife-bar's dynamics during its idle movement is described by the dependency (4):

$$P_n - T = m_n \frac{dv_n}{dt}, \quad (4)$$

where:

P_n – horizontal force $P_n = -P_x$,
T – abrasive force of a knife-bar in a slide,
m_n – knife-bar's mass,
v_n – knife-bar's velocity described by the equation.

Assuming that the rod's movement is a flat movement and designating the point of rod's center of gravity as a point used for describing the motion, an analysis has been carried out which provided three equations:

- sum of ingredient forces on *x* axis equals center of gravity's force of inertia,
- sum of ingredient forces on *y* axis equals center of gravity's force of inertia,
- sum of torques toward the center o f gravity equals a derivative of rod's winding.

The three equations described above in combination with the equation (3) produce a closed system of four equations, from which forces can be designated.

The sum of torques toward center of gravity c can be described by the following dynamic equation:

$$R_y \frac{l}{2} sin\left(\frac{\pi}{2} + \beta\right) + P_y \frac{l}{2} \; sin\left(\frac{\pi}{2} + \beta\right) - R_x \frac{l}{2} sin(\pi - \beta) - P_x \frac{l}{2} sin(\pi - \beta) = J_k \frac{d\omega_k}{dt}, \quad (5)$$

where:

l – rod's length,
J_k – mass moment of inertia,
ω_k –rod's angular velocity toward rod's center of gravity.

After transforming the equation (5) a formula for calculating the abrasive factor μ is received:

$$\mu = \frac{\frac{\bar{M}}{r} + l m_k \omega^2 f_1 - m_n \omega^2 r f_2}{m_n g f_3 - l m_k \omega^2 f_4}. \quad (6)$$

Equation (6) is an entangled dependence due to the abrasive factor μ that is why its designation requires an application of numeric procedures used for solving nonlinear equations.

The whole dynamic analysis of the scissor-fingers cutting unit, including the designation of the abrasive factor μ was carried out based on original computer program written using Turbo Pascal.

Dependency (6) enables to designate the abrasive factor for each component of a scissor-fingers cutting unit and crank's given angular velocity. In order to designate the abrasive factor μ it is necessary to know the average torque $\bar{M}$ working on the crank. Exemplary results of abrasive factor μ calculations are compared In Tab. 1. Torque's value $\bar{M}$ of the idle movement at crank's given angular velocities have been determined experimentally.

Tab. 1. Exemplary abrasive factor values calculated from dependence (6)

Crank's angular velocity ω $[rad/s]$	***Torque of the idle movement*** $\bar{M}$ $[Nm]$	***Abrasive factor*** μ
30,92	22,80	1,416
47,57	23,36	1,234
103,70	28,44	0,710

3. Summary

The dynamic analysis of a scissor-fingers cutting unit presented in this paper allows to determine an abrasive factor μ in the machine's real working conditions.

During the analysis of the bibliography a similar approach in order to determine the abrasive factor in working conditions of a cutting unit has not been found..

Values of the abrasive factor presented in publications on the subject are most probably based on experiments on a moving bar without an installed crank [1]. The values of the abrasive factor determined in such manner are several times lower than the results presented in this article.

Based on dependence (6) it is conclusive from the determined values of the abrasive factor μ that with the increase of the crank's angular velocity ω the value of the abrasive factor decreases.

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