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Technological effect of vibroprocessing by flows of organic granular media

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Abstract. The analysis of approaches to modeling of vibrational processing by granulated media is carried out. The vibroprocessing model which provides effective finishing of the surfaces of the parts due to the stone fruit organic media granules is developed. The model is based on the granule flow energy impact on the surface being treated. As the main characteristic of the organic media processing, a specific volumetric metal scrap is used, the physical meaning of which is the increase rate in the thickness of the material removed from the surface at a given velocity and pressure of the medium. It is shown that the metal scrap depends on the medium flow velocity, the height of the loading column of the granular medium, and the conditions for the formation of a medium stationary circulation motion. Based on the analysis of the results of experimental studies of the influence of amplitude-frequency characteristics on the removal of metal in the process of vibroprocessing with abrasive granules, the dependence of the specific volume metal removal is proposed for organic media processing, taking into account the threshold amplitude and frequency of oscillations of the working chamber, at which the effect of surface treatment is observed. The established set of relationships describing the effective conditions for vibroprocessing with stone organic media was obtained using experimental data, which allows us to assume that the model obtained is valid.

1. Introduction

Organic media represent an independent group of processing media, the use and application of which in the technology of machine parts' manufacturing extends the range of vibration processing technological possibilities as well as increases its efficiency. However, insufficient study of these media, the lack of techniques for designing finishing operations with their use limits the area of their technological application.

Therefore, the purpose of these studies is to justify the regularities of vibroprocessing, which ensure effective finishing of parts surfaces with the help of stone fruit organic media granules.

2. Basic approaches to simulation of processes of vibratory finishing by granular media

The technological effect of finishing processing in the conditions of technological vibration systems is caused by the cutting and deforming effect of streams of particles of the working medium on the part surface. The vibro-abrasive processing and the technological effect achieved due to its usage have been thoroughly studied and presented in scientific works [1-4].

Among the first fundamental works on the disclosure of the physical essence of technological processes of vibration-abrasive treatment, it is necessary to single out the works of A P Babichev [1]. His research on the mechanics of abrasive media interaction and parts with vibratory action allowed him to formulate a mechanical-physical-chemical model of the processes of surface destruction of a part in the environment of vibrating abrasive granules, which was the initial prerequisite for further research in this field.

To determine the specific metal removal depending on various parameters, he proposed a generalized empirical equation in the following form:

$$q = 3.8 \cdot A^{1.25} \cdot HB^{-0.91} \cdot C_n \cdot C_3 \cdot C_G \cdot C_d \cdot C_V \text{ , kg/s,}$$

where A - amplitude of oscillations, mm; HB - hardness of the processed material; C_n, C_3, C_G, C_d, C_V - coefficients reflecting frequency of vibration influence, granularity of abrasive granules; mass of the part; granulation of the processing medium; the volume of working chamber loading respectively.

Further development of research in the field of vibro-abrasive processing was obtained in the works of M A Tamarkin [2]. On the basis of theoretical and experimental research, he proved that the most expedient, corresponding to the actual process of metal removal, is a method consisting in determining the removal of metal in a single interaction of an abrasive particle with the surface of a part, followed by multiplying by the number of such interactions during the treatment. To determine the specific metal removal, he proposed the following relationship:

$$\gamma_{\text{vt}} = P_1 \cdot P_2 \cdot \omega \cdot q \cdot \frac{S_{\text{part}}}{4R^2}, \text{ kg/s,}$$

where P_1- the geometric probability of an event that any point of the package square is covered by a contact spot in one cycle of exposure to a mass of abrasive granules; P_2- probability of the event that the interaction of the abrasive particle with the part surface will lead to microcutting; ω - oscillation frequency of the working chamber, s^{-1}; q - metal removal with a single interaction of the abrasive granule with the workpiece surface, kg; S_{part} - surface area of the workpiece, mm^2; R - radius of the abrasive granule, mm.

In S N Shevtsov's paper [3], it is proposed to analyze the technological effect of a moving granulation processing medium, to consider only the metal removal effect without taking into account the phenomena caused by the deformation-hardening effect of abrasive granules, the observability of which, in the author's opinion, is complicated by the fact that the surface deformation process by microstrikes of granules stabilizes gradually by smoothing the roughness and hardening. In his view, the effect of metal removal is due not to the intensity of the impact of abrasive granules, but to the volume specific metal removal that is proportional to the energy density of the abrasive medium. This approach qualitatively correctly reflects the regularity established in numerous studies that the increase in velocity and pressure independently increases the specific metal removal.

Specificity of organic granular media is caused by plant origin. Their physical-mechanical, biological-chemical and cutting properties are formed during maturation and subsequent processing. Unlike inorganic media, the crushed fruit stone media do not have high hardness (0.37061 ÷ 0.58165 GPa) and low mass. As a result, the characteristics of the dynamic state of the organic medium, the shaping and energy properties have lower values compared with the vibration processing of parts by natural and synthetic media at similar amplitude-frequency characteristics of the process. Cutting properties of stone organic media are acquired as a result of their crushing. When the crust of the pits is destroyed, granules of 4-6 mm in size are formed, having edges with different angles. The presence of corner edges in the particles predetermines their cutting ability when they interact with the surface to be treated during vibroprocessing. In this regard, the technological efficiency of the processing by organic granular media is most preferably considered from the point of view of the intensity of the energy impact of the flow of granules on the surface being treated, without taking into account the phenomena due to the deformation-hardening effect.

3. Modeling of the process of treatment with flows of granules of fruit stone organic media

Experiments on the study of the relationship between the parameters of the movement of the abrasive medium in vibro containers with the intensity of the metal scrap, presented in [3], indicate the following regularities. Metal surfaces, streamlined by the medium at a higher speed, with other things being equal, demonstrate a greater removal of metal. With a constant speed of medium flow, the discharge is always higher with increasing "pressure" – its own pressure from the side of the medium due to its greater height above the sample, or external, created by the loading device. In these experiments, the material, shape, size and orientation of the samples in the flow were deliberately kept unchanged to distinguish the net contribution of the parameters of the moving abrasive medium to the dynamics of the metal removal.

As the main characteristic of the process of treatment with the help of organic media, let us use a specific volumetric metal removal γ_{vm} with the m / h dimension, the physical meaning of which is the rate of increase in the thickness of the material removed from the surface at a given velocity and pressure of the medium. And the main factors of the process are: the density of the medium - ρ (kg / m^3); additional external and internal "hydrostatic pressure" in the medium - p (Pa); the average flow velocity of the medium - v (m / h).

Assuming that the organic granular medium is continuous, let us use the hydrodynamic analogy proposed in [3] to describe the removal, according to which one of the characteristics of moving continuous media is the energy flux density, which is the amount of energy "flowing out" per unit time from the unit volume allocated in environment. Neglecting the thermal effects in a granular medium, the expression for the energy flux density is written as:

$$E = \left(\frac{\rho \cdot v^2}{2} + p \right) \cdot v \ . \tag{1}$$

The first term is the kinetic energy transferred per unit time passing through the unit surface by the mass of the medium, the second is the work done by the pressure forces over the medium. Thus, expression (1) characterizes both the kinematics and the energy of the medium flow, and when fixing the cutting properties of the granules and the orientation of the surface to be treated, the cutting properties of the flow as well.

For a fixed direction of flow relative to the surface, the expression for the metal-removal can be written in a scalar form:

$$\gamma_{vm} = E \cdot \Pi_{\varphi} \quad ,$$

where index φ indicates the mutual orientation of the surface and the flow.

Taking into account the dimensionality of the energy flow: E (kg / h^3) and volumetric metal scoop, the dimension of the value of Π_{φ} should be: m · h^2 / kg. It follows that the inverse of Π_{φ} : Σ (kg / m · h^2), has the dimension of mechanical stress. Then the expression for the metal removal will look like:

$$\gamma_{vm} = \frac{E}{\Sigma} = \frac{\left(\rho \cdot v^2 / 2 + p\right) \cdot v}{\Sigma}, \tag{2}$$

from which it follows that the volumetric specific metal scoop is proportional to the energy flux density of the organic granular medium. In this case, the parameters Σ and Π_{φ} have a meaning, respectively, of the "resistance modulus" and the fracture compliance parameter inherent in the surface of a given material exposed to the flow of a given granular medium. Relation (2) qualitatively describes the established regularity, consisting in the fact that the increase in speed and "pressure" independently increase the specific metal scoop, and when the medium stops, the scoop also stops.

For the practical use of this relation, it is necessary to know the medium velocity in the working chamber and the parameter Σ.

The studies given in [3,4] have convincingly shown that the metal scrap depends on the medium flow velocity, the height of the loading column of the granular medium. The conditions for the formation of a stationary circulatory motion of the medium along the slightly eccentric (close to the circumference) ellipses are:

$$\frac{H}{L} \cong 1; \frac{H}{d_g} > 6; \frac{(A \cdot \omega)^2}{g \cdot H} < 0{,}5,$$

where H – the medium loading height; L- the chamber section width; d_g - average diameter of the medium granules.

The value Σ is called the wear module, which depends only on the nature of the medium granules and material properties, it is a complex parameter characterizing the wear micromechanics in a given tribosystem. The module Σ, is a constant that does not depend on the dynamic state of the medium, can be expressed as a function of the physical-mechanical properties of the material being processed.

Assuming that the working chamber is not too elongated or oblate along the axis, it is possible to express the loading height H through the working volume of the V chamber. Then the formula that determines the hydrostatic pressure created in the working chamber will look like:

$$p = \rho \cdot g \cdot H = \rho \cdot g \cdot \sqrt[3]{V} \tag{3}$$

To determine the flow velocity of the medium [5, 6, 7], let us take into account the fact that in a state of steady flow along a vibrating surface, the flow velocity is proportional to the vibration velocity of the surface itself. According to [3], the maximum velocity of the circulation motion of the medium inside the U-shaped chamber is determined by the relation:

$$v_{max} = \frac{A \cdot \omega}{2} = \frac{A \cdot 2\pi \cdot f}{2} = A \cdot \pi \cdot f \tag{4}$$

Which validity is proved by independent experimental results [6]. Figure 1 shows the results of measuring the flow rate with variations in the amplitude and frequency of the vibration of the chamber.

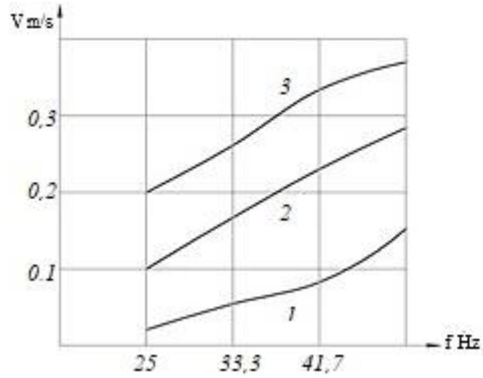

Figure 1. Dependence of the medium circulation flow velocity on the camera vibration amplitude and frequency [3]: 1)A=0.5 mm; 2) A=1.5 mm; 3) A=2.5 mm

Substituting (4) and (3) into (2), one obtains:

$$\gamma_{vm} = \frac{\rho \cdot A \cdot f}{\Sigma} \cdot \left(\frac{A^2 \cdot f^2}{2} + \pi \cdot g \cdot \sqrt[3]{V} \right). \tag{5}$$

In the expression obtained, ρ, Σ characterizes the properties of the processing medium, and A, f, $\sqrt[3]{V}$ - the dynamic mode and the dimensions of the chamber.

However, based on the analysis of the experimental data presented in [1, 2, 6, 8], it should be noted that there is a significant drawback of the formula (5), namely, the absence of a threshold amplitude and a threshold frequency of oscillations below which the movement of the granular organic medium and material removal do not occur.

Thus, in [1, 8], the dependence of metal removal on the amplitude of oscillations on a machine with a U-shaped chamber of 25 liters, loaded by 2/3, was investigated. The experiments were carried out without the use of process fluid. Abrasive medium - crushed crumb was washed with soda ash. The oscillation frequency was 25 Hz. Based on the research results, the graphical dependencies shown in Figure 2, on which the growth of removal with increasing amplitude of the oscillations is clearly visible.

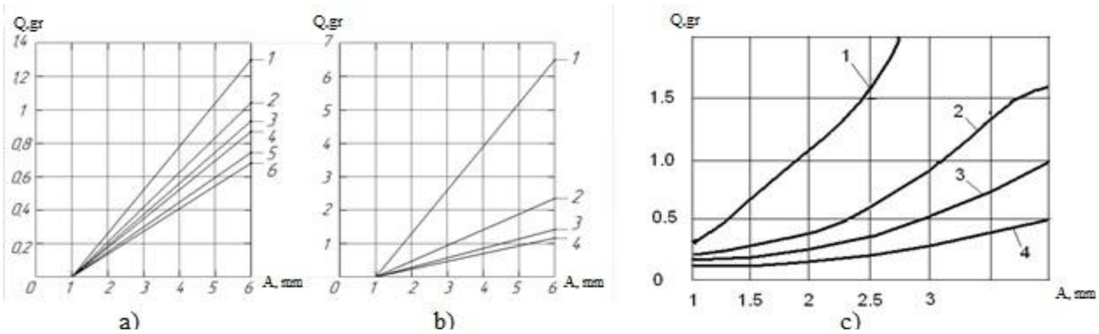

Figure 2. Dependence of metal mass removal from samples from the amplitude of oscillations (abrasive EB63STK granulation - 25-40 mm, frequency - 25 Hz, time - 3 hours) a) 1-SCH-12- 28; 2-Steel 3; 3- PF-KCH; 4- steel 45; 5-Steel 6 (hardened), 6 - U10A (hardened) [10]; b) 1- babbitt B - 83;2- bronze Br014; 3- D1; 4-Al 3 [8], c) 1- Babbitt B-83; 2- Bronze Br 014; 3- cast iron SCH12; 4- steel U8 (hardening) [6]

It follows from Fig. 2, such a threshold amplitude is the amplitude, somewhat less than 1 mm. An analysis of a sufficiently large number of experimental data shows that the threshold amplitude depends on vibration frequency. And with increasing frequency, the threshold amplitude decreases. The justification of this phenomenon is contained in the works [9, 10, 12], devoted to the dynamics of granular bodies subjected to vibration. An analysis of the equations of the dynamics of particles located on a rough vibrating surface shows that the motion in the "tossing" mode (namely, this mode is realized in the vibratory machines) can begin with the magnitude of the vibration overload [7]:

$$G = A \cdot \frac{\omega^2}{g} > 1 ,$$

where g=9.8m/s^2- acceleration of gravity.

Returning to the results of Figure 2, one sees that at a frequency of 25 Hz, at which the experiment was conducted, the threshold amplitude will be:

$$A_0 \cdot \omega^2 \geq g \Rightarrow A_0 \cong \frac{g}{4\pi \cdot f^2}; \quad A_0 > 0.4\text{mm} \tag{6}$$

As follows from [7], the value of A_0 depends on the friction of the particles on the supporting surface, the thickness of the particle layer and their density, but in the absence of condensing factors, A_0 can be determined with a sufficient degree of accuracy (error up to 15%) from (6).

Taking into account the above studies, the dependence of the specific volume removal (5) with allowance for the threshold amplitude will be written as follows:

$$\gamma_{vm} = \frac{\rho(A - A_0) \cdot f}{\Sigma} \cdot \left(\frac{(A - A_0)^2 \cdot f^2}{2} + \pi g \sqrt[3]{V} \right), \quad A > A_0 \tag{7}$$

The curves in Figure 3 show the dependencies that at low frequencies, when there is no motion of the medium, the removal of the metal is not observed. With an increase in frequency above some optimal, corresponding to the most intensive load movement, the increase in removal is reduced.

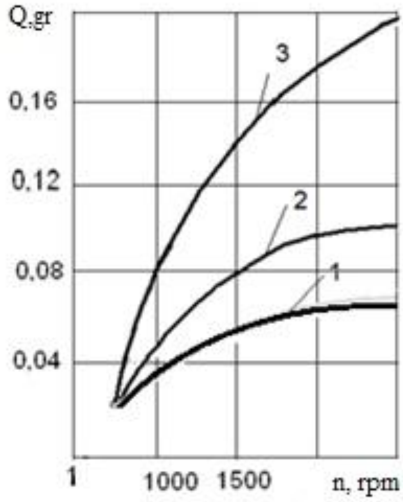

Figure 3. Dependence of metal mass removal from samples on the oscillation frequency (abrasive EB63STK granulation of 25-40mm, amplitude of 1.5 mm, time 1 hour):1- bronze Br014; 2-Al3; 3- steel St3 [8].

Therefore, it seems correct to introduce a threshold frequency similar to the amplitude, from which the abrasive medium can come into motion. Naturally, this threshold frequency f_0 will depend on the amplitude of the excited oscillations, however, as the experimental data of [1,6,11] show, the value of f_0 is in the range of 10-15 Hz for the majority of vibration machines with a circulation character of motion.

Expressing the modulus of Σ as a function of the physical-mechanical characteristics of the material being processed and, in particular, of its hardness, $\Sigma = C \cdot HV$, where C is the experimentally established complex coefficient characterizing the physical-mechanical and biological properties of organic medium granules, as well as processing conditions (with the use of technological fluid or without it), let us obtain a set of dependencies describing the vibration processing with the help of organic granular media consisting of crushed seeds of fruit trees:

$$\gamma_{vm} = \frac{\rho \cdot (A - A_0) \cdot (f - f_0)}{C \cdot HV} \cdot \left(\frac{(A - A_0)^2 \cdot (f - f_0)^2}{2} \right) + \pi \cdot g \cdot \sqrt[3]{V}$$

$$A > A_0, \quad f > f_0$$

$$A_0 = \pi \cdot \frac{g}{4 \cdot \pi^2 \cdot f_0^2}$$

$$\frac{H}{L} \cong 1; \quad \frac{H}{d_ч} > 6; \quad \frac{(A \cdot \omega)^2}{g \cdot H} < 0{,}5$$

4. Conclusions

The resulting dependence of the metal removal and the conditions presented in the form of inequalities that correspond to the stationary circulation movement of the organic granular medium along elliptical trajectories ensure the efficiency of the vibration of the surface of the parts by stone organic media. Neglecting these conditions can lead to the fact that the dynamic state of the process will differ from normal, and the formula for the metal removal will become incorrect.

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