DEVELOPMENT OF THEORY OF THE DRIVE OF STATIONARY AGRICULTURAL MACHINES WITH LEVER MECHANISMS

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Abstract: *The improvement of the efficiency of agricultural machines of a modern technical level can be achieved when new methods of the theory of mechanisms and machines are used during calculations and design of their working bodies and in general of* machine aggregates. *The task of the research was to develop a new algorithm for solving the second problem of dynamics of lever mechanisms with electric drive, which are used in modern agricultural machines A new algorithm for solving the second problem of dynamics of lever mechanisms of agricultural machines equipped with an electric drive has been developed. The algorithm finds application in calculations of flat lever mechanisms of stationary agricultural machines.*

KEY WORDS: LEVER MECHANISM, RESISTANCE FORCES, MOMENT OF INERTIA, FLYWHEEL, ALGORITHM, CALCULATION.

1. Introduction

Significant increase in the efficiency of agricultural machines of the modern technical level can be achieved when the calculations and design of their working bodies and in general machine aggregates use new methods of the theory of mechanisms and machines. In stationary agricultural machines, lever gears with electric drive are widely used. Therefore, the search for new methods for solving the second problem of dynamics of lever mechanisms with electric drive is considered the most actual mechanical and mathematical problem.

2. Preconditions and means for resolving the problem

2.1. Review of literary sources

In [2], the solution in quadratures of the equation of motion of a machine-unit with an electric drive for the combined moments of inertia and resistance forces described by functions of the general type from the angle of the crank. On its basis, simple algorithms and formulas for calculating the flywheel and process analysis are obtained. However, it is possible to use a new algorithm to solve problems of the dynamics of lever mechanisms, which can be applied in researches of agricultural machines of the modern technical level.

2.2. Purpose of the study

To develop a new algorithm for solving the second problem of dynamics of lever mechanisms with electric drive, which are used in modern agricultural machines.

3. Results and discussion

In order to make calculations it is expedient to develop an algorithm for solving the second problem of dynamics of lever gears with an electric drive in such a sequence. According to the known formulas, we find a consolidated moment of forces of useful resistance and gravity forces M_{OT} depending on the angle of rotation of the crank φ. Next, it is necessary to determine the work of the summary moment of forces the strength of the of strength and gravity M_{OT} during the cycle of steady motion:

$$A_{OT} = A_{OT}(\varphi) = \int_0^{\varphi} M_{OT} d\varphi . \qquad (1)$$

For a full cycle of steady motion, this work is:

$$A_C = A_{OT}(2\pi) = \int_0^{2\pi} M_{OT} d\varphi . \qquad (2)$$

The rated power of an electric motor is determined by this dependence:

$$P = \frac{|A_C| n}{60 \eta_V \eta_P} , \qquad (3)$$

where n – given the average speed of the crank, rpm; η_V, η_P – coefficients of efficiency of the lever mechanism and transmission mechanisms.

For lever mechanisms with two successively combined structural groups (mechanisms for the processing and shredding of agricultural products, planing and grooving machines, presses, mechanisms for giving of preparations, etc.) can be roughly taken $\eta_V = 0.64…0.77$, for mechanisms of compressors with parallel connected structural groups of the second type – $\eta_V = 0.8…0.88$.

The coefficient of efficiency of a single-stage gear is equal to η_o = 0.96 ... 0.98. The efficiency of one-row and two-row planetary mechanisms is η_{pl} = 0.97...0.99. For a planetary mechanism, which is a sequential combination of two one-row planetary mechanisms, $\eta_p = 0.94…0.98$ [1].

Installed power of the engine will be equal:

$$P_y = k_y P, \qquad (4)$$

where k_y = 1,2 – factor of the reserve of installation power.

According to GOST 19523-74 choose a three-phase asynchronous motor of the 4A series with a short-circuited rotor nearest the greater rated power for a given synchronous frequency n_{snd}, [rpm]. For this electric motor, nominal slip s_n, ratio of maximum torque to nominal m_k, moment of inertia of the rotor of the electric motor J_p.

The rated frequency of the electric motor will be equal:

$$n_{nd} = n_{snd}(1 - s_n) . \qquad (5)$$

Next we find the given value of the gear ratio of the drive. At the same time, we assume that the nominal rotation frequency of crankshaft n_n is equal to the given speed of rotation n. Then the given value of the transfer ratio will be:

$$u_z = \frac{n_{nd}}{n} . \qquad (6)$$

Select the number of gear teeth so that the relative error ξ of the actual gear ratio u was in limits [4]:

$$\xi = \left| 1 - u / u_{1H_2 з} \right| \le 4 \%. \qquad (7)$$

Find the true value of the transfer ratio u of the drive.

The total moment of inertia J_e of the rotor, the couplings with the brake pulley and the rotational masses of the parts connected to the shaft of the electric motor, is:

$$J_e = k_c J_p, \qquad (8)$$

where coefficient $k_c = 1.7…2.6$.

Value k_c specifies when designing mechanisms.

Converted to the crank moment of inertia J_k of the parts, which are connected with it constant transmission ratios:

$$J_k = J_e u^2 . \qquad (9)$$

According to known formulas, we find the moment of inertia J_v of the lever part of the machine aggregate reduced to the crank.

The moment of inertia of machine without a flywheel given to a crank:

$$J_b = J_k + J_v . \qquad (10)$$

We determine average moment of inertia J_{cb} of the machine without the flywheel given to a crank, as the average of its values for various mechanism positions.

We consolidate the static mechanical characteristic of the engine to a crank.

To synchronous rotation frequency n_{snd} of engine there corresponds synchronous rotation frequency of a crank:

$$n_{sn} = n_{snd} / u \,, \quad (11)$$

– synchronous angular crank speed:

$$\omega_{sn} = \pi n_{sn} / 30 \,. \qquad (12)$$

To nominal rotation frequency n_{nd} of engine there corresponds nominal crank rotation frequency:

$$n_n = n_{nd} / u \,, \qquad (13)$$

– nominal angular crank speed:

$$\omega_n = \pi n_n / 30 \,. \qquad (14)$$

The nominal moment of the engine given to a crank:

$$M_n = P_n \eta_n \eta_m / \omega_n \,. \qquad (15)$$

Here power costs of overcoming of friction forces in kinematic couples are conditionally carried to the drive mechanism.

We approximate the static mechanical characteristic of the engine provided to a crank on its working part by parabola, with equation:

$$M_r = \beta(\omega_{sn}^2 - \omega^2) \,,$$

where $\beta = M_n / (\omega_{sn}^2 - \omega_n^2)$; $M_r = M_r(\omega)$ – the engine momentum given to a crank, which depends on the variable of the angular velocity ω crank.

Find the approximate value of the mean angular velocity ω_s. The average driving moment of the engine given to a crank:

$$M_{rs} = \frac{|A_c|}{2\pi} \,. \qquad (16)$$

We assume that at this moment the average angular velocity of the crank corresponds to the mechanical characteristic:

$$\omega_s = \sqrt{\omega_{sn}^2 - \frac{M_{rs}}{\beta}} \,. \qquad (17)$$

When installing the flywheel, the moment of inertia of the machine increases and in this case, the coefficient of unevenness of motion decreases. That is, the coefficient of unevenness of machine without a flywheel δ_b is greater than coefficient of unevenness δ of the machine with the flywheel, or $\delta \le \delta_b$.

The value of δ_b is determined by the approximate calculations by this formula [2]:

$$\delta_b = c\left(\frac{2}{1+\exp(-2\beta(2\pi - \varphi_r + \varphi_n)/J_{sb})} - 1\right), \qquad (18)$$

where $c = \dfrac{\omega_{sn}^2}{\omega_s^2} - 1$.

The condition is not overturning of engine [3] will be:

$$M_{r\max} \le \lambda M_n \,,$$

where $\lambda = (0,8 \ldots 0,85)\, m_\kappa$; $m_k = M_k/M_n$; M_k – the critical or overturning engine moment.

The condition of overturning can be presented in the form [2]: $\delta \le \delta_n$, where:

$$\delta_n = \frac{\lambda(\omega_{sn}^2 - \omega_n^2) - \omega_{sn}^2}{\omega_s^2} + 1 \,. \qquad (19)$$

Value δ_n represents the greatest possible coefficient of irregularity which meets a condition of not overturning.

In addition, the unevenness coefficient δ should not exceed a certain maximum value δ_T, which is chosen based on the technological or operational requirements for this type of machine. That is $\delta \le \delta_T$.

To satisfy all three inequalities, from the three values of δ_b, δ_n, δ_T we select the least value δ. If the smallest value is $\delta = \delta_b$, then the flywheel is not needed ($J_M = 0$). In the other case, the moment of inertia of flywheel is determined by the smallest value δ. The last thing we do in an approximate way [2], moment of inertia of the flywheel will be equal:

$$J_M = -\frac{2k_z\beta(2\pi - \varphi_r + \varphi_n)}{\ln\left(\dfrac{2}{1+\delta/c} - 1\right)} - J_{sb} \,, \qquad (20)$$

where k_z =0.93...1.04 – a coefficient that takes into account the approximate nature of the formula.

– flywheel inertia moment, given to a shaft of electric motor:

$$J_{md} = \frac{J_M}{u^2} \,. \qquad (21)$$

– moment of inertia of the machine with the flywheel:

$$J = J_M + J_b \,. \qquad (22)$$

For each of provisions of the mechanism we determine parameters [2]:

$$P_1 = 2\beta / J \,, \qquad (23)$$

$$Q_1 = \beta\omega_{sn}^2 + M_{OT} \qquad (24)$$

– and the integral:

$$I_1 = \int_0^{\varphi} P_1 d\varphi \,. \qquad (25)$$

Find the parameter:

$$u_1(\varphi) = \exp(I_1) \,. \qquad (26)$$

Define integral:

$$I_2(\varphi) = \int_0^{\varphi} Q_1 u_1(\varphi) d\varphi \,. \qquad (27)$$

During the cycle of steady motion, we find the kinetic energy of the machine assembly. It will be equal:

$$T(\varphi) = \frac{1}{u_1(\varphi)}\left(\frac{I_2(2\pi)}{u_1(2\pi) - 1} + I_2(\varphi)\right). \qquad (28)$$

The angular speed of the crank will be:

$$\omega(\varphi) = \sqrt{\frac{2T}{J}} \,. \qquad (29)$$

According to the results of calculations $\omega(\varphi)$ during the cycle of steady motion we find the maximum $\omega_{\max}$ and the minimum $\omega_{\min}$ angular velocity of crank. Determine the mean angular velocity of the crank:

$$\omega_{sr} = (\omega_{\max} + \omega_{\min})/2, \qquad (30)$$

– the actual coefficient of unevenness of the movement:

$$\delta_d = (\omega_{\max} - \omega_{\min}) / \omega_{sr}. \qquad (31)$$

We select the value of the coefficient k_z in formula (20) and repeat the calculations by the formulas (20)...(31), until the actual coefficient δ_d of motion unevenness becomes close to given coefficient δ and does not exceed it.

We find the driving moment of the engine given to a crank. It will equal:

$$M_r = \beta(\omega_{sn}^2 - \omega^2) \,. \qquad (32)$$

Thus, calculations are carried out sequentially according to the formulas (1) … (32).

4. Conclusions

A new algorithm of solving the second problem of dynamics of lever mechanisms of stationary agricultural machines with electric drive is developed. The algorithm can be widely used in the calculation and design of flat lever mechanisms of many stationary agricultural machines.

5. References

1. Dobrovolsky V.A., Zablonsky K.I., Mack S.L., Radchik S.A., Erlich L.B. Machine parts. – M.: Mashinostroyeniye, 1972. – 496 p. (in Russian language).
2. Yeremenko O.I. Determination of the moment of inertia of the flywheel for lever mechanisms operating from the electric drive // The Bulletin of the National Technical University of Ukraine "KPI". Mechanical engineering. Issue 41. – Kiev, 2001, P. 213-220. (in Ukrainian language).
3. Kozhevnikov S.N. Theory of mechanisms and machines. – M.: Mashinostroyeniye, 1973. – 592 p. (in Russian language).
4. Frolov K.V., Popov S.A., Musatov A.K. et al. Theory of Mechanisms and Machines. – M.: Vysshaya shkola, 1987. – 504 p. (in Russian language).