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INVESTIGATION OF ABRASIVE GRANULE MOVEMENT RELATIVELY TO THE WORKPIECE SURFACE DURING VIBRATION TREATMENT

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Summary*. The review of vibration treatment is carried out in this paper. The workpiece vibration treatment is essential in ensuring the engineering products quality. The schemes of abrasive granule interaction with the workpiece surface during vibration and vibration-centrifugal treatment are considered. Process analysis is based on the nature of the abrasive pellet interaction with the workpiece surface. The whole process of roughness forming on VCP is divided into certain stages. The proposed models reveal the physical nature of the granules interaction with the workpiece surface.*
Key words: *vibration treatment, technological process, abrasive granule, granule speed, kinetic energy.*

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Statement of the problem. The widespread introduction of advanced technologies, materialization of sound scientific and technical ideas, creation of new tools, machine systems determining progress in various economy sectors is an important direction of scientific and technological progress. This lays the foundations for access to fundamentally new, resource-saving technologies, increase of labour productivity and product quality.

Highly productive methods of clearing, grinding and strengthening treatment of parts with intricate profiles and low rigidity are of great importance important for ensuring the engineering products quality. The solution of the problems concerning effective mechanization of these operations is the development and implementation of new highly productive finishing methods, one of which is vibration. This, undoubtedly, requires further comprehensive investigation of vibration treatment process, solution of a number of problems of the required equipment designing, creation or selection of effective low-deficit working environments, development and research of new types of vibration methods [1], especially treatment of intricate profiles and low rigidity in case when cutting tools access is limited or impossible.

Analysis of available investigations and publications. One of the main directions of intensification of vibration treatment is the development of its new varieties. The intensity of vibration treatment (ViT) is determined by metal removal, or degree of surface plastic deformation as a result of interaction of abrasive granule with the part. The higher the environment energy level, the greater the strength of such interaction. Different ways of various types of ViT activation are used for this purpose.

During spindle vibration treatment (SViT), the intensity increase is achieved by combining the granule energy received from the vibrating chamber, and the energy of additional movement of the fixed part. The peculiarity of vibroabrasive electrochemical treatment (ViAECT) is that the energy of the electrochemical reaction is additionally supplied to the area of interaction between the granule and the part. Anodic dissolution of the workpiece surface

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layer and its mechanical removal by granules takes place. The process productivity increases in comparison with ViT. The essence of magneto-vibroabrasive treatment (ViMtAT) method is in the fact that the energy of constant or alternating magnetic field is supplied from a separate source into the working area of the vibration machine. The vibrothermomechanical method (ViTMT) is carried out processing with parts heating.

Since vibration treatment of the parts in free-vibrating bodies environment is the multifactorial process, its intensity depends on the amplitude and frequency of the working chamber oscillations, its trajectory, treatment duration, brand of machined material, characteristics and size of the working medium particles, working chamber volume and its filling degree, mechanical properties of the workpiece material and other factors [1, 2, 7].

The objective of the paper is the substantiation of the basic principles of vibration treatment method in terms of machined surface quality and treatment process productivity.

Implementation of the work. In the above mentioned cases, the increase of ViT intensity is reached due to the simultaneous action on the working environment of two or more types of energy, or additional workpiece movements. The energy level of the working environment can be increased if the vibrating chamber performes additional displacements [2, 3]. The complication of the chamber kinematic movement should be carried out in such a way that the loaded working medium is subjected to simultaneous interaction of directed vibrations and centrifugal forces of inertia. During vibration treatment (ViT) the following types of the working chamber movement are determined: with planar vibration of the working chamber; with three-dimensional vibration of the working chamber; with simple rotation of the working chamber; with complex rotational movement of the chamber relatively to two or three own axes; with angular oscillations of the working chamber; with angular vibration of the working chamber moving along the complex spatial curve; with planetary motion of the working chamber; with three-dimensional angular vibration of the working chamber; with combined (combination or overlapping of the above mentioned varieties) vibration of the working chamber.

This idea is the basis for the development of new processes of vibration-centrifugal treatment (VCT) and equipment for its implementation, especially for parts with intricate configuration and low rigidity. For complete analysis of ViT processes, at first we consider the interaction between abrasive granule and the surface of the part with planar vibration of the working chamber for classical scheme of vibration machine. In order to determine the value of abrasive particle speed at the moment of its separation from the working chamber surface, we use the known Babichev dependence [1]

$$V = k_v \cdot A \cdot \omega, \tag{1}$$

where A is the amplitude of working chamber oscillations, m;
ω is the oscillation frequency, s^{-1};
k_v is the coefficient of speed loss during granule removal from the working chamber walls.

If the value of the amplitude of working chamber oscillations is A = 0.004 m, the oscillations frequency is ω = 15 s^{-1}, the coefficient of speed loss is k_v = 1, then the speed of abrasive granule is equal to V = 0.06 m/s.

The diagram of interaction between the abrasive granule and the part surface during planar vibration of the working chamber is shown in Figure 1.

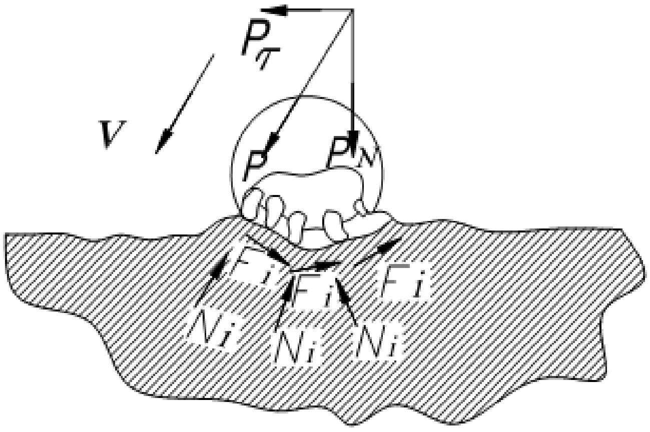


Figure 1. The diagram of interaction between granule and treated surface during planar vibration of the working chamber

The treating granule, having received the energy impulse from the surface of the chamber, which oscillates with speed *V*, strikes the part surface. Let us decompose the vibration force *P* into two components: normal P_N, due to which the granule penetrates into the machined surface, and tangent P_τ, which displaces the granule along the surface. From the side of the part, the grains of abrasive granule located in the cutting area, are affected by the components of the normal reaction N_i and the friction force F_i. The projection of loose abrasive medium circulation the under the action of these forces passes mainly along flat elliptical trajectory.

Analysis of VCT processes is based on the nature of interaction between the abrasive granule and the surface of the part having volumetric angular working chamber vibration. In the case of VCT, in addition to the vibration force *P*, the centrifugal force $P_в$ acts on the granule (Figure 2) [4]. The total impact force *R* at VCT is equal to the geometric sum of forces *P* and $P_в$. Under the components action the granule leaves larger scratch on the surface than under P_N and P_τ action. The circulation of the working medium under the action of total forces turns in spiral direction, which is coordinated by the fixing points of the moving working chamber to the immovable part (housing) of the vibration-centrifugal installation. Determination of the value of abrasive particle velocity at the moment of its separation from the surface for this case is carried out by the formula [4]:

$$V_{0\max}^{*} = R\omega_1 + A\omega \cdot \cos\omega\, t_0\,, \tag{2}$$

where ω is the circular frequency of oscillating motion, s^{-1};
ω_1 is the angular rotation velocity of the radius vector of the moving coordinate origin position s^{-1};
R is the trajectory radius relatively to the coordinate origin m;
A is the amplitude of oscillating motion, m;
t is time, s.

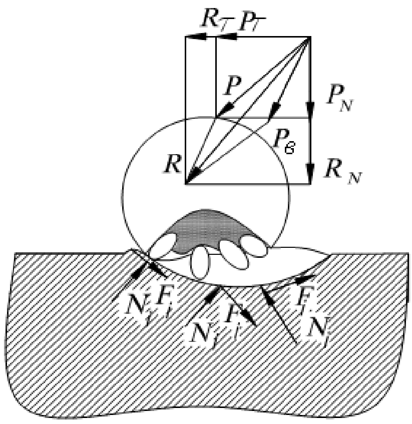


Figure 2. The diagram of interaction between abrasive granules and treated surface during VCT

Substituting the values of circular frequency of oscillating motion ω =15 s^{-1}, angular rotation velocity of the radius vector of the moving coordinate system origin position ω_1=15 rad/s, trajectory radius relatively to the coordinate origin R = 0.15 m, amplitude of oscillating motion A = 0.004 m; we obtain the graph of the change in the speed of abrasive particle at the moment of its separation from the working chamber surface during VCT (Figure 3). This makes it possible to determine the change and direction of the interaction force between the abrasive granule and the machined part surface.

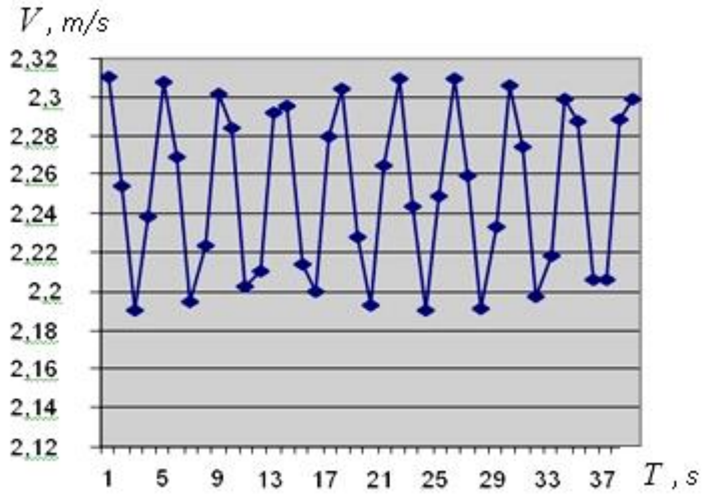


Figure 3. The graph of the change in the speed of the abrasive particles at the moment of its separation from the working chamber surface during VCT

The whole process of the part roughness forming during VCT can be divided into the following stages. In the initial treatment period, the granules impact the microasperity tips of the samples original surface. There is intensive jamming of the microrelief crest resulting in intensive roughness reduction and increase of the machined surface strength. This stage ends with the formation of the surface having higher indicators of surface quality. For our purpose, this part of technological operation can be called the vibration passage. The duration of such a passage in VCT is within the range 15–30 minutes. During this time, the entire original surface of the part is covered with traces of interaction with the working medium granules.

In the following period the surface which is formed by the first vibration passage is treated. The treatment mode is not changed, and the stability of the working medium provides its almost unchanged processed property.

The granule of the working medium, having the same energy as in the first passage, leaves on the surface the second trace with the depth slightly greater than the height of the micro-irregularities formed by the first passage. The granule deforms the metal at the base of the protrusions of the original sample surface microrelief. In this case the degree and depth of sharpening increases.

The second vibration passage is characterized by increase of roughness parameters, but the numerical value R_a at the end of the passage is less than the original one (before treatment). This passage ends approximately 45 minutes after the beginning of treatment.

The next passage is characterized by roughness decrease. This is explained by two factors. First, with each subsequent passage, the area of interaction between granule and the surface approaches the bases of the microrelief protrusions, resulting in the increase of interaction area between the granule and the surface. Second, the first two passages result in the increase of surface strength of the sample material. This additionally leads to the increase o0f the surface response during its force interaction with the working medium granules. The elastic phase of granule impact with the surface increases from passage to passage.

The analysis of the first VCT passages shows that formation of surface roughness takes place discretely with the decrease in the discreteness degree while processing time is increased. With constant roughness approaching, the force interaction between the granule and the part surface takes form of elastic impact.

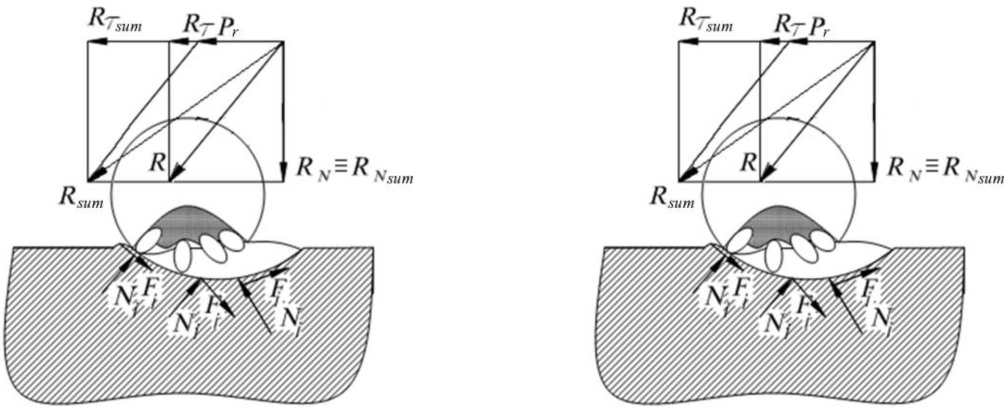
In order to extend the possibilities of vibration-centrifugal treatment, new devices are created in which besides vibration forces P and centrifugal forces P_v, there are additional forces, such as forces from the rotation of the working chamber with vibration-centrifugal oscillations mechanism P_r. The nature of the type of total interaction forces between the abrasive granule of the loose working medium and the treated surface of the parts and their variety are proposed in schemes (a) and (b) Figure 4, which correspond to the combined vibration of the working chamber.

Analyzing the given schemes of possible versions of interaction between the abrasive granule and the part surface, we can come to the conclusion that the total impact force depends on the directions of rotation of the working chamber with vibration-centrifugal oscillations mechanism. The value of the speed of abrasive particle at the moment of its separation from the working chamber surface for this case is calculated by formula [6]:

$$V^{\tilde{n}\hat{o}\grave{i}} = V^{*}_{0mac} + signV = R\omega_1 + A\omega \cdot \cos\omega \ t_0 + sign(\omega_{\ddot{o}} R + \omega_{\div} r)\,, \qquad (3)$$

where ω is the circular frequency of oscillating motion, s^{-1};
ω_1 is the angular rotation velocity of the radius vector of the moving coordinate origin position s^{-1};
R is the trajectory radius relatively to the coordinate origin m;
A is the amplitude of oscillating motion, m;
$\omega_{ц}$ is the angular speed of working rotation s^{-1};
$\omega_{ч}$ is the angular speed of abrasive particle rotation, s^{-1}.

When the directions of working chamber rotation and vibration-centrifugal oscillations coincide (Figure 4 a), the total impact force R_{sum} is equal to the geometric sum of vibration-centrifugal forces R and the rotational force of the working chamber with the vibration-centrifugal oscillations P_r mechanism. The process of roughness forming in the initial treatment period, in contrast to the previous VCT process, is faster. The granule under components R_{sum} and P_r action leaves on the surface the scratch identical to that one during VCT, as R_N is equal to R_{Nsum} R and the abrasive granule pressure on the machined surface does not change. In this case the speed of abrasive granule movement relatively to the treated surface increases, because $R_{\tau sum}$ is greater than R_τ. All other stages of forming the roughness and strength of the treated surface are similar to the stages of the previous VCT process. Here, the circulation of the working medium under the total forces action turns in spiral, where the lead between spiral turns is increased resulting in «laminar», smooth character of loose abrasive medium movement. The discreteness of the surface roughness change during the entire treatment period slightly decreases.

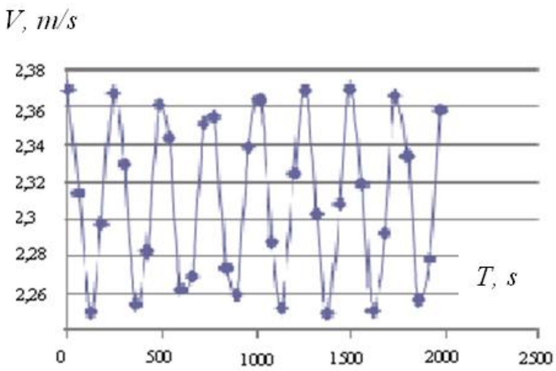


a) b)

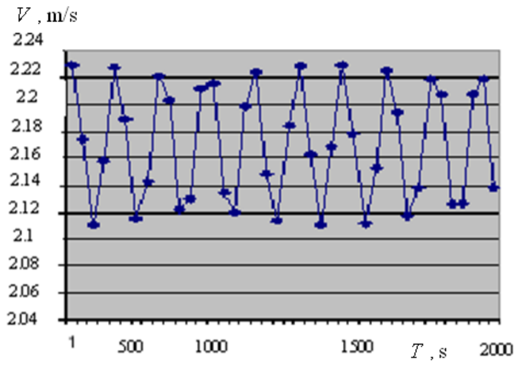
Figure 4. The diagram of interaction between abrasive granule and treated surface while combining VCT and working chamber rotation

When the directions of working chamber rotation and vibration-centrifugal oscillations are opposite (Figure 4 b), the total impact force R_{sum} is equal to the geometric sum R and P_r. The granule leaves the scratch similar to that one during VCT, as R_N equals to R_{Nsum} and the abrasive granule pressure on the treated surface does not change. In this case the speed of abrasive granule movement relatively to the treated surface decreases because $R_{\tau sum}$ is less than R_τ. The forming process is characterized by intensive decrease in roughness and increase in the treated surface strength due to the growth of the number (frequency) of abrasive granule impacts. This fact increases the discreteness of the surface roughness change during the whole period of treatment. The working medium circulation the under the action of total forces turns in spiral, where the lead between spiral turns is reduced, resulting in «turbulent», more aggressive character of loose abrasive medium movement.

Substituting the values of circular frequency of oscillating motion ω=15s^{-1}, angular rotation velocity of the radius vector of the moving coordinate system origin position ω_1=15s^1, trajectory radius relatively to the coordinate origin R=0.15m, amplitude of oscillating motion A=0.004m; angular velocity of working chamber rotation ω=0.5s^{-1}, angular speed of the abrasive particle ω=1s^{-1} we obtain the graph of the change in the speed of abrasive particle at the moment of its separation from the working chamber surface during VCT with changeable working chamber rotation (Figure 5).



a) – angular velocity of working chamber rotation $\omega = 0.5$ s[-1]



b) – angular speed of the abrasive particle $\omega = 1$ s[-1]

Figure 5. Graph of the change in the speed of abrasive particle at the moment of its separation from the working chamber surface during VCT with changeable working chamber rotation

The obtained graphs of the change in the velocity of the abrasive particle at the time of its separation from the working chamber surface prove that the nature of the change in particle accelerations and the magnitude of their velocity is determined by main, more intensive, vibration treatment method. Therefore, the vibration-centrifugal process of the parts surface treatment by abrasive granules is considered to be the main, and others are auxiliary ones for technological process correction in any direction. This makes it possible to extend the capabilities of the existing VCT technological process.

Conclusion. The proposed models reveal the physical essence of the interaction between granule and part surface. When the directions of working chamber rotation and vibration-centrifugal oscillations coincide, conditions for accelerating the clearing and grinding VCT operations are created. If the directions of working chamber rotation and vibration-centrifugal oscillations are opposite, then conditions for accelerating the strengthening and polishing VCT operations are created. Simultaneous actions of vibration force, centrifugal force and rotational forces on abrasive granule increase the volume, and hence the weight of the removed microchip, change the nature of loose abrasive medium movement providing the increase of VCT intensity and extension of its technological capabilities.

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ДОСЛІДЖЕННЯ РУХУ АБРАЗИВНОЇ ГРАНУЛИ ВІДНОСНО ОБРОБЛЮВАНОЇ ПОВЕРХНІ ДЕТАЛІ ПРИ ВІБРАЦІЙНІЙ ОБРОБЦІ

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Резюме. *Проведено огляд вібраційної обробки, аналіз взаємодії абразивної гранули робочого середовища в різних її формах. Їх застосування спонукає інтенсифікацію різновидних процесів, зростання* *рівня механізації й автоматизації багатьох трудомістких робіт, підвищує економічну ефективність і продуктивність праці. При дослідженні вібраційного оброблення деталей в сипучому абразивному середовищі виявлено основні закономірності процесу, визначено вплив основних технологічних параметрів на продуктивність і якість оброблюваних поверхонь. Визначено основні типи циркуляції сипучого абразивного середовища. Охарактеризовано циркуляційний процес і види взаємодії абразивної гранули з поверхнею деталі, що визначає рівень енергії та інтенсивність обробки деталей. Розглянуто схеми взаємодії абразивної гранули з поверхнею деталі, що піддається вібраційній і вібровідцентровій обробці. Аналіз процесу заснований на характері взаємодії абразивної таблетки з поверхнею заготовки. Весь процес формування шорсткості на VCP був розділений на певні етапи. Характеристики етапів і зміна цих характеристик були використані для описування різних схем процесів взаємодії абразивної гранули з поверхнею заготовки. Різноманітність технологічних схем визначає тип циркуляції абразивного середовища. Пропоновані моделі розкривають фізичну природу взаємодії гранул з поверхнею заготовки. Одночасний вплив вібраційних, відцентрових і обертальних сил на абразивну таблетку збільшує обсяг, і, отже, вага фільтрованої мікрополоска змінює характер потоку об'ємного абразивного середовища, що забезпечує збільшення інтенсивності ВКП і збільшує свої технологічні можливості. Тому доцільно розробляти та впроваджувати нові, ефективніші теоретичні моделі вібраційного та вібраційно-відцентрового процесів.*

Ключові слова: *вібраційна обробка, технологічний процес, абразивна гранула, швидкість гранули, кінетична енергія.*

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