The evaluation of reliability of the mixer-homogenizer on a basis of the wear of the working organ calculation

Shved S.V., Popolov D.V., Zaselskiy I.V.

Krivoy Rog Metallurgical Institute of Krivoy Rog National University

Abstract
The method of calculation of wear of the working organ of the mixer-homogenizer is considered in the article. The analytical dependence between the wear of rotor blade and amount of the material moved is received by the calculation method.

Objectives setting and its topicality. Employees of the Krivoy Rog Metallurgical Institute of Krivoy Rog National University together with Krivoy Rog Higher Metallurgical School developed a mixer for the simultaneous operations of disintegration and homogenization of oxide scale-peat mixture, using the effect of natural gravity, reducing the energy consumption by moving the material in the mixer chamber from loading to unloading.

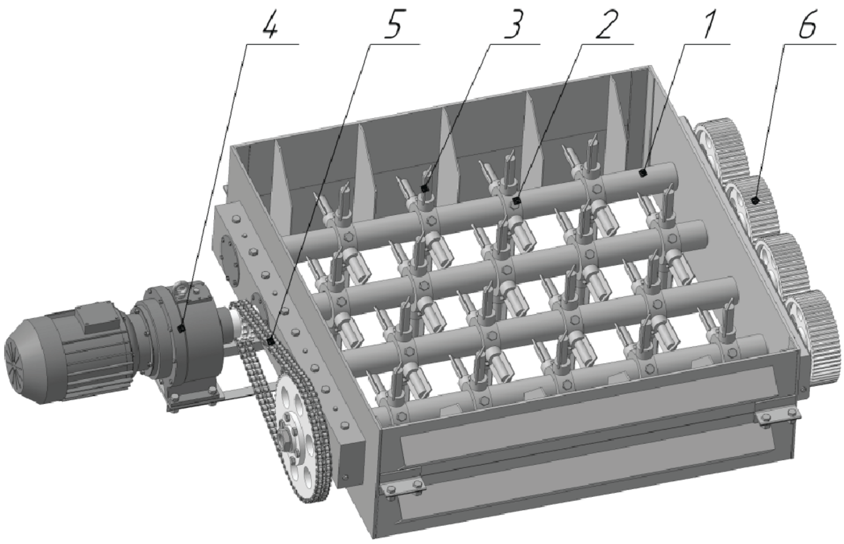

Figure 1 - Cylinder shell: 1-shaft; 2-agitator; 3-blade; 4-gear motor; 5-chain transmission; 6-sync gear

The main elements of mixer are cylinder shells (Fig. 1) mounted with rotation in a plane at an angle of 90° relative to the previous one, comprising two pairs of counter-rotating rolls 1 with agitators 2, which are installed at a certain step, decreasing from the upper to the lower cylinder shell. Agitators formed as opposing set of blades 3 inclined at an angle to the horizon. In turn, one of four shafts of the cylinder shell is main, the other three are driven. The drive of main shaft consists of gear motor 4 and chain transmission 5, the rotation to the driven shafts is transmitted from the main one by the sync gears 6. [5]

The key to successful implementation and subsequent operation of developed mixer-homogenizer is a selection or creation of a rational system of maintenance and repairs, which would ensure its reliable and safe operation in the conditions of metallurgical production. The solution to this problem is possible by creating a theory-based maintenance schedule, on the basis of time charts showing the mixer-homogenizer parts wear and tear in time, ensuring its performance and technological component of the preparatory process of an oiled mill scale for agglomeration performed by this unit.

Analysis of recent research and publications

Using of standard methods for calculating the reliability of technical systems, such as structural, logical-probabilistic [1,2,4], gives the possibility to obtain a generalized reliability indicator - the probability of failure-free operation, for definition of which the statistical reliability data of each structural element of the mixer-homogenizer proceeding from a given operating time are necessary. Today, such data exist only for standard structural elements (bearing units, chain drive, gear drive, gear motor). Thus, the calculation performed on the above methods does not allow to take into account the wear of the mixer working body, which will lead to a result with significant error.

The purpose of study

The purpose of study was to obtain the analytical dependence that sets the interconnection between the mixer-homogenizer rotor blade wear and the amount of transported material, taking into account its work in a linear-viscous fluid.

The materials of research

The wear of mixer-homogenizer working body blades is determined by the material motion on its surface, and current forces. Mainly wear is connected with occurrence of the Coriolis force applied at the zone of material contact with blade and with harmonic gravity force of the overlying layers of material (Fig. 2).

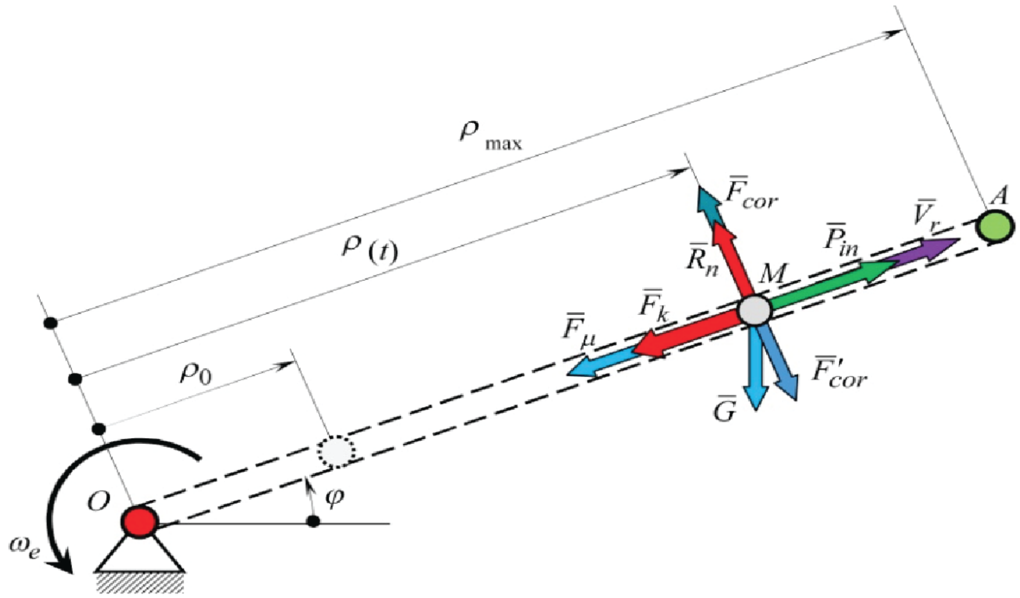

Figure. 2 - Design model of the single particle movement of mixed material on the blade of working body

The calculation scheme shows that he particle M during its sliding over the surface of uniformly rotating blade is acted by:

- the force of inertia in its portable motion

$$P_{in} = m \cdot \omega_e^2 \cdot \rho \text{ H}, \quad (1)$$

Where m – the mass of a single particle, kg; ω_e – the angular velocity of blade, s^{-1}; ρ–the coordinate of particle relative position (the current particle position radius), m;

– the supporting force

$$R_n = F_{cor} + m \cdot g \cdot \cos(\varphi) \text{ H}, \quad (2)$$

where g – acceleration of free fall m/s²; φ – blade rotation angle defined by the formula

$$\varphi = \varphi_0 + \omega_e \cdot t \text{ rad}, \quad (3)$$

where φ_0 – the current blade rotation angle at its interaction with the particle, rad;

- the strength of the Coulomb friction (friction force unit)

$$F_k = k \cdot R_n = k \cdot m \cdot 2 \cdot \omega_e \cdot \dot{\rho} + k \cdot m \cdot g \cdot \cos(\omega_e \cdot t + \varphi_0) \text{ H}, \quad (4)$$

where k – the coefficient of sliding friction on the surface of blade;

- the force of viscous resistance

$$F_\mu = \mu \cdot \dot{\rho} \quad \text{H}, \tag{5}$$

where μ – the empirical coefficient of viscous resistance while unit particle motion in fluid, kg/s.

The Coriolis force $\overline{F}'_{cor}$ works from the side of blade surface perpendicular to the velocity of relative sliding $\overline{V}_r$. In accordance with the static axiom [3] about the equality of forces action and reaction, the oppositely directed force, which causes abrasion wear, acts on the blade from the particle and is defined as:

$$\overline{F}_{cor} = \overline{F}'_{cor} = 2 \cdot m \cdot \left(\overline{\omega}_e \times \overline{V}_r\right) \text{ H.} \tag{6}$$

The particle motion in the direction of forces, shown in the model (see Fig. 2), was described by the fundamental equation of dynamics for the relative motion of a material point

$$m \cdot \ddot{\rho} = P_n - F_k - F_\mu - m \cdot g \cdot \sin(\omega_e \cdot t + \varphi_0) \;. \tag{7}$$

The solution of obtained differential equation allowed to determine the relative velocity of particles:

$$\overline{V}_r(t) = \left[\sqrt{\left(k \cdot \omega_e + \frac{\mu}{2 \cdot m}\right)^2 + \omega_e^2} - k \cdot \omega_e - \frac{\mu}{2 \cdot m}\right] \cdot C_1 \cdot e^{\left[\sqrt{\left(k \cdot \omega_e + \frac{\mu}{2 \cdot m}\right)^2 + \omega_e^2} - k \cdot \omega_e - \frac{\mu}{2 \cdot m}\right] \cdot t} -$$
$$- \left[\sqrt{\left(k \cdot \omega_e + \frac{\mu}{2 \cdot m}\right)^2 + \omega_e^2} + k \cdot \omega_e + \frac{\mu}{2 \cdot m}\right] \cdot C_2 \cdot e^{-\left[\sqrt{\left(k \cdot \omega_e + \frac{\mu}{2 \cdot m}\right)^2 + \omega_e^2} + k \cdot \omega_e + \frac{\mu}{2 \cdot m}\right] \cdot t} -$$
$$- g \cdot m \cdot \frac{4 \cdot k \cdot \omega_e \cdot m + \mu}{(2 \cdot k \cdot \omega_e \cdot m + \mu)^2 + 4 \cdot \omega_e^2 \cdot m^2} \cdot \sin(\omega_e \cdot t + \varphi_0) -$$
$$- g \cdot m \cdot \frac{2 \cdot k^2 \cdot \omega_e \cdot m + k \cdot \mu - 2 \cdot \omega_e \cdot m}{(2 \cdot k \cdot \omega_e \cdot m + \mu)^2 + 4 \cdot \omega_e^2 \cdot m^2} \cdot \cos(\omega_e \cdot t + \varphi_0)$$

(8) m/s.

The integration constants C_1 and C_2 were determined from the initial condition

$$\rho(0) = \rho_0; \;\; \dot{\rho}(0) = V_0 \,. \tag{9}$$

To determine the force, causing abrasive wear, the expression (8) was substituted into the formula (6)

$$F_{cor}(t) = 2 \cdot m \cdot \omega_e \cdot \left[\sqrt{\left(k \cdot \omega_e + \frac{\mu}{2 \cdot m}\right)^2 + \omega_e^2} - k \cdot \omega_e - \frac{\mu}{2 \cdot m}\right] \cdot C_1 \cdot e^{\left[\sqrt{\left(k \cdot \omega_e + \frac{\mu}{2 \cdot m}\right)^2 + \omega_e^2} - k \cdot \omega_e - \frac{\mu}{2 \cdot m}\right] \cdot t} -$$
$$- 2 \cdot m \cdot \omega_e \cdot \left[\sqrt{\left(k \cdot \omega_e + \frac{\mu}{2 \cdot m}\right)^2 + \omega_e^2} + k \cdot \omega_e + \frac{\mu}{2 \cdot m}\right] \cdot C_2 \cdot e^{-\left[\sqrt{\left(k \cdot \omega_e + \frac{\mu}{2 \cdot m}\right)^2 + \omega_e^2} + k \cdot \omega_e + \frac{\mu}{2 \cdot m}\right] \cdot t} -$$
$$- 2 \cdot \omega_e \cdot g \cdot m^2 \cdot \frac{4 \cdot k \cdot \omega_e \cdot m + \mu}{(2 \cdot k \cdot \omega_e \cdot m + \mu)^2 + 4 \cdot \omega_e^2 \cdot m^2} \cdot \sin(\omega_e \cdot t + \varphi_0) -$$

$$-2\cdot\omega_e\cdot g\cdot m^2\cdot\frac{2\cdot k^2\cdot\omega_e\cdot m+k\cdot\mu-2\cdot\omega_e\cdot m}{(2\cdot k\cdot\omega_e\cdot m+\mu)^2+4\cdot\omega_e{}^2\cdot m^2}\cdot\cos(\omega_e\cdot t+\varphi_0) \quad (10) \quad \text{m/s.}$$

The harmonious effect of gravity was averaged by introducing mean-integrated coefficient. Thus, for a single harmonic current strength its mean-integrated value over some period T at the angular frequency takes the form

$$\frac{2}{T}\cdot\int_0^{T/2}\sin(\omega_e\cdot t)dt=\frac{\omega_e}{\pi}\cdot\int_0^{\pi/\omega_e}\sin(\omega_e\cdot t)dt=\frac{\omega_e}{\pi}\cdot\left.\frac{-\cos(\omega_e\cdot t)}{\omega_e}\right|_0^{\frac{\pi}{\omega_e}}=\frac{2}{\pi} \quad (11)$$

In this case, the harmonic effect of gravity on the particle can be represented by the average value:

$$\widetilde{G}=\frac{2\cdot m\cdot g}{\pi} \text{ H.} \quad (12)$$

Since the wear depends mainly on the material friction during its movement on the mixer blades, accept the hypothesis that the wear amount of the working body is proportional to the friction forces capacity flow at the contact of blade-material. In this case, the volumetric blades wear depending on length of mixer operation can be written as

$$J_{\rho\tau}=\lambda\cdot\tau\cdot Q_{N\rho} \text{ , m}^3 \quad (13)$$

where λ –the proportionality coefficient, determined experimentally, m³/W; τ–the duration of abrasive wear, s.; $Q_{N\rho}$ –the friction force power flow at the point with radial coordinate, W/s.

The friction force flow capacity at the point with radial coordinate is defined by the relation:

$$Q_{N\rho}=N_{0\rho}\cdot n_c \text{ ,W/s.} \quad (14)$$

where $N_{0\rho}$ –friction force capacity in longitudinal sliding of one material particle, W; n_c–the frequency of material particles passage through a point of the blade surface at a predetermined longitudinal coordinate ρ, num/s.

Friction force capacity in axial sliding on the blade surface for one material particle is expressed as follows:

$$N_{0\rho}=k\cdot\left(F'_{cor}+\widetilde{G}\right)\cdot V_r \text{ , W.} \quad (15)$$

To determine the frequency of material particles passage through a given point of blade assume that the particle flow that rushes along its surface in the radial direction is continuous. Therefore, while one taken separately particle is moving from its initial radius ρ_0 to the radius of descent from the blade ρ_{max} during some period of time T_r, there are as many particles going down from the blade as there were on the blade at the initial moment in front of it. The number of particles which are placed along the entire length of the blade can be defined as

$$n_L=\frac{L}{d} \text{ , pcs} \quad (16)$$

where $L=\rho_{max}-\rho_0$ –the length of the blade from the place of loading by particles to the place of its descent, m; d –the average particle size, m.

Thus, the frequency of the particles passage by a single point on the blade n_c can be determined by the relation:

$$n_c=\frac{n_L}{T_r}=\frac{\rho_{max}-\rho_0}{T_r\cdot d} \text{ num/s.} \quad (17)$$

Taking into account (8), (10), (12), (14), (15) and (17) the equation (13) becomes

$$J_{\rho\tau}(\tilde{t})=\lambda\cdot\frac{\rho_{max}-\rho_0}{T_r\cdot d}\cdot\tau\times$$

where $\tilde{t}$ – substantially is not the current time of particle motion, but it is a time parameter that implicitly links the wear with radial coordinate of an arbitrary point of the blade, this approach is justified by the fact that the computer program mathematical methods make it easy to establish such a link.

$$\times\left\{\begin{aligned}&2\cdot k\cdot m\cdot\omega_e\cdot\left\{\begin{aligned}&\left[\sqrt{\left(k\cdot\omega_e+\frac{\mu}{2\cdot m}\right)^2+\omega_e^2}-k\cdot\omega_e-\frac{\mu}{2\cdot m}\right]\cdot C_1\cdot e^{\left[\sqrt{\left(k\cdot\omega_e+\frac{\mu}{2\cdot m}\right)^2+\omega_e^2}-k\cdot\omega_e-\frac{\mu}{2\cdot m}\right]\cdot t}-\\&-2\cdot m\cdot\omega_e\cdot\left[\sqrt{\left(k\cdot\omega_e+\frac{\mu}{2\cdot m}\right)^2+\omega_e^2}+k\cdot\omega_e+\frac{\mu}{2\cdot m}\right]\cdot C_2\cdot e^{-\left[\sqrt{\left(k\cdot\omega_e+\frac{\mu}{2\cdot m}\right)^2+\omega_e^2}+k\cdot\omega_e+\frac{\mu}{2\cdot m}\right]\cdot t}-\\&-2\cdot\omega_e\cdot g\cdot m^2\cdot\frac{4\cdot k\cdot\omega_e\cdot m+\mu}{(2\cdot k\cdot\omega_e\cdot m+\mu)^2+4\cdot\omega_e^2\cdot m^2}\cdot\sin(\omega_e\cdot t+\varphi_0)-\\&-2\cdot\omega_e\cdot g\cdot m^2\cdot\frac{2\cdot k^2\cdot\omega_e\cdot m+k\cdot\mu-2\cdot\omega_e\cdot m}{(2\cdot k\cdot\omega_e\cdot m+\mu)^2+4\cdot\omega_e^2\cdot m^2}\cdot\cos(\omega_e\cdot t+\varphi_0)\end{aligned}\right\}+\\&+k\cdot\frac{m\cdot g}{\pi}\cdot\left\{\begin{aligned}&\left[\sqrt{\left(k\cdot\omega_e+\frac{\mu}{2\cdot m}\right)^2+\omega_e^2}-k\cdot\omega_e-\frac{\mu}{2\cdot m}\right]\cdot C_1\cdot e^{\left[\sqrt{\left(k\cdot\omega_e+\frac{\mu}{2\cdot m}\right)^2+\omega_e^2}-k\cdot\omega_e-\frac{\mu}{2\cdot m}\right]\cdot t}-\\&-2\cdot m\cdot\omega_e\cdot\left[\sqrt{\left(k\cdot\omega_e+\frac{\mu}{2\cdot m}\right)^2+\omega_e^2}+k\cdot\omega_e+\frac{\mu}{2\cdot m}\right]\cdot C_2\cdot e^{-\left[\sqrt{\left(k\cdot\omega_e+\frac{\mu}{2\cdot m}\right)^2+\omega_e^2}+k\cdot\omega_e+\frac{\mu}{2\cdot m}\right]\cdot t}-\\&-2\cdot\omega_e\cdot g\cdot m^2\cdot\frac{4\cdot k\cdot\omega_e\cdot m+\mu}{(2\cdot k\cdot\omega_e\cdot m+\mu)^2+4\cdot\omega_e^2\cdot m^2}\cdot\sin(\omega_e\cdot t+\varphi_0)-\\&-2\cdot\omega_e\cdot g\cdot m^2\cdot\frac{2\cdot k^2\cdot\omega_e\cdot m+k\cdot\mu-2\cdot\omega_e\cdot m}{(2\cdot k\cdot\omega_e\cdot m+\mu)^2+4\cdot\omega_e^2\cdot m^2}\cdot\cos(\omega_e\cdot t+\varphi_0)\end{aligned}\right\}\end{aligned}\right\},\ \text{m}^3 \quad (18)$$

Calculation by formula (18) gives a different wear value for each of the blades. This is due to the different initial conditions on the angle of rotation for each of them, the last has an impact on the gravity effect at different points of time. Due to the fact that in the course of continuous operation, the same blade is subjected to varying initial conditions, for example, at the initial angle of its installation, there is a need to estimate the maximum wear by some averaged blade among four, thus, the nature of its wear accept as uniform.

From the viewpoint of the practical use of the data, it is convenient to use not a wear volume, but the depth of the blade wear.

To move to the calculation of the blade wear depth for a certain allotted time τ, first of all, find the wear radius of cylindrical blade *r*, if ts initial constructive radius R is known (Fig. 3).

Volumetric wear of blade, calculated by the program - is the volume of the hollow cylinder, which is given by the relation

$$J_{\rho\tau}=\pi\cdot(\rho_{max}-\rho_0)\cdot\left(R^2-r^2\right)\ \text{m}^3. \quad (19)$$

Where the wear radius is defined as follows

$$r=R\cdot\sqrt{1-\frac{J_{\rho\tau}}{(\rho_{max}-\rho_0)\cdot\pi\cdot R^2}}\ \text{m}. \quad (20)$$

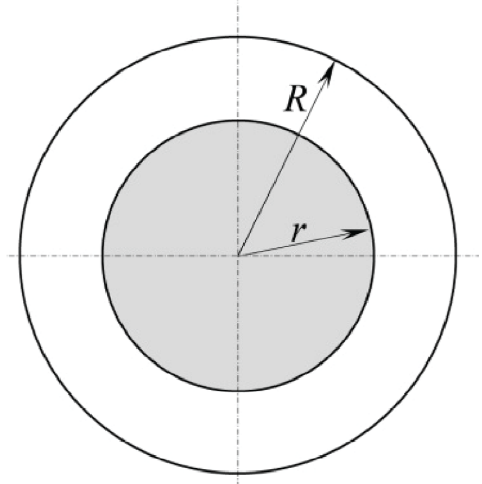

Figure 3 - Calculation of the radius of worn cylindrical blade

Then, the depth of wear is determined by the difference between the initial radius and wear radius

$$\Delta=R-r\ \text{m}. \quad (21)$$

Conclusions.

The proposed method allows for forecasting the amount of blades wear at the design stage, it enables to provide the necessary measures to reduce it in accordance with the physical and mechanical properties of the processed material, design and operational parameters-set of the mixer, and to set the time range of measures for its for its maintenance.

References

1. Plakhtin V.D. *Nadezhnost' remont i montazh metallurgicheskikh mashin.* [The reliability of the repair and the installation of metallurgical machines]. Moscow, Metallurgy Publ., 1983. 415 p.
2. Ryabinin I.A., Cherkesov G.I. *Logiko-veroyat-nostnyye metody issledovaniya nadezhnosti strukturno-slozhnykh system.* [Logical and probabilistic methods for studying the reliability of structural complex systems]. Moscow, Radio and Communication Publ., 1981. 264 p.
3. Yablonskiy A.A, Nikiforova V.M. *Kurs teoreticheskoy mekhaniki*. [The course of theoretical mechanics]. Moscow, Lan' Publ., 2002. 768 p.
4. Yahyaev N.Ya., Karablin A.V. *Osnovy teorii nadezhnosti i diagnostiki.* [Basic theory of reliability and diagnostics]. Moscow, The publishing center "Academy" Publ., 2009. 256 p.
5. Zasel'skiy, V.Y.,Popolov, D.V, Zasel'skiy, I.V. (2014). Experimental research on the optimization of parameters of a homomixer. *New technologies,* 3-4, 33-39.

UDC 621.771.06

New methods of monitoring and diagnostics of the technical state of rolling mills

Verenev V.V.

D.Sc. in engineering,
Senior researcher
Z.I. Nekrasov Institute of Ferrous Metallurgy of NAS of Ukraine
Dnipropetrovsk

Podobedov N.I.

PhD in Technical Sciences,
Senior researcher
Z.I. Nekrasov Institute of Ferrous Metallurgy of NAS of Ukraine
Dnipropetrovsk

Korennoy V.V.

Junior research assistant,
Senior researcher
Z.I. Nekrasov Institute of Ferrous Metallurgy of NAS of Ukraine
Dnipropetrovsk