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MANUFACTURING ENGINEERING AND AUTOMATED PROCESSES

МАШИНОБУДУВАННЯ, АВТОМАТИЗАЦІЯ ВИРОБНИЦТВА ТА ПРОЦЕСИ МЕХАНІЧНОЇ ОБРОБКИ

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INTERACTION OF ABRASIVE WORKING ENVIRONMENT PARTICLES AT VIBRATING PROCESSING WITH THE TREATED SURFACE DETAILS

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Summary. *The paper carries out the review of the vibration processing, the analysis of the interaction of the granule with the element, the energy level of working environment, and ways of their increasing. Basic parameters are determined of the vibration processing, which increases its intensiveness. The factor determining the force of the working environment granule interaction with the processed surface is its speed provided by the complexity of kinetic motion applied to it. There is suggested the theoretic model of the granule interaction with the surface of the part in which the abrasive granule is simultaneously influenced by the forces of vibration and centrifugal ones increasing the total force of interaction.*

Key words: *vibration processing, the energy level, the granule, abrasive working environment.*

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Problem setting. When designing and implementing a new high-performance finishing treatment, a vibratory method is used to process parts of complex forms in granular abrasive environment. The process of vibration-mechanical treatment (VMT) is characterized by a combination of factors that influence the workpiece being processed: a large number of micro impulses of the working medium particles, which provides plastic deformation, removal of metal and its oxides, variable accelerations, which provide high mobility and shock nature of the interaction of particles of the working medium and work-pieces, the presence of chemical and surface-active solutions that are part of the LCL (lubricating and cooling liquids). A large number of varieties of this method requires thorough study and research.

Analysis of recent research and publications. Increasing the productivity and quality of vibration processing of parts creates the preconditions for the development and improvement of the technological process, the intensity of which is determined by the magnitude of the force of interaction of the abrasive granule with the treated surface [1, 2]. One of the most intensive methods of this technological process is the vibration processing of parts in machines with rigid

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kinematic schemes, which create a complex movement of the working medium in the middle of the chamber. In addition to being spatial or planetary, the motion of the working chamber can also follow the complex spatial curve. Parts-processing machinery that uses this principle of the technological process in granular abrasive environment provides an increase in its productivity and intensity [2]. At the same time, the improvement of the technological process requires further research and testing.

Research objectives. The aim of the work is to study the interaction of the granule during the vibration-mechanical treatment of parts in granular abrasive environment, modeling the technological process and determining its optimal parameters.

Implementation of work. The combination of such elements of the process as the consistent application of a large number of micro impulses, the intense movement of the operating medium and work-pieces, with their different mutual orientation, depending on the nature of the composition of the working environment and treatment mode, creates conditions for determining the ways to improve the productivity of cleaning, polishing, finishing and strengthening operations.

The intensity and quality of the vibration treatment process determines the nature of the circular movement of the granular working medium and the work-pieces being processed. Among the main factors that shape this process are the oscillation modes, the design of the working chambers, the volume and degree of their filling, the characteristics and size of the working environment, the presence or absence of LCL, chemical solutions and electrolytes.

Circulating process of the working environment of vibration treatment is provided by harmonic and bi-harmonic oscillations of the working chamber, whose points move along regular paths, which depend on the kinematics of the VMT machine. In this case, the particles of the working abrasive medium during each period of oscillation in some areas move together with the working chamber and in this period their trajectory and speed coincide or are close. Then there is a separation of particles from the walls of the working chamber due to different values and directions of their speed and accelerations. After separation, these particles carry on their „free“ movement with a very complex trajectory.

The motion trajectory of the working medium particles depends on the type of motion of the working chamber and its shape (cylindrical, spherical, toroidal, V-shaped, etc.), and may be:

• with plane vibration of the working chamber;
• with volumetric (three-dimensional) vibration of the working chamber;
• with a simple rotation of the working chamber;
• with a complex rotating motion of the chamber relative to two or three proper axes;
• with angular oscillations of the working chamber;
• with angular vibration of the working chamber, which moves along a complex spatial curve;
• with the planetary motion of the working chamber;
• with volumetric angular vibration of the working chamber;
• with combined vibration of the working chamber (combining or overlaying of the above-mentioned vibration varieties).

The factors that influence the circulation of the vibration treatment process include the following: the use of various combinations of solid, liquid and mixed components of the working media; a combination of the mechanical treatment process in the form of cutting and plastic deformation with the physical and chemical process, by introducing certain materials into the working environment together with solutions and electrolytes; the presence of high pressure and temperature in the working chamber.

Increasing the productivity and quality of vibration processing of parts creates the preconditions for the development and improvement of the technological process, the intensity of which is determined by the magnitude of the force of interaction of the abrasive granule with the treated surface. The basis of the study of vibration processing and its varieties is the phenomenon of the energy level of the working environment. The intensity of the vibration-mechanical treatment (VMT) is determined by the removal of the metal, or the degree of plastic deformation of the surface as a result of the interaction of the abrasive granule with the workpiece. The higher the energy level of the medium, the greater the power of such interaction. The processing granule receives an energy impulse from the surface of the chamber, which fluctuates at a certain speed, and strikes the surface of the workpiece. The vibration impact strength is determined by the working environment particle separation speed. Therefore, we have already established analytical dependencies of trajectories, velocities and accelerations, which characterize the kinematics of working chambers of VMT machines and determine the productivity of the selected vibration process.

Machines with plane vibration and simple rotation of the working chamber are characterized by the dependence of speed change and acceleration on time, which is shown in Fig. 1.

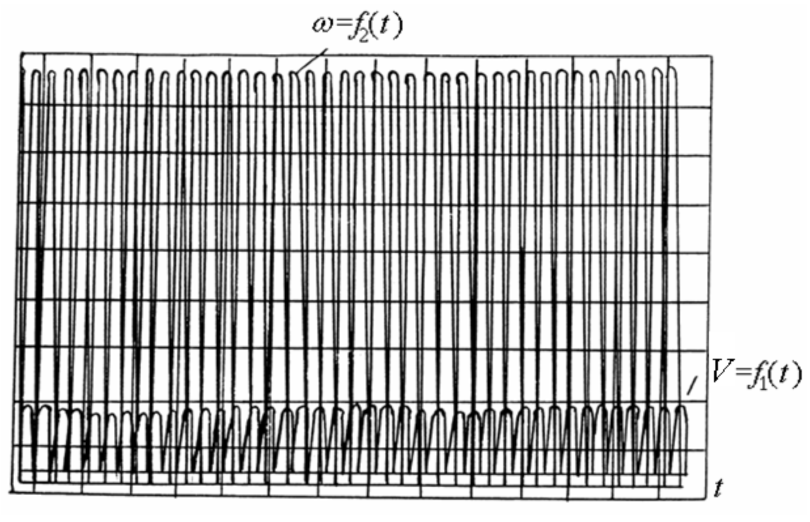

Figure 1. Dependence of speed change and acceleration of the camera on time with plane vibration and simple rotation of working chambers

The speed and acceleration of the points of the lateral surface of the working chamber vary with a large frequency and are roughly equal to the value which determines the direction of movement of the abrasive working medium and the intensity of its „boiling“ (rotation of the abrasive granule around its axis).

Machines in which the working chamber carries out a complex spatial motion with various kinds of oscillations imposed on it, namely those in which the chamber carries simultaneously a rotary motion relative to two intersecting axes, and the mechanism of the oscillatory motion gives the containers radial fluctuations, are characterized by the dependence of the change in velocity and acceleration on time, are shown in Fig. 2 and 3.

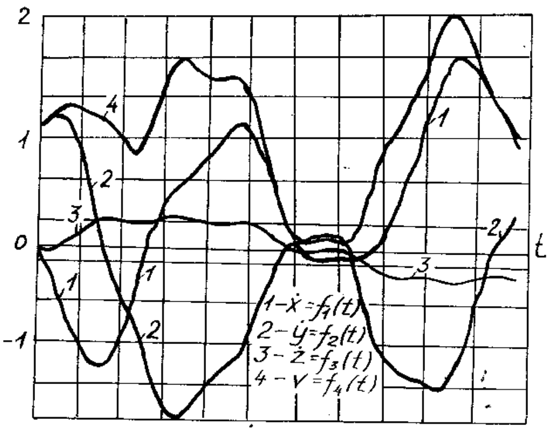

Figure 2. Dependence of the change of chamber speed on time

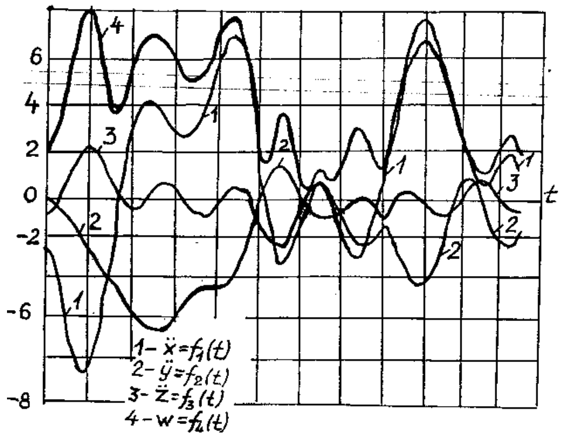

Figure 3. Dependence of the change of chamber acceleration in time

The speed and acceleration of the points of the surface of the working chamber changes cyclically with respect to the coordinate axes with different periodicity and unstable quantities, which leads to a complex movement of the abrasive working medium with varying intensity of mixing.

An analytical description of the kinematics of vibration-centrifugal machines, whose working chambers move along a complex spatial curve with angular oscillations imposed on them, is shown in Fig. 4, 5, 6, 7.

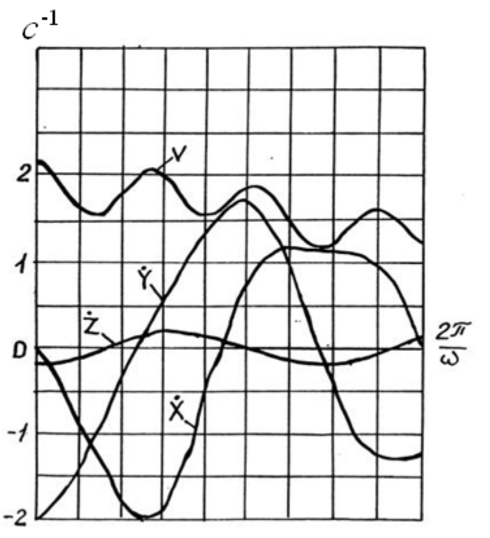

Figure 4. Dependence of the change of chamber speed on time

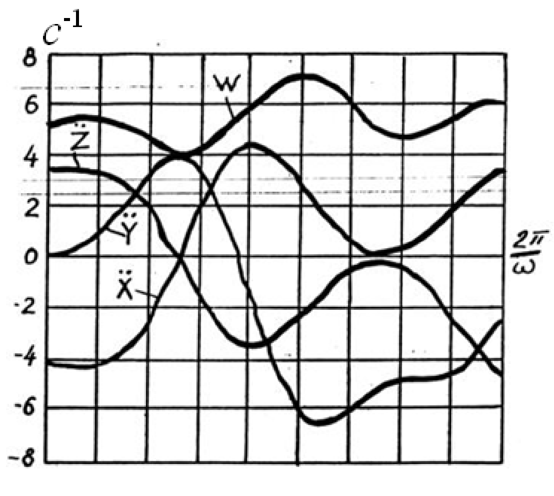

Figure 5. Dependence of the change of chamber acceleration on time

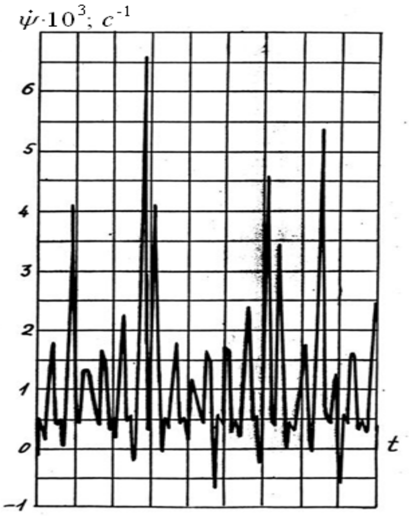

Figure 6. Dependence of the change of the angular speed of the chamber on time

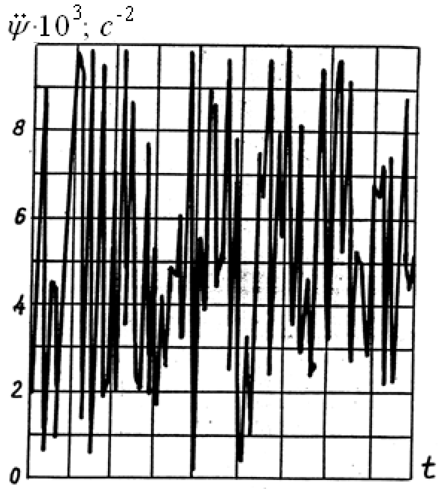

Figure 7. Dependence of the angular acceleration of the working chamber on time

The speed and acceleration of the working chamber surface varies periodically with different magnitude and phase shift, which predicts a smooth movement of the abrasive working medium, and the change in angular velocity and angular acceleration determines the strength and intensity of its movement.

In these cases, an increase in the intensity of VMT is achieved through simultaneous influence of two or more types of energies on the working environment or additional movements of the parts being processed. The energy level of the working environment increases if the vibrating chamber is given additional movements. Conclusion drawn from the above mentioned material states that the main parameter of the technological process of vibratory treatment is the force of interaction of the abrasive granule with the surface of the machined parts.

Fig. 8 shows the scheme of interaction of the abrasive granule with the surface of the part at VMT. The processing granule, having received an energy impulse from the chamber surface, which fluctuates with the speed V, strikes the surface of the workpiece. The vibration force P can be expanded into two components: the normal P_N, with the help of which the granule penetrates into the surface to be treated, and the tangent P_τ, which shifts the granule along the surface.

Components of the normal reaction N_i and the frictional forces of F_i influence the grains of the abrasive granules in the cutting zone from the side of the workpiece.

During the vibration-centrifugal processing (VCP) in addition to the vibrational force P, the granule is also influenced by the centrifugal force $P_в$ (Fig. 9). The total force of impact R at VCP is equal to the geometric sum of forces P and $P_в$. The granule under the action of the components R_τ and R_N leaves on the surface a scratch of bigger size than that caused by P_N and P_τ.

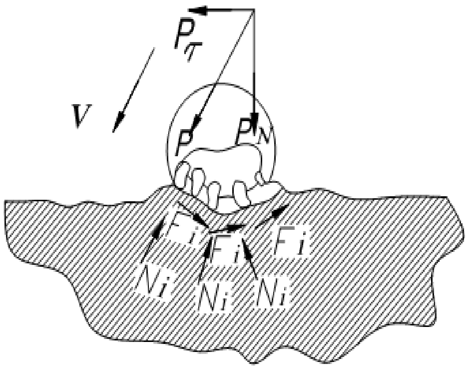

Figure 8. Schematic diagram of the interaction of the granule with the treated surface at VMT

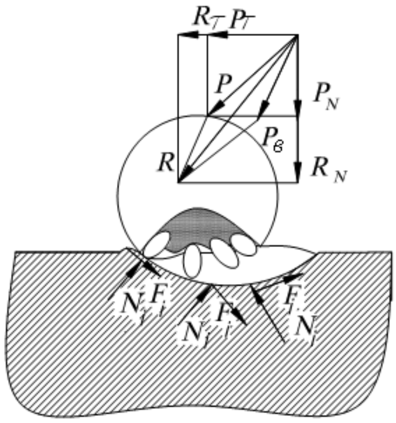

Figure 9. Schematic diagram of interaction of the abrasive granule with the treated surface at VCP

The proposed theoretical model reveals the physical essence of the interaction of the granule with the surface of the workpiece. The simultaneous action of both vibration and centrifugal forces on the abrasive granule increases the volume, and hence the weight of the removed micro-scrap, thus providing an increase in intensity. When determining the force of the mutual impact of the working medium particles with the treated work-pieces using different methods of vibration-centrifugal processing in a granular abrasive environment, along with other parameters, an important role is played by instantaneous friction factor λ of the granule on the corresponding working surface, which characterizes the rigidity of the surface of the bodies in the contact area at their impact.

Due to the variety of forms and sizes of granules and their variants of orientation at the moment of their impact with the working surface, it is very difficult to experimentally determine the value of λ. To define it analytically let us assume that the pulse of the forces acting upon the granule at the impact on the tangent is due only to the force of friction, and the granule begins to shift on the working surface at the maximum limiting value of the momentum of this force.

$$|P_\tau| = \lambda |P_n|, \tag{1}$$

where P_n – is the impulse of normal pressure at impact.

Face offset at impact is absent when

$$|P_\tau| \leq \lambda |P_n|. \tag{2}$$

By analogy with sliding friction it is assumed that the coefficient λ will be maximum at the moment of transition from impact without slipping of the granule to impact with its sliding on the working surface

$$\lambda = \left|\frac{P_\tau}{P_n}\right|. \tag{3}$$

To analytically solve the problem of determining the coefficient of instantaneous friction λ of the granule on the corresponding working surface, consider the analytical model of the impact of the granule on the working plane shown in Fig. 10

At the moment of transition from one type of impact into another type, the dependence, which describes the impact without slipping, is true:

$$\left.\begin{aligned} &m\left(V_{1\xi}-V_{\xi}\right)=P_{\tau}\\ &m\left(V_{1\eta}-V_{\eta}\right)=P_{n}\\ &I_{c}\omega_{1}=P_{\tau}\cdot p_{\eta}-P_{n}\cdot p_{\xi}\\ &V_{1\eta}=e\left|V_{\eta}\right|\\ &V_{1\xi}-\omega_{1}\cdot p_{\eta}=0 \end{aligned}\right\}. \tag{4}$$

where *m* – is the mass of the granule; $V_{1\xi}$, $V_{1\eta}$, and, V_{ξ}, V_{η} – the projections of the velocity of the granule mass center C at the end and at the beginning of the impact; ω_1 – angular velocity of the granule after impact; *e* – is the recovery factor of the normal component of the speed of the granule at impact.

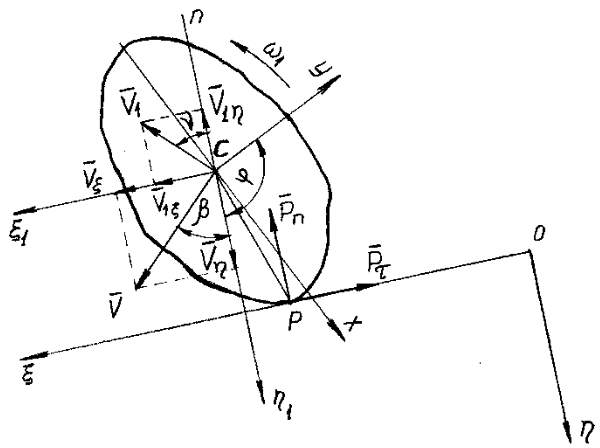

Figure 10. Analytical model of the impact of the granule on the plane
$\xi O\eta$ – fixed coordinate system; $\xi_1 C\eta_1$; *Cxy* – moving coordinate systems, connected with a granule;
n – normal to the plane; β, ν, φ – angle of incidence, reflection and orientation of the granule

The moment of inertia of the granule relative to the main axis, perpendicular to the impact plane $\xi O\eta$,

$$I_c = \tfrac{1}{5}\, m\left(a^2+b^2\right). \tag{5}$$

Where a, b are the dimensions of the half of the main axis of the middle section, which lies in the plane of impact (b <a).

Projections of the radius-vector CP, defining the orientation of the granule relative to the plane

$$p_{\eta}=\sqrt{b^2+\left(a^2-b^2\right)\cdot\sin^2\varphi}\,, \tag{6}$$

$$p_{\xi}=\left(a^2-b^2\right)\cdot\sin\varphi\cdot\cos\varphi/\sqrt{b^2+\left(a^2-b^2\right)\cdot\sin^2\varphi}\,. \tag{7}$$

Taking into account the substitution of equations (5) – (7) into (4), from it we obtain

$$P_\tau = \frac{mV\left[5(1+e)\left(1-k^2\right)\sin\varphi\cdot\cos\varphi+\left(1-k^2\right)\sin\beta\right]}{6+k^2-5\left(1-k^2\right)\cdot\cos^2\varphi}, \tag{8}$$

$$P_n = mV(1-e)\cos\beta\,, \tag{9}$$

where $k = b/a$.

Substituting (8) and (9) into (3), after transformations we will have an equation that is convenient for analysis

$$\lambda = \frac{5\left[\left(1-k^2\right)\big/\left(1+k^2\right)\right]\cdot\sin 2\varphi + 2tg\beta/(1+e)}{7-5\left[\left(1-k^2\right)\big/\left(1+k^2\right)\right]\cdot\cos 2\varphi}. \tag{10}$$

As it can be seen from dependence (10), with the increase of the coefficient e and the decrease of the elongation of the shape of the granule (i.e. with a larger value of k), the value λ decreases. The parameter β is determined for the specific conditions of impact, the angle of the fall of the granule, in which the impact without slipping of the granule transforms into an impact with slipping. When solving the problem, premise, accepted at the beginning, substantiate the angle β as the constant value in equation (10). The angle β is determined by the movement of the operating chamber, which is determined by the kinematics of the vibration unit. Also, the coefficient λ depends on the orientation angle φ of the granules relative to the working surface at impact and the specific frictional properties of the surface of the bodies that undergo mutual impact. In most cases, the angle of incidence β and the orientation angle φ of the granule depends on the type of selected kinematic pattern of the vibration unit.

Conclusions. The intensity of the vibration process depends on the magnitude of the interaction force of the granule of the abrasive granular medium with the surface of the part being processed. The crucial factor of the interaction force of the granule of the working medium with the treated surface is its velocity, which is provided by the surface of the operating chamber and is determined by the complexity of its kinematic motion.

References

1. Babichev A.P. Osnovy vibracionnoj tehnologii. Rostov-n/D.: Izdatel'skij centr DGTU, 2008, 694 p. [In Russian].
2. Moroz V.M. Analiz konstruktivnyh shem oborudovanija dlja vibracionno-centrobezhnoj obrabotki, Progressivnaja otdelochno-uprochnjajushhaja tehnologija, Rostov n/D, RISHM, 1982, pp. 76 – 87. [In Russian].
3. Kondratjuk O.M., Romejko I.V. Analiz cirkuljacii̇ robochogo seredovishha pri vibracijno-vidcentrovij obrobci detalej, Visnik NUVGP, Vipusk 2 (3), Rivne: 2006, pp. 253 – 271. [In Ukrainian].
4. Kondratjuk O.M. Optimizacija tehnologichnogo procesu vibracijno-vidcentrovoї obrobki detalej, Vinnicja: Vseukr.nauk-tehn.zh. „Vibracii̇ v tehnici ta tehnologijah“ no. 1 (61), 2011, pp. 87 – 93. [In Ukrainian].
5. Kondratjuk O.M. Teoretichna model' procesu vibracijno-vidcentrovoї obrobki, Visnik NUVGP, Zb. nauk. pr, Vipusk 2 (38) Rivne: 2007, pp. 286 – 293. [In Ukrainian].

Список використаної літератури

1. Бабичев, А.П. Основы вибрационной технологии [Текст] / А.П. Бабичев // Ростов-н/Д.: Издательский центр ДГТУ, 2008. – 694 с.

2. Мороз, В.М. Анализ конструктивных схем оборудования для вибрационно-центробежной обработки [Текст] / В.М. Мороз // Прогрессивная отделочно-упрочняющая технология. – Ростов н/Д. РИСХМ, 1982. – С. 76 – 87.
3. Кондратюк, О.М. Аналіз циркуляції робочого середовища при вібраційно-відцентровій обробці деталей [Текст] / О.М. Кондратюк, І.В. Ромейко // Вісник НУВГП. Випуск 2 (3). – Рівне, 2006. – С. 253 – 271.
4. Кондратюк, О.М. Оптимізація технологічного процесу вібраційно-відцентрової обробки деталей [Текст] / О.М. Кондратюк, Л.С. Серілко // Всеукр.наук-техн.ж. «Вібрації в техніці та технологіях». – №. 1 (61). – 2011. – С. 87 – 93.
5. Кондратюк, О.М. Теоретична модель процесу вібраційно-відцентрової обробки [Текст] / О.М. Кондратюк // Вісник НУВГП. Зб. наук. пр. – Випуск 2 (38) – Рівне, 2007. – С. 286 – 293.

УДК 621.9.048

ДОСЛІДЖЕННЯ ВЗАЄМОДІЇ ЧАСТИНКИ АБРАЗИВНОГО РОБОЧОГО СЕРЕДОВИЩА ПРИ ВІБРАЦІЙНІЙ ОБРОБЦІ З ОБРОБЛЮВАНОЮ ПОВЕРХНЕЮ ДЕТАЛІ

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Резюме. *Проведено огляд вібраційної обробки, аналіз взаємодії гранули з деталлю, енергетичний рівень робочого середовища, шляхи його підвищення. Виявлено основні параметри вібраційної обробки, які підвищують інтенсивність обробки. Визначним фактором сили взаємодії гранули робочого середовища з оброблюваною поверхнею є її швидкість, яка надається поверхнею робочої камери і визначається складністю наданого їй кінематичного руху. Запропоновано теоретичну модель взаємодії гранули з поверхнею деталі, в якій на абразивну гранулу одночасно діють сили вібрації й відцентрові сили, збільшуючи сумарну силу взаємодії.*

Ключові слова: *вібраційний процес, енергетичний рівень, абразивне робоче середовище.*

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