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Defining the critical kinematic parameters of rotary harrow with vertical axis of rotation

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Abstract. *Experimental research of rotary harrow Arterra Grip 400 was carried out to determine the value of vertical rotors' kinematic parameter which provides the necessary soil's crushing to pieces depending on the constructive parameters and the harrows duty. Two-factor experiment was implemented to determine soil's crushing to pieces depending on the forward speed and harrow's working depth. Vertical rotor's critical kinematic parameter -* $\lambda_{кр}$*=2,97, harrow's marginal forward speed v=1,8 m/s and step S=15,8 cm were determined as a result of the research. During the research it was determined that 85% of soil fractions up to 50 mm can be achieved: at working depth 6 cm forward speed maximum of 2,3 m/s; working depth of 9 cm forward speed maximum of 1,8 m/s.*

Keywords: soil tilling, rotary harrow, critical kinematic parameter

Introduction

Rotary harrows with a vertical axis and active drive ensure maximum improvement of soil structure by intensive crushing, aeration of the cultivated soil layer and its separation in fractions. Fine soil is concentrated in the lower area of the cultivated layer. In coarse soil aggregates and residues from grown vegetables remain on the surface, preventing soil from claying, drying, wind and water erosion. Provides excellent levelling of the soil surface, a prerequisite for precise execution of subsequent technological operations. The object of study is rotary harrow Arterra Grip 400 manufacturing company VOGEL & NOOT Landmaschinen GmbH (Technical data of the rotary harrow Arterra Grip 400). Brant has a working width B=4,0 m, number of vertical rotors 16 with diameter D= 300 mm and rotational speed n=340 min^{-1}. Every rotor is mounted on two vertical blades phase shift of $\Phi=\pi$. Motion of the rotary harrow has a velocity v towards the ordinate axis Oy. Rotating driving force with angular velocity ω, with the axis of rotation perpendicular to the plane Oxy (Figure 1).

The purpose of the study is to create theoretically justified methods and determine the value of the critical kinematic parameter, the critical forward velocity and the critical step of picking and experimentally to determine the degree of crushing of soil, depending on forward speed and working depth of harvesting.

Material and methods

Basic kinematic characteristics of the modes of vertical rotors is the type and nature of the trajectory of the vertical blades.

Equations describing the path of the vertical blades (A and B), obtained by joint resolution of the parametric equations of motion (Guglev, 2004; Guglev, 2009), excluding the time "t":

$$y_A = \frac{R}{\lambda}\left[2k\pi \pm \arccos\left(\frac{x_A}{R}\right)\right] \pm \sqrt{R^2 - x_A^2}\ , \qquad (1)$$

$R \leqslant x_A \geqslant -R$, (k=0, 1, 2, 3, …..)

B blade

$$y_B = \frac{R}{\lambda}\left[2k\pi \pm \arccos\left(-\frac{x_B}{R}\right)\right] \mp \sqrt{R^2 - x_B^2}\ , \qquad (2)$$

$-R \leqslant x_B \leqslant R$, (k=0, 1, 2, 3, ….)

where: R is the radius of the circle described by the sword A and B

$\lambda = \frac{u}{v}$ - a kinematic parameter;

$u=\omega R$ - peripheral speed of the rotor.

Nature of trochoids described by equations (1) and (2) is determined by the value of the kinematic parameter. The analysis of equations (1) and (2) shows that the diversity of modes exists in a critical regime where the trajectories of the vertical blades of one rotor do not intersect twice in crude soil layer in the formation of soil chip and at the end of the process curves only touch (Figure 1).

It is obvious that the first point (P) in which the trajectories of the blades is touching the first local maximum of the curve describing the trajectory of the blade A and the second local minimum of the curve describing the trajectory of the blade B.

Hence the condition $Y_{Amax}=Y_{Bmin}$

$$y_{A_{max}} = \frac{R}{\lambda}\left[\pi - \arccos\left(\frac{1}{\lambda}\right) + \sqrt{\lambda^2 - 1}\right] \qquad (3)$$

$$y_{B_{min}} = \frac{R}{\lambda}\left[2\pi + \arccos\left(\frac{1}{\lambda}\right) - \sqrt{\lambda^2 - 1}\right] \qquad (4)$$

Therefore:

$$\frac{R}{\lambda}\left[\pi - \arccos\left(\frac{1}{\lambda}\right) + \sqrt{\lambda^2 - 1}\right] = \frac{R}{\lambda}\left[2\pi + \arccos\left(\frac{1}{\lambda}\right) - \sqrt{\lambda^2 - 1}\right] \qquad (5)$$

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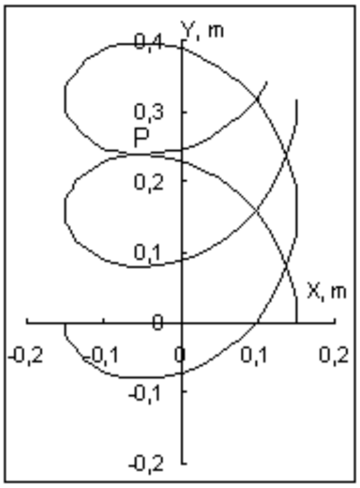

Figure 1. Trajectory of blade A and B at critical regime enough work (v=1,8 m/s,$\lambda_{кр.}$=2,97, R=150 mm, ω=35,6 s^{-1})

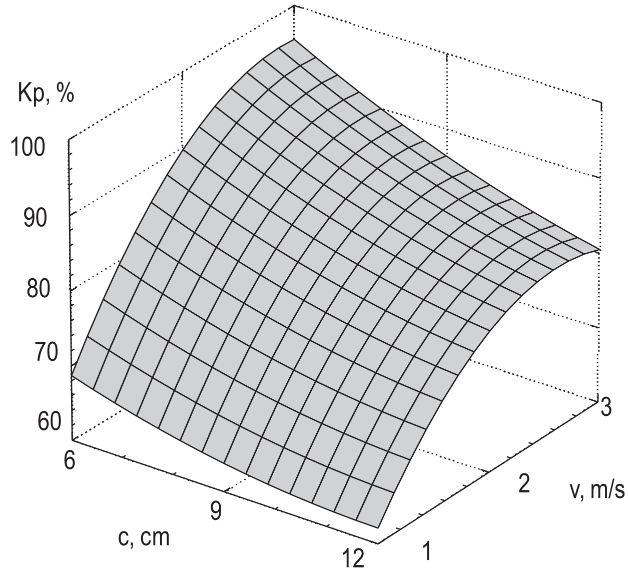

Figure 2. Rate of the soil layer crushing

After solving equation (5) we obtain the function:

$$f_{(\lambda_{KP})} = \frac{\pi}{2} + \arccos\left(\frac{1}{\lambda_{KP}}\right) - \sqrt{\lambda_{KP}^2 - 1} \qquad (6)$$

Function (6) is solved by iteration. Rotor with two blades, the critical value of the kinematic parameter $_{кр}$=2,97. Critical step and the forward speed of the harvest are determined by the formulas (Guglev and Vassileva, 2010):

$$S_{KP} = \frac{\pi D}{2\lambda_{KP}} \qquad (7)$$

$$v_{KP} = \frac{\pi Dn}{60\lambda_{KP}} \qquad (8)$$

Critical step picking - $S_{KP.}$=15,9 cm. Critical forward speed of the harvest - $v_{KP.}$=1,8 m/s.

The coordinates of point P (x, y), in which trajectories of the blades A and B from one rotor are touching are given in Table 1.

For experimental verification of the theoretical research a two-factor experiment was conducted to establish the crushing of the soil depending on the forward speed and working depth of harvesting.

Experimental studies were conducted in the fall on a field with ploughed land in the village of Pop Grigorov, region of Dobrich. The test area is with the following parameters: inclination of the field – 1,2%; type of soil, leached chernozem, soil background – aside, density and humidity =1,171,43 g/cm^3, W_a=12,317,8 %. The experiments were conducted using tractor FENDT 926 Vario. For independent control factors are taken: working speed – v, m/s; working depth – c, cm. Levels of the intervals of variation of steered factors in natural values are given in Table 2.The degree of crushing of the soil is the indicator for agro-technical structure - K_p.

Table 2. Levels and intervals of variation of factors steered

Factor	Natural values	
	v	c
Levels of variation	m/s	cm
Basic level	2.0	9
Lower level	1.0	6
Upper level	3.0	12
Interval of variation	1.0	3

Based on experimental data, the degree of crushing of the soil it calculated using the formula:

$$K_P = \frac{m_{50}}{m} 100\%$$

where m_{50} is the mass of soil fractions with sizes up to 50 mm of soil samples;

Table 1. The coordinates of touching values for both knifes A and B

Knife	x		y		Angle of rotation of the rotor	
	mm					rad
A	$\frac{R}{\lambda_{KP}}$	-50.5	$\frac{R}{\lambda_{KP}}\left[\pi - \arccos\left(\frac{1}{\lambda_{KP}}\right) + \sqrt{\lambda_{KP}^2 - 1}\right]$	237.9	$\varphi = \pi - \arccos\left(\frac{1}{\lambda_{KP}}\right)$	1.914
B	$\frac{R}{\lambda_{KP}}$	-50.5	$\frac{R}{\lambda_{KP}}\left[2\pi + \arccos\left(\frac{1}{\lambda_{KP}}\right) - \sqrt{\lambda_{KP}^2 - 1}\right]$	237.9	$\varphi = 2\pi + \arccos\left(\frac{1}{\lambda_{KP}}\right)$	7.511

m - mass of the whole soil sample from the same area.

Agro- technical requirement for crushing the cultivated soil layer is - $K_{P.} \geqslant 85\%$ (Mezhdunarodnaya systema mashin 1981).

Results and discussion

Table 3 specified average degree of crushing of soil. After processing the experimental results with the program "STATISTIKA", the following equation for crushing the soil layer in clear form is presented:

$$K_P=118{,}1+12{,}8v-6{,}4c-7{,}6v^2+0{,}7vc+0{,}18c^2 \qquad (9)$$

Table 3. Matrix of planned experiments and experimental results (mean values)

№ of experience	Managed factors		Crushing layers (average) K_P. %
	v. m/s	c. cm	
1.	3.0	12.0	62.1
2.	1.0	12.0	80.5
3.	3.0	6.0	68.7
4.	1.0	6.0	95.5
5.	3.0	9.0	63.8
6.	1.0	9.0	86.4
7.	2.0	12.0	78.9
8.	2.0	6.0	89.7

The analysis of equation (9) shows that the conditions of experimental research crushing of the soil layer are amended as follows:

At defined working depth of c = 6 cm, the maximum of crushing soil layer K_{max}=96,3% (Figure 2.) is achieved at operating speed of 1 m/s. With increasing the operating speed, the amount of soil fractions with sizes up to 50 mm, is reduced and at operating speed of 3 m/s, crushing of the soil layer is a minimum for this depth, K_{min}=69,5%, which does not meet agricultural requirements for 85% of soil fractions of up to 50 mm. When working at critical forward velocity ($v_{KP.}$=1.8 m/s), 92.2% of the soil fractions with sizes up to 50 mm is achieved.

At defined working depth of c = 9 cm, the amount of soil fractions with dimensions up to 50 mm decreased from 88,2% in operating speed of 1 m/s to 84,5% in operating speed of 2 m/s, and to 65,6% in operating speed of 3 m/s (Figure 2). This decrease is very well demonstrated for the operating speed above 2 m/s. At critical forward speed the amount of soil fractions of up to 50 mm is 84,9%.

At defined working depth of c = 12 cm, rotary harrow ARTERRA 400 does not provide agro-technical requirement for 85% of the soil fractions with sizes up to 50 mm in the tested speed regimes. The amount of soil fractions with sizes up to 50 mm is 80,8% in operating speed of 1 m/s. With increasing the operating speed to 3 m/s, the percentage decreases to 62.4%. At critical forward speed the soil fractions with sizes up to 50 mm are 80.8%.

To determine the maximum operating speed of the sampled depths of operation, providing 85% percent of the soil fractions with sizes up to 50 mm, it is necessary to solve the equation:

$$118{,}1 + 12{,}8v - 6{,}4c - 7{,}6v^2 + 0{,}7vc + 0{,}2c^2 = 85 \qquad (10)$$

At working depth of 6 cm, rotary harrow Arterra Grip 400 provides 85 percent of the soil fractions with sizes up to 50 mm at operating speed not greater than 2,3 m/s. At working depth c=9 cm, at an operating speed not greater than 1,8 m/s, 85% of the soil fractions with sizes up to 50 mm is achieved. At working depth of 12 cm, rotary harrow Arterra Grip 400 does not achieve 85% of the soil fractions with sizes up to 50 mm at the examined working speeds.

Conclusion

A method for determining the critical value of kinematic parameter of rotary harrow with vertical axis of rotation $_{KP}$=2,97 was established. For Rotor blade with two knifes for rotary harrow Arterra Grip 400, the critical step is S_{KP}.=15,9 cm and the critical speed v_{KP}=1,8 m/s.

For the conditions of experience, 85% of the soil fractions with sizes up to 50 mm are achieved: at working depth of 6 cm, forward speed is not higher than 2,3 m/s; at working depth of 9 cm, forward speed is not higher than 1,8 m/s; at working depth of 12 cm, rotary harrow ARTERRA 400 does not provide agro-technical requirement for 85% of the soil fractions with sizes up to 50 mm for the studied speed regimes.

The amount of soil fractions with sizes up to 50 mm for working depth of 12 cm is as follows: 83,7% in operating speed of 1 m/s; 79,2% in operating speed of 2 m/s; 65,3% in operating speed of 3 m/s.

In dealing with critical forward velocity ($v_{KP.}$=1,8 m/s), quantity of soil's fractions up to 50 mm is as follows: at working depth of 6 cm – 92,2%; at working depth of 9 cm – 84,9%; at working depth of 12 cm – 80,8%.

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