Theoretical Determination of Wear and Lifetime of the Screen Sowing Surface

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Abstract

In the article researches of wear of polymeric sowing surfaces of vibrating screens are given. The mathematical model was obtained with analytical methods that allow one to describe the effect of the regime and technological parameters of a vibrating screen, as well as the physical properties of the material being transported, on the wear of a polymeric sowing surface. The obtained equations allow us to determine the lifetime of a surface made of polymer, taking into account the wear of the contact surface, as well as the change in the size of the sieve aperture.

Keywords: polymer, sowing surface, wear, vibrating screen.

1. Introduction

Studying of the mechanism and the main regularities of wear of the sowing surface of screen made with the basis of polymers comprised of two tasks: the first is to determine the wear which affects the main dimensions of screen; the second is to determine the maximum lifetime of the product. In the first case, the wear significantly influences the value of the screen natural oscillation, which ensure the screen resonance in case they are equal to the forced oscillations of the screen, which leads to its self-cleaning from the stuck material. In the second one, the lifetime of the screen, apart from the actual forces, depends directly on the physico-mechanical characteristics of polymer itself.

Today, a lot of researches are devoted to the wear of polymers [1-3]. For the vibrating screens sowing surfaces made from the mentioned materials, however, these questions haven't been studied sufficiently.

2. Materials and methods

By the nature of the main process, the wear of the sowing surface made of polymers can be divided into abrasive and fatigue. During the evaluating of the polymers abrasive wear the power criterion is often used (the product of the pressure on the sliding speed). In case the pressure is constant, the wear depends on the sliding speed. In other researches devoted to the wear of work tool determination during the material vibration transmission [4, 5], it is established that the specific work value of the frictional forces A_f on the contact 'sowing surface-charge material', during the oscillation period T, is also proportional to the sliding speed:

$$A_f = \int_0^T F(t) \cdot \dot{\xi}_1(t)\, dt \ \ [\text{J/m}^2], \tag{1}$$

where $F(t)$ is the instantaneous value of the abrasive material specific frictional force on contact with the sowing surface [N/m^2]; $\dot{\xi}_1(t)$ instantaneous speed of relative slip of the material, [m/s].

So, considering expression (1), the main task is to determine the material frictional forces at the contact with the sowing surface, and also to determine the material's relative slippage. Taking into account all the factors of vibration influence during the calculation of these parameters is extremely difficult. In order to avoid considering the material layer internal forces, we shall use the following assumptions:

– the dependence of the amplitudes damping of vertical and horizontal oscillations in the layer is exponential and in the frequency band $\omega = 70\ldots120$ [s^{-1}] retains constant values;

– when the material slips at any moment, the frictional force is determined by the Coulomb's law (in our case it is permissible, because the temperature regime is constant and does not exceed 50 °C on the average)

$$F(t) = \frac{f \cdot N(t)}{S_s - S_h} \ [\text{N/m}^2], \tag{2}$$

where f is the friction coefficient; $N(t)$ is the sowing surface normal reaction, [N]; S_s is the area of the sowing surface, [m^2]; S_h is the area of the holes in the sowing surface, [m^2].

3. Mathematical modeling of wear and lifetime of the sowing surface

Let's consider the volume movement of the element of a layer of material in reference to the sowing surface inclined at an angle to the horizon and oscillating along a circular trajectory (Figure 1).

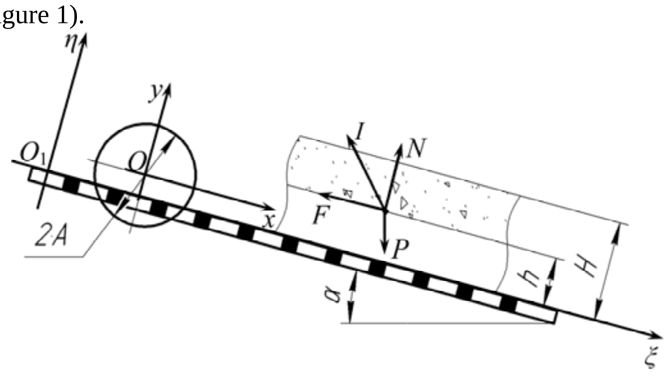

Figure 1. Analytical model

In the fixed *xOy* coordinate system, the equation of the trajectory of the points displacement of the sowing surface in the parametric form is

$$\begin{cases} x(t) = A \cdot \cos(\omega t) \\ y(t) = A \cdot \sin(\omega t) \end{cases} \text{[m]}, \tag{3}$$

where A is the oscillation amplitude, [m]; ω is the oscillation frequency, [s^{-1}].

Projections of the absolute movement of material at height *h*, taking into account the assumed admission of the damping of oscillations law in the absence of relative slip of material over a vibrating sowing surface:

$$\begin{cases} x(h) = x \cdot e^{-\beta_t \cdot h} = A \cdot \cos(\omega t) \cdot e^{-\beta_t \cdot h} \\ y(h) = y \cdot e^{-\beta_l \cdot h} = A \cdot \sin(\omega t) \cdot e^{-\beta_l \cdot h} \end{cases} \text{[m]}, \tag{4}$$

where β_t and β_l are the transverse and longitudinal oscillations attenuation coefficients in the charge material layer respectively, [m^{-1}] [6].

In the moving coordinate system $\eta O_1 \xi$ associated with the oscillating sowing surface, the relative motion of a layer, equations of material of thickness $H - h$ located at the height h from the plane of the sowing surface in the absence of its slipping or tearing will be

$$\begin{cases} m \cdot \ddot{\xi} = m \cdot g \cdot \sin\alpha - m \cdot \ddot{x}(t) - F(t,h) \\ m \cdot \ddot{\eta} = -m \cdot g \cdot \cos\alpha + m \cdot \ddot{y}(t) + N(t,h) \end{cases}, \tag{5}$$

where m is the mass of material in a layer of thickness $H - h$, [kg]; $F(t,h)$ and $N(t,h)$ are the frictional force and the regular reaction at height h respectively, [N]; $\ddot{\xi}$ and $\ddot{\eta}$ are the average relative accelerations of the material layer, [m/s^2].

Taking into account (3), considering the assumption (2), the system (5) takes following form

$$\begin{cases} m \cdot \ddot{\xi} = m \cdot g \cdot \sin\alpha + m \cdot A \cdot \omega^2 \cdot \cos(\omega t) - f \cdot N(t,h) \\ m \cdot \ddot{\eta} = -m \cdot g \cdot \cos\alpha - m \cdot A \cdot \omega^2 \sin(\omega t) + N(t,h) \end{cases}. \tag{6}$$

The average relative accelerations in the material $\ddot{\xi}$ and $\ddot{\eta}$ layer are obtained by integrating the relative acceleration of the material in reference to the height h in the range from h to H :

$$\ddot{\xi} = \frac{1}{H-h} \cdot \int_h^H \frac{d^2 x(h)}{dt^2} dh + \frac{d^2 x(t)}{dt^2}; \tag{7}$$

$$\ddot{\eta} = \frac{1}{H-h} \cdot \int_h^H \frac{d^2 y(h)}{dt^2} dh + \frac{d^2 y(t)}{dt^2}. \tag{8}$$

Taking into account (3) and (4) the expression (7) and (8) will take the form of

$$\ddot{\xi} = \frac{A \cdot \omega^2}{(H-h) \cdot \beta_t} \cdot \cos(\omega\, t) \cdot \left(e^{-\beta_t \cdot H} - e^{-\beta_t \cdot h}\right) - A \cdot \omega^2 \cdot \cos(\omega\, t) \text{ [m/s}^2\text{]}; \qquad (9)$$

$$\ddot{\eta} = \frac{A \cdot \omega^2}{(H-h) \cdot \beta_l} \cdot \sin(\omega\, t) \cdot \left(e^{-\beta_l \cdot H} - e^{-\beta_l \cdot h}\right) - A \cdot \omega^2 \cdot \sin(\omega t) \text{ [m/s}^2\text{]}. \qquad (10)$$

Substituting (10) into (6), we determine the expressions for the force of a regular reaction at the time when the material is on a vibrating sowing surface, expressing the mass of material in the layer as

$$m = \rho \cdot S \cdot (H-h) \text{ [kg]}, \qquad (11)$$

where ρ is the bulk density of material, [kg/m^3]; S is the material layer base area, [m^2]; $H-h$ is the height of layer, [m]

$$N(t,h) = \rho \cdot S \cdot (H-h) \cdot g \cdot \cos\alpha + \frac{\rho \cdot S \cdot A \cdot \omega^2}{\beta_l} \cdot \sin(\omega\, t) \cdot \left(e^{-\beta_l \cdot H} - e^{-\beta_l \cdot h}\right). \qquad (12)$$

In the slip phase, the movement of the material layer is described by the first equation of the system (6), characterized by the acceleration $\ddot{\xi}$ which is the average acceleration of the layer in the presence of slip, and the normal reaction $N(t,h)$ takes the corresponding value $h = 0$. Since the material is in contact with the perforated screening surface, it is necessary to take into account its clean opening with the aid of the coefficient

$$K_{co} = \frac{S_h}{S_s}, \qquad (13)$$

where K_{co} is the coefficient of the clear opening of the seeding surface.

Taking into account the aforenamed, the first equation of system (6) and expression (12) take following form

$$m \cdot \ddot{\xi}_1 = m \cdot g \cdot \sin\alpha + m \cdot A \cdot \omega^2 \cdot \cos(\omega\, t) - f \cdot N(t) \text{ [N]}, \qquad (14)$$

$$N(t) = \left[\rho \cdot S \cdot H \cdot g \cos\alpha + \frac{\rho \cdot S \cdot A \cdot \omega^2}{\beta_l} \cdot \sin(\omega\, t) \cdot \left(e^{-\beta_l \cdot H} - 1\right)\right] \cdot (1 - K_{co}) \text{ [N]}. \qquad (15)$$

The frictional forces at the slippage time are equal to the maximum possible and they are determined by the relations

$$F = \begin{cases} -f \cdot N \text{ if } \ddot{\xi}_1 > 0 \\ f \cdot N \text{ if } \ddot{\xi}_1 < 0 \end{cases}. \qquad (16)$$

Putting (11) and (15) into expression (14), taking into account condition (16), we obtain the expression for determining the average acceleration of the layer in the presence of slippage

$$\ddot{\xi}_1(t)_{\pm} = g \cdot \sin\alpha + A \cdot \omega^2 \cdot \cos(\omega\, t) \pm f \cdot g \cdot \cos\alpha \cdot (1 - K_{co}) \pm f \cdot \frac{A \cdot \omega^2}{\beta_l \cdot H} \cdot \sin(\omega\, t) \times$$
$$\times \left(e^{-\beta_l \cdot H} - 1\right) \cdot (1 - K_{co}) \text{ [m/s}^2\text{]}. \qquad (17)$$

By integrating (17) we get the relative speed of material with slipping that takes the following form on rearrangement

$$\dot{\xi}_1(t)_{\pm} = \int \ddot{\xi}_1(t)dt = g \cdot t \cdot \sin\alpha + A \cdot \omega \cdot \sin(\omega t) \pm f \cdot t \cdot g\cos\alpha \cdot (1 - K_{co}) \mp f \cdot \frac{A \cdot \omega}{\beta_l \cdot H} \times$$
$$\times \cos(\omega t) \cdot \left(e^{-\beta_l \cdot H} - 1\right) \cdot (1 - K_{co}) + C \text{ [m/s]}. \quad (18)$$

The integration constant is found from the initial conditions

$$\dot{\xi}_1(t*) = \dot{\xi}_1^*, \quad (19)$$

where $\dot{\xi}_1^*$ is the initial velocity of the material layer in the slip phase, [m/s].

Then the expression (18) takes the form

$$\dot{\xi}_1(t)_{\pm} = g \cdot \sin\alpha \cdot \left(t - t^*\right) + A \cdot \omega \cdot \left(\sin(\omega t) - \sin\left(\omega t^*\right)\right) \pm f \cdot g \cdot \cos\alpha \cdot (1 - K_{co}) \times$$
$$\times \left(t - t^*\right) \mp f \cdot \frac{A \cdot \omega}{\beta_l \cdot H} \cdot \left(e^{-\beta_l \cdot H} - 1\right) \cdot (1 - K_{co}) \cdot \left(\cos(\omega t) - \cos\left(\omega t^*\right)\right) + \dot{\xi}_1^* \text{ [m/s]}. \quad (20)$$

Taking into account (15) and (2) the instantaneous value of the abrasive material specific frictional force on contact with the sowing surface will be:

$$F(t) = \left[f \cdot (1 - K_{co}) \cdot \left[\rho \cdot H \cdot S \cdot g \cdot \cos\alpha + \frac{\rho \cdot S \cdot A \cdot \omega^2}{\beta_l} \times \right.\right.$$
$$\left.\left. \times \cdot \sin(\omega t) \cdot \left(e^{-\beta_l \cdot H} - 1\right)\right]\right] \Big/ (S_s - S_h) \text{ [N/m}^2\text{]}. \quad (21)$$

Substituting (20) and (21) into expression (1) and integrating at the sliding stage from δ_+ to φ_+, and at the stage of sliding back from δ_- to φ_-, we obtain the specific work of the frictional force on the contact sowing surface charge material

$$A_f = \int_{\delta_+}^{\varphi_+} F(t) \cdot \dot{\xi}_+(t)dt - \int_{\delta_-}^{\varphi_-} F(t) \cdot \dot{\xi}_-(t)d\,t \text{ [J/m}^2\text{]}. \quad (22)$$

Knowing the specific work of frictional forces A_f during the oscillation period, we can find the specific work of friction during the operation of the screen during τ hours

$$A_\tau = 3600 \cdot A_f \cdot \frac{\omega}{2 \cdot \pi} \cdot \tau \text{ [J/m}^2\text{]}. \quad (23)$$

Then the wear value at the contact "sowing surface - material" can be defined as

$$I = K_e \cdot A_\tau \text{ [m]}, \quad (24)$$

where K_e is the coefficient determined experimentally for the interacting pair "sowing surface - material", [m^3/J].

The obtained formulas make it possible to determine the wear of the sieve by the height of its surface, but, in addition to surface wear, wear occurs the walls of the sieve holes, too. The reason of the walls wear of the sieve holes is the interaction of the flow of particles passing through it. When the wear of the walls occurs only due to frictional forces on the contact "material hole of the screen" (in our case, the impact forces are neglected), the value of such wear can be determined as for the sowing surface by the formula (1). Only in this case the normal reaction of the walls to the material in accordance with [4] will be determined as

$$N' = \frac{m_0 \cdot A \cdot \omega^2 \cdot \cos\alpha}{P \cdot h_{s.t}} \ \text{[N/m}^2\text{]}, \tag{25}$$

where P is the hole's perimeter, [m]; $h_{s.t}$ is the screen's thickness, [m]; m_0 is the mass of particles in the hole, which is defined as

$$m_0 = \frac{q \cdot h_{s.t}}{n \cdot \sqrt{2 \cdot g \cdot h_{s.t}}} \ \text{[kg]}, \tag{26}$$

where q is the flow of material passing through the unit of the screen area per unit time; n is the number of holes per unit area of the screen.

The specific frictional force of the material against the wall of the sieve hole in this case will be

$$F' = N' \cdot f = \frac{m_0 \cdot A \cdot \omega^2 \cdot \cos\alpha}{P \cdot h_{s.t}} \cdot f \ \text{[N/m}^2\text{]}. \tag{27}$$

In this formula, the friction coefficient is assumed to be the same as in the case of determining the frictional force for surface wear. The average slip velocity of the material relative to the wall surface in our case will be

$$V_s = \frac{1}{2} \cdot \sqrt{2 \cdot g \cdot h_{s.t}} + A \cdot \omega \ \text{[m/s]}. \tag{28}$$

Substituting (27) and (28) in (1), we will be able to determine the specific work of the forces of A'_f dry friction at the contact of the screen hole surface with the material during the oscillations period $\omega/(2 \cdot \pi)$

$$A'_f = \left[\frac{m_0 \cdot A \cdot \omega^2 \cdot \cos\alpha}{P \cdot h_{s.t}} \cdot f \cdot \left(\frac{1}{2} \cdot \sqrt{2 \cdot g \cdot h_{s.t}} + A \cdot \omega \right) \right] \cdot \frac{\omega}{2 \cdot \pi} \ \text{[J/m}^2\text{]}. \tag{29}$$

Then the friction work during the screen operation during hours by analogy with (23) can be defined as

$$A'_\tau = 3600 \cdot A'_f \cdot \frac{\omega}{2 \cdot \pi} \cdot \tau \ \text{[J/m}^2\text{]}. \tag{30}$$

The wear value of the sowing surface walls of the screen is determined by taking into account (29) and (30) as

$$I' = K_e \cdot A'_\tau \ \text{[m]}. \tag{31}$$

During the studying of the sowing surface of the screen made of polymer, determining the wear of its surface and walls is important when we chose dynamic screening parameters that allow it to provide resonant oscillations due to frequency regulation (which leads to better screening efficiency due to a decrease in the screening capacity of the screen), however it doesn’t provide an opportunity to determine the term of its lifetime.

To determine the life (necessary at the design stage) of a surface made of polymer, it is possible to calculate the limiting number of deformation cycles n' of its surface layers in accordance with [1], starting from the fatigue failure of the material:

$$n' = \left(\frac{\sigma_0 \cdot \varphi}{3 \cdot f \cdot P_1} \right)^{t_{d.e}}, \qquad (32)$$

where σ_0 is the polymer strength [Pa]; φ is the relative area of the actual contact is equal to the ratio of the area of the actual contact S_a to the S_n nominal contact, i.e. $\varphi = S_a / S_n$; f is the friction coefficient; P_1 is the material pressure on the contact area, equal to $P_1 = N(t,h)$, [N/m^2]; $t_{d.e}$ dynamic endurance coefficient of the material (determined experimentally in $\ln\delta - \ln n'$ coordinates).

4. Conclusions

So, (24), (31), (23) and (30) entering into them (with allowance of (32)) are the mathematical model to determine of engineering characteristics basis the polymer sowing surfaces of the screen , taking into account the mode and technological characteristics of the vibration machine, the peculiarity of this technique is that when assessing the operating time of the gray surface for failure, based on fatigue failure of the material, the wear is not only superficial layers, but also the change in the cross-section of the holes of the sowing surface.

The method was based on a phenomenological model in which the intralayer power of the charge material takes into account the damping factors of the oscillations in it, which allows one to take into account the features of the vibration displacement of the layers along the plane making circular plane-parallel oscillations.

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