

Mathematical Modelling in 3D of Opener with Scatterer of the Grain-Fertilizer Seeder

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crossref <http://dx.doi.org/10.5755/j01.mech.24.6.22476>

1. Introduction

One of the ways of increasing the yield of crops is the applying the subsoil scattered sowing of grain crops, which is allowed to optimally use of the feeding area by the crop plants and provide the utilization of 70-100% of the field area at the scattered sowing [1-4].

In this regard, an experimental model of the seeding opener of the grain-fertilizer seeder with the scatterer for subsoil scattered sowing of seeds was developed [5].

The offered seeding opener contains a shank, seed delivery tube and sweep tine furrow opener. The sweep tine furrow opener with a visor form a closed subsoil space for uniformly seeding over the whole seedbed area. Inside, under the sweep tine furrow opener space the oscillating scatterer in the form of a pendulum hemisphere is hanged by a pin, guide bracket and rob. The scatterer-pendulum hemisphere is full volume, all-metal and on the horizontal plane has two degrees of freedom.

The sowing process occurs as follows. During the falling of the seed mass, they are hit to around the oscillating scatterer-pendulum hemisphere and are scattered in all directions, are uniformly being distributed over the entire width of the sweep tine furrow opener.

The process of seeds scattering and distribution by different types of scatterers of seeding openers of the grain-fertilizer seeders was studied by many researchers, namely, A. P. Svevchenko, V. A. Domrachev, E. V. Krasilnikov, N. M. Bespamyatnova, P. V. Lavrukhin and etc. [6-9]. However, the scatterer in the form of pendulum hemisphere has not been drawn a research attention. In doing so, modelling of the different mechanical systems by the matrix methods has been done by numerous researchers, in particular, J. Denavit, R.S. Hartenberg, J.J. Uicker, I. Angelov, V. Slavov, F.M.L. Amiroche and etc. [10-13].

Hence, the purpose of these studies is the mathematical modelling in 3D space of the developed oscillating scatterer-pendulum hemisphere of seeding opener of the grain-fertilizer seeder using the matrix method.

2. Materials and methods

For the mathematical modelling have been used the matrix method. The investigated model is presented as a mechanical system with eight degrees of freedom. The calculation procedure has been done in the computing

mathematical program Wollfram.

To describe the motion of seeding opener with the oscillating scatterer of the grain-fertilizer seeder a kinematic model of the investigated mechanical system by using the following designations is considered (Fig. 1):

$O_0X_0Y_0Z_0$ – initial rectangular coordinate system;

$O_1X_1Y_1Z_1$ – rectangular coordinate system connected with the frame of seeder (body 1);

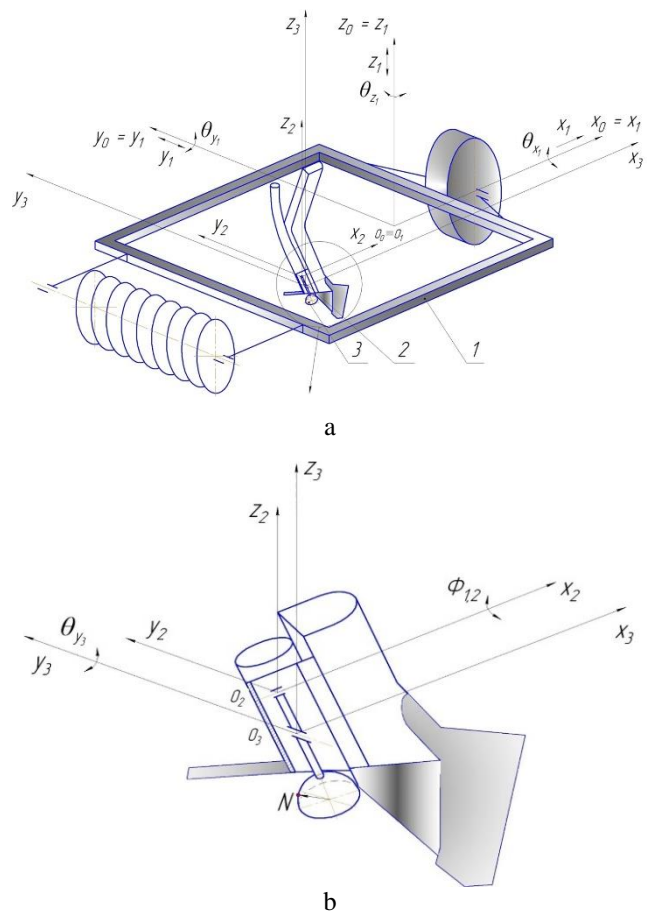


Fig. 1 Kinematic model in 3D space: a – the mechanical system of the units of the grain-fertilizer seeder; b – the seeding opener with the oscillating scatterer

$O_2X_2Y_2Z_2$ – rectangular coordinate system connected with the guide bracket (body 2);

$O_3X_3Y_3Z_3$ – rectangular coordinate system connected with the oscillating scatterer-pendulum hemisphere (body 3);

x_1, y_1, z_1 – a small movements of the frame of seeder along the coordinate axes (body 1);

$\theta_{x1}, \theta_{y1}, \theta_{z1}$ – a small rotation of the frame of seeder around the coordinate axes (body 1);

Φ_{12} – degree of freedom – rotation of guide bracket around the axis O_2X_2 (body 2);

θ_{y3} – degree of freedom – rotation of the oscillating scatterer-pendulum hemisphere around the axis O_3Y_3 (body 3);

N_1, N_2, N_3 – the considered points on the oscillating scatterer-pendulum hemisphere.

3. Research results

The vector of the generalized coordinates of the mechanical systems is written as follows:

$$\mathbf{q} = [x_1 \quad y_1 \quad z_1 \quad \theta_{x1} \quad \theta_{y1} \quad \theta_{z1} \quad \Phi_{12} \quad \theta_{y3}]^T_{8 \times 1}. \quad (1)$$

The transition matrix between coordinate systems:

For body 1:

- small transitions by coordinates:

$$\mathbf{At}_1^0 = \begin{bmatrix} 1 & 0 & 0 & x_1 \\ 0 & 1 & 0 & y_1 \\ 0 & 0 & 1 & z_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}. \quad (2)$$

- a small rotation around the $O_1X_1Y_1Z_1$ coordinate system axis:

$$\mathbf{Au}_{x1} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta_{x1} & -\sin\theta_{x1} & 0 \\ 0 & \sin\theta_{x1} & \cos\theta_{x1} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}. \quad (3)$$

$$\mathbf{Au}_{y1} = \begin{bmatrix} \cos\theta_{y1} & 0 & \sin\theta_{y1} & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\theta_{y1} & 0 & \cos\theta_{y1} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}. \quad (4)$$

$$\mathbf{Au}_{z1} = \begin{bmatrix} \cos\theta_{z1} & -\sin\theta_{z1} & 0 & 0 \\ \sin\theta_{z1} & \cos\theta_{z1} & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}. \quad (5)$$

- the rotation matrix on the $O_1X_1Y_1Z_1$ spatial coordinate system:

$$\mathbf{Au}_1 = \mathbf{Au}_{x1} \cdot \mathbf{Au}_{y1} \cdot \mathbf{Au}_{z1}. \quad (6)$$

- the transition matrix $O_1X_1Y_1Z_1$ coordinate system to $O_0X_0Y_0Z_0$:

$$\mathbf{A}_1^0 = \mathbf{At}_1^0 \cdot \mathbf{Au}_1^0. \quad (7)$$

For body 2:

- the distance between the centers of $O_1X_1Y_1Z_1$ and $O_2X_2Y_2Z_2$ coordinate systems:

$$\mathbf{At}_2^1 = \begin{bmatrix} 1 & 0 & 0 & l_{x12} \\ 0 & 1 & 0 & l_{y12} \\ 0 & 0 & 1 & l_{z12} \\ 0 & 0 & 0 & 1 \end{bmatrix}. \quad (8)$$

- rotation around O_2X_2 axis:

$$\mathbf{Au}_2 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\Phi_{12} & -\sin\Phi_{12} & 0 \\ 0 & \sin\Phi_{12} & \cos\Phi_{12} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}. \quad (9)$$

The transition matrix of the $O_2X_2Y_2Z_2$ coordinate system to $O_1X_1Y_1Z_1$:

$$\mathbf{A}_2^1 = \mathbf{At}_2^1 \cdot \mathbf{Au}_2. \quad (10)$$

The transition matrix of the $O_2X_2Y_2Z_2$ coordinate system to $O_0X_0Y_0Z_0$:

$$\mathbf{A}_2^0 = \mathbf{A}_1^0 \cdot \mathbf{A}_2^1. \quad (11)$$

For body 3:

- the distance between the centers of $O_2X_2Y_2Z_2$ and $O_3X_3Y_3Z_3$ coordinate systems:

$$\mathbf{At}_3^2 = \begin{bmatrix} 1 & 0 & 0 & l_{x23} \\ 0 & 1 & 0 & l_{y23} \\ 0 & 0 & 1 & l_{z23} \\ 0 & 0 & 0 & 1 \end{bmatrix}. \quad (12)$$

- small rotation of pendulum hemisphere around the O_3Y_3 axis:

$$\mathbf{Au}_3 = \begin{bmatrix} \cos\theta_{y3} & 0 & \sin\theta_{y3} & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\theta_{y3} & 0 & \cos\theta_{y3} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}. \quad (13)$$

The transition matrix of the $O_3X_3Y_3Z_3$ coordinate system to $O_1X_1Y_1Z_1$:

$$\mathbf{A}_3^2 = \mathbf{At}_3^2 \cdot \mathbf{Au}_3. \quad (14)$$

The transition matrix of the $O_3X_3Y_3Z_3$ coordinate system to $O_0X_0Y_0Z_0$:

$$\mathbf{A}_3^0 = \mathbf{A}_2^0 \cdot \mathbf{A}_3^2. \quad (15)$$

The radius vector of the point N on the surface of the oscillating scatterer-pendulum hemisphere in the $O_3X_3Y_3Z_3$ coordinate system:

$$\mathbf{r}_{N3} = [l_{xN3} \quad l_{yN3} \quad l_{zN3} \quad 1]^T. \quad (16)$$

The position of the radius vector at N point on the surface of the oscillating scatterer-pendulum hemisphere, in the $O_0X_0Y_0Z_0$ initial coordinate system:

$$\mathbf{R}_{N3}^0 = \mathbf{A}_3^0 \cdot \mathbf{r}_{N3}. \quad (17)$$

By differentiation in time the expression (17) of the radius-vector provisions of the point, we get the speed of the point N on the surface of the oscillating scatterer-pendulum hemisphere in $O_0X_0Y_0Z_0$ coordinate system:

$$\mathbf{V}_{N3}^0 = \frac{d\mathbf{R}_{N3}^0}{dt}. \quad (18)$$

The angular velocity projection of the body 1 in the $O_1X_1Y_1Z_1$ coordinate system is determined by the formula:

$$\boldsymbol{\omega}_{11} = \mathbf{A}\mathbf{u}_{z1}^T \cdot \mathbf{A}\mathbf{u}_{y1}^T \cdot \boldsymbol{\omega}_{1x1} + \mathbf{A}\mathbf{u}_{z1}^T \cdot \boldsymbol{\omega}_{1y1} + \boldsymbol{\omega}_{1z1}, \quad (19)$$

where:

$$\boldsymbol{\omega}_{1x1} = \begin{bmatrix} \omega_{x1} \\ 0 \\ 0 \\ 0 \end{bmatrix}; \quad \boldsymbol{\omega}_{1y1} = \begin{bmatrix} 0 \\ \omega_{y1} \\ 0 \\ 0 \end{bmatrix}; \quad \boldsymbol{\omega}_{1z1} = \begin{bmatrix} 0 \\ 0 \\ \omega_{z1} \\ 0 \end{bmatrix}. \quad (20)$$

The angular velocity projection of the body 2 in the $O_2X_2Y_2Z_2$ coordinate system is defined as:

$$\boldsymbol{\omega}_{22} = \mathbf{A}\mathbf{u}_2^T \cdot \boldsymbol{\omega}_{11} + \boldsymbol{\omega}_{2x2}, \quad (21)$$

where:

$$\boldsymbol{\omega}_{2x2} = \begin{bmatrix} \omega_{x2} \\ 0 \\ 0 \\ 0 \end{bmatrix}. \quad (22)$$

The angular velocity projection of the body 3 (scatterer-pendulum hemisphere) in the $O_3X_3Y_3Z_3$ coordinate system is defined as:

$$\boldsymbol{\omega}_{33} = \mathbf{A}\mathbf{u}_3^T \cdot \boldsymbol{\omega}_{22} + \boldsymbol{\omega}_{3y3}, \quad (23)$$

where:

$$\boldsymbol{\omega}_{3y3} = \begin{bmatrix} 0 \\ \omega_{y3} \\ 0 \\ 0 \end{bmatrix}. \quad (24)$$

4. Discussion

For the calculation of the considered mechanical system the real constructive parameters of the investigated

seeding opener with the oscillating scatterer of the grain-fertilizer seeder have been used. In doing so, the travel speed of the seeder was $V=1,94$ m/s. Coordinates of points N_1, N_2 and N_3 in the $O_3X_3Y_3Z_3$ coordinate systems:

$$\begin{aligned} \mathbf{r}_{N1} &= [l_{Nx1} \quad l_{Ny1} \quad l_{Nz1}]^T = [-0,040 \quad 0 \quad -0,030]^T, \\ \mathbf{r}_{N2} &= [l_{Nx2} \quad l_{Ny2} \quad l_{Nz2}]^T = [0,040 \quad 0 \quad -0,030]^T, \\ \mathbf{r}_{N3} &= [l_{Nx3} \quad l_{Ny3} \quad l_{Nz3}]^T = [0 \quad 0,040 \quad -0,030]^T. \end{aligned}$$

The considered points N_1, N_2 and N_3 characterize the points on the rear, front and side parts of surface of the oscillating scatterer-pendulum hemisphere respectively.

The distance between the $O_1X_1Y_1Z_1$ and $O_2X_2Y_2Z_2$ coordinate systems:

$$\mathbf{R}_2^1 = [l_{x12} \quad l_{y12} \quad l_{z12}]^T = [-0,5 \quad 0 \quad -0,2]^T.$$

The distance between the $O_2X_2Y_2Z_2$ и $O_3X_3Y_3Z_3$ coordinate systems:

$$\mathbf{R}_3^2 = [l_{x23} \quad l_{y23} \quad l_{z23}]^T = [0 \quad 0 \quad -0,03]^T.$$

The Figs. 2 and 3 demonstrate the trajectories of the points on the surface of the oscillating scatterer-pendulum hemisphere in 3D space and their projections on the XOZ and XOY coordinate planes for the time interval of $0 < t < 5$ s.

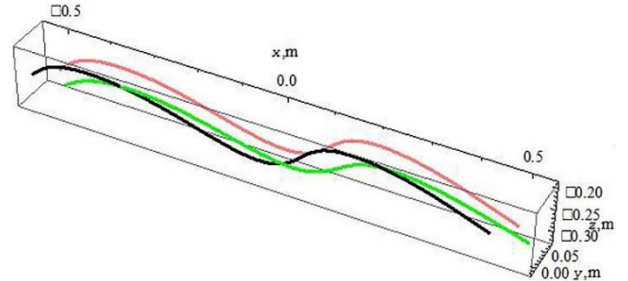


Fig. 2 The trajectory of the points N_1, N_2 and N_3 on the surface of the oscillating scatterer-pendulum hemisphere in 3D space

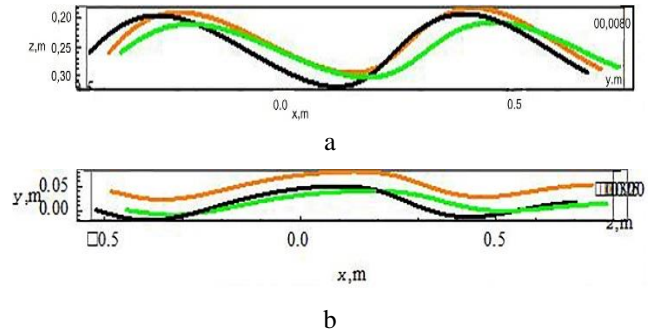


Fig. 3 The oscillation trajectory projections of the points N_1, N_2 and N_3 on the surface of the oscillating scatterer-pendulum hemisphere on the coordinate planes: a – XOZ ; b – XOY

From these data is seen that the considered points on the surface of the oscillating scatterer-pendulum hemi-

sphere have different trajectories. It is revealed that the points N_1 and N_2 (red and green lines respectively) have a lengthened trajectory in comparison with the trajectory of the point N_2 (black line) on the XOZ and XOY coordinate planes. The indicated allows us to state that the interaction of falling seed mass with the rear and side parts of the surface of the oscillating scatterer-pendulum hemisphere will have a positive effect on the range of their flight, consequently the spread and distribution of seeds.

There were derived the linear velocity components of the corresponding points N_1 , N_2 and N_3 on the surface of the oscillating scatterer-pendulum hemisphere (Fig. 4).

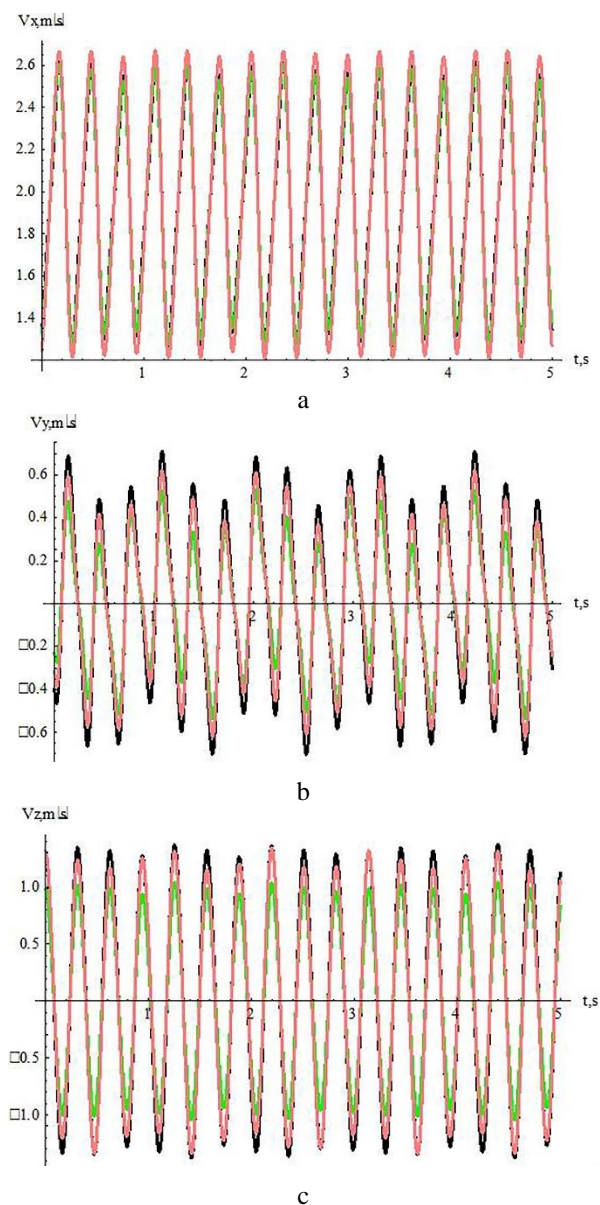


Fig. 4 The linear velocity components the considered points N_1 , N_2 and N_3 on the surface of the oscillating scatterer-pendulum hemisphere: a – V_X ; b – V_Y ; c – V_Z

It is revealed that oscillation amplitudes of the longitudinal component V_X of the considered points are varied from 1.2 to 2.7 m/s, while the lateral and vertical components V_Y and V_Z are changed in the range of -0,6-0,6 and -1,4-1,4 m/s respectively. In doing so, the points N_1

and N_3 have the maximum absolute values of amplitude. The point N_2 has the minimal value of the linear velocity in all three axis. These will lead to the fact that the front and side part of the surface of the oscillating scatterer-pendulum hemisphere will have a greater impact force during its contact with the falling seeds, which will have a positive effect on the fright range and spread of seeds as well.

There were plotted the angular velocity components of the oscillating scatterer-pendulum hemisphere (Fig. 5).

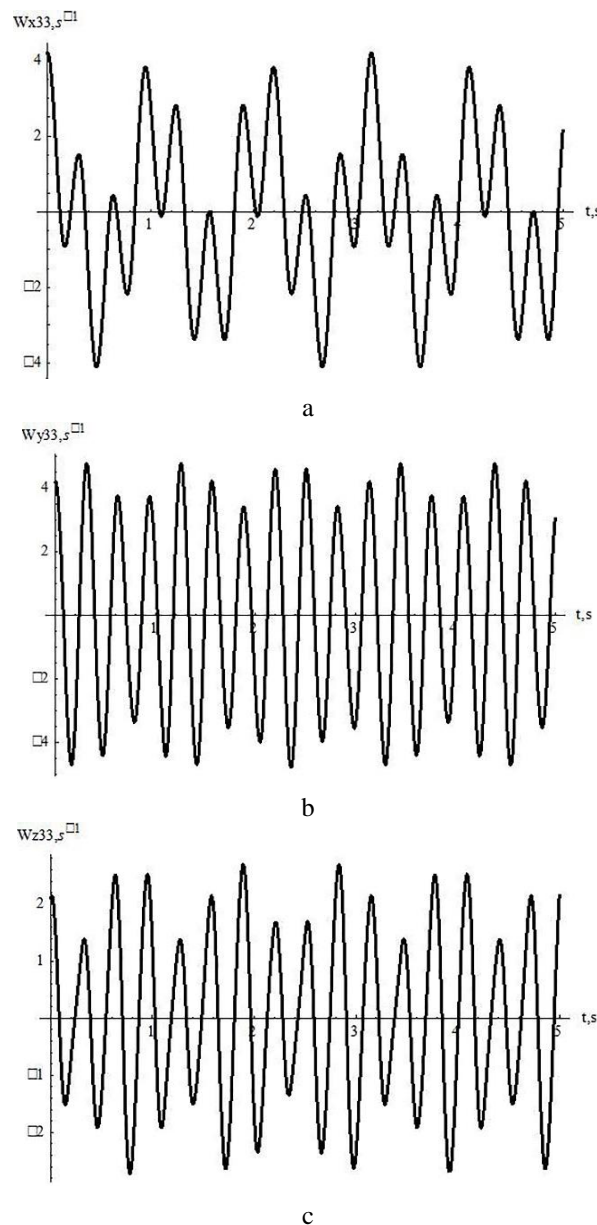


Fig. 5 The angular velocity components of the oscillating scatterer-pendulum hemisphere: a – W_X ; b – W_Y ; c – W_Z

It is revealed that the angular velocity components W_X and W_Y have the maximum oscillation amplitude values. These obtained data will be used in further studies of mechanical system dynamics of the investigated seeding opener with scatterer of the grain-fertilizer seeders.

5. Conclusions

1. A mathematical modelling of the developed scatterer of seeding opener of the grain-fertilizer seeder using the matrix method in 3D space has been created. The investigated model is presented as a mechanical system with eight degrees of freedom.

2. Based on the results of simulation, the trajectories of the points on the surface of the oscillating scatterer in the form of pendulum hemisphere in 3D space and their projections on the *XOZ* and *XOY* coordinate planes are plotted. They show that the considered points on the scatterer have different trajectories, which will have a positive effect during the falling seeds – scatterer-pendulum hemisphere interaction in terms of the flight range, spread and distribution of seeds.

3. There were derived the linear velocity components of the considered points as well as the angular velocity components of the oscillating scatterer-pendulum hemisphere. It is revealed that oscillation amplitudes of the linear and angular velocity components are varied in wide range. The indicated leads to the increase in the impact force during the contact of the falling seeds with the investigated scatterer, which will have a positive effect on the flight range and spread of seeds as well.

4. Obtained data will be used in further studies of mechanical system dynamics of the investigated seeding opener with scatterer of the grain-fertilizer seeder.

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MATHEMATICAL MODELING IN 3D OF OPENER WITH SCATTERER OF THE GRAIN-FERTILIZER SEEDER

S u m m a r y

This paper presents a mathematical modelling in 3D space of the scatterers of seeding opener of the grain-fertilizer seeder using the matrix method. The investigated model is presented as a mechanical system with eight degrees of freedom. Based on the results of simulation, the trajectories of the points on the oscillating scatterer in the form of a pendulum hemisphere and their projections on the *XOZ* and *XOY* coordinate planes as well as the linear velocity components of the considered points and the angular velocities components of the investigated scatterer are derived. The obtained data allow us to state that the use of the oscillating scatterer-pendulum hemisphere will improve the quality of sowing in terms of the flight range, spread and distribution of seeds, consequently, it will increase in the yield of crops. The results will also be used in further studies of mechanical system dynamics of the investigated seeding opener with scatterer of the grain-fertilizer seeders.

Keywords: kinematics model, matrix method, scatterer-pendulum hemisphere, the seeding opener, the grain-fertilizer seeders.

Received March 07, 2017

Accepted December 12, 2018