KAPITEL 5 / CHAPTER 5 [5]
DEVELOPMENT OF PULSED DRIVES OF END WORKING ORGANS OF EARTHMOVING MACHINES

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Introduction

The main workloads of the earthmoving machine with the end working member are loads from digging forces. In the development of medium and high strength rocks, cutting forces make up the predominant part of the digging forces.

Known calculation methods allow to determine the average and average cutting force under the specified conditions based on the experimental strength factors of the material [1-3].

However, when determining the actual workloads of the machine, it is not enough to determine the average or average axial loads, since it is found that the fluctuations in the cutting and digging forces are random and therefore can be described sufficiently completely only by statistical methods. Moreover, according to the values of the average and average maximal forces of cutting and digging, the working member of the machine is designed, and its drive is designed according to the maximum load value during the development of a certain soil category.

This approach leads to the fact that the designed earthmoving machine has a low efficiency due to the lack of adaptation of the working organ and the drive to changes in the working environment.

5.1. Dynamics of earthmoving machine with end working element

Highly efficient soil development can be carried out using an earthmoving machine with an end working member. Determining the nature of the load change from the digging and cutting forces for this machine will allow the design of a special drive, which will allow changing the power parameters of the end working member during the development of the soil.

For the disk working member operating on the end side, the trajectory of the cutting elements is sickle-shaped, and the teeth are placed on the principle of overlapping. Soil located in the area of the working element, but not in contact with

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the cutting element, under the influence of deformation waves propagating in the working medium, is previously destroyed. In the future, these particles of soil collapse and are carried out with slaughter. It is important that the total component of the cutting force, depending on the total area of contact of the soil with the cutting elements, is significantly reduced in the case of the modular arrangement of the cutting elements. This allows you to reduce the power required to drive the working organ at the same parameters of work.

For a working member with a modular arrangement of cutting members, the number of cutting member lines n, the number of main modules n_1 and the period of one rotation of the working member are determining T.

The total load on the working body is determined by the equality:

$$Q(t) = \overline{Q}(t) + \overset{0}{Q}(t), \tag{1}$$

where $\overline{Q}(t)$ – expectation (determinative component) load $Q(t)$; $\overset{0}{Q}(t)$ – random component of the total load $Q(t)$.

Take the following assumptions with respect to the tangent component P_x: mathematical expectation $\overline{P}_x$ force P_x during digging remains proportional to the cross section area F.

Then it will be convenient to determine the cutting force for the *m*-th cutting element by the shape of the cutting forces.

The total load on the working organ is determined by equality (for sharp incisors):

$$Q(t) = 2p\sum_{i=0}^{n-1}\varphi\left(t + i\frac{T}{n}\right)\xi_{2i}(t) - p\sum_{i=0}^{\frac{n}{n_1}-1}\varphi\left(t + i\frac{n_1 T}{n}\right)\xi_{1i}(t) \tag{2}$$

where $Q(t)$ – one of the common load components applied to the top of the frame hinge (force directed along the axis x, force directed along the axis y); p – average specific cutting force; $\varphi(t)$ – some periodic function with a rotation period of the working organ T; $\xi_{1i}(t)$ – dimensionless stationary random function with mathematical expectation $\xi_{1i} = 1$ and variance $D_{\xi 1i} = W_P^2$, where W_P – coefficient of variation of cutting force by one cutter; it characterizes the relative magnitude of random fluctuations of this force; $\xi_{2i}(t)$ – stationary random function equal to half the sum of two independent stationary random functions $\xi_{1i}(t)$ and $\xi'_{1i}(t)$ with the same statistical characteristics.

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Correlation function of random variable $\xi_{1i}(t)$:

$$K_{\xi 1}(\tau) = W_{\text{P}}^2 \rho_{\text{P}}(\tau), \tag{3}$$

where $\rho_{\text{P}}(\tau)$ – normalized correlation function of cutting force.

The main statistical characteristics of the random function $\xi_{2i}(t)$ according to the known position of the theory of random processes [4] are determined by the equality:

mathematical expectation $\overline{\xi}_{2i} = 1$;

variance $D_{\xi 2i} = 0{,}5W_P^2$;

correlation function $K_{\xi 2}(\tau) = 0{,}5W_{\text{P}}^2 \rho_{\text{P}}(\tau)$.

Mutual correlation function between stationary random functions $\xi_{2i}(t)$ and $\xi_{1i}(t)$:

$$R_{\xi 2\xi 1}(\tau) = 0{,}5K_{\xi 1}(\tau) = 0{,}5W_{\text{P}}^2 \rho_{\text{P}}(\tau). \tag{4}$$

Consider each application of the total load. Expectation of load $Q(t)$:

$$\overline{Q}(t) = 2p\sum_{i=0}^{n-1} \varphi\left(t + i\frac{T}{n}\right) - p\sum_{i=0}^{\frac{n}{n_1}-1} \varphi\left(t + i\frac{n_1 T}{n}\right). \tag{5}$$

The first application in the formula is a periodic function with a period T/n, another module is a periodic function with a period Tn_1/n.

To describe the periodic components of the loads, we decompose the function into a Fourier series:

$$\overline{Q}(t) = \frac{A_0}{2} + \sum_{K=1}^{\infty} A_K \cos\left(\frac{2\pi n}{n_1 T} Kt\right) + \sum_{K=1}^{\infty} B_K \sin\left(\frac{2\pi n}{n_1 T} Kt\right). \tag{6}$$

Function $\overline{Q}(t)$ has a period of Tn_1/n; the predominant part of this function is a periodic function with a period T/n. Fourier coefficients are defined by formulas:

$$A_K = -\frac{2pn}{n_1 T}\int_0^T \varphi(t)\cos\left(\frac{2\pi n}{n_1 T} Kt\right)dt,$$

$$B_K = -\frac{2pn}{n_1 T}\int_0^T \varphi(t)\sin\left(\frac{2\pi n}{n_1 T} Kt\right)dt,$$

if K not multiple n_1, where $K = 0, 1, 2, 3\ldots$. In case when K multiple n_1, then the coefficients acquire the form:

$$A_K = -\frac{4pn}{T}\left(1-\frac{1}{2n_1}\right)\int_0^T \varphi(t)\cos\left(\frac{2\pi n}{n_1 T}Kt\right)dt;$$

$$B_K = -\frac{4pn}{T}\left(1-\frac{1}{2n_1}\right)\int_0^T \varphi(t)\sin\left(\frac{2\pi n}{n_1 T}Kt\right)dt;$$

$$A_0 = \frac{2pn}{T}\left(1-\frac{1}{2n_1}\right)\int_0^T \varphi(t)dt.$$

Load $Q(t)$ characterized by two components:

I – efforts $R_X(t)$, directed along the axis x:

$$R_X(t) = \sum_{i=1}^{n} P_i(t),$$

where $P_i(t)$ – angent cutting force (component of cutting force);

II – efforts $R_Y(t)$, directed along the axis y:

$$R_Y(t) = \sum_{i=1}^{n} N_i(t),$$

where $N_i(t)$ – normal cutting force.

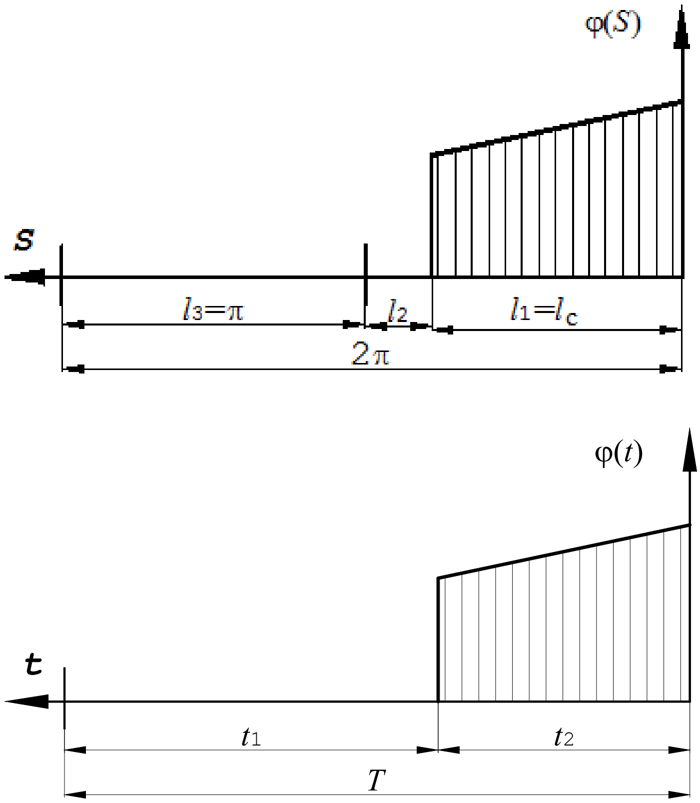

Figure 1 – Diagram of interaction of cutting element with soil

5.2. Determination of oscillation frequencies on the working organ

It is necessary to define Fourier coefficients for each component without taking into account the resistance to movement of the line of cutting elements

If you consider the passage of one line of cutting elements in the face (see Figure 1), then the entire path of its passage can be divided into two sections:

cutting path;

distance traveled by the cutting element line after leaving contact with soil.

If the cutting edge speed is taken constant, the time of contact of the teeth with the soil is generally determined from the equality:

$$t_1 = \frac{2\pi - \alpha_1}{\omega_w},\ t_2 = \frac{2\pi - \alpha_2 - \alpha_3}{\omega_w}, \tag{7}$$

or

$$t_1 = \frac{2l_3 - l_c}{V_K},\ t_2 = \frac{l_3 + l_2}{V_K}, \tag{8}$$

where 2π – full turnover of beam; $\alpha_2 + \alpha_3$ – angle, passed by a line of cutting elements after exit from the face (in this case $\alpha_3 = \pi$); α_1 – angle passed by beam during cutting; ω_w – speed of rotation of the working member; $l_2 + l_3$ – length of passage of the point of application of equal soil resistance force to destruction after exit from the face; l_c – length of passage of the point of application of equal soil resistance to destruction during cutting; V_K – speed of movement of the point of application of equal force of soil resistance to destruction $(V_K = \omega_w \cdot R_w 2/3)$; t_1 – time to interaction of cutting elements line with soil; t_2 – duration of interaction of cutting elements line with soil.

If $t_1 = 0$, then at $Q(t) = R_X(t)$ and $Q(t) = R_Y(t)$ we get the expression:

$$\varphi(t) = \begin{cases} F, \text{at } t < t_2 \\ 0, \text{ at } t > t_2 \end{cases},$$

where F – cut area of one cutter.

Thus, the expression for the constant member of the Fourier series, will take the form:

$$A_0 = 2pFn\left(1 - \frac{1}{2n_1}\right)\frac{l_{PI3}}{V_K}.$$

Calculate Fourier coefficients for individual harmonics (Fig. 2). At K not multiple n_1:

$$A_K = -\frac{pF}{\pi K} \cdot \sin\left(\frac{2\pi n K}{n_1} \cdot \frac{l_c}{V_K}\right);$$

$$B_K = \frac{pF}{\pi K} \cdot \left[\cos\left(\frac{2\pi n K}{n_1} \cdot \frac{l_c}{V_K}\right) - 1\right].$$

At K multiple n_1:

$$A_K = \frac{2pFn_1}{\pi K}\left(1 - \frac{1}{2n_1}\right)\sin\left(\frac{2\pi n K}{n_1} \cdot \frac{l_c}{V_K}\right);$$

$$B_K = \frac{2pFn_1}{\pi K}\left[1 - \cos\left(\frac{2\pi n K}{n_1} \cdot \frac{l_c}{V_K}\right)\right].$$

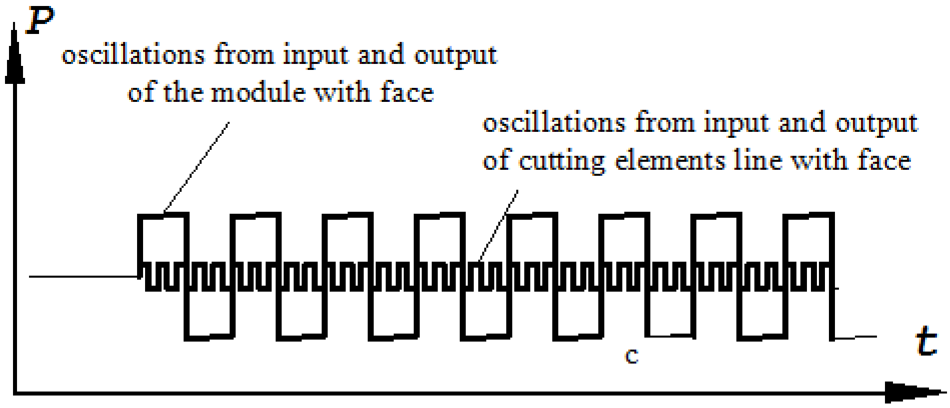

Figure 2 – Diagram of periodic load components from cutting forces on end working member

For effort R_Y, Fourier coefficients can be obtained by multiplying the values found A_0, A_K and B_K on $ctg(\delta + \mu)$, where δ – cutting angle; μ – angle of soil friction along the cutting material.

When describing a component R_Y, value A_0, A_K and B_K for R_X with sharp incisors, you need to multiply by $ctg(\delta + \mu)$, value A_{03}, A_{K3}, B_{K3} for R_X with blunted cutters – on $ctg(\delta + \mu)$ and subtract, then we get the general values:

$$A_{0(gen)} = A_0 \text{ctg}(\delta + \mu) - A_{03} \text{ctg}(\delta_1 + \mu),$$

$$A_{K(gen)} = A_K \text{ctg}(\delta + \mu) - A_{K3} \text{ctg}(\delta_1 + \mu),$$

$$B_{K(gen)} = B_K ctg(\delta + \mu) - B_{K3} ctg(\delta_1 + \mu),$$

where δ_1 – angle of inclination of wear area.

From expression (1) it can be seen that the random component of the total load

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can be defined as:

$$\overset{0}{Q}_0(t) = Q(t) - \overline{Q}(t), \tag{9}$$

or

$$\overset{0}{Q}_0(t) = 2p\sum_{i=0}^{n-1}\varphi\left(t + i\frac{T}{n}\right)\overset{0}{\xi}_{2i}(t) - p\sum_{i=0}^{\frac{n}{n_1}-1}\varphi\left(t + i\frac{n_1 T}{n}\right)\overset{0}{\xi}_{1i}(t), \tag{10}$$

where $\overset{0}{\xi}_{1i}(t) = \xi_{1i}(t) - 1$; $\overset{0}{\xi}_{2i}(t) = \xi_{2i}(t) - 1$.

Component correlation function $\overset{0}{Q}(t)$ defined by:

$$K_Q(t, t+\tau) = 2p^2 W_p^2 \rho_p(\tau)\sum_{i=0}^{n-1}\varphi\left(t + i\frac{T}{n}\right)\varphi\left(t + i\frac{T}{n} + \tau\right) -$$

$$- 2p^2 W_p^2 \rho_p(\tau)\sum_{i=0}^{\frac{n}{n_1}-1}\varphi\left(t + i\frac{n_1 T}{n}\right)\varphi\left(t + i\frac{n_1 T}{n} + \tau\right).$$

In formula, the first sum is a periodic function of time t with period T/n, and the second – with a period $n_1 T/n$, therefore, the whole correlation function is a periodic function of time with period $n_1 T/n$.

Given that the relative oscillation amplitudes of said sums are small with respect to random load oscillations $Q(t)$ correlation function can be averaged $K_Q(t, t+\tau)$ within $n_1 T/n$. We get the average correlation function:

$$K_Q(\tau) = 2p^2 W_p^2 \rho_p(\tau)\frac{n}{n_1 T}\int_0^{n_1 T/n}\sum_{i=0}^{n-1}\varphi\left(t + i\frac{T}{n}\right)\varphi\left(t + i\frac{T}{n} + \tau\right)dt -$$

$$- p^2 W_p^2 \rho_p(\tau)\frac{n}{n_1 T}\int_0^{n_1 T/n}\sum_{i=0}^{\frac{n}{n_1}-1}\varphi\left(t + i\frac{n_1 T}{n}\right)\varphi\left(t + i\frac{n_1 T}{n} + \tau\right)dt.$$

When you enter a replacement

$$t + i\frac{T}{n} = T_1; \quad dt = dT_1;$$

$$t + i\frac{n_1 T}{n} = T_2; \quad dt = dT_2;$$

get:

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$$K_Q(\tau) = p^2 W_p^2 \rho_p(\tau) x$$

$$x\left[\frac{2n}{T}\sum_{i=0}^{n-1}\int_{iT/n}^{(i+1)T/n}\varphi(T_1)\varphi(T_1+\tau)dT_1 - \frac{n}{n_1 T}\sum_{i=0}^{\frac{n}{n_1}-1}\int_{in_1T/n}^{(i+1)n_1T/n}\varphi(T_2)(T_2+\tau)dT_2\right].$$

Final:

$$K_Q(\tau) = \frac{n}{T} p^2 W_p^2 \rho_p(\tau)\left(2 - \frac{1}{n_1}\right)\int_0^T \varphi(t)\varphi(t+\tau)dt. \qquad (11)$$

Similarly, we obtain an average mutual correlation function for components $Q_i(t)$ and $Q_K(t)$:

$$R_{Q_iQ_K}(\tau) = \frac{n}{T} p^2 W_p^2 \rho_p(\tau)\left(2 - \frac{1}{n_1}\right)\int_0^T \varphi_i(t)\varphi_K(t+\tau)dt. \qquad (12)$$

Recommendations for choosing the coefficient of variation W_p cutting forces are described in the work [5, 6].

Based on this, we get that the general nature of vibrations on the working organ during its operation is determined by:

basic frequency v_1 determined by oscillation from input-output of the working element module;

additional frequency v_2 determined by oscillation from input-output of the line of cutting elements of the working element;

random component determined by a variation in cutting forces.

Determination of the full spectrum of oscillation frequencies on the working body, allows to form a corresponding total load $Q(t)$, which in turn determines the force and strength calculations of the earth-moving machine taking into account the adaptive properties of its working element to the working medium.

Conclusions

Creation of promising end working bodies of earth-moving machines on the basis of improved forecasting methods, experimental verification of predictive technical solutions, wide application of physical and mathematical modeling of interaction of working bodies with the working environment and optimization of parameters of

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working equipment of earthmoving machines taking into account the soil background of operation made it possible to obtain scientifically substantiated results, the use of which provides a solution to a large applied problem to increase the efficiency of earthmoving machines and the implementation of an industrial-innovative program in the field of creating earthmoving machines.

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