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DYNAMICS OF MOVEMENT IN SCISSOR-FINGER CUTTING ASSEMBLY

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Abstract: *The analysis of the dynamics of the shear-finger cutting assembly the drive of was performed by the rotating disc with a crank in asymmetric system is presented in this article. The conducted analysis as the only one in the generally available literature, describes thoroughly the dynamics of the working assembly by considering of all the components of the shear-finger cutting assembly. The analysis of the dynamics of the cutting assembly presented in the study makes it possible to determine the friction coefficient in the conditions of the real machine's operation.*

Keywords: Dynamics of the cutter bar's movement, Friction in the shear-finger cutting assembly, Cutting of plant materials, Shear-finger cutting assembly, Simulation calculations.

1. Introduction

The shear-finger cutting assembly is the basic assembly occurring in many working machines. The essence of its construction lies in the fact, that this assembly consists of a movable cutter bar and an immovable finger bar, and the rule of operation consists in the fact, that the knives riveted to the cutter bar make a to-and-fro motion, shifting in fingers' cut-outs which at the same time constitute a crosscut edge. The plant material between the side knife's edge and the finger is cut. In Fig. 1 there is presented a typical construction of a shear-finger cutting assembly.

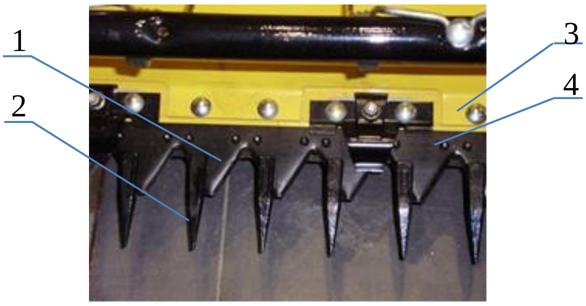

Fig. 1: Construction of the shear-finger cutting assembly in the example [own study]: 1-knife, 2-finger, 3-finger bar, 4-cutter bar.

For the drive of the cutter bar making a to-and-fro movement (in and out) there are most of all used the asymmetric crank mechanisms. The existing constructional solutions of the cutting assemblies are characterised by a high energy-consumption of the cutting process, and what's connected with that – their power transmission systems are equipped with engines of high powers. It points out to the fact, that the known constructional solutions originated mainly based on a constructor's intuition. It is connected with the absence of a detailed analysis of the dynamics of the shear-finger movement's dynamics of the cutting assembly and the absence of mathematical models describing the cutting process of the shear-finger cutting assembly, on the basis of which there may be conducted simulation calculation, construction's optimization and the improvement of the improvement of functioning efficiency of the cutting assemblies. The authors then dealing with these issues were among the others Zastempowski and Bochat (2013, 2015). Other authors within the frames of machines construction, mainly dealt with the

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issues connected with the rules of design and analysis of construction's strength (Strzelecki et al., 2016), with the rules of use of MES and numerical analysis (Ligaj and Szala, 2014, Knopik et al., 2016) with mathematical modelling and construction's optimization (Keska and Gierz, 2011, Peszynski et al., 2016, Tomporowski, 2012 and Zastempowski et al., 2013, 2014, 2015).

2. Analysis of the issue

The analysis of operation of the shear-finger cutting assembly in the aspect of its dynamics is awkward because of the complexity of the whole system. In the cutting system the following components may be distinguished: a rotating disc with a crank, a connecting rod (pitman), a cutter bar and a finger bar with a slide bearing. On the basis of the energy model developed by the article's authors based on the results of the experiments it was found, that the resistances occurring most of all in the idle movements, which are connected with the necessity to overcome among the others the frictional resistance and amount up to 90 % of the total demand for power, have an essential share in the whole process's energy consumption. Due to that, the authors of the study have conducted the analysis of dynamics of the components' movement of the shear-finger cutting assembly. The model of that movement's dynamics has been developed with the following assumptions: the rotating disc rotates with the constant angle speed ω, between the cutter bar and slide bearing there occurs the Coulomb's friction, frictional resistances in connection of the cutter bar with a connecting rod and of the connecting rod with a crank have been omitted. In Fig. 2 there is presented the diagram of the system driving the cutter bar taking into account the forces affecting the connecting rod and the cutter bar.

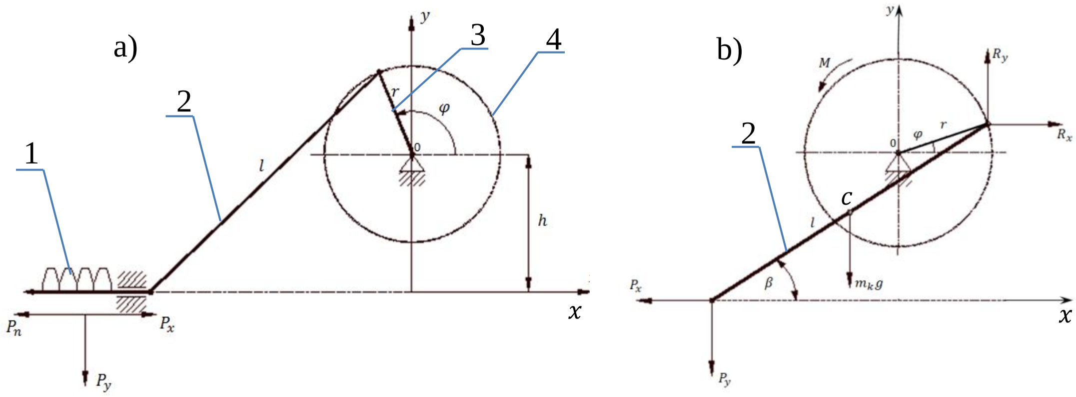

Fig. 2: Force system in the cutting assembly for the dead movement: a- force system for the cutter bar, b- system of forces on the connecting rod at the cutter bar's slide in; 1- cutter bar, 2- connecting rod, 3- crank, 4- rotating disc with a crank.

Process of the cutter bar's slide out is described by the following equations:

$$R_x\, r\, sin\varphi - R_y\, rcos\varphi = M, \tag{1}$$

$$-R_x + P_x = m_k\, a_x, \tag{2}$$

$$-R_y + P_y = m_k\left(a_y + g\right), \tag{3}$$

$$R_x \frac{l}{2} sin\beta - R_y \frac{l}{2} cos\beta + P_x \frac{l}{2} sin\beta - P_y \frac{l}{2} cos\beta = J_k \varepsilon_k, \tag{4}$$

where:

a_x, a_y – acceleration of the connecting rod's centre of gravity,
m_k – mass of the connecting rod,
g – gravitational acceleration,
ε_k – the connecting rod's angle acceleration,
J_k – mass moment of the connecting rod's inertia.

The equations describing the process of the cutter bar's slide in are analogical to the above presented equations with consideration of the opposite movement's direction.

In order to determine the forces P_x i P_y influencing the cutter bar, following transformations of equations describing the process of sliding in and out of the cutter bar, the following matrix equation was received:

$$\begin{vmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{vmatrix} \begin{vmatrix} P_x \\ P_y \end{vmatrix} = \begin{vmatrix} M+b_1 \\ b_2 \end{vmatrix}. \tag{5}$$

The elements a_{ij} and b_{ij} have appropriately been accepted for the to-and-fro motion of the cutter bar.

Respectively for the sliding out: $a_{11} = rsin\varphi,\ a_{12} = -r\, cos\varphi,\ a_{21} = l\, sin\beta,\ a_{22} = -l\, cos\beta$ and for sliding in: $a_{11} = -rsin\varphi,\ a_{12} = r\, cos\varphi,\ a_{21} = -l\, sin\beta,\ a_{22} = l\, cos\beta$.

Parameters b_1 and b_2 for a full revolution of a disc rotating with a crank takes the following values:

$$b_1 = sin\varphi\, a_x - cos\varphi\left(a_y + g\right),\quad b_2 = sin\beta\, a_x - cos\beta\left(a_y + g\right),$$

Solution of the equation (5) may be presented in the form:

$$P_x = M\frac{a_{22}}{W} + \frac{c_1}{W}, \tag{6}$$

$$P_y = -M\frac{a_{21}}{W} + \frac{c_2}{W}. \tag{7}$$

Expression describing the coefficients c_1 and c_2 and the determinant W are the following:

$$c_1 = b_1\, a_{22} - b_2\, a_{12},\qquad c_2 = b_2\, a_{11} - b_1\, a_{21},\qquad W = a_{11}\, a_{22} - a_{12}a_{21}.$$

Equation of the cutter bar's movement takes the form:

$$M(\varphi)\frac{a_{22}}{W} + \frac{c_1}{W} + \mu\, M(\varphi)\frac{a_{21}}{W} - \mu\frac{c_2}{W} = m_n a_n = 0. \tag{8}$$

Equation (8) describing the process of the cutter bar's sliding out may be presented in the following form:

$$M(\varphi) + F_{wy}(\varphi,\mu) = 0, \tag{9}$$

And the sliding in process in the form:

$$M(\varphi) + F_{ws}(\varphi,\mu) = 0, \tag{10}$$

where: $F_{wy}(\varphi,\mu) = \frac{c_1}{f\,W} - \mu\frac{c_2}{f\,W} - \frac{m_n}{f}a_n,\quad F_{ws}(\varphi,\mu) = \frac{c_1}{f\,W} - \mu\frac{c_2}{f\,W} + \frac{m_n}{f}a_n,\quad f = \frac{a_{22}}{W} + \mu\frac{a_{21}}{W}.$

Integrating the equation (9) in the interval of angles $\left(\varphi_p, \varphi_k\right)$ and the equation (10) in the interval of angles $\left(\varphi_k, 2\pi + \varphi_p\right)$, and then adding them with sides, there was received the averaging equation of the cutter bar's movement, in the form:

$$M_{śr} + \frac{1}{2\pi}\int_{\varphi_p}^{\varphi_k} F_{wy}(\varphi,\mu)d\varphi + \frac{1}{2\pi}\int_{\varphi_k}^{2\pi+\varphi_p} F_{ws}(\varphi,\mu)d\varphi = 0. \tag{11}$$

where:

$\mu -$ friction coefficient,

φ_p i $\varphi_k -$ angles determining the extreme location of a cutter bar described with dependencies:

$$\varphi_p = arcsin\frac{h}{l-r},\qquad \varphi_k = \pi + arcsin\frac{h}{l+r}.$$

Equation (11) is a confounded dependency due to the friction coefficient μ that is why its determination requires the use of numerical procedures used in case of solving of non-linear equations. The whole dynamic analysis of the shear-finger cutting assembly, together with determination of the friction coefficient μ has been conducted on the basis of the author's computer programme. The dependence (11) makes it possible to determine the friction coefficient μ for the given construction parameters of the shear-finger cutting assembly and for a given crank's angle speed. For the purposes of the friction coefficient's μ determination, it is necessary to know the mean moment $M_{śr}$ running on the crank, which has been determined on the basis of experiments. For the purposes of this study's performance, the experimental tests have been conducted. For these tests there has been used the test point with the shear-finger cutting assembly reflecting the real conditions of the machine's operation. The conducted tests are presented in a separate publication (Zastempowski et al., 2014). The exemplary results of calculation of the friction coefficient μ between finger bar and cutter bar are presented in Tab. 1.

Tab. 1: Exemplary values of the friction coefficient calculated from the dependence (6).

Crank's angle speed $\boldsymbol{\omega}$ $[\boldsymbol{rad/s}]$	***Turning moment of the dead movement*** $\boldsymbol{M_{śr}}$ $[\boldsymbol{Nm}]$	***Friction coefficient*** $\boldsymbol{\mu}$
30.92	22.80	1.48
47.57	23.36	1.19
103.70	28.44	0.28

Development of an innovative shear-finger cutting assembly's construction in which the impact of friction and inertial force were minimised (Zastempowski and Bochat, 2014) was an additional effect of the continuously conducted works at the Faculty of Mechanical Engineering UTP in Bydgoszcz.

3. Summary

The dynamic analysis of the shear-finger cutting assembly presented in the study, makes it possible to determine the friction coefficient μ in the conditions of the real machine's operation. From the analysis of the obtained values of the friction coefficient μ on the basis of dependencies (11) it results, that together with the increase of the crank's angle speed ω its value decreases. The results of friction coefficient μ occur directly from the operating conditions of the machine (dust, dirt, sand and plant material). During the literature's analysis, a similar approach has not been found. The values of the friction coefficient presented by other authors are based most probably on the experience conducted in the conditions of unnatural operation with slow movement of a batten and dissembled drive (Gach et al., 1991). The values of the friction coefficienttermined like that, are several times lower than the ones occurring in the conditions of the real operation of a machine and presented in the article.

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