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JUSTIFICATION OF THE DIBBER DRILL MACHINES WHEEL PARAMETERS UNDER THE CONDITION OF ROTATION UNIFORMITY

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Abstract. The article presents theoretical and experimental study results of rotation uniformity for seed drill wheel and possibilities of using wheeled dibber drills in the design of sowing machines. The main purpose of research is to obtain mathematical models of wheel dynamic model expressing the dependence of wheel sliding on the technological and design factors. The objectives were to determine rolling coefficients in order to use their numerical characteristics in the analysis of wheel dynamic model and in particularity, the axial load, wheel radius, parameters of the dibber drills wheel and speed of movement. Freely rotating wheels with a rim width of 170 mm and diameters of 524 mm and 712 mm were used in the experiments. Soil in the channel was brought close by properties to the soil prepared for sowing. Measurement of the driving force was made by strain gauge equipment at a wheel speed of 0.47 m/s. The optimal axial load at the masses of 35-55 kg and diameter in the range of 500-800 mm of the wheeled dibber drills was determined. It was proved, that wheel slip within 10-12% will assure the quality of sowing crops technological process execution at speeds up to 3 ms-1. Numerical values of wheel sliding coefficients are on average 58% lower for rolled soil than for loose soil for equal conditions.

Key words: Wheel; Dibber drills; Moment of inertia; Angular acceleration; Axial load.

INTRODUCTION

Nowadays, even if agriculture 4.0 offers us new technologies such as drones and agrobots for smart agriculture, wheeled agriculture machines are mostly used to carry out day by day agricultural technological processes. The main purpose of wheel in agriculture machines is to ensure traction force of tractors (Battiato, A., Diserens, E. 2017; Kim, W.S. et al. 2020; Kim, Y.S. et al. 2022), precise actuation of working organs or transportation (Diserens, E. 2009) of the agriculture machines without sliding.

However, there is a lack of information about wheels sliding coefficients on the prepared soil for agriculture process in the scientific literature or is not available. Therefore, the average sliding coefficient can be considered as a criterion characterizing wheeled dynamic uniformity.

Academician V. P. Goryachkin considered the wheel rolling from a kinematic point of view as a body continuous overturning with an infinitely large number of faces (Brown, F.R. et al. 1994; Cui, K. et al. 2007; Diserens, E. 2009; Jiang, M. et al. 2018; Rubinstein, D. et al. 2018). Similarly, a wheel with dibber drill has a finite number of faces with a sufficiently wide support plane. The rolling peculiarity of such wheel is that when it is overturned through the dibber drills, there is a consistent soil crumpling to its length depth (Brown, F.R. et al. 1994; Gray, D. et al. 1995; Janulevičius, A., Giedra, K. 2009; Miles, S.J., Reed, J.N. 1999). In this case, certain conditions must be met: the first is a sufficient connection force of wheel rims with a support surface, on which the rolling occurs(Du, Y. et al. 2018; Hiroma, T. et al. 1997); and the second - the proper location in height, relative to support surface driving force (Badgujar, C.M. et al. 2022; Diserens, E. 2009; Elwaleed, A.K. et al. 2006; Kim, Y.S. et al. 2022; Saengprachatanarug, K. et al. 2009; Taghavifar & Mardani, 2015). With a wide support and location near its driving force, the wheel rolling, as a rule, occurs with sliding. The wheel connection with soil, support base and driving force location are the main factors, on which the slide value depends (Badgujar, C.M. et al. 2022; Kim, Y.S. et al. 2021, 2022; Taghavifar, H., Mardani, A. 2015). They are determined mainly by the axial load of the wheel, its radius and dibber drills length.

MATERIALS AND METHODS

The slipping increment at the overturning moment in relation to the background, as already shown, is accompanied by the appearance of negative angular acceleration. Therefore, in the context of solved problem, it is desirable to establish such ratios of determining factors in which the unevenness of wheel rotation and equally slipping increment were unmarkable.

The angular acceleration of the wheel is included in the equation $J_c\ddot{\varphi} = F_T r - f_\kappa N - Qd - M_n$. Using the condition $f(G-Q)r \geq (G-Q)f_k + Qd + M_П$ let's write it down in this form:

$$J_c\ddot{\varphi} = f(G-a)r - (G-Q)f_k - Qd - M_п$$

$$J_c\ddot{\varphi} = G(fr - f_k) - Q(fr + f_k + d) - M_п \quad (1)$$

By substituting the moment of inertia values, gravity and soil reaction, we obtain:

$$m\rho\ddot{\varphi} = mg(fr - f_k) - qSh(fr + f_k + d) - M_п$$

At function extreme point, this equation will be:

$$m\rho\ddot{\varphi} = mg(fr - f_k) - qSh_Э(fr + f_k + d_Э) - M_п \quad (2)$$

where: ρ is the wheel moment of inertia radius.

Let us remind that at the extremum point, the values $d_э$ and $h_э$ are determined respectively by expressions $d = \sqrt{(a-h)(2r+a+h)}$ and $h_Э = \dfrac{\sqrt{9r^2 + 8a(2r+a)} - 3r}{4}$.

Solving the last equation relatively to angular acceleration, we found:

$$\ddot{\varphi} = \frac{g}{\rho}(fr - f_k) - \frac{qSh_Э}{m\rho}(fr + f_k + d_Э) - \frac{M_п}{m\rho} \quad (3)$$

Let's use this equation to interpret the conditions that cause the wheel to increment slide in the phase of tipping it through the dibber drill. A sign that indicates that the sliding changes in magnitude is a negative value of angular acceleration. With positive acceleration, the wheel slide is either absent or uniform. In order, for the angular acceleration to be positive, at least two requirements must be met. First of all, the first member of the right side of the equation must be positive, i.e.

$$(fr - f_k) \rangle 0 \quad (4)$$

and, in addition, it must be greater than the amount drawn up from the remaining members:

$$\frac{g}{\rho}(fr - f_k) \geq \frac{qSh_Э}{m\rho}(fr + f_k + d_Э) + \frac{M_п}{m\rho} \quad (5)$$

The meaning of this expression can be interpreted as follows. In its left part there is a reserve or, in other words, the potential of angular acceleration, the value of which is due to the degree of wheel rim interaction with the soil but depends mainly on the radius of the wheel. The terms on the right equation side, contain an acceleration that, figuratively speaking, it is spent on overcoming various kinds of rolling resistances. When the expendable acceleration exceeds its potential, then the total acceleration becomes negative, which causes a jumping increase in sliding.

Therefore, in order, to not slow down wheel rotation when rolling through the dibber drill, the following conditions must be met:

$$\ddot{\varphi} \rangle 0 \quad (6)$$

Equation (3) is a dynamic model of a dibber drill wheel. It includes, in addition to three independent variable parameters of the dibber drill, mass and radius of the wheel - several quantities taken as constants, the numerical characteristics of which are of an empirical nature. In particularity, experimental data on the friction and volumetric crumble coefficients of the soil are widely presented in the literature. Such, however, information about wheels rolling coefficients on the prepared soil for sowing in the scientific literature is either not available, or we could not find them. Therefore, special experiments were put to determine rolling coefficients, in order, to use their numerical characteristics in the analysis of wheel dynamic model.

The experiments used freely rotating wheels with a rim width of 170 mm and diameters of 524 and 712 mm. Before each experiment, the soil in the channel was brought to its original physical state by loosening and leveling, close in properties to the soil prepared for sowing. Measurement of the driving force was made by strain gauge equipment at a wheel speed of 0.47 m/s. Axial load on the wheels, expressed by mass, was taken at two levels - 20 and 40 kg.

Calculations of experimental rolling friction coefficients were carried out according to the formulas [1, 7]:

$$f_k = \frac{\Pr}{N} \Rightarrow \frac{\Pr}{G} \Rightarrow \frac{\Pr}{mg} \tag{7}$$

where: P - driving force.
G - axial load on the wheel.

The results of experiments processing are presented in table 1.

Table 1. *Statistical characteristics of coefficients rolling friction*

Indicators	Wheel diameter, mm	
	524	**712**
Average value of coefficients, cm	3,44	5,17
Standard deviation σ, cm	0,567	0,768
Value m average error, cm	0,232	0,314
Coefficient of variation v, %	16,48	14,86

Taking into account the experimental data, dynamic models analysis with a rolling friction coefficient of 4 and 6 cm was carried out.

Calculations of the function (3) given as:

$$\ddot{\varphi} = f(a, r, m) \tag{8}$$

were carried out on a computer. [5, 7].

The members of the calculation formula were given the following formal names:

$$\ddot{\varphi} \Rightarrow y;\ g\rho^{-1}(fr - f_k) \Rightarrow y1;\ M_{\bullet}(m\rho)^{-1} \Rightarrow y3;$$

$$qSh_Э(fr + f_k + d_Э)(m\rho)^{-1} \Rightarrow y2;$$

$$h_Э = \left(\sqrt{9r^2 + 8a(2r + a)} - 3r\right)\cdot 4^{-1} \Rightarrow HE$$

$$d_Э = \sqrt{(a - h_Э)(2r + a + h_Э)} \Rightarrow DE$$

In the program block diagram (Figure1), in addition to the angular acceleration of the wheel, envisaged values of its elementary components - the potential and the consumption of accelerations to overcome wheel rolling resistance were provided. Calculation results systematization is presented in the form of graphs in figure 2, 3, 4. They reflect, respectively, the wheel radius influence, dibber drill departure, and wheel mass on the rotation uniformity, depending on whether the dynamic model under study has a positive or negative acceleration potential.

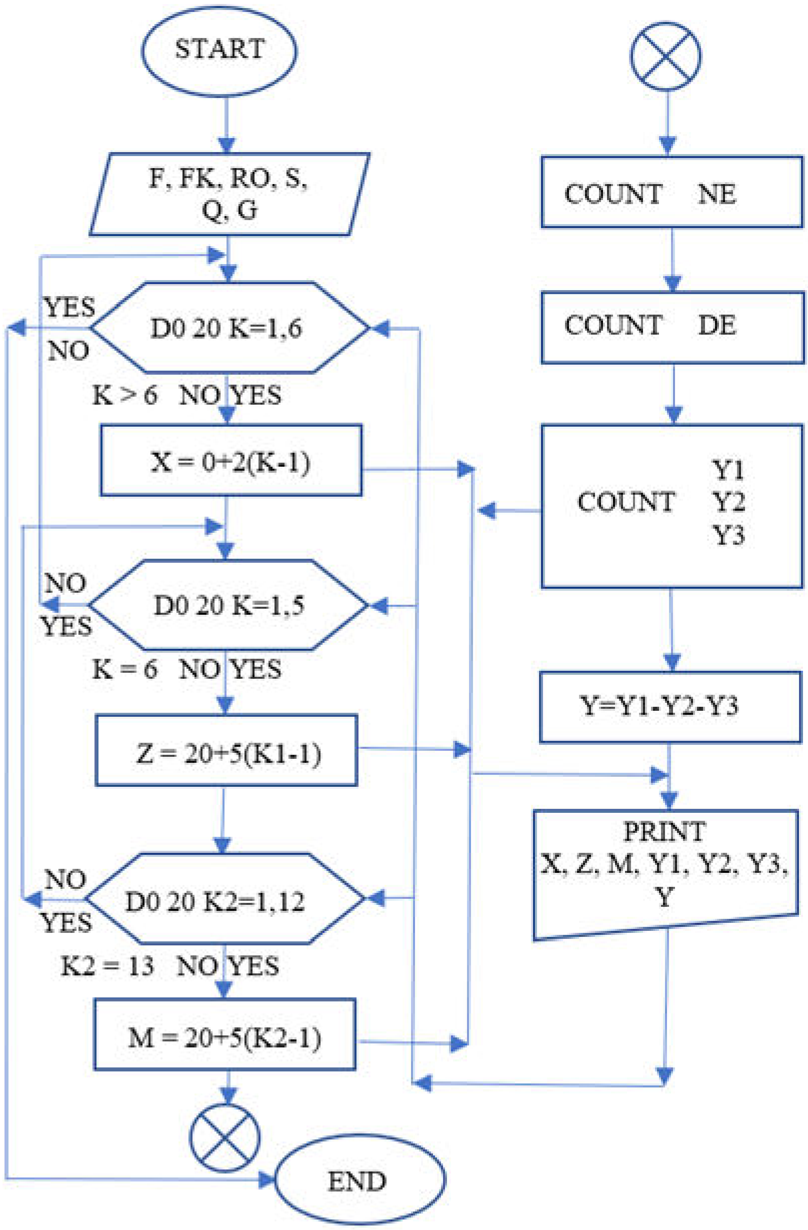


Figure 1. *Program block - scheme for calculating dibber drill wheel angular acceleration*

The following characters and numeric values of constants were applied:

$$f \Rightarrow F = 0{,}5;\ f_k \Rightarrow FK = 4 \ldots 6\text{см.};$$

$$q \Rightarrow Q = 3\text{Нсм}^{-3};\ S \Rightarrow S = 8\text{см}^2$$

$$\rho \Rightarrow RO = 20\text{см};\ M_п \Rightarrow MP = 600\text{Нсм}.$$

Variable values:

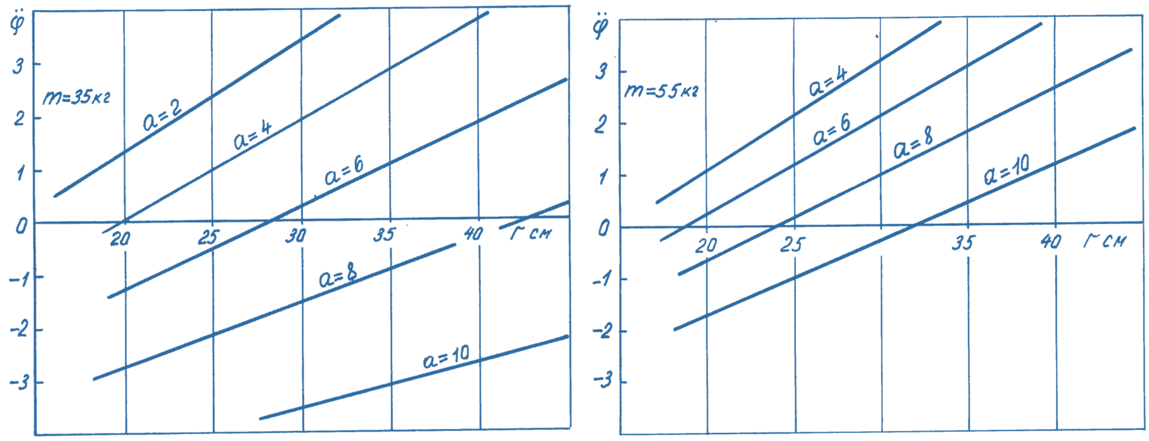
$$\rho \Rightarrow RO = 20\text{см};\ M_п \Rightarrow MP = 600\text{Нсм}.$$

$$m \Rightarrow M = 20 \ldots 75\text{кг};\ \Delta m = 5\text{кг}.$$

In the program block diagram (Figure1), in addition to the wheel angular acceleration, the values of its elementary components - accelerations potential and consumption to wheel rolling resistance overcoming were provided.

RESULTS AND DISCUSSION

Calculation results systematization are presented in the form of graphs in figure 2, 3, 4. They reflect, respectively, wheel radius effect, dibber drill departure, and wheel mass on rotation uniformity, depending on whether it is positive or negative acceleration potential has the dynamic model under study.

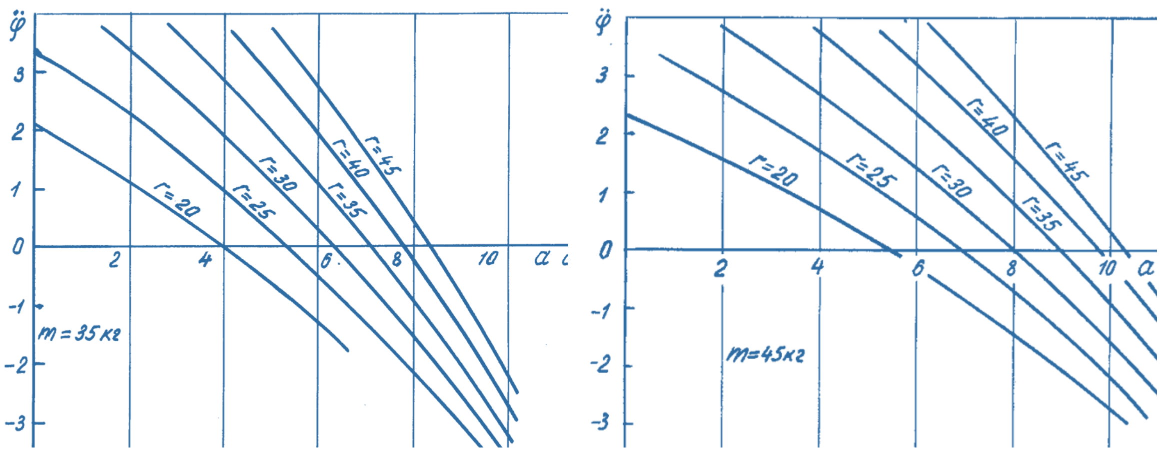


a) b)

Figure 2. *Effect of radius on wheels angular acceleration: a)- with a mass of 35 kg; b) - with a mass of 55 kg*

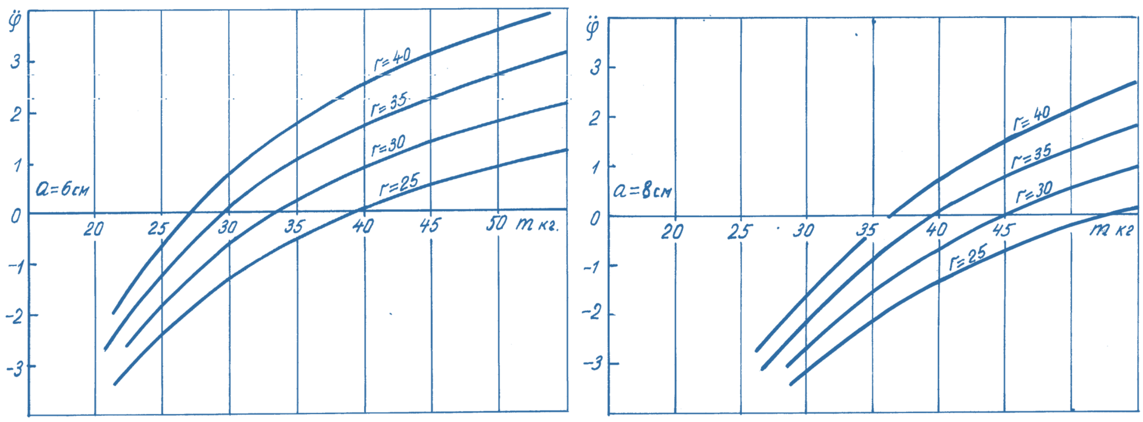
With a wheel mass increase, the radius optimization boundary area shifts along the abscissa axis to the origin. So, for a wheel weighing 55 kg and with a departure of 4 cm, this border is shifted to 15 cm, and with dibber drill length of 8 cm, the radius of the wheel should be at least 25 cm. In general, these graphs clearly reflect the trend that relatively large radius of the wheel reduce the degree of overall sliding and in particular, its peak components, other things being equal.

Impulse or peak slippage of the wheel is mainly a consequence of its movement resistance to dibber drill. It manifests itself, at moment when the positive part of the angular acceleration is completely spent on acceleration compensation, caused by the dibber drill braking effect.



a) b)

Figure 3. *Graphs of wheels angular speeds in dependence on dibber drills departure: - with a mass of 35 kg; b) - with a mass of 45 kg*



a) b)

Figure 4. *Graphs of wheels angular speeds in dependence on mass at the dibber drills length a) - 6 cm.; b) - 8 cm*

As it can be seen from the graphs (Figure 3), with an increase dibber drill length, negative angular accelerations increase at an ever-increasing rate. Already with a dibber drill length of 4 cm for a wheel weighing 35 kg and a radius of 20 cm, the balance of angular acceleration becomes zero. With such parameters, the possibility of pulsed wheel slippage is not excluded.

To get rid of this phenomenon, it is necessary either to increase wheel radius to 25 cm, or to increase the axial load equivalent to a mass of 45 kg. When sowing seeds to a depth of 8 cm, the work of the drill without impulse slippage of the wheel is provided according to calculations, by the following parameters: wheel radius - 45 cm, section weight - 35 kg or wheel radius - 35 cm and section weight - 45 kg.

The mass of the wheel, as well as its radius, contributes to an increase in the positive potential of angular acceleration (Figure 4). Therefore, with an increase in the radius of the wheel, its need for mass decreases, and vice versa, with an increase in mass, a decrease in its radius is allowed accordingly. The resulting graphs also show that pulsed sliding with increasing seed depth tends to increase dramatically. It can be partially compensated or eliminated by large masses and radius.

CONCLUSIONS

Dibber drills cause dynamic perturbations of the rolling wheel proportional to their length, manifested in the abruptness of its angular velocity and traction resistance.

The change in angular velocity at negative angular accelerations is accompanied by an increase in the sliding of the wheel in the phase of deepening the dibber drills into the soil. Therefore, the average sliding coefficient can be considered as a criterion characterizing wheeled dibber drill dynamic stability. The lower the sliding coefficient, the more uniform is rotation dibber drill wheel.

Analytical and experimental methods were obtained mathematical models expressing the dependence of wheel sliding on the technological and design factors of under study object, including, in particularity, the axial load, wheel radius, parameters of the dibber drills and speed of movement.

Depending on the technological permissible values of the sliding coefficients, the areas of optimization of the axial load or the corresponding mass and radius of wheeled dibber drill are determined. It is proved that the search for optimal masses must be made in the range of 35-55 kg, and the choice of diameters - in the range of 500-800 mm. Under these conditions, wheel sliding remains within the permissible, technological requirements - 10-12%.

Increasing wheeled dibber drill speed to 3.0 m/s gives almost a small increase in the sliding coefficient: on loose soil - no more than 4%, on rolled - about 1.6%.

Numerical values of wheel sliding coefficients on loose and rolled soil are established for equal conditions, which are on average 58% lower for rolled soil than for loose soil.

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