IMPROVING EFFICIENCY OF MOBILE COMBINED FEED MIXER

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Abstract. The article is devoted to increasing the efficiency of the combined feed mixer in the process of feeding animals. The unit provides simultaneous grinding and mixing of the components of the feed ration, both in the forage area and during transportation, followed by their dosed distribution. With the simultaneous movement of the mobile feed mixer along the road and the operation of the screw mixer, dynamic forces arise, leading to oscillations of the unit in the transverse and longitudinal directions, relative to its axis. Compensation for these movements is carried out by the tires of the unit, which leads to their intensive wear. The results of studies that allow to identify and balance the dynamic loads that occur in the structural elements of the unit during the preparation and distribution of feed are presented. A dynamic and mathematical model of a mobile combined feed preparation unit has been developed. The resulting graphs show the dynamics of its work, the nature of the change in loads. An analysis of the graphs proves that when the mobile mixer moves, the tires and the mixer itself vibrate, which can lead to a loss of balance of the unit. To avoid such a phenomenon, it is proposed to reduce the unbalance of the rotor of the unit. To do this, it is proposed to improve the screw working body, which is made two-way with a phase shift of the screws. After the improvement, the maximum deflection angle of the bunker of the feed preparation unit is 0.034 rad. The speed of bending oscillations does not exceed $\pm$ 1 s^{-1}. The angular acceleration of the screw at the beginning has a jerk, then it reaches a steady motion with a constant nature of the change in oscillations within $\pm$ 6.3 s^{-2}. The justified rational design of the rotor in the form of a two-way conical auger makes it possible to increase the durability of the tires of the mobile combined feed preparation unit by 16-20%.

Keywords: feed components, mixtures, mixing, dynamic loads, tires.

Introduction

Depending on the technology of fodder preparation, when choosing a set of machines and equipment, one should adhere to rational modern methodological approaches and promising solutions [1; 2]. At the present stage development of animal husbandry, both in the world practice and in Ukraine, for preparation of feed mixture, combined feed preparation units are becoming more common, combining the operations of grinding, mixing, and provide delivery and metered distribution of feed. Their positive attributes are mobility, simplicity of the design and profitability. When analyzing the operation of the mobile combined feed preparation unit, wear of the wheel tread was found (Fig. 1), which, in our opinion, is associated with a change in the center of mass of the feed mixture inside the hopper in the process of simultaneous grinding and mixing the ingredients of the feed ration by the auger working body.

Fig. 1. **Wear of the forage mixer wheel tread**

The process of preparation the feed mixture (grinding and mixing) is carried out by a single-thread screw working body of a cone-shaped type. With the simultaneous movement of the mobile feed preparation unit along the road and the operation of the screw mixer, dynamic forces arise that lead to the movement of the unit in the transverse and longitudinal directions, relative to its axis. Compensation for these movements is carried out by the tires of the unit, which leads to their intensive wear. To eliminate wear of the tire tread and ensure stability of the unit, a utility model patent No. 62767 was proposed, which provides for changes in the design of the working body [3]. The lower expanded part is equipped with an additional helical winding, that is, two helical windings are located symmetrically to each

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other, while one of the windings has a limited length. Studies [4-9] indicate that an increase in the number of turns leads to improvement in mixing of feed components with each other, since the speed of the particle movement increases. Problems of balancing dynamic loads exist in other industries as well. For example, in [10], it was proposed to dynamically balance the drive mechanism of a roller molding plant by installing a recuperative drive. The method of dynamic calculation of machines with elastic and elastic-dissipative links is given in [11; 12].

Materials and methods

To determine the dynamic loads in the structural elements of the mobile feed mixer, a three-mass dynamic model with four degrees of freedom was built (Fig. 2). Note that the characteristics of the drive are not considered, if the shaft of the screw mixer has a constant angular velocity, and the elastic properties of the suspension and tires are considered, and the other links of the feed preparation unit are considered to be absolutely rigid bodies.

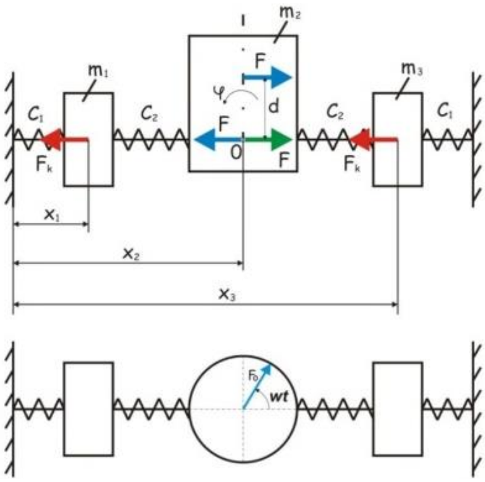

Fig. 2. **Dynamic model of the mobile feed mixer:** φ – mixer rotation angle; C_2 – transverse stiffness of tires interacting with the road surface; C_2 – suspension stiffness in transverse direction; $m_1 = m_3$ – wheel weights; m_2 – mixer weight; F_0 – centrifugal force from the unbalanced mass of the mixing feed mixture; F – projection of the centrifugal force from the unbalanced mass of the load on the transverse axis; F_k – frictional force between the wheel and the road surface; x_1, x_2, x_3 – linear coordinates of the centers of mass of wheels with suspensions and a mixer in the transverse direction, which, together with the angular coordinate, are taken as generalized coordinates; d – distance to the center of mass of the mixer from the axis of the wheels in the vertical direction

To construct a mathematical model of the mixer motion dynamics, the Lagrange equation of the second kind was used

$$\begin{cases} \frac{d}{dt}\frac{\partial T}{d\dot{x}_1} - \frac{\partial T}{dx_1} = Q_{x_1} - \frac{\partial \Pi}{dx_1}; \\ \frac{d}{dt}\frac{\partial T}{d\dot{x}_2} - \frac{\partial T}{dx_2} = Q_{x_2} - \frac{\partial \Pi}{dx_2}; \\ \frac{d}{dt}\frac{\partial T}{d\dot{x}_3} - \frac{\partial T}{dx_3} = Q_{x_3} - \frac{\partial \Pi}{dx_3}; \\ \frac{d}{dt}\frac{\partial T}{d\dot{\varphi}} - \frac{\partial T}{d\varphi} = Q_{\varphi} - \frac{\partial \Pi}{d\varphi}, \end{cases} \tag{1}$$

where T – kinetic energy of the system;
Π – potential energy system;
x_1, x_2, x_3 – transverse linear coordinates of the centers of mass, respectively, of the first, second and third masses;
Qx_1, Qx_2, Qx_3, Q_φ – generalized forces corresponding to generalized coordinates x_1, x_2, x_3 and φ.

Kinetic energy of the system:

$$T = \frac{1}{2} m_1 \dot{x}_1^2 + \frac{1}{2} m_2 \dot{x}_2^2 + \frac{1}{2} I_2 \dot{\varphi}^2 + \frac{1}{2} m_3 \dot{x}_3^2, \tag{2}$$

where I_2 – moment of inertia of the mixer rotor and the mixture contained in it relative to the axis of rotation.

Note that

$$\frac{\partial T}{dx_1} = \frac{\partial T}{dx_2} = \frac{\partial T}{dx_3} = \frac{\partial T}{d\varphi} = 0,$$

since the kinetic energy does not depend on generalized coordinates but depends only on generalized velocities.

The potential energy of the system is represented by the dependence:

$$\Pi = \frac{1}{2} C_1 x_1^2 + \frac{1}{2} C_2 \left((x_2 + d \sin \omega t) - x_1 \right)^2 + \frac{1}{2} C_K \varphi^2 + \ldots + \frac{1}{2} C_2 \left(x_3 - (x_2 + d \sin \omega t) \right)^2 + \frac{1}{2} C_1 x_3^2, \tag{3}$$

where $C_к$ – angular torsional stiffness, which, in turn, is determined by the formula:

$$C_K = \frac{M}{\Delta \varphi}, \tag{4}$$

where M – moment causing angular deformation of the mixer shaft $\Delta\varphi$.

Generalized forces corresponding to generalized coordinates x_1, x_2, x_3, φ are defined by dependencies:

$$\begin{aligned}
Q_{x_1} &= -F_K = -\left(m_1 + \frac{m_2}{2} \right) g \cdot f \cdot \sin \dot{x}_1; \\
Q_{x_2} &= F = F_0 \cos \omega t = m \omega^2 R \cos \omega t; \\
Q_{x_3} &= -F_K = -\left(m_1 + \frac{m_2}{2} \right) g \cdot f \cdot \sin \dot{x}_3; \\
Q_{\varphi} &= -Fd = -m \omega^2 R d \cos \omega t,
\end{aligned} \tag{5}$$

where f – coefficient of friction between the wheels and the road surface;
m – mass of the mixture.

It should be noted that at $C_1 x_1 > F_k$ emergency work will be observed.

Substituting expressions (2-5) into the system of equations (1), we obtain differential equations of motion of the feed preparation unit:

$$\begin{cases}
m_1 \ddot{x}_1 = -\left(m_1 + \frac{m_2}{2} \right) g \cdot f - (C_1 + C_2) x_1 + C_2 x_2 \\
m_2 \ddot{x}_2 = m \omega^2 R \cos \omega t - C_2 (2x_2 - x_1 - x_3) \\
m_3 \ddot{x}_3 = -\left(m_1 + \frac{m_2}{2} \right) g \cdot f - (C_1 + C_2) x_3 + C_2 x_2 \\
I_2 \ddot{\varphi} = -m \omega^2 R d \cos \omega t - C_K \varphi.
\end{cases} \tag{6}$$

Results and discussion

The resulting differential equations (4) are non-linear differential equations of the second order, so they cannot be integrated analytically. To solve them, a numerous method is used, implemented using the computer program Mathematica. The laws of changing the linear movement of tires (x_1, x_3), center of mass of the feed preparation unit (x_2), as well as the law of change of the angular coordinate of the vertical deviations of the feed preparation unit, which are shown in Fig. 2, were obtained for such initial data:

$$m = 4000 \text{ kg};\ R = 0.6 \text{ m};\ d = 1 \text{ m};\ m_1 = m_3 = 26 \text{ kg};\ m_2 = 7500 \text{ kg};\ \omega = 3.14 \text{ rad}\cdot\text{s}^{-1};$$

$$C_1 = 6000 \text{ N}\cdot\text{m}^{-1};\ C_1 = 248000 \text{ N}\cdot\text{m}^{-1};\ C_1 = 271989 \text{ N}\cdot\text{m}\cdot\text{rad}^{-1};\ f = 0.5;\ I_2 = 720 \text{ kg}\cdot\text{m}^{-2}.$$

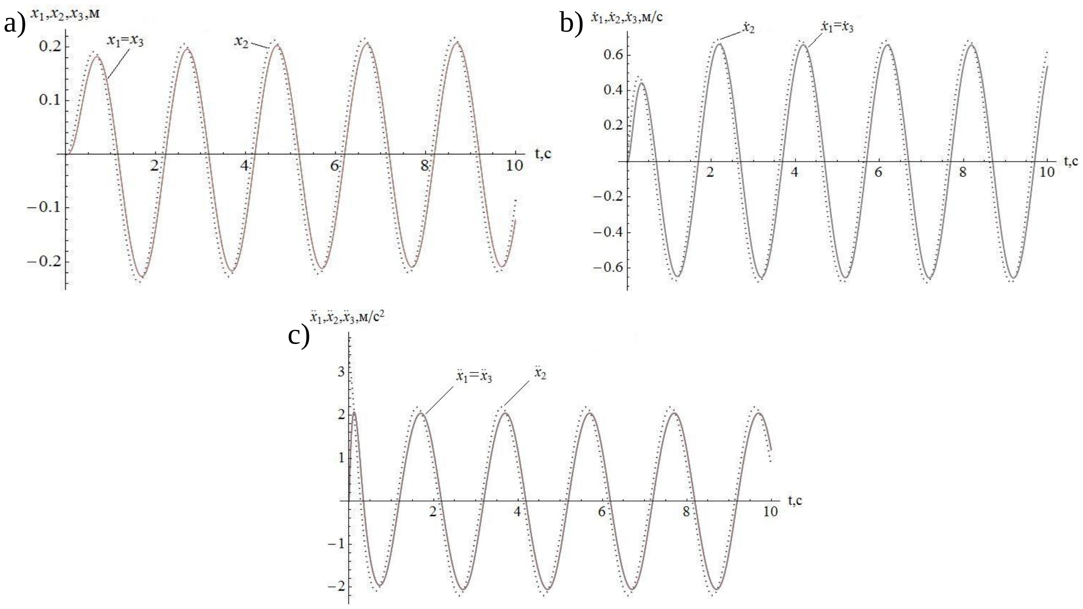

Fig. 3. **Results of the study of dynamics of operation of the mobile feed preparation unit:** a – movement schedule; b – speed graph; c – acceleration graph

The analysis of the obtained graphs shows that there is an oscillatory process with changes in linear displacements, velocities, and accelerations of the centers of mass of the elements of the mixer, which can lead to loss of balance. The law of change of linear movement of tires, in the transverse direction (x_1, x_3) is the same, so the curves overlap. The maximum displacement is 0.18 m. The hopper of the mixer, namely its center of mass (x_2), deviates by 0.19 m (Fig. 3, a).

The range of the change in linear velocities of the centers of mass of the wheels and the mixer, in the transverse direction, is within 1.2 m·s^{-1} (Fig. 3 b). Graphs of the change of accelerations of the centers of masses of wheels and the mixer also have a fluctuating character. The value of ac celeration ranges from -2 m·s^{-2} to 2 m·s^{-2} (Fig. 3 c). Fig. 4 shows bending oscillations of the mixer rotor from the action of unbalanced mass of the mixture during operation.

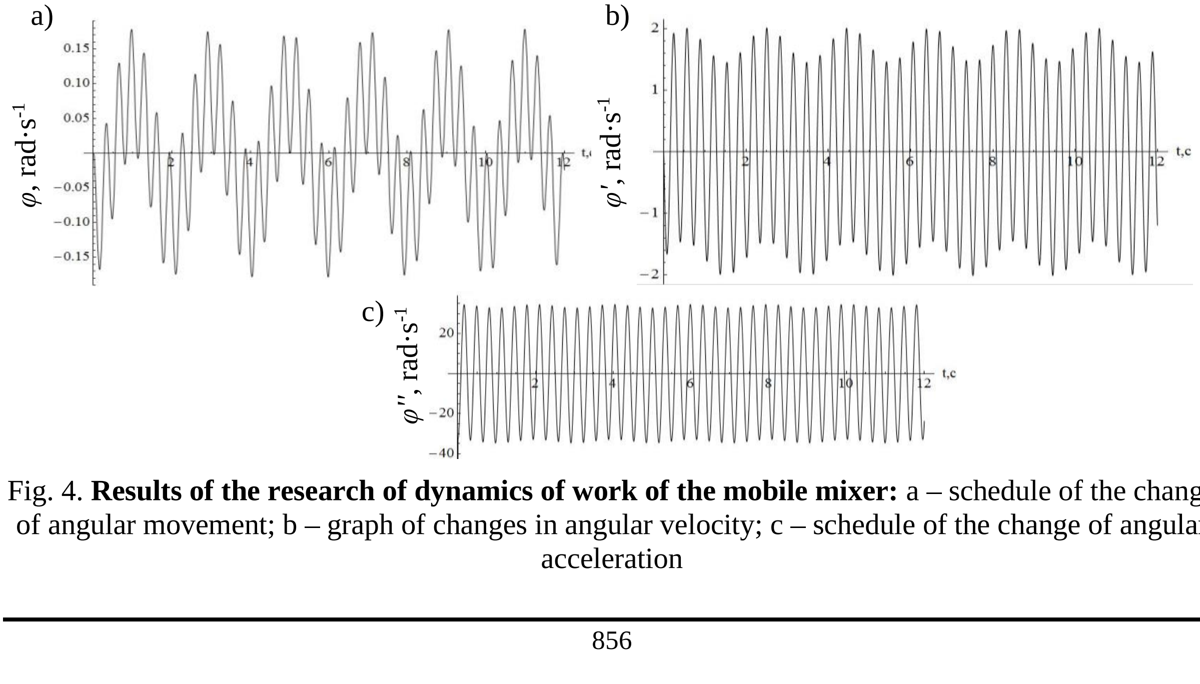

Fig. 4. **Results of the research of dynamics of work of the mobile mixer:** a – schedule of the change of angular movement; b – graph of changes in angular velocity; c – schedule of the change of angular acceleration

As it can be seen from Fig. 4 a, the maximum deflection angle of the hopper is 0.17 rad. The speed of bending oscillations does not exceed ± 2 rad·s^{-1} (Fig. 4 b). The graph of the change of angular acceleration at the beginning has a jerk, then goes to a steady motion, with a constant nature of changes in oscillations, within ± 30 rad·s^{-2}. To avoid this phenomenon, it is proposed to reduce the unbalance of the rotor of the feed preparation unit. To do this, it is proposed to improve the auger working body, which is made two-way, with a shift of the phases of the screws at an angle $\pi/2$, and its length should not exceed $D/2$, where D – diameter of the mixer.

We obtain differential equations of motion of the mixer for the improved screw working body of the feed preparation unit:

$$\begin{cases} m_1\ddot{x}_1 = -\left(m_1 + \dfrac{m_2}{2}\right)g \cdot f - (C_1 + C_2)x_1 + C_2(x_2 + d\sin\omega t) \\ m_2\ddot{x}_2 = m\omega^2 R\cos\omega t - C_2(2x_2 + d\sin\omega t - x_1 - x_3) \\ m_3\ddot{x}_3 = -\left(m_1 + \dfrac{m_2}{2}\right)g \cdot f - (C_1 + C_2)x_3 + C_2(x_2 + d\sin\omega t) \\ I_2\ddot{\varphi} = -m\omega^2 Rd\cos\omega t - C_K\varphi. \end{cases} \tag{7}$$

The advanced auger working body received the laws of change of linear movement of tires (x_1, x_3), center of mass of the feed preparation unit (x_2), as well as the law of change of the angular coordinate of the vertical deviations, which are shown in (Fig. 5), and were obtained for the following initial data:

m = 4000 kg; R = 0.3 m; d = 1 m; $m_1 = m_3$ = 26 kg; m_2 = 7500 kg; ω = 3.14 rad·s^{-1};

C_1 = 6000 N·m^{-1}; C_1 = 248000 N·m^{-1}; C_1 = 271989 N·m·rad^{-1}; f = 0.5; I_2 = 720 kg·m^{-2},

where R – radius of the upper turn of the auger, m.

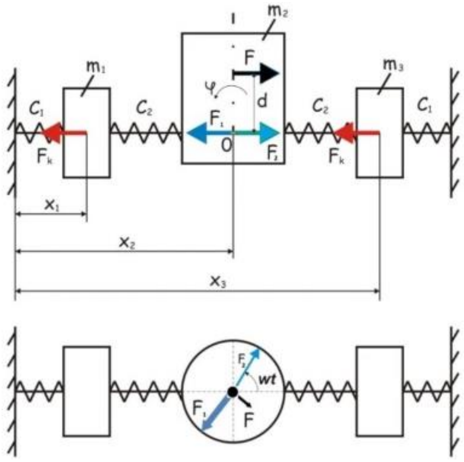

Fig. 5. **Dynamic model of the mobile combined forage preparation unit with the improved working body**

The law of the change of linear movement of tires in the transverse direction (x_1, x_3) is the same, so the curves overlap. The maximum displacement is 0.04 m. The hopper of the feed preparation unit, namely its center of mass (x_2), deviates by 0.043 m (Fig. 6 a).

The magnitude of the change in the linear velocities of the centers of mass of the wheels and the hopper of the feed preparation unit, in the transverse direction, is within 0.25 m·s^{-1} (Fig. 6 b).

Graphs of the change of acceleration of the centers of masses of the wheels and the mixer also have a fluctuating character. The value of acceleration ranges from -1 m·s^{-2} to 1 m·s^{-2} (Fig. 6 c).

Fig. 7 shows the bending oscillations of the mixer rotor due to the unbalanced mass of the mixture during operation.

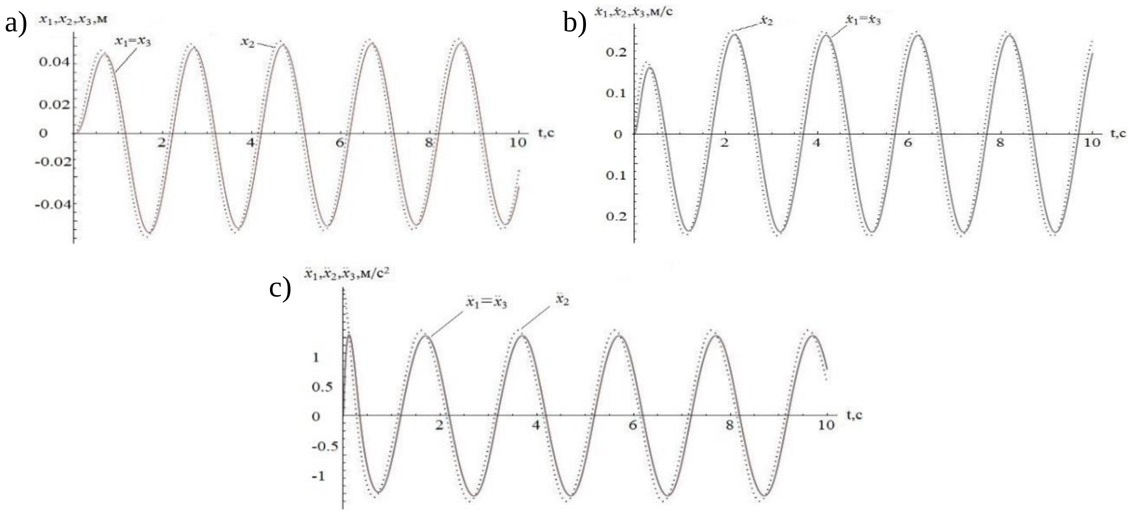

Fig. 6. **Results of the research of dynamics of work of the mobile forage preparation unit with the two-western screw working body:** a – schedule of movement; b – speed chart; c – schedule of acceleration

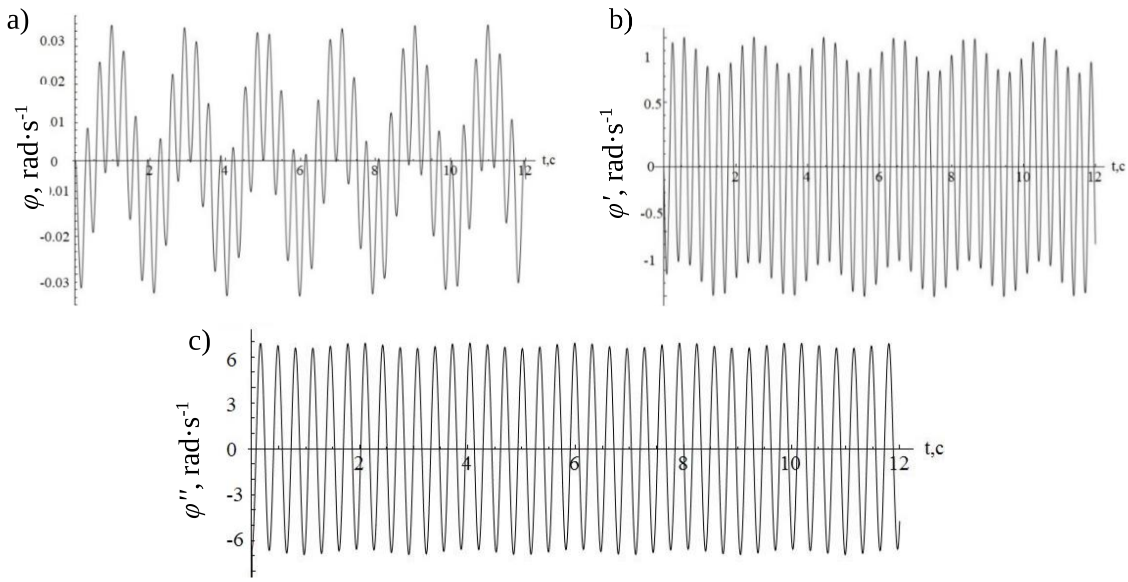

Fig. 7. **Results of the study of dynamics of the mobile feed preparation unit:** a – schedule of changes in angular displacement; b – graph of changes in angular velocity; c – schedule of changes of angular acceleration

As it can be seen from (Fig. 7 a), the maximum deflection angle of the hopper of the feed preparation unit is 0.034 rad. The speed of bending oscillations does not exceed ± 1 rad·s^{-1} (Fig. 7 b). The graph of the change of angular acceleration at the beginning has a jerk, then goes to a steady motion with a constant nature of changes in oscillations within ± 6.3 rad·s^{-2} (Fig. 7 c).

Conclusions

1. Dynamic and mathematical models of the mobile feed preparation unit have been developed, which show the dynamics of its operation and the nature of load changes. The analysis of the graphs shows that during the movement of the mobile feed preparation unit there are oscillations of both the tires and the hopper itself, which can lead to loss of balance of the unit. To avoid this phenomenon, it is proposed to reduce the unbalance of the rotor of the feed preparation unit.
2. It is proposed to improve the auger working body, which is made two-way with a shift of the phases of the screws at an angle $\pi/2$, and its circumferential length should not exceed $D/2$, where D is the diameter of the lower base of the hopper.

3. The substantiated rational design of the rotor, in the form of a two-way conical screw installed with a wide base to the bottom, allows to intensify the technological process of forage preparation in the mobile combined forage unit, increase its balance and durability of tires by 16-20%. In this case, the maximum deflection angle of the hopper of the feed preparation unit is 0.034 rad. The speed of bending oscillations does not exceed ± 1 $rad \cdot s^{-1}$. The change in angular acceleration initially has a jerk, then goes to a steady motion, with a constant nature of changes in oscillations, within ± 6.3 $rad \cdot s^{-2}$.

References

[1] Revenko I., Khmelovsky V., Belik D. Ways to improve units for preparation and distribution of feed to cattle. Bulletin of the Petro Vasylenko Kharkiv National Technical University of Agriculture, 2010, vol. 95, pp. 250-258.
[2] Revenko I., Lisovenko T., Khmelovsky V. Mobile feeders in modern conditions. Scientific Bulletin of the National University of Life and Environmental Sciences of Ukraine, 2009, vol. 134, iss. 2, pp. 185-92.
[3] Revenko I., Khmelovsky V, Pylypaka S. Patent 62767 Ukraine A01K 5/02 (2006.01). Combined unit for preparation and distribution of feed with the working body of the two-way screw winding. Industrial property, 2011, Bull. No. 17, p. 3
[4] Robinson M., Cleary P. Flow and mixing performance in helical ribbon mixers. Chemical Engineering Science, 2012, vol. 84, pp. 382-398. DOI: 10.1016/J.CES.2012.08.044.
[5] Ortega-Casanova J., Tech A., Ramos O. CFD study on mixing enhancement in a channel at a low Reynolds number by pitching a square cylinder. Computers and Fluids, 2017, vol. 145, pp. 141-152.
[6] Driss Z., Karray S., Kchaou H., Abid M.S. CFD simulation of the laminar flow in stirred tanks generated by double helical ribbons and double helical screw ribbons impellers. Central European Journal of Engineering, 2011, vol 1 (4), pp. 413-422.
[7] Aubin J., Naude I., Xuereb C., Bertrand J. Blending of newtonian and shear-thinning fluids in a tank stirred with a helical screw agitator. Chemical Engineering Research and Design, 2000, vol. 7(8), pp. 1105-1114.
[8] Abdessalam H., Bouzit M., Kamla Y., Ameur H. A new geometrical model for mixing highly viscous fluids by combining two-blade and helical screw agitators. Polish Journal of Chemical Technology, 2017, vol 3, pp. 83-91.
[9] Nurul Farhana Mohd Y., Edmund Ung Eng S., Iman Fitri I., Akmal Nizam M. Mixing performance of anchor and helical stirrer blades for viscous fluid applications. CFD Letters Journal, 2021, vol. 1, pp. 58-71.
[10] Loveykin V., Pochka K. Dynamic balancing of the drive mechanism of the roller forming unit. Automation of production processes in mechanical engineering and instrument making, 2015, vol. 49, pp. 61-72.
[11] Loveykin V., Romasevich Y. Dynamics of machines: monograph. Kyiv. Comprint, 2013, pp 227.
[12] Fuyang T., Chen F. Element Simulation and Performance Test of Loading and Mixing Characteristics of Self-Propelled Total Mixed Ration Mixer. Journal of Engineering, 2020, vol. 12, pp. 1-15.