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KINEMATICS AND DYNAMICS OF THE MOVEMENT OF THE SELECTED CONSTRUCTIONS OF THE DISC CUTTING ASSEMBLIES

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Abstract: *The mathematical dependencies describing the kinematics and dynamics of the movement of the adisc cutting assemblies used in agrarian mowing machines for cutting of the plant material for windrow are described in this study.*

Keywords: Mowing machines, Disc cutting assemblies, Kinematics, Dynamics, Plant material.

1. Introduction

The cutting assemblies of the disc type are commonly used in agrarian mowing machines for cutting of plant material for windrow. Cutting of plants takes place with the use of inertia of plants' blades, that is without the use of the crosscut edge. The discs of the discussed cutting assemblies are equipped with straight knives ($\propto = 0^0$). Knives are fastened to discs self-aligning with the use of clevis pins (Bochat, 2010).

From the analysis of the commonly available literature it results, that the subject area of kinematics and dynamics of movement of the machines' has been presented only by Bochat and Zastempowski (2013) in their publications. Other authors, within the frames of machines' construction, have mainly dealt with the subject matter connected with the rules of designing and the analysis of a construction's strength (Piatkowski et al., 2014, Tomaszewski et al., 2014), with the rules of the use of MES and the numerical analysis (Szala, 2014; Knopik et al, 2016;) with mathematic modeling and a construction's optimization (Knopik et al., 2016; Peszynski et al., 2016; Ligaj and Szala, 2010, Zastempowski and Bochat, 2014, 2015) as well as the interaction of technical devices on the environment (Karwowska et al., 2013, 2014).

Correct designing of the cutting assemblies, that is disco with knives, is the basic problem that a disc mowing machines' constructor has been facing. It shall be possible on condition of thorough getting to know the dependencies between the geometric and kinematic parameters of the construction of discs with knives and the operating parameters of the machine – mowing machine. That is why, in this study, there is an attempt to describe the movement of the cutting discs of the mowing machine's mathematically.

2. Analysis of the issue

The discs with knives in agrarian mowing machines, make a movement composed of a rotational movement around its own axis and the translational movement resulting from the movement of the machine – mowing machine. The trajectories of movement of the two neighbouring knives are presented in Fig. 1. The individual knives cut the plants from the surface limited by two cycloids, that is the cycloid determining the path of movement of the external knife's edge and the cycloid determining the path of movement of the internal knife's edge. Both the pairs of cycloids intersect what means, that a knife shifting as the second runs in the part of its idle movement above the area cut by the first knife (double hatched area). Between the cycloids there may also remain the area from which the plants shall not be cut down (unshaded area).

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The trajectories of the external cutting edges' movement may be described with the parametric equations having the below form:

- For the point a'

$$x_{a'} = v_m t + R\, sin\omega t \tag{1}$$

$$y_{a'} = R\cos\omega t \tag{2}$$

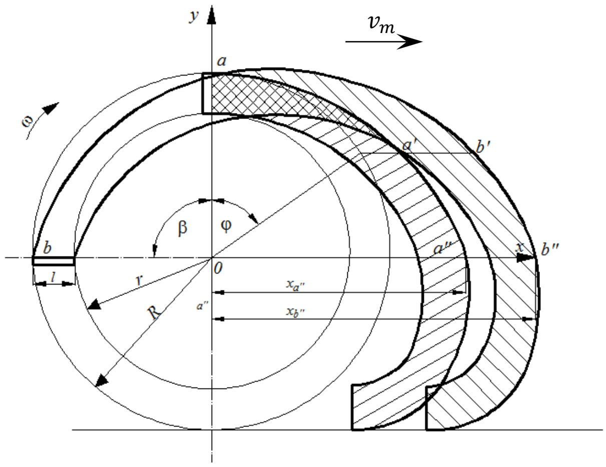

Fig. 1: Trajectories of movement of the rotational knife's of the cutting assembly.

- For the point b'

$$x_{b'} = v_m t + R\sin(\omega t - \beta) \tag{3}$$

$$y_{b'} = R\cos(\omega t - \beta), \tag{4}$$

where: v_m- speed of machine's movement,

t - time,

R - distance from the end of a knife to the axis of a disc's rotation,

ω- angle speed of the disc with knives,

φ, β- appropriate angles (according to Fig. 2), where $\varphi = \omega t$.

In order to avoid forming of uncut areas, the so-called underlaps there has to be fulfilled the condition that in place in which trajectories of two adjacent knives are distant from each other to the highest extent on the axis *x*, the horizontal coordinates of these knives' cutting edges have to be distant from each other maximum to the length equal to the knives' length. So, according to the Fig. 1, there has to be fulfilled the condition:

$$x_{b''} - x_{a''} = h = l\, cos\alpha, \tag{5}$$

where: l - length of a knife's blade (in case of straight knives $\alpha = 0^0, h = l$).

For the point (a) following a disc's rotation for the angle $\varphi = \frac{\pi}{2}$ we receive:

$$\varphi = \frac{\pi}{2} = \omega t \tag{6}$$

and following conversion:

$$t = \frac{\pi}{2\,\omega}. \tag{7}$$

So:

$$x_{a''} = v_m \frac{\pi}{2\,\omega} + R. \tag{8}$$

For point (b) following rotation for the angle $\frac{\pi}{2} + \beta$we receive:

$$\omega t = \frac{\pi}{2} + \beta, \text{and after the transformations } t = \frac{\pi + 2\beta}{2\omega}. \tag{9}$$

So:

$$x_{b''} = v_m \frac{\pi+2\beta}{2\omega} + R\, sin\left(\frac{\pi}{2} + \beta - \beta\right) = v_m \frac{\pi+2\beta}{2\omega} + R, \tag{10}$$

from where:

$$l = v_m \frac{\pi+2\beta}{2\omega} + R - \left(v_m \frac{\pi}{2\omega} + R\right) = v_m \frac{\beta}{\omega}. \tag{11}$$

Substituting to the formula (11):

$$\beta = \frac{2\pi}{z}, \tag{12}$$

where: z - number of knives on a disc,

we receive:

$$l = \frac{2\,\pi\, v_m}{\omega\, z}. \tag{13}$$

To ensure cutting of plants with the whole length of a knife, the below condition has to be fulfilled:

$$\frac{v_{n\dot{z}}}{v_m} \geq \frac{2\pi R}{4l\; cos\alpha}, \tag{14}$$

where: $v_{n\dot{z}}$ - knife's peripheral speed.

In order to determine the resultant speed v and acceleration a of a knife, the equations (1) and (2) have to be correctly differentiated and an appropriate mathematical operation be performed. Differentiating the equations (1) and (2) once, there has been received:

$$v_{xa} = \frac{dx_{a'}}{dt} = v_m + R\,\omega\, cos\omega t, \tag{15}$$

$$v_{ya} = \frac{dy_{a'}}{dt} = -R\,\omega\, sin\omega t. \tag{16}$$

Taking into account the fact, that the resultant knife's speed is described by the dependency:

$$v = \sqrt{v_{xa}^2 + v_{ya}^2}. \tag{17}$$

We have received following conversions:

$$v = \sqrt{v_m^2 + 2v_m R\omega\, cos\omega t + R^2\,\omega^2}\,. \tag{18}$$

However differentiating the equations (1) and (2) twice, we have received:

$$a_{xa} = \frac{dv_{xa}}{dt} = -R\,\omega^2\, sin\omega t, \tag{19}$$

$$a_{ya} = \frac{dv_{ya}}{dt} = -R\,\omega^2\, cos\omega t. \tag{20}$$

So:

$$a = \sqrt{(-R\omega^2 sin\omega t)^2 + (-R\,\omega^2\, cos\omega t)^2} = R\omega^2. \tag{21}$$

Dynamic equation of the rotational movement of a disc with knives may be described with the use of the equation:

$$M = J\varepsilon, \tag{22}$$

where: M - turning moment on the shaft driving a disc with knives,

J- mass inertia moment of a disc with knives,

ε- angular acceleration of the disc with knives, $\varepsilon = \frac{a}{R}$.

3. Final conclusions

In the light of the conducted analysis of this issue, the following conclusions may be formed:

1. The mathematical dependencies describing the kinematics and dynamics of the movement of the disc cutting assemblies applied in mowing machines presented in the study, constitute the first attempt of the comprehensive issue's presentation.
2. Derived dependencies make it possible to establish the relations between the geometrical and kinematic parameters of construction of disc with knives and the operating parameters of the machine – mower, in the aspects of its operation's effectiveness.
3. The established dependencies may be applied in the phase of simulation tests concerning new mowers' constructions.

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