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A STUDY OF THE MOVEMENT DYNAMICS OF THE WORKING TOOL FOR THE FURROW FORMATION

Summary

The furrow depth in the corn furrow drilling is directly connected with the working depth of the furrower hoe, their evenness being determinative for the stability of the drill ploughshare depth. The main factors which influence the furrower movement stability are the field microrelief, the soil condition, the tillage mode and their design parameters. The effect of first two factors on the hoe of the furrower is of a random character and is determined as the sum of dispersions of each variable at the output of the dynamic unit. A transfer function has been determined on the basis of the obtained mathematical model. It reproduces fluctuations of angle ψ as the fluctuations of the tillage depth and represents a conservative link. The obtained transfer function allowed to calculate the amplitude-frequency characteristics of the dynamic system. The analysis of the theoretical amplitude-frequency characteristics showed that an elastic articulated joint of the cultivator hoe with the furrower in the form of wing flaps or blades connected to the frame of the row-crop drill results in increased amplitude fluctuation in a transversely-vertical plane. It has been established that this occurs within a frequency range from 1.3 to 1.6 Hz representing the field microrelief fluctuations, yet they do not belong to the range of resonance oscillations. It has been proved that significant decrease in the fluctuations of the furrower is possible after its equipment with a spring of high deflection rate. Under real conditions the elastic articulated joint of a combined working tool with a row-crop drill frame practically corresponds to the rigid one with more than 20 kN m^{-1} deflection rate.

***Key words**: soil, working tool, furrower, draft resistance.*

1. Introduction

The analysis of literary sources shows that in the corn furrow drilling the evenness of the working depth of the drill hoes depends, to a significant degree, on the evenness of the furrow depth [1] which, in its turn, is connected with the working depth of the furrower hoe [2]. Besides, the value of the draft resistance of the furrower is of great importance [3-5]. Therefore it is important to study the influence of the design parameters, the mode of the furrower motion, and the type of its connection to the frame upon its draft resistance and its working depth stability.

The working depth stability of the furrower hoes was examined in the work by N. Shabala [6]. The author makes a detailed investigation of the hoe movement in a transversely-vertical plane as a dynamic system with two inputs, from the viewpoint of statistical dynamics. A detailed analysis of the movement resistance of the wedge-shaped working tools in the ground was made by G. Sineokov [7]. The author suggests determining the total movement resistance of a wedge-shaped working tool in the ground according to four components of resistance. In our case it is this approach that is appropriate.

The working depth stability of the discussed tool is one of the most important indicators of the soil tillage quality [8]. Penetration of the working tools over the established norm leads to throwing of the wetted ground into inter-rows, increasing the resistance of the aggregate, and, vice versa, penetration under the established norm leaves soil in the furrow, deteriorating the conditions for the seed germination, which leads to thinned sprouting.

The aim of the investigations is to develop and study a mathematical and a dynamic model of the working tool movement in a transversely-vertical plane, as well as to determine the draft resistance and the design and performance parameters of furrowers with wing flaps and blades.

2. The object and methodology of research

The article deals with the movement of furrowers having flat hoes equipped with wing flaps and blades at their ends. The furrow should be formed from the upper dry layer of the ground without bringing the lower wet layer to the surface. The ground (soil) must be laid well from both the sides of the furrow, and the field must have an appearance of a corrugated surface [6]. Considering the fact that the movement of the ground is carried out by several parts of the working tool simultaneously and their impact upon the ground is not uniform, the task of the profile formation of the field should be solved in a complex way. In order to achieve this target, statistical methods (a theory of random functions and dispersion determination of a variable output parameter to be studied) were applied. In order to determine dispersion, spectral density of the input signal and the transfer function of the dynamic system were determined. The expression for a generalised momentum of forces acting upon the investigated working tool was found using the Lagrange equation [9].

3. Results and discussions

The basic factors affecting stable movement of the furrower tools [1] are the field microrelief, the soil condition, the tillage mode and their design parameters. The character of the microrelief of the field surface depends on the quality of previously performed operations of the technological process – cultivation and harrowing. The soil condition is characterised by the tillage resistance, which basically depends on the mechanical composition (hardness) and moisture of soil. The tillage mode is characterised by the depth setting of the working tools and the speed of the aggregate. To the design parameters of the working tools belong the corner angle, the angle of crushing, the working width, etc.

The effect of the first two groups of factors upon the furrower hoe is of a random character. The impact of the tillage mode and the design parameters is determinative.

A section of the furrower with an articulated suspension or on a rigid joint may be regarded as a dynamic system which receives the action of variable factors (input variables) and transforms them, changing the output value, in our case – the working depth H(t) [10]. In this case the input variables will be microirregularities of the field relief h(t) and the reactive resistance of soil R(t). The microirregularities of the field surface lead to a change in the working depth of the tool. The same result is produced also by the reactive resistance of soil whose value varies in the tillage process due to its variable physical properties [11].

Since it is not possible to exert immediate impact on h(t) and R(t) during the tillage process of the field, the stability of the tillage depth will basically depend on the properties of the dynamic system expressed via the design parameters and the working mode of the aggregate. The input effects bear a random character; therefore stability of the tillage depth can be determined only by probability characteristics.

It is known from the theory of random functions that the characteristic of a random process which allows judging about the changes of the investigated output parameter is its dispersion. To determine it, it is necessary to know spectral density of the input signal and the transfer function of the dynamic system [12, 13].

If we have two independent input variables (signals), as in our case, dispersion at the output of the dynamic unit is equal to the sum of dispersions from each constituent variable

$$D_H = D_{H1} + D_{H2} \ , \qquad (1)$$

where: D_{H1} – dispersion of the tillage depth influenced by the reactive resistance of soil,
D_{H2} – dispersion of the tillage depth influenced by the microirregularities of the field relief.

Let us determine dispersion of the tillage depth depending on the reactive resistance of soil. For this we are using the expression:

$$D_{H1} = \frac{1}{2\pi j} \int_{-j\infty}^{j\infty} W_1(p) \cdot W_1(-p) \cdot S_{R_z}(p) \cdot dp, \qquad (2)$$

where $W_1(p)$ – the transfer function of the dynamic unit of the reactive resistance of soil,
S_{Rz} – spectral density of the reactive resistance of the ground,
p – a parameter of the Laplace transformation.

In order to determine the transfer function $W_1(p)$ based on the scheme (Fig. 1), an equation for the oscillations of the working tool is built in relation to the frame (point O) with a generalised coordinate ψ on condition that the working tool is moving at a constant forward speed V, all the elements are absolutely rigid, there are no gaps in the articulated joints, and angle ψ is small [14-16].

The kinetic energy of the hoe moving in a transversely vertical plane will have the appearance:

$$T = \frac{1}{2}\left[I_{\text{ро}} + I_{\text{п}} + m_{\text{ро}}\left((l_{\text{п}} + l_{\text{ом}})^2 + (H_{\text{п}} - a_{\text{ом}})^2\right) + \frac{1}{4} m_{\text{ро}} l_{\text{п}}{}^2 \right] \overset{\bullet}{\psi}{}^2 + (m_{\text{ро}} + m_{\text{п}}) V_0^2 \ , \qquad (3)$$

where:

$I_{\text{ро}}$, $I_{\text{п}}$ – central inertia moments in a transversely-vertical plane of the working tool (the hoe with blades) and the arm , respectively,
$m_{\text{ро}}$, $m_{\text{п}}$ – masses of the how with blades and the arm , respectively.

By differentiation of the kinetic energy we obtain the Lagrange equation of the appearance:

$$\left[I_{\text{ро}} + I_{\text{п}} + m_{\text{ро}}\left((l_{\text{п}} + l_{\text{ом}})^2 + (H_{\text{п}} - a_{\text{ом}})^2\right) + \frac{1}{4} m_{\text{п}} l_{\text{п}}{}^2 \right] \overset{\bullet\bullet}{\psi} = Q_\psi \ , \qquad (4)$$

where:

Q_ψ – the generalised moment of forces.

Applying a small increment to the links Δψ and considering that sin(Δψ)≈Δψ, and cos(Δψ)≈1, we obtain an equation for the generalised moment of forces:

$$\begin{aligned} Q_\psi = \Sigma M(R_i)_O \approx R_{\text{лп}}[H_{\text{п}} - a_{\text{ол}} - (l_{\text{п}} + l_{\text{ол}})\Delta\psi] + \\ + R_{\text{вп}}[H_{\text{п}} - a_{\text{ов}} - (l_{\text{п}} + l_{\text{ов}})\Delta\psi] - R_{\text{лв}}[l_{\text{п}} + l_{\text{ол}} + (H_{\text{п}} - a_{\text{ол}})\Delta\psi] - \\ - G[l_{\text{п}} + l_{\text{ом}} + (H_{\text{п}} - a_{\text{ом}})\Delta\psi] - R_{\text{вв}}[l_{\text{п}} + l_{\text{ов}} + (H_{\text{п}} - a_{\text{ов}})\Delta\psi] - P_{\text{пр}} \cdot l_{\text{пр}} \end{aligned} \qquad (5)$$

where:

$R_{\text{лв}}$, $R_{\text{лп}}$ – the vertical and the horizontal constituents of the hoe resistance to the movement in the soil;
$R_{\text{вв}}$, $R_{\text{вп}}$ – the same for the blade resistance;
G – the total weight of the working tool;
$P_{\text{пр}}$ – the compressed spring force (characterising the parameter of its rigidity).

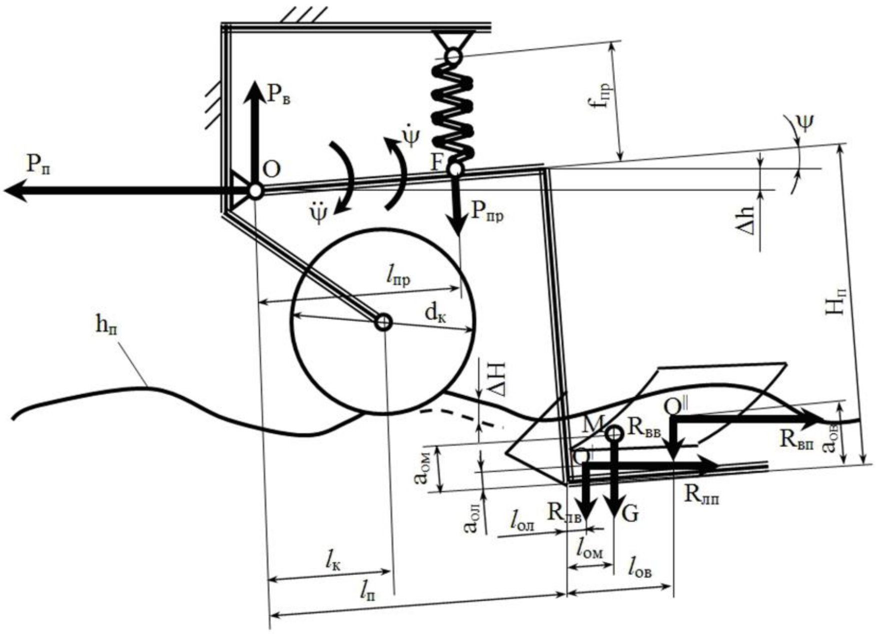

Fig. 1. A scheme of oscillations of the working tool in a transversely-vertical plane

On the basis of expressions (4) and (5), after performing transformations in relation to the generalising coordinate ψ, let us write a mathematical model for the movement of the working tool in a transversely-vertical plane in the form of a differential equation

$$a_0 \cdot \ddot{\psi} + a_1 \cdot \dot{\psi} + a_2 \cdot \psi + a_3 = 0 \tag{6}$$

where:
$a_0, \ldots, a_3$, – the coordinates which depend on the design and technological parameters of the working tool.

On the basis of the mathematical model (6) a transfer function $W_1(p)$ is obtained which reproduces fluctuation of angle ψ as the fluctuation of the tillage depth and represents a conservative link:

$$W_1(p) = \frac{K}{T^2 \cdot p^2 + 1}, \tag{7}$$

where $K = -l_п \cdot a_3/a_2$ – the amplification coefficient of the input effect by the dynamic system – angle ψ,
$T = (a_0/a_2)^{0.5}$ – the constant of time which characterises the inertia properties of the working tool.

The resonance frequency of oscillations (ω) of the particular conservative link depends on the design and technological parameters of the working tool which are a part of the coefficients a_0 and a_2 of the mathematical model (6):

$$\omega = \frac{1}{T} = \langle \frac{a_2}{a_0} \rangle^{0.5} \tag{8}$$

On the basis of the obtained transfer function $W_1(p)$ the amplitude-frequency characteristics of the dynamic system were calculated when angle ψ changes.

The numerical analysis of theoretical amplitude-frequency characteristics showed that aggregation of a combined working tool by means of elastic articulated joints causes additional amplitude of its oscillations in a transversely-vertical plane. This is particularly felt in the frequencies 1.3…1.6 Hz, representing the field microrelief fluctuations, yet they do not belong to the range of resonance oscillations. This phenomenon is undesirable since these frequencies belong to the region of actions both of the reactive forces and the microrelief of the field surface, which leads to the increase in the amplitude (swaying) of the working tool in a vertical plane and to significantly increased dispersion of its working depth [5].

The calculations, in their turn, indicate that installation of a spring with a deflection rate more than 20 kN m^{-1} and its preliminary tensioning significantly (almost 20 times) decreases the amplification coefficient of the transfer function, which correspondingly decreases the dispersion of the working depth of the hoe.

However, an elastic articulated joint of the working tool with the frame of the row-crop drill will not completely remove oscillations in a transversely-vertical plane even at an optimum deflection rate and setting of the spring. An elastic articulated joint of the working tool with the frame is important for tilling rocky soils (for instance, in the Baltic countries and Scandinavia). Under real conditions of non-rocky soils in most regions of Ukraine with the specific resistance of the ground up to 50 kN m^{-1} the elastic articulated joint can be completely replaced with a rigid one. In this case, in order to avoid damage of the working tool, it is purposeful to use shear bolts ensuring emergency rising in overload cases.

4. Conclusions

1. The developed mathematical model considers the design parameters and working modes of the aggregate, and it may be applied to determine the optimum values of rigidity of elastic elements of the suspension, ensuring minimal oscillations of the combined working tool in a transversely-vertical plane.
2. The analysis of the theoretical amplitude-frequency characteristics showed that aggregation of the combined working tool by means of an elastic articulated joint results in additional increase in the amplitude of its oscillations in a transversely-vertical plane. This is particularly felt in the frequencies 1.3…1.6 Hz representing the field microrelief

fluctuations, yet they do not belong to the range of resonance oscillations.

3. Essential reduction of oscillations of the furrower can be gained if it is equipped with a spring having a great deflection rate, which is possible for the designs working on non-rocky soils. Under real conditions of non-rocky soils in most regions of Ukraine with the specific resistance of the ground up to 50 kN m^{-1} the elastic articulated joint can be completely replaced with a rigid one, and, in order to avoid damage of the working tool, it is purposeful to use shear bolts.

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