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Method for estimating the spectrum density of the resistance moment on the working body of a peat milling unit

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The main source of dynamic loads in the drive elements and the design of the peat milling unit is the working body. The forces of external resistance arising in the process of performing a technological operation are sharply variable, random in nature. The article proposes a model of formation of the moment of resistance on the mill when interacting with peat. The case when there are several cutting planes with the same radius at the ends of the cutting elements is considered. When developing the model, it was taken into account that the operating conditions of the knives, determined by the type of cutting (blocked, semi-blocked, etc.), their width and type in each cutting plane can vary.

Factors that determine the nature of loading, such as the frequency of interaction of the cutting elements with the fallow and the randomness of the operating conditions of the unit, lead to the presentation of the loads in the form of a sequence of pulses with random parameters. Expressions are obtained for determining the spectral density of the moment of resistance on the mill at the design stage, taking into account its design, operating modes, physico-mechanical properties of peat and their probabilistic characteristics.

To illustrate the application of the developed approaches, a technique is presented for determining the spectral density of the moment on the working body of deep milling machines and in their drive elements based on a linear model. An example of calculation is given, and the obtained expressions are verified on the basis of experimental data.

The probabilistic characteristics of the loads on the mill serve as initial information for the dynamic analysis of the drive system and the design of the unit, its strength analysis, the selection of optimal parameters and operating modes.

***Key words*:** peat milling units; dynamic loads; moment of resistance; model; spectral density

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Introduction. Currently, machines with milling-type working bodies have found wide application in the peat industry [5, 11]. They have high performance, allow to reduce the number of technological operations, make it possible to ensure their complex mechanization.

The structural heterogeneity of the peat deposit, the variability of the physicomechanical properties, the profile of the surface of the production fields, the presence of wood inclusions determine the sharply variable, random nature of the moment of resistance on the mill [10]. This leads to significant dynamic loads in the drive elements and the design of the unit [10], which is one of the reasons for the insufficient reliability of the operating machines [2].

Further development and intensification of production processes in the peat industry [1, 14], their seasonal nature require the creation of high-performance and reliable machines, which is associated with the solution of a number of problems, one of which is the development of effective methods of design and calculation. Their accuracy is determined by the extent to which the magnitude and nature of the force factors acting in the structural elements adopted in the strength analysis correspond to the real ones [12, 18].

For dynamic analysis of peat milling units, a number of approaches to modeling the moment of resistance on the working body during the technological operation have been developed. The methods were systematized [10]: representation of the load in the form of a sequence of determinate pulses (G.F.Vekoveshnikov); as a continuous random function of a path, speed and time (N.M.Karavaeva); methods combining the two previous ones (M.V.Murashov, O.A.Golovnina) and taking into account three components – a constant, deterministic periodic and random function of time. At the same time, rich experience was used to solve similar problems in the field of mining engineering [3, 4].

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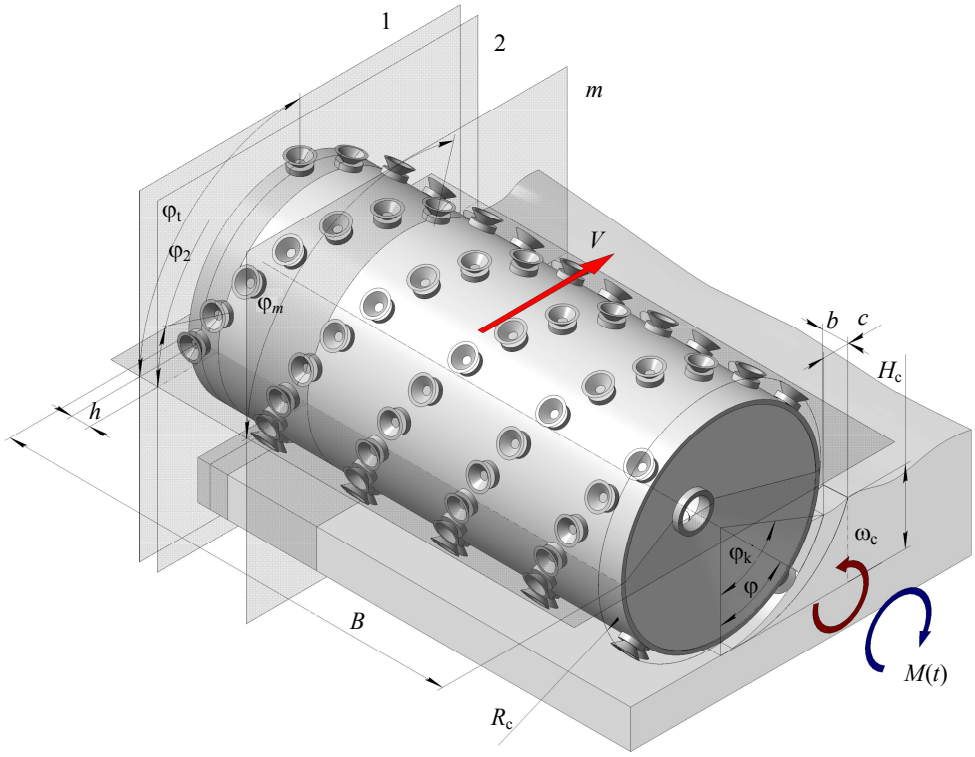


Fig.1. The interaction of the working body with peat deposits

The disadvantages of the considered models include: the artificiality of separation into components without sufficient physical justification; the difficulty of obtaining the mathematical expectation and spectral density of the resistance moment at the design stage.

In calculational practice, methods of statistical modeling (N.M.Karavaeva, F.A.Shestachenko, O.A.Golovnin, V.F.Sinitsyn) were widely used [10]. Despite the universality, they require a significant amount of machine time required for analysis and selection of optimal parameters and operating modes of the milling unit by numerical methods.

In a number of studies [9, 15], the loads on the working bodies are presented in the form of a sequence of pulses with random parameters. Based on the proposed models, analytical methods have been developed to determine the probabilistic characteristics and distribution densities of moments and forces at the design stage [9, 10, 15] that arise when interacting with peat and wood inclusions.

The obtained dependencies do not take into account the fact that the cutting elements can work in different conditions depending on the type of cutting (blocked, semi-blocked, etc.), have a different width and type.

Models and research methods. Consider a milling cutter (Fig.1) having M cutting planes with z knives in the plane. Radius at the ends of the cutting elements R_c. The working conditions determined by the type of cutting (blocked, semi-blocked), the width of the knives and their type in each cutting plane can vary. The angular speed of rotation of the cutter ω_c, the speed of movement of the unit V.

When analyzing the interaction of the working body with peat, for simplicity, we assume that its physical and mechanical properties, milling depth, angular speed of rotation of the cutter and the speed of movement of the unit change quite smoothly, so that within the feed to the knife (as a rule, it is 2-30 mm) they can be considered constant values.

Given the frequency of contact of the cutting elements with the fallow and the random nature of the parameters that determine the operating conditions of the unit, the moment of resistance during the technological operation can be represented as a sequence of pulses with random parameters (Fig.2):

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$$M(t)=\sum_{m=1}^{M}\sum_{n=-\infty}^{\infty}k_m M_{mn}\left(t-t_{mn};P_{mn}\right), \quad (1)$$

where M – is the number of cutting planes; n is the number of the loading pulse on the mth cutting plane; k_m is a coefficient depending on the type of cutting (blocked, half-blocked, etc.), the width and type of cutting elements in the mth cutting plane; $M_{mn}(t; P_{mn})$ – a function that describes the change in the resistance torque on a single cutting element within the contact angle with the deposit on the mth cutting plane (excluding k_m); t_{mn} is the moment of occurrence of the nth load impulse on the mth cutting plane; P_{mn} – random parameters of the nth pulse on the mth cutting plane.

The parameters of loading pulses in general are random and are determined by the nature of the change in the physicomechanical properties of peat, the milling depth, the angular velocity of rotation of the working body, the variability of the chip thickness due to the uneven movement of the aggregate, and many other factors.

The variation of the milling depth and, accordingly, the contact angle of the knife with the deposit φ_k depends on the change in the surface profile of the card and the cutter suspension scheme, as well as on the displacements caused by the cutting forces and the forces associated with its imbalance. These factors, along with fluctuations in the angular velocity of rotation ω_c, lead to a random pattern of change in the pulse duration $\tau = \varphi_k/\omega_c$, the period of their repetition on a single cutting plane $T = \varphi_t/\omega_c$ and the time shift between load pulses on the mth cutting plane and the starting point of reference $t_m = \varphi_m/\omega_c$, where φ_k – is the contact angle of the knife with the deposit, φ_t – is the angle between adjacent cutting elements in one cutting plane, φ_m – is the shear angle between the knives of the mth cutting plane and the reference point.

The random nature of the loads for analysis requires the application of the theory of random functions [3, 6, 12]. It is known that for a complete description of such processes it is necessary to know multidimensional, in the general case, time-dependent distribution functions [6, 13]. For practical needs, as a rule, they are limited to considering the mathematical expectation, dispersion, and spectral density of the process, based on which, using the methods of statistical dynamics of mechanical systems [3, 12, 18], it is possible to calculate the probabilistic characteristics of force factors acting in elements drive and design of the peat milling unit, and obtain initial information for its strength analysis and selection of optimal parameters and operating modes.

One of the most important characteristics of a random process giving a frequency distribution of energy is spectral density. To determine it, we use the concept of the energy spectrum of a random pulsed process [6]

$$F(\omega)=\lim_{N\to\infty}\frac{2}{(2N+1)T}m_1\left\{\left|Z^{(k)}(j\omega)\right|^2\right\}, \quad (2)$$

where N – number of pulses considered; T – average pulse repetition period; $m_1\{\}$ – averaging sign; $Z^k(j\omega)$ – spectrum of the kth implementation of a random process (hereinafter in the expressions we omit the index k).

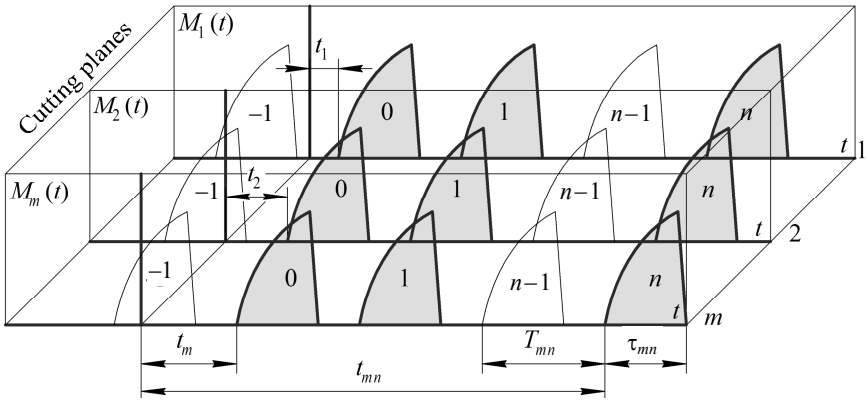


Fig.2. Model of moment of resistance on the working body formation

The energy spectrum is related to the spectral density S(ω) by the relation [6]

$$F(\omega)=S(\omega)+2\pi m^2\delta(\omega),$$

where m – mathematical expectation of a random process; $\delta(\omega)$ – delta function.

The variance of a stationary random function is [6]

$$D=\frac{1}{2\pi}\int_{-\infty}^{\infty}F(\omega)d\omega-m^2.$$

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When deriving the expression for the energy spectrum of the moment of resistance on the working body, taking into account the influence of the change in angular velocity random nature, we use the randomization method [13]. Assuming the value of the angular velocity to be fixed, we determine the energy spectrum.

Using the properties of the Fourier transform [6, 13], for the moment spectrum (1) we obtain:

$$Z_M(j\omega)=\sum_{m=1}^{M}\sum_{n=-N}^{N}k_m S_{M_{mn}}(j\omega;\omega_c;P_{mn})\exp\left(-j\frac{\omega}{\omega_c}\varphi_m\right)\exp\left(-j\frac{\omega}{\omega_c}n\varphi_t\right), \quad (3)$$

where $S_{M_{mn}}(j\omega;\omega_c;P_{mn})$ – spectrum of a single loading impulse on a cutting element,

$$S_{M_{mn}}(j\omega;\omega_c;P_{mn})=\int_0^{\varphi_k/\omega_c}M_{mn}(\omega_c t;P_{mn})\exp(-j\omega t)dt\,.$$

Substituting expression (3) into (2) and limiting ourselves to the case when the probabilistic characteristics of the parameters do not depend on the temporal position of the pulses (the stationary nature of the distribution of the operating conditions of the unit), but only on their relative position, i.e. from the difference of numbers of two pulses $p=n-i$, transforming and considering that [6]

$$\lim_{N\to\infty}\frac{1}{(2N+1)}\sum_{\substack{n=-N\\ n\neq i}}^{N}\sum_{i=-N}^{N}\exp\left(-j\frac{\omega}{\omega_c}(n-i)\varphi_t\right)=\frac{2\pi\omega_c}{\varphi_t}\sum_{r=-\infty}^{\infty}\delta\left(\omega-\frac{2\pi r\omega_c}{\varphi_t}\right)-1,$$

we obtain the expression for the energy spectrum at a constant angular speed of the cutter

$$F_M(\omega)=\frac{2}{T}\left[\frac{1}{2}\sum_{q=1}^{Q}\left[\frac{\partial^2F_{M_1}(\omega;\omega_c;P)}{\partial P_q^2}\right]_m D_q\sum_{m=1}^{M}k_m^2-\frac{1}{2}\sum_{q=1}^{Q}\left[\frac{\partial^2F_{M_2}(\omega;\omega_c;P)}{\partial P_q^2}\right]_m D_q\sum_{m=1}^{M}k_m^2+\right.$$

$$+\sum_{q<s}\left[\frac{\partial^2F_{M_2}(\omega;\omega_c;P)}{\partial P_q\partial P_s}\right]_m\sum_{m=1}^{M}\sum_{l=1}^{M}k_m k_l K_{qsml}\exp\left(-j\frac{\omega}{\omega_c}(\varphi_m-\varphi_l)\right)+$$

$$+2\sum_{q<s}\left[\frac{\partial^2F_{M_2}(\omega;\omega_c;P)}{\partial P_q\partial P_s}\right]_m\sum_{m=1}^{M}\sum_{l=1}^{M}\sum_{p=1}^{\infty}k_m k_l K_{qsmlp}\exp\left(-j\frac{\omega}{\omega_c}(\varphi_m-\varphi_l)\right)\cos\left(\frac{\omega}{\omega_c}p\varphi_t\right)+$$

$$+\left(F_{M_1}(\omega;\omega_c;m_q)+\frac{1}{2}\sum_{q=1}^{Q}\left[\frac{\partial^2F_{M_2}(\omega;\omega_c;P)}{\partial P_q^2}\right]_m D_q\right)\times$$

$$\left.\times\sum_{m=1}^{M}\sum_{l=1}^{M}k_m k_l\exp\left(-j\frac{\omega}{\omega_\phi}(\varphi_m-\varphi_l)\right)\frac{2\pi\omega_c}{\varphi_t}\sum_{r=-\infty}^{\infty}\delta\left(\omega-\frac{2\pi r\omega_c}{\varphi_t}\right)\right], \quad (4)$$

where the following notation is introduced:

$$F_{M_1}(\omega;\omega_c;P)=\left|S_{M_{mn}}(j\omega;\omega_c;P)\right|^2;$$

$$F_{M_2}(\omega;\omega_c;P)=S_{M_{mn}}(j\omega;\omega_c;P_q)S^*_{M_{mn}}(j\omega;\omega_c;P_s),$$

$S^*_{M_{mn}}$ – complex conjugate value.

In the derivation of expression (4), we used the expansion of the functions to be averaged into a Taylor series in the vicinity of the point with coordinates corresponding to the average values of the parameters with the restriction of terms to the second order inclusively [1],

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$$F(\omega;P)=F(\omega;m_q)+\sum_{q=1}^{Q}\left[\frac{\partial F(\omega;P)}{\partial P_q}\right]_m(P_q-m_q)+\frac{1}{2}\sum_{q=1}^{Q}\left[\frac{\partial^2 F(\omega;P)}{\partial P_q^2}\right]_m(P_q-m_q)^2+$$

$$+\sum_{q<s}\left[\frac{\partial^2 F(\omega;P)}{\partial P_q\partial P_s}\right]_m(P_q-m_q)(P_s-m_s).$$

In this case, the average values $F(\omega;P)$ equal to:

$$m_1\{F(\omega;P)\}=F(\omega;m_q)+\frac{1}{2}\sum_{q=1}^{Q}\left[\frac{\partial^2 F(\omega;P)}{\partial P_q^2}\right]_m D_q+\sum_{q<s}\left[\frac{\partial^2 F(\omega;P)}{\partial P_q\partial P_s}\right]_m K_{qs},$$

where P_q – pulse sequence parameters; m_q – mathematical expectations of parameters; D_q – dispersion of parameters; K_{qs} – correlation coefficients and cross-correlation of parameters; Q is the number of parameters; the sign $q<s$ means, that summation extends to all pairwise combinations of terms.

The energy spectrum (spectral density) has a complex structure and consists of two parts: continuous and discrete. The first is determined by the squared modulus of the spectrum of the function, which describes the shape of the loading pulse and the form of the correlation and cross-correlation functions of the parameters. It is proportional to the variance of the pulse parameters. The second (the so-called kinematic component) is due to the frequency of interaction of the knives with the deposit and is proportional to the average parameters of the pulse process. Under the same conditions of load formation for all cutting planes ($k_m=1$) the expression presented in [15] as a special case will be obtained.

By averaging expression (4) over the angular velocity of rotation of the working body, in the case of its statistical independence from other random parameters of pulses for the moment of resistance, it follows:

$$F_M(\omega)=\frac{2}{T}\left[\frac{1}{2}\sum_{q=1}^{Q}\Psi_{1M_q}(\omega)D_q\sum_{m=1}^{M}k_m^2-\frac{1}{2}\sum_{q=1}^{Q}\Psi_{2M_q}(\omega)D_q\sum_{m=1}^{M}k_m^2+\right.$$

$$+\sum_{q<s}^{M}\sum_{m=1}^{M}\sum_{l=1}^{M}\Psi_{3M_{qsml}}(\omega)k_mk_lK_{qsml}+2\sum_{q<s}^{M}\sum_{m=1}^{M}\sum_{l=1}^{M}\sum_{p=1}^{\infty}\Psi_{4M_{qsmlp}}(\omega)K_{qsmlp}k_mk_l+$$

$$+\sum_{r=-\infty}^{\infty}\left(F_{M_1}\left(\frac{2\pi r}{\varphi_t};m_q\right)+\frac{1}{2}\sum_{q=1}^{Q}\left[\frac{\partial^2 F_{M_2}(2\pi r/\varphi_t;P)}{\partial P_q^2}\right]_m D_q\right)\times$$

$$\left.\times\sum_{m=1}^{M}\sum_{l=1}^{M}k_mk_l\exp\left(-j\frac{2\pi r}{\varphi_t}(\varphi_m-\varphi_l)\right)\frac{\omega\varphi_t}{2\pi r^2}W\left(\frac{\omega\varphi_t}{2\pi r}\right)\right], \qquad (5)$$

where

$$\Psi_{1M_q}(\omega)=\int_{-\infty}^{\infty}\left[\frac{\partial^2 F_{M_1}(\omega;\omega_c;P)}{\partial P_q^2}\right]_m W(\omega_c)d\omega_c;$$

$$\Psi_{2M_q}(\omega)=\int_{-\infty}^{\infty}\left[\frac{\partial^2 F_{M_2}(\omega;\omega_c;P)}{\partial P_q^2}\right]_m W(\omega_c)d\omega_c;$$

$$\Psi_{3M_{qsml}}(\omega)=\int_{-\infty}^{\infty}\left[\frac{\partial^2 F_{M_2}(\omega;\omega_c;P)}{\partial P_q\partial P_s}\right]_m \exp\left(-j\frac{\omega}{\omega_c}(\varphi_m-\varphi_l)\right)W(\omega_c)d\omega_c;$$

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$$\Psi_{4M_{qsmlp}}(\omega)=\int_{-\infty}^{\infty}\left[\frac{\partial^2 F_{M_2}(\omega;\omega_c;P)}{\partial P_q \partial P_s}\right]_m \exp\left(-j\frac{\omega}{\omega_c}(\varphi_m-\varphi_l)\right)\cos\left(\frac{\omega}{\omega_c}p\varphi_t\right)W(\omega_c)d\omega_c;$$

$W(\omega_c)$ – distribution density of the angular speed of rotation of the cutter.

In case of $k_m=1$ for all cutting planes, expression (5) takes the form obtained in [9].

When taking into account the random nature of the change in the angular velocity of the cutter, the energy spectrum was transformed, as a result of which both its discrete part and the continuous part were transformed. Instead of discrete lines, peaks appeared in the composition of the spectrum in the form of corresponding functions describing the distribution density of the change in the angular velocity.

Research results. Consider an example of the implementation of the developed technique in calculating the spectral density of the moment of resistance on the working bodies of deep milling machines. They are used in preparing the deposit for operation and repairing the extraction fields, milling peat along with woody plants, stumps, rhizomes, grass and moss cover [11]. They are characterized by a high level of dynamic loading of structural elements.

The load on the working body during the technological operation can be represented as the sum of the loads that arise when interacting with peat and wood inclusions.

The methods for determining the probabilistic characteristics of the resistance moment during the milling of wood inclusions are given in [10, 16].

When analyzing the interaction of the working body with peat, the design feature of machines of this type should be taken into account. The presence of a baffle plate, resting on the surface of the deposit [11], provides a constant angle of contact of the cutting element with the reservoir. In this case, for the spectral density of the moment of resistance from expression (5) it will be obtained:

$$S_M(\omega)=\frac{2}{T}\left[K_{1M}(\omega)\sum_{m=1}^{M}k_m^2+\sum_{m=1}^{M}\sum_{l=1}^{M}k_m k_l K_{3M_{ml}}(\omega)+2\sum_{m=1}^{M}\sum_{l=1}^{M}\sum_{p=1}^{\infty}k_m k_l K_{4M_{mlp}}(\omega)+\right.$$

$$\left.+m_A^2\sum_{r=-\infty}^{\infty}\left|S_{M_0}\left(\frac{\omega\varphi_t}{2\pi r};m_q\right)\right|^2\sum_{m=1}^{M}\sum_{l=1}^{M}k_m k_l\exp\left[-j\frac{2\pi r}{\varphi_t}(\varphi_m-\varphi_l)\right]\frac{\omega\varphi_t}{2\pi r^2}W\left(\frac{\omega\varphi_t}{2\pi r}\right)\right],\ r\neq 0, \qquad (6)$$

where T – average repetition period of pulses formed by one cutting plane,

$$T=\frac{\varphi_t}{\int_{-\infty}^{\infty}\omega_c W(\omega_c)d\omega_c}.$$

In the expression (6), the following notation are introduced:

$$K_{1M}(\omega)=\int_{-\infty}^{\infty}\left|S_{M_0}(j\omega;\omega_c)\right|^2 D_A(\omega_c)W(\omega_c)d\omega_c;$$

$$K_{3M_{ml}}(\omega)=\int_{-\infty}^{\infty}K_{Aml}(\omega_c)\left|S_{M_0}(j\omega;\omega_c)\right|^2\exp\left(-j\frac{\omega}{\omega_c}(\varphi_m-\varphi_l)\right)W(\omega_c)d\omega_c;$$

$$K_{4M_{mlp}}(\omega)=\int_{-\infty}^{\infty}K_{Amlp}(\omega_c)\left|S_{M_0}(j\omega;\omega_c)\right|^2\exp\left[-j\frac{\omega}{\omega_c}(\varphi_m-\varphi_l)\right]\cos\left(\frac{\omega}{\omega_c}p\varphi_t\right)W(\omega_c)d\omega_c,$$

where $m_A, D_A(\omega_c)$ – the mathematical expectation and variance of the amplitudes of the pulses, respectively,

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$$m_A = R_c bc\left(m_\tau \frac{C_t}{\delta^{0,4}} + m_\gamma \frac{m_{\omega_c}^2 R_c^2}{2\cdot 10^3}\right);\ D_A(\omega_c) = R_c^2 b^2 c^2\left[D_\tau\left(\frac{C_t}{\delta^{0,4}}\right)^2 + \frac{D_\gamma \omega_c^4 R_c^4}{4\cdot 10^6}\right],$$

where R_c – cutter diameter at the ends of the cutting elements; b – width of the cut layer; c – feed on one cutting element; C_t – coefficient depending on the type of cutting element [11]; δ – average chip thickness [11]; m_τ, m_γ – the mathematical expectation of the ultimate shear stress τ and peat density γ respectively; D_γ, D_τ – the variance of the density and ultimate shear stress, respectively;

$$K_{Aml}(\omega_c) = R_c^2 b^2 c^2\left[D_\tau K_{\tau\perp}[(m-l)h]\left(\frac{C_t}{\delta^{0,4}}\right)^2 + D_\gamma K_{\gamma\perp}[(m-l)h]\frac{\omega_c^4 R_c^4}{4\cdot 10^6}\right];$$

$$K_{Amlp}(\omega_c) = R_c^2 b^2 c^2\left[D_\tau K_\tau[(m-l);p]\left(\frac{C_t}{\delta^{0,4}}\right)^2 + D_\gamma K_\gamma[(m-l);p]\frac{\omega_c^4 R_c^4}{4\cdot 10^6}\right],$$

$K_\tau[(m-l);p]$, $K_\gamma[(m-l);p]$ – the normalized correlation coefficients of the spatial variation of the ultimate shear stress and peat density, respectively.

In some cases, it is possible to separate the correlation coefficients of changes τ and γ in the direction of aggregate movement $K_{\tau//}(\tau)$, $K_{\gamma//}(\tau)$ and perpendicular to it $K_{\tau\perp}(\tau), K_{\gamma\perp}(\tau)$:

$$K_\tau[(m-l);p] = K_{\tau\perp}[(m-l)h]K_{\tau//}(pc);$$

$$K_\gamma[(m-l);p] = K_{\gamma\perp}[(m-l)h]K_{\gamma//}(pc),$$

where h – distance between cutting planes.

The square of the module of the spectrum of the unit amplitude pulse on the cutting element

$$\left|S_{M_0}(j\omega;\omega_c)\right|^2 = \frac{1}{4}\left\{\left|U(\omega-\omega_c;\omega_c)\right|^2 + \left|U(\omega+\omega_c;\omega_c)\right|^2 - \right.$$

$$\left. - 2U(\omega-\omega_c;\omega_c)\times U(\omega+\omega_c;\omega_c)\cos\varphi_k\right\},$$

where $U(j\omega;\omega_c) = \frac{2}{\omega}\sin\frac{\omega\varphi_k}{2\omega_c}$.

The distribution density of the working body angular velocity can be determined using the technique proposed in [10].

When using the linear dynamic model of the drive of a deep milling machine for the spectral density of the moment in the ith element of the drive can be written as [10, 12]:

$$S_{Mi}(\omega) = (C_i + \beta_i\omega)^2 S_{\Sigma M}(\omega)\sum_{p=1}^{P}\frac{(a_{ip} - a_{i+1;p})^2 a_{\mu p}^2}{M_p^2}\frac{1}{(\omega_p^2 - \omega^2)^2 + 4n_p^2\omega^2}, \quad (7)$$

where C_i – stiffness of the ith element; β_i – inelastic coefficient of ith element; $S_{\Sigma M}(\omega)$ – spectral density of the total moment of resistance on the cutter; P is the number of natural frequencies of the drive system; $a_{ip}; a_{i+1;p}$ – forms of natural vibrations of the drive masses, between which the ith element is located; $a_{\mu p}$ – pth form of natural vibrations of the mass of the drive to which the load is applied; ω_p – pth own system frequency;

$$M_p = \sum_{n=1}^{N} a_{np}^2 I_n; \quad n_p = \frac{1}{M_p}\sum_{n=1}^{N-1}\beta_n a_{np} a_{n+1;p},$$

N – number of masses of the dynamic drive model; I_n – nth mass moment of inertia.

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As an example of calculation, consider a machine for deep milling MP-20 [17]. It is trailed to a tractor of the 6th traction class (4th traction class in the ISO standard) and consists of a frame with a jack plate, front and rear support rollers, a mill, a hydraulic system and a transmission.

The working body is a cylindrical drum, to the surface of which cutting elements are attached in special sockets. The cutter cuts peat and wood during rotation from bottom to top. The milling depth is 0.25-0.4 m. The cutter diameter is 1.2 m, the width is 2.24 m. One cutting element is located in the cutting plane. Their total number is 18. Of these, L-shaped – 16, segmented knives – 2, which are located on the extreme 1st and 18th cutting planes. The width of the L-shaped knife is 0.14 m, segment – 0.1 m. Figure 3 shows the layout of the cutting elements on the mill.

MP-20 operates with increased feed per cutting element, which allows the separation of wood inclusions and increase productivity by 1.3-1.5 times [17]. In turn, such operating modes lead to increased dynamic loads.

The dynamic design of the working body drive is shown in Fig.4.

The initial data for calculating the loads in the drive elements are presented in Table 1, the values of natural frequencies and vibration modes obtained on their basis in Table 2 [10].

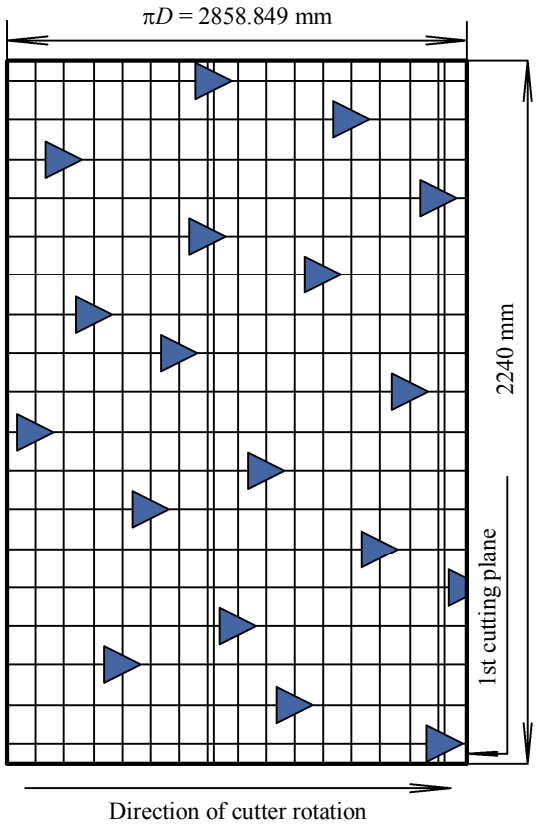


Fig.3. The layout of the cutting elements on the cutter

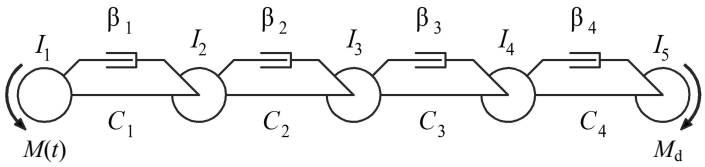


Fig. 4. The calculated dynamic drive circuit of the working body MP-20

Table 1

Parameters of the MP-20 dynamic drive system (reduced to the shaft of the working body, the first mass is the working body)

Parameters	Element number				
	1	2	3	4	5
Moments of inertia, kg·m^2	206.76	2.22	2.15	24.74	411.3
Stiffness, Nm/deg	$7.639\cdot10^5$	$0.593\cdot10^7$	$8.97\cdot10^5$	$3.225\cdot10^5$	–

Table 2

Natural frequencies and vibration modes of MP-20 drive

Frequency, s^{-1}	Mass number				
	1	2	3	4	5
36.25	1	0.6565	0.6119	0.3460	−0.5135
171.25	1	−6.907	−7.85	−12.95	0.2374
654.84	1	$-0.115\cdot10^3$	$-0.1115\cdot10^3$	$0.1206\cdot10^2$	−0.9291

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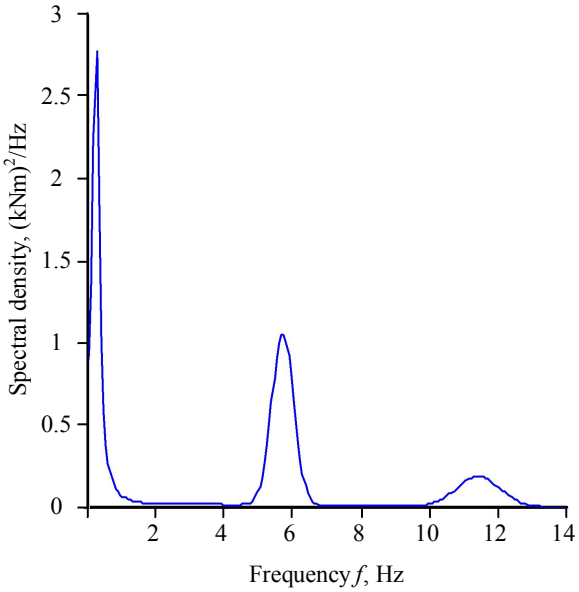


Fig.5. Spectral density of the moment of resistance on the working body MP-20 when interacting with peat

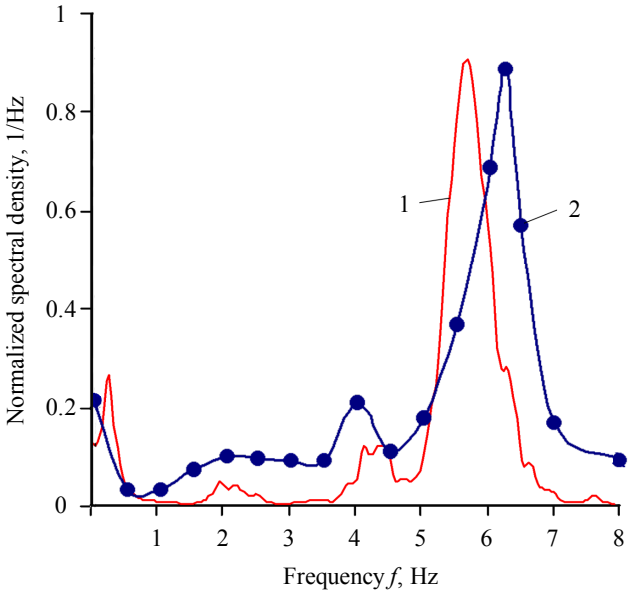


Fig.6. Normalized spectral density of the moment of loading on the drive shaft
1 – calculation; 2 – experiment [8]

The spectral density of the moment of resistance on the working body when interacting with peat calculated using expression (6) is shown in Fig.5. The probabilistic characteristics of the moment in the interaction with wood inclusions were determined using the technique [16].

The normalized spectral density of the moment on the driveshaft of the unit (the 4th elastic element of the dynamic calculation scheme) obtained using expressions (7) is shown in Fig.6. The average moment value is 0.597 kNm, the standard deviation is 0.142 kNm.

The experimental determination of the loads was carried out by methods of strain gauging [8] on a lowland deposit with a porosity of 2 % at a speed of 0.144 m/s. The milling depth was 0.35 m.

During the tests, the values of the moment of loading on the driveshaft, the revolutions of the working body and the speed of movement of the unit were recorded. The angular speed of the cutter is 18 s^{-1}. The normalized spectral density of the moment obtained as a result of the experiment is shown in Fig.6. The average value was 0.655 kNm, and the standard deviation was 0.126 kNm.

Comparison of calculation results with strain gauging data suggests that the proposed dependencies generally correctly reflect the nature of the load in the drive.

Conclusions

1. The probabilistic models of the formation of the moment of resistance on the working bodies of peat milling aggregates when interacting with peat are presented. The case when there are several cutting planes with the same radius at the ends of the cutting elements is considered. This takes into account that the knives can have a different width, type and working conditions, determined by the type of cutting (blocked, semi-blocked, etc.). The load can be represented as a sequence of pulses with random parameters.

2. Expressions are obtained that allow, at the design stage, to calculate the spectral density of the moment on the working body, taking into account the operating modes, its design, the physico-mechanical properties of peat and their probabilistic characteristics. They serve as initial information for the analysis of dynamic loads in drive elements and the design of peat milling units, the calculation of their reliability and technical and economic performance indicators.

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