Processing of Parts Under Pulse Loading of a Vibrating Hopper

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Abstract. In the article, the critical analysis of the current state of processing of vibrating methods of grinding, the advantages of their existing methods of processing machine parts and devices with traditional grinding are indicated. The inspection of the developed vibration installation, the influence of the regime of vibrating on the movement of the working environment in a vibration bunker are analyzed, the process of conducting a scientific experiment is planned. The results of experimental researches on the process of vibroabrasive processing of details, the reproducibility of the experiment, and the reliability of the obtained results were considered. It has been determined that the results of mathematical modelling coincide with the results of the experiment. To determine the patterns vortex circulation movement of the working environment, a specially introduced coordinate system was used and a single shooting was performed, which made it possible to determine the movements of parts and abrasive granules. In addition, from the analysis of demonstration shooting, the trajectory of parts movement in the volume of the working environment was predicted. The analysis of technological possibilities of vibroprocessing in a wide range of frequency and oscillation scope is carried out. The reasons for the problem selection of optimum modes of vibration processing and possible directions for overcoming them are presented. different modes of vibration machine operation are modeled. The results of the analysis made it possible to determine the principles of optimal selection of vibration treatment modes. The method of operation of a vibrating machine with the most effective use of mechanical energy of vibrations is established.

Keywords: Vibroprocessing · Vibrosetting · Circulation movement · Electromagnetic · Abrasive material · Vibrohopper

1 Introduction

The relevance of vibration abrasive methods for machining parts is explained by the advantages of this method over traditional finishing operations such as ripping, grinding, polishing [1–6]. Vibroabrasive treatment allows providing mechanization of the machining process, to improve the processing of geometrically complex external and internal hard-to-reach surfaces of details, as well as the processing of fragile and non-rigid parts without disturbing their geometric shape and damage to the surfaces [2, 4, 7, 8]. The use of vibration treatment as a finishing operation can significantly reduce

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the cost of manufacturing parts with a surface roughness Ra > 0. Vibration processing, which provides micro-roughness of the order of 0.15–0.25 μm, in some cases, can replace fine tuning, the cost of which is 4–5 times higher. The accuracy of the geometric shape of the workpiece obtained by grinding is not compromised, as a result of vibration removes a layer of the metal, not more than 1–2 μm [4, 5, 9–11].

2 Literature Review

Information technical sources indicate the high performance of vibration processing [1, 4, 5, 12–14]. However, the lack of complete information on the processes that occur during the machining of details in the work environment and the technological capabilities of vibration treatment, as well as recommendations for the technological support of mechanical vibration abrasion impedes the widespread industrial implementation and further development of this progressive method [2, 4, 7, 8, 15]. The interest in vibrating abrasive methods of machining parts is explained by the advantages of this method over such traditional finishing operations as ripping, grinding, and polishing as it provides the mechanization of the machining process, machining of geometrically complex external, and internal hard-to-reach surfaces of details and not the machining of the curves of the details, as well as machining and damage to surfaces and parts that tend to clutch when machined in rotating drums. An important advantage of vibration treatment is the high stability of the machining results of all parts in one batch, which is especially important when machining high precision parts.

3 Research Methodology

The vibration unit (Fig. 1) contains a working chamber mounted on the supports connected to the base, the ends of each are equipped with springs, and the bottom of the working chamber is equipped with vibrators made in the form of electromagnets. The number of supports and electromagnets is four. Depending on the sequence of activation of the electromagnets, the necessary circulating motion of the working medium is formed [4]. The working environment is a quasi-homogeneous liquid-fluid substance with nonlinear characteristics. At a shock impulse load, the vibrating hopper of the working environment changes its properties. Shock loads can be carried out symmetrically when all four electromagnets are switched on and in asymmetric schemes [4, 8–10]. Moving elements of the working environment cause circulatory motion, which is formed in radial planes (Fig. 2). Equivalent flow lines (element trajectories) are closed and are annular lines having lower branches L1, L2, L3, L4 and upper branches L5, L6, L7, L8. The circulation is slow. It covers the entire volume of the work environment. The circulating motion looks like a vortex ring centered at points O1 and O2. Thus, at the impulse load of the vibrating hopper in the working environment, there is a vortex circulation motion, which covers the spherical region. In the center of the spherical region (points O1 and O2), there is a focus of the current, where its translational velocity is close to zero. The basic provisions of the theory of hydraulic shock are used to calculate the dynamic parameters of the environment during the shock impulse loading. The propagation time of the shock wavefront from the bottom of the vibrating hopper to the free surface is the phase of the hydraulic shock τ:

$$\tau = \frac{H}{v_a} \tag{1}$$

where H – the height of the working environment; v_a – shock wave speed.

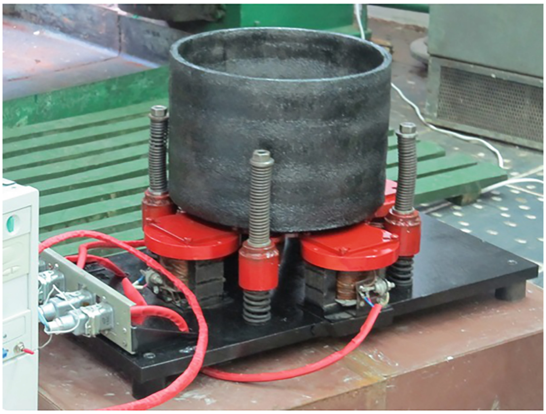

Fig. 1. The vibration installation.

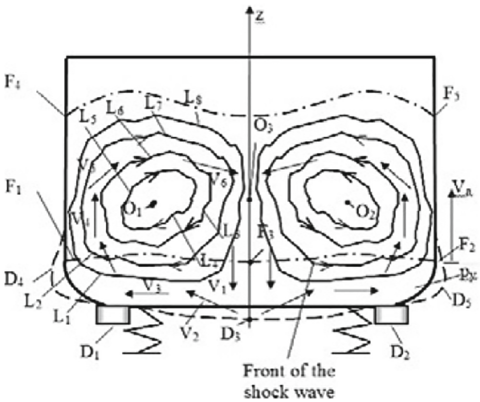

Fig. 2. The scheme of axisymmetric vertical movement of the vibrating hopper and circulation of the working environment.

The pressure increase is determined by the energy balance equation. In a hydraulic impact, the kinetic energy of the working environment E_k is converted into the potential energy of compression of the environment E_{np} and the potential energy of the deformed bottom of the walls of the vibrating hopper E_{nm}. Thus, the energy balance equation is as follows:

$$E_k = E_{nm} + E_{np} + E_d \quad (2)$$

where Ed – energy lost to environmental resistance and non-linear deformation processes in the work environment.

The kinetic energy of the medium moving with the average velocity v_0 in the vibro-bunker height H and radius r_0 is determined by the equation:

$$E_k = 0,5\rho\pi r_0^2 H v_0 \quad (3)$$

where ρ – the average equivalent density of the working environment, which includes the parts and pellets of the abrasive.

The potential energy of the compressed work environment is equal to the work of compression under the action of shock change of pressure Δp_y and is defined as:

$$E_{np} = 0,5\rho\pi r^2 \Delta p_y \Delta W \quad (4)$$

Where ΔH – changing the height of the working environment; ΔW – changing the volume of the work environment.

Assume in the first approximation that the change in the volume of the working environment depends linearly on the change in pressure:

$$\Delta W = \frac{W \Delta p_y}{E_a} \quad (5)$$

where W – a volume of the work environment; E_a – the average value of the equivalent modulus of elasticity of the working environment.

Defining the volume of the environment as $W = \rho\pi r^2 H$, we obtain an expression for the potential energy compression of the working environment:

$$E_{np} = \frac{0,5\rho\pi r_0^2 H (\Delta p_y)^2}{E_a} \quad (6)$$

The potential energy of deformation of the vibrohopper walls is:

$$E_{nm} = 0,5\Delta p_y \rho\pi r_0 H \Delta r$$

where Δr – vibrating hopper wall deformation in the radial direction.

According to Guka Law:

$$\Delta r = \frac{\sigma r}{E}$$

where σ – normal stress in the material of the vibrohopper; E – elasticity module of the vibrohopper wall.

Define the tension as:

$$\sigma = \frac{\Delta p_y r}{\delta}$$

where δ – hopper wall thickness.

The potential energy deformation:

$$E_{nm} = \frac{\pi r^3 H}{\delta E}(\Delta p_y)^2 + E_{bm}$$

$$E_{bm} = \frac{\pi r^3}{\delta E} K_d (\Delta p_y)^2$$

where E_{bm} – the potential energy hopper bottom, K_d – factor.

Set the value of energies in the energy balance equation and get:

$$0,5\pi r^2 H \rho V_0^2 = \frac{\pi r^2 (H + K_d)}{\delta E}(\Delta p_y)^2 + \frac{\pi r^2 H}{2E_a}(\Delta p_y)^2 \quad (7)$$

Shock pressure values:

$$\Delta p_y = \rho V_0 V_a \quad (8)$$

where, $V_a = \sqrt{\frac{E_p}{\rho}}$ – the shock wave propagation speed; E_p – the attached bunker elasticity module.

4 Results

Experimental researches were carried out for the clarification dependence of indicators of intensity and quality of vibroprocessing from the amplitude of oscillation of the vibrohopper. The duration of each experiment was 3 h. Mark is abrasive 38A (normal electrocorundum). The details of the type of bodies of rotation, which have external and internal cylindrical, flat and torsion surfaces, which are obtained in different ways (milling, precision) and have different initial roughness are used as test samples. This allows determining the degree of processing of each type of surface, estimate the degree of rounding of sharp edges. Samples from two different materials are used in experiments to clarify the dependence of indicators of the intensity and quality of vibration processing from the amplitude and frequency of oscillations: from non-magnetic steel 1.4878 and brass CW607N. In the study of the influence of the electromagnetic field on the process of vibroabrasive processing, it was used as the experimental samples of the ring of Cardan bearings after punching of steel (100Cr6). Experiments were conducted in the following sequence: flushing specimens with a warm soapy solution of dirt; drying of samples; determination of the primary mass of m_1, gram and roughness Ra_1, mkm samples for processing; tagging on swatches conducting research; cleaning and flushing of samples from abrasive residues; drying; measuring of the mass of m_2, gram, and roughness of Ra_2, mkm samples after processing; calculation of metal chip removal by the weighing of marked samples by the formula:

$$Q = m_1 - m_2 \quad (9)$$

Based on obtained values, the graphs of the dependence of metal chip removal Q, gram and roughness Ra, mkm from amplitude A, frequency f for each material (steel 1.4878 and brass CW607N) were constructed. As a result of the experiment, the following values of a span of a container oscillation were obtained depending on a load of its working mixture (Table 1).

Table 1. Results of experimental measurement of a range of container oscillations, mm.

Download level		0 kg			1,5 kg			3 kg		
№ repeatiness		1	2	3	1	2	3	1	2	3
Number of the electromagnet	1	2,0	1,5	2,0	1,5	1,5	1,5	1,0	1,0	1,0
	2	2,5	1,5	2,0	1,5	1,5	2,0	1,0	1,5	1,0
	3	2,5	2,5	2,0	1,5	1,0	1,0	1,0	1,0	1,0
	4	2,5	2,5	2,5	2,0	1,5	2,0	2	1,5	1,5
Arithmetic mean		2,4	2,0	2,1	1,6	1,4	1,6	1,2	1,2	1,1
Quadratic mean		2,4	2,0	2,1	1,6	1,4	1,7	1,3	1,3	1,1

In the table you can see that the average of the arithmetic and the average quadratic value of a span of vibrations are not significantly different, that is, it is possible to conclude about small random error measurements. Based on Table 1, a table is compiled for mathematical processing of experiment results (Table 2). This data evaluates the criterion of Kohrena: G = 0,722. The table value of the Kohrena G_T = 0,977. Since the value of the criterion of Kohrena, suggested by the experiment results, is less than the table, the experimental data can be considered authentic, and the experiment itself is reproducible. According to experimental data, the projection of the three points of the dependence of the range of vibrations of the container from its load working mixture is:

$$R = b_0 + b_1 m + b_2 m^2 \quad (10)$$

where R – container oscillations; m – the weight of container loading; b_0, b_1, b_2 – extrapolating factors.

Table 2. Experimental results.

Download level, kg	Oscillation frequency by repetition, mm			The arithmetic mean, mm	Dispersion, mm^2 I
	I	II	III		
0	2,4	2,0	2,1	0	2,4
1,5	1,6	1,4	1,6	1,5	1,6
3	1,2	1,2	1,1	3	1,2

The method of sequential lookup in Eq. (6) of experiment data in each of three points is found extrapolating coefficient (with precision to two significant digits). After that, the Eq. (6) took the form:

$$R = 2,17 - 0,52\ m + 0,06\ m^2 \tag{11}$$

Adequacy of this equation is tested according to the Fisher criterion. For Eq. (11) variance of adequacy is $S^2_{ad} = 1,417 \times 10^{-4}$. In accordance with the criterion of fisher, F = 7,077*10^{-3}. A table value for the Fisher criterion for this case is F = 5,987. Since the value of the Fisher criterion for Eq. (11) is less than the table value for this case, the description of the dependence of the range of vibration of the container from its loading by the Eq. (11) can be considered adequate.

The measurement of circulating vortex movement of the working environment was carried out under different laws of management of electromagnetic drives [4]. An optical method is applied when measuring the position of the elements of the working environment. The wood surveying of the surface of the working environment in the vibrobunker is carried out. The frame rate was 1 s. The coordinates of the working environment element and their change by individual frames are defined in cartesian rectangular and polar in curved or special coordinate systems.

We will accept a cartesian rectangular coordinate system XOY with a center in the central part of the vibrobunker (Fig. 3). For several adjacent frames, we define the coordinates of separate abrasive granules or the marker. We will establish successive provisions of individual granules on the surface of the working environment. The array of vectors of the position of separate individual elements in the form of a set of vectors:

$$\begin{bmatrix} x_{A1} \\ y_{A1} \end{bmatrix}, \begin{bmatrix} x_{A2} \\ y_{A1} \end{bmatrix}, \ldots, \begin{bmatrix} x_{An} \\ y_{An} \end{bmatrix}; \begin{bmatrix} x_{B1} \\ y_{B1} \end{bmatrix}, \begin{bmatrix} x_{B2} \\ y_{B1} \end{bmatrix}, \ldots, \begin{bmatrix} x_{Br} \\ y_{Br} \end{bmatrix}; \begin{bmatrix} x_{C1} \\ y_{C1} \end{bmatrix}, \begin{bmatrix} x_{C2} \\ y_{C1} \end{bmatrix}, \ldots, \begin{bmatrix} x_{Cq} \\ y_{Cq} \end{bmatrix}.$$

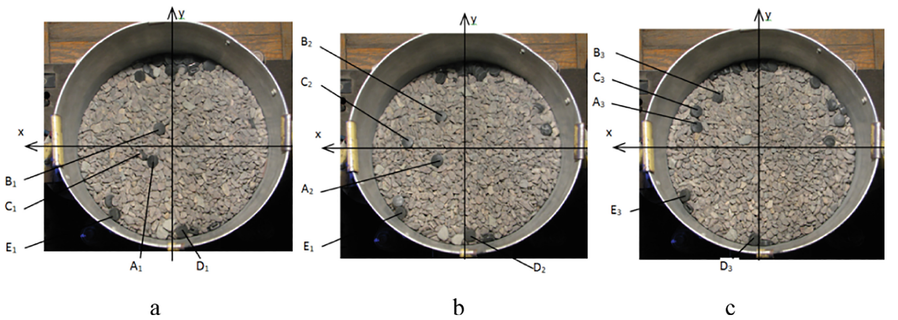

Fig. 3. The scheme of determining the position of details on separate shooting frames when using a cartesian rectangular coordinate system.

Vectors determine the position of an element of the working environment on the surface in the form of points A_1, A_2, A_n; B_1, B_2, B_r; C_1, C_2, C_q. To determine the speed of the slow circulating movement of the working environment are determined by increments of coordinates of elements in the neighboring positions, which are formed in the form of vectors:

$$\begin{bmatrix}\Delta_x A_1\\ \Delta_y A_1\end{bmatrix},\begin{bmatrix}\Delta_x A_2\\ \Delta_y A_2\end{bmatrix},\ldots,\begin{bmatrix}\Delta_x A_n\\ \Delta_y A_n\end{bmatrix};\begin{bmatrix}\Delta_x B_1\\ \Delta_y B_1\end{bmatrix},\begin{bmatrix}\Delta_x B_2\\ \Delta_y B_2\end{bmatrix},\ldots,\begin{bmatrix}\Delta_x B_n\\ \Delta_y B_n\end{bmatrix};\begin{bmatrix}\Delta_x C_1\\ \Delta_y C_1\end{bmatrix},\begin{bmatrix}\Delta_x C_2\\ \Delta_y C_2\end{bmatrix},\ldots,\begin{bmatrix}\Delta_x C_n\\ \Delta_y C_n\end{bmatrix}.$$

Resulting increments can be submitted in the form of the distances between the individual provisions of points. For example, point A.

$$\Delta_{A1} = \sqrt{\Delta^2_{xA1} + \Delta^2_{yA1}}, \ldots, \Delta_{Ai} = \sqrt{\Delta^2_{xAi} + \Delta^2_{yAi}}$$

The average speed of the circulating movement was defined from the dependencies:

$$v_{xA1} \approx \frac{\Delta_{xA1}}{\Delta t}, \ldots, v_{yA1} \approx \frac{\Delta_{yA1}}{\Delta t}$$

Thus, the field of velocity on the surface of the working environment was defined. To improve the quality of the field, velocities are introduced in a special coordinate system. They allow defining the features of a local Vortex motion desktop (coordinate system in the form of an arc K_1M_1 (Fig. 4), provide an opportunity to identify local moving items in the diametric intersection of the working environment. The coordinate system in the form of an arc or line allows installing features and limits of the current. This system allows determining the degree of the passing of the elements into the work environment. Similarly, the coordinate system in the form of a closed polygon (polyhedron) is used. In Figure ABCD, the elements combined in a quadrilateral are shown. Its move from the frame to frame describes the average speed of the elements of the working environment within the quadrangle. The deformation of the quadrangle characterizes the differences between the elements of the working environment.

Change the position of the quadrangle, in particular, its surface characterizing the local vortex movement of elements of the work environment.

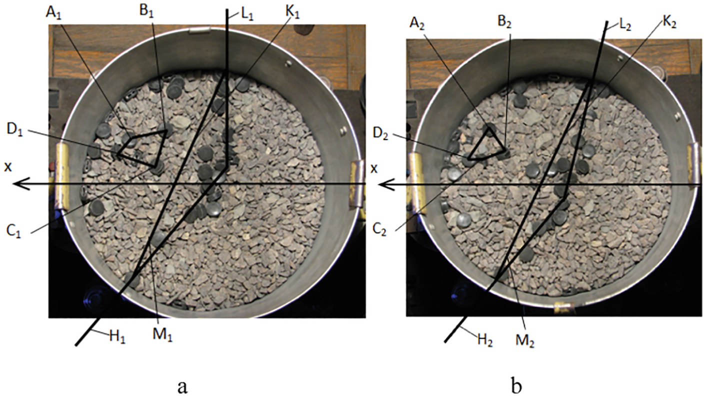

Fig. 4. The determination of regularities of the vortex circulation movement working environment with the use of especially typed coordinate systems.

A frame-by-frame survey provides an opportunity to determine the rotational movements of the parts and abrasive granules. For this purpose, bullets of cylindrical shape with a small value (in the form of the disc) are applied. On individual frames, registered angular position details and use the normal to its control surface (Fig. 5). Vectors of normal for neighboring leaders $\overrightarrow{n_2}, \overrightarrow{n_3}, \overrightarrow{n_4}, \overrightarrow{n_5}$ are determined by the position of the disc. An angular position of the parts is determined by the angle θ, which is associated with the ratio of axes of an ellipse, respectively:

$$\theta = \arccos\left(\frac{b}{a}\right).$$

The angular position of the disc in the plane of the coordinate axes XOY is determined by an angle φ between the small axis of an ellipse and the X-axis. The analysis of time-lapse shooting can predict the trajectory of the parts in the volume of the work environment. The definition of the forecast trajectory of movement simulates the scheme (Fig. 5). For details (markers) frame-by-frame shooting is made. On frames fixed position details, starting from the point of the A_1 and ending point of the AK.

Further reorganization of the frame-by-frame shooting took as long as the piece again appeared on the surface (about point A_1). Trajectories of the details are shown with the dotted line. The time of finding parts in the volume of the work environment is exactly determined.

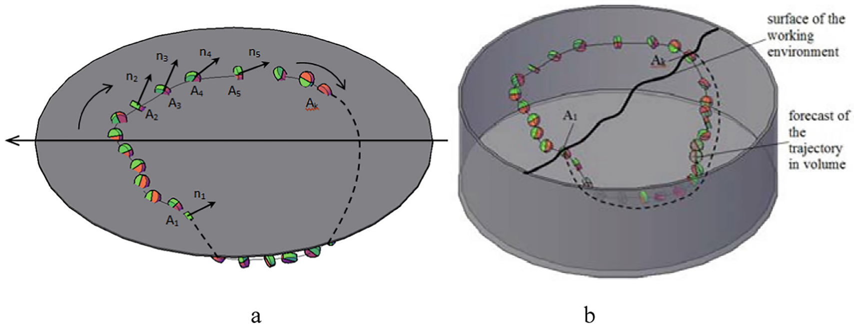

Fig. 5. The determination of the predictive values of the trajectory of motion of the parts in the volume of work environment: a – fixed movement parts on the surface; b – the spatial movement of parts (the trajectory shown in the dotted line).

5 Conclusions

The result of studies showed that the shock impulse load on the vìbrobunker lead to a slow circulation of the movement work environment. This movement intensification in the non-symmetrical shock load. The circulation motion is circular or arcuate vortex ring that covers the entire volume of the desktop environment. To determine the nature of the Vortex motion, the application of the law changes the amount of movement in the integral form for the selected control the volume of the working environment is accepted. The average speed of the circulating movement depends on the intensity of impact, speed vibrobunker to the punch, and the mass of the working environment. The angular speed of the vortex movement is proportional to the average velocity of the circulating traffic. In the working environment, a movement of individual items (blasting media granules) is chaotic, which is caused by shock loads of the granules from the neighboring granules. The chaotic movement manifests itself in the form of deviations of the trajectory of a single pellet from the high trajectory of a circulating movement. The deviation of the trajectory is close to harmonic (sinusoidal).

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