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DETERMINATION OF THE SIZE OF MEDIUM GRANULES IN FREE ABRASIVE PROCESSING TECHNOLOGY AND THE SIZE OF THE RESERVOIR OF A MACHINE FOR VIBRATION PROCESSING OF PARTS

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Abstract. *It is noted that the process of vibration processing of parts is carried out by the relative movement and mutual pressure of granules of the medium and the parts being processed circulating in the oscillating reservoir. It is noted that the removal of defects from the surface of a part is carried out by the processes of microcutting and elastoplastic deformation. It is indicated that despite the effectiveness of vibration processing, its capabilities are limited to performing simple operations and have not been sufficiently studied. The effectiveness of vibration processing depends on a number of factors, among which the size of the medium granules and the size of the machine reservoir play a significant role. To determine these factors, the kinematics of the finishing and grinding process was considered, and the joint movement of the medium granule and the part was taken into account. The removal of microchips along the entire length of the machined surface during one period of oscillation of the machine reservoir and the damping properties of the material of the working medium used were also taken into account. It has been established that, depending on the shape of the part, its position and direction of movement in the reservoir, the angle of contact with the granules can vary from 0 to 90º. In this regard, cases of encounters between granules and parts are considered. It has been established that the unfavorable case of a meeting occurs at the right angle of their collision. It is concluded that the removal of microchips from the surface of parts is theoretically inversely proportional to the size of the medium granules. It has been determined that the increase in damping of the medium caused by a decrease in the size of the granules can be compensated by increasing the amplitude of the oscillations of the reservoir and the use of granules with a large specific gravity. The choice of granule size is also limited by the conditions of their access to the surfaces being treated, while the conditions for eliminating the possibility of granules jamming are met. It has been experimentally confirmed that the reservoir with a "U" – shaped cross-section turned out to be the best, due to the absence of stagnant zones in it. It has been established that as the cross-section of the reservoir increases, the productivity of the machine will decrease. Intensifying the process by increasing the amplitude is unacceptable, since this causes the appearance of deep defects on the treated surfaces. To increase processing efficiency, it is necessary to increase the volume of the reservoir by lengthening it, rather than increasing its cross-section.*

Keywords: *vibration treatment; granular medium; physical and technological parameters; contact angle; reservoir; productivity of vibration processing.*

1. Introduction

The process of vibration processing is accompanied by microcutting and elastoplastic deformation and is carried out due to the relative movement and mutual pressure of the granules of the working medium and the parts during their circulation movement in an oscillating reservoir [1].

Despite the effectiveness of vibration processing, its use until recently was limited to performing such simple operations as cleaning parts, removing burrs, and rounding sharp edges. The underestimation of the capabilities of this technological process is explained by the lack of knowledge about it [2].

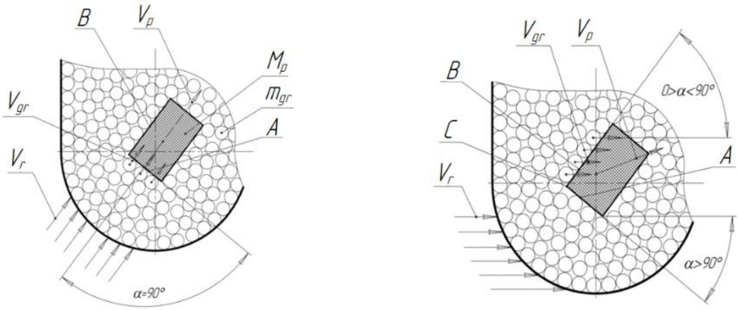
The research carried out so far has involved solving particular problems of identifying the influence of one or a small number of factors on the efficiency of vibration processing. At the same time, ongoing comprehensive studies have shown that the effectiveness of vibration processing depends on many factors, the main ones of which include the size of the granules of the abrasive medium and the size of the reservoirs of machines for vibration finishing and grinding.

2. Features of the kinematics of the finishing and grinding process

To determine the above factors, it is necessary to consider the features of the kinematics of the process of vibration finishing and grinding, represented by the joint movement of a granule of the abrasive medium and the part. When considering the kinematics of the process, it is necessary to take into account the removal of microchips along the entire length of the machined surface during one period of oscillation and the damping properties of the material of the abrasive medium used [3, 4].

Granules of an abrasive medium with a mass of m_1 (Fig. 1, a), moving at a speed of V_{gr}, encounter a part with a mass of M on their way. In this case, the part can be either in a state of relative rest, or have counter or parallel movement at the speed of V_{p} part. At certain moments, the velocity vectors V_{gr} and V_{p} can make a certain angle.

The vector difference $\vec{V}_{\text{gr}} - \vec{V}_{\text{p}}$ represents the relative speed V_{gr} with which the interaction of granules and parts occurs. Depending on the shape of the part, its position in space and the direction of movement, the angle of contact with abrasive granules can vary from zero to 90º. Let's consider the most typical cases of abrasive granules meeting parts (Fig. 1).



a b

Fig. 1.7. Diagram of the meeting of the part and the granules of the abrasive medium: (a) – at a right angle; (b) – at an acute angle

The most unfavorable case of granules meeting the surface being treated occurs at a right angle to their collision (Fig. 1, a). The wall of the machine's reservoir imparts movement to the granules at a speed of V_{gr} .The granules, when compacted, strike the surface of the part at a right angle. The average value of the force F_{imp} acting on the part during the collision with the granule can be expressed by the following formula:

$$F_{\text{imp}} = \frac{MV_{\text{rel}}\left(1+k\right)}{\tau}, \tag{1}$$

where M – is the mass of the part; V_{rel} – relative speed of granules and parts at the moment of impact; k – recovery coefficient, depending on the elastic properties of the part and the granule; τ – impact time.

The use of this formula is permissible, since the masses of the reservoir and granules after compaction, located between the wall and the surface, are large compared to the mass of the part.

3. Efficiency of vibration processing at different angles of impact of granules with the processed surface

The effectiveness of vibration processing when granules collide at right angles with the surfaces being processed is relatively low, since the abrasive granules are not so much removed as they are crushed by this surface, leaving micro-nicks on it.

This removal of metal from surface B occurs under unsatisfactory conditions. Abrasive granules slide along it with a small interaction force, which is determined only by the static pressure of the overlying layers of granules and parts. It is many times less than the forces arising at the surface A.

Other processing conditions occur at an impact angle other than 90º (Fig. 1, b). In this case, the impact on surface A has less elasticity. Surface B, which had not previously experienced impacts, also receives an oblique impact. During such a collision, the granules slide over both surfaces, removing chips.

The greatest destruction of the surfaces of the parts will occur in weakened areas of their perimeter, namely at the corners and edges (Fig. 1). In this position, corresponding to maximum destruction, there is rib C of the part.

4. Study of changes in the granule size of an abrasive medium and the effectiveness of its impact on the treated surface

With an increase in the mass of m abrasive granule, its kinetic energy increases, and consequently, the force that causes destruction and removal of surface layers of metal increases. However, an increase in the size of the granule, beyond certain limits, reduces the effectiveness of its impact on the part surface, as can be seen from the following.

Let us denote the size of the granule by d, the length of the surface of the part in contact with the granules by l, and the length of the granule sliding along the surface being processed by one oscillation by a.

To simplify the discussion, we represent the shape of the part in the form of a rectangular parallelepiped. Then the total length of the surface from which microchips will be removed during one oscillation of the reservoir can be expressed as

$$l_1 = a\frac{l}{d}. \qquad (2)$$

For one of the part surfaces, with its linear dimension L perpendicular to the drawing plane, the surface from which chips will be removed is equal to:

$$l_2 = a\frac{l}{d}\cdot\frac{l_1}{d}. \qquad (3)$$

From the resulting expression it follows that the dimensions of the processed surface for one relative movement of the granules, that is, for one period of oscillation of the machine reservoir, are inversely proportional to d^2.

You can choose the size of the granule so that it is equal to the value a, that is, $d_1 = a$. Then

$$l_1 = \frac{al}{d_1} = l, \tag{4}$$

that is, microchips are removed along the entire length of the surface. For the plane, we correspondingly find

$$l_2 = \frac{Ll}{d_1}. \tag{5}$$

Thus, the removal of microchips from the surface of the part is theoretically inversely proportional to the size of the granules of the working medium.

As the granule size decreases, the damping properties of the entire medium change. Therefore, with small sizes of abrasive granules, the length of the surface from which microchips can be removed during one period of oscillation of the reservoir will be significantly less than the calculated one.

An increase in the damping of the medium caused by a decrease in the size of abrasive granules can be compensated by increasing the amplitude of vibrations of the reservoir and using granules with the highest possible specific gravity [5].

From the practice of vibration processing it follows that the most suitable for processing complex-profile parts with internal planes, pockets, holes are granules of the working medium made of mineral ceramics TsM-332, the specific gravity of which is 3.93...3.95 g/cm^3. The choice of the size of such granules will be limited by the conditions of their access to the treated surfaces. In this case, the size of the granules should be selected to exclude the possibility of their jamming in the listed surface elements of the part.

Abrasive granules made from the TsM-332 material have a dense structure, high hardness and have shown great wear resistance, so they are most suitable for finishing operations. At the same time, they have a small grain size (1...3 μm), which, when used in grinding operations, leads to an increase in processing time, to speed up which it is advisable to add grinding powders of various grain sizes to the reservoir with an appropriate amount of a chemically active solution [6, 7].

When choosing materials for abrasive granules, abrasive granules from broken abrasive wheels, crushed granite and porcelain chips, as well as from mineral ceramics TsM-332 were studied. During the experiments, cylindrical samples made of steel 45 weighing up to 100 grams were processed. They had original purity classes of $Ra = 2.5$ μm to $Ra = 0.16$ μm.

The processing was carried out under constant vibration modes, amplitude $A = 2.0$ mm, frequency $\omega = 2200$ oscil/min, ellipse coefficient $K_A = 1.5 \pm 0.15$. The ratio of the volume of processed parts to the volume of abrasive granules was taken to be 1:3.

Experiments have established that grinding media made from broken abrasive wheels, crushed granite and porcelain chips are unacceptable for obtaining surfaces of high cleanliness classes. Therefore, for finishing processing, the use of TsM-332 mineral ceramics was proposed as an abrasive medium. It showed high durability: plates measuring 18×15×8 mm worked effectively for 700...800 hours. Their low wear made it possible to maintain the cleanliness of the environment in the reservoir and reduce the number of washes. A small amount of waste ensured higher grades of surface cleanliness. This was also facilitated by the small size of the grains from which the plates are made, – 1...4 μm.

When studying the influence of the weight and shape of abrasive granules and the amplitude of vibrations on the cleanliness of the surface, mineral-ceramic granules from the material TsM-332 were used, cylindrical in shape weighing 20...30 grams, rectangular in shape weighing 10, 7, 5 grams, respectively, and spherical in shape weighing 2...3 grams.

Before the experiments, all abrasive granules, with the exception of the spherical one, had their sharp corners and edges rounded. When processing steel samples 45 (eq. C45 DIN 10277) with mineral-ceramic granules, an alkaline chemically active solution was used.

Five samples from each batch of parts were measured and the average value Ra was calculated.

After the first tests, abrasive granules weighing 20...30 grams were excluded from further research, since they caused the appearance of a large number of micro-holes, the depth of which did not meet the requirements for cleanliness of processing.

Based on the research results, graphical dependencies were constructed (Fig. 2). It is clear from the dependencies that processing at all amplitudes gives a sharp decrease in roughness in the first hours of operation. Each amplitude corresponds to a certain achievable surface frequency. During further processing, the achieved value for a given amplitude remains constant.

A decrease in the vertical amplitude to $A_y = 0.5$ mm causes a sharp drop in the speed of rotational motion of the medium, which worsens the mixing of parts in the oscillating reservoir. Increasing the rotational effect in the reservoir is possible by increasing the oscillation frequency, for example, up to 2550 oscil/min. As a result, value Ra can be reduced to 0.5 μm.

To determine the possibilities of further reducing processing time, grinding and polishing experiments were carried out with the addition of various grinding powders. The material for them was normal electrocorundum with a grain size of 25, 8, 5, 3 and white electrocorundum with a grain size of M20. The amount of grinding powder in all experiments was 3 % of the reservoir volume.

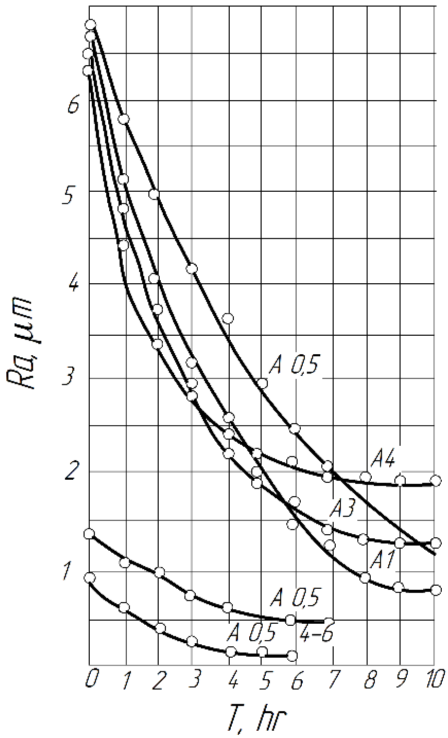


Fig. 2 Dependence of roughness Ra on amplitude A and processing time

In this series of experiments, plates made of mineral ceramics TsM-332 weighing 5...10 grams also served as abrasive granules. The volume ratio of parts and abrasive granules was taken to be close to that used to obtain high cleanliness classes, namely 1:4. The oscillation frequency for all experiments remained constant – 2140 oscil/min. The ellipse coefficient was taken to be 1.5, except when fine-grained M20 powders were used. The amplitude during the experiments varied within 1...4 mm. The amount of alkaline solution was 3...3.5 % of the reservoir volume.

The solution and grinding powder were replaced every hour of operation of the vibrating machine. During the studies, the roughness of the processed surface was measured on a batch of samples every hour of processing. The dependence of the height of the roughness of the processed surface on the granularity of the powder, amplitude and processing time was obtained (Fig. 3).

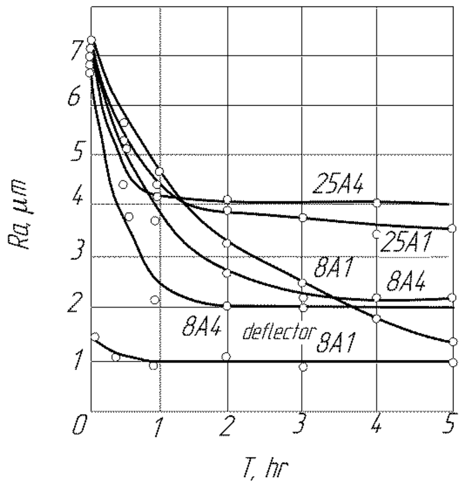


Fig. 3 Dependence of surface roughness Ra on the grain size of the grinding powder, amplitude and processing time

5. Research on Reservoir Sizing

The optimal dimensions of the reservoir have been experimentally determined. The “U” – shaped reservoir turned out to be the best in view of the absence of stagnant zones in it, as well as the possibility of installation in the internal space, intensifying the process of moving abrasive granules and machined parts, deflectors of the working medium of various shapes and sizes [8, 9].

The same conditions indicate that as the distance of granules and parts from the bottom and walls of the reservoir increases, their relative speeds decrease; layers of granules and parts, as they approach the center of the reservoir, are partially or completely excluded from the zone of vibration influence of its walls. Processing of parts located in these layers stops.

To determine the optimal cross-sectional dimensions of the reservoir, a series of experiments were carried out.

The studies were carried out for three weight groups of abrasive granules: 2.5...3; 10; 30 grams. The velocity determination for each of them was carried out at amplitudes of A – 1, 2, 4 mm. The oscillation frequency for all experiments remained constant – 2140 oscil/min with an ellipse coefficient of $K_A = 1.5$.

Together with measuring the speed of the sensor-part, the speed of the reservoir was measured. Based on the ratio of these speeds, the damping of the medium was determined, that is, the degree of vibration damping. Graphic dependencies were constructed (Fig. 4), showing the change in the speeds of the sensors – parts at different distances from the reservoir wall.

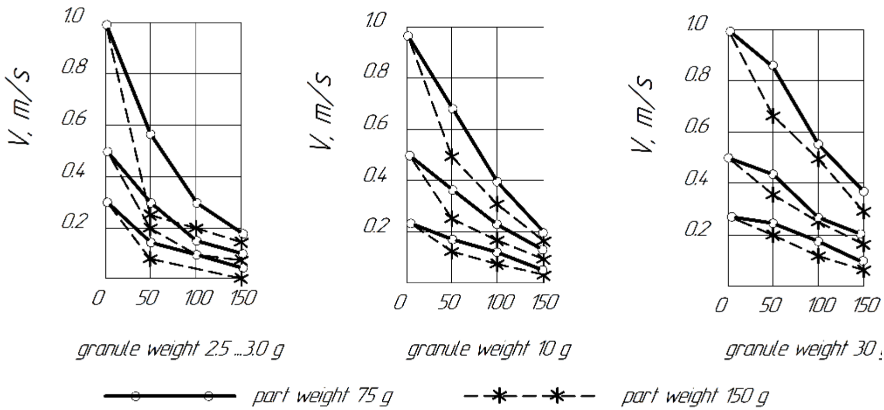


Fig. 4 Change in the speed of the sensor-part depending on its distance from the walls of the reservoir, the weight of the part, the amplitude and weight of the abrasive granule

The speed of heavy parts decreases more intensely than that of light ones. Under the same processing conditions, a heavy part has a lower speed than a lighter one. As the speed of the abrasive granules remains constant, the relative speed between them and heavier parts increases. The decrease in speed of a weighted part occurs more slowly than the increase in its weight. This causes an increase in the mutual specific pressure of the granules and parts. This explains the faster processing of heavy parts compared to lighter ones.

Increasing the weight of abrasive granules also increases the efficiency of the processing process. This is explained by an increase in specific pressure due to an increase in the mass of the granule and a decrease in damping.

At the same time, it is noted that an increase in specific pressure can create conditions for the appearance of various defects on the surfaces being processed. At the same time, obtaining high frequency classes is difficult.

As the oscillation amplitude increases, the degree of damping of the medium decreases and the damping coefficients increase. For an amplitude of $A_y = 1$ mm, its smallest value is 0.11, and for an amplitude of $A_y = 4$ mm – 0.32. For the above processing conditions, the damping coefficient values ranged from 0.89 to 0.11.

When the frequency increased from 2040 oscil/min to 2500 oscil/min, the speed of movement of the sensors changed in the medium as follows (Table 1).

Table 1. Changing the speed of the sensor in an abrasive environment

Distance of the sensor from the wall, mm	Sensor speed, m/s at oscillation frequency, min		Speed increase, m/s
	2140	2500	
50	0.14	0.16	0.02
150	0.04	0.05	0.01

With large sections of the reservoir, the productivity of the machines will decrease despite the number of simultaneously processed parts. Intensifying the process by increasing the amplitude for finishing operations is not acceptable due to a significant increase in specific pressures in the layers of the medium close to the wall, as this causes the appearance of deep defects of great depth on the treated surfaces.

Measurements of the speed of the sensor placed in a reservoir with an increasing cross-section showed that its speed at a distance of 200 mm from the bottom is practically zero.

Thus, to increase processing productivity, it is necessary to increase the volume of the reservoir by lengthening it, rather than increasing its cross-section. This explains the appearance of vibrating machines with two or more small-section reservoirs mounted on one vibrating platform.

Based on the conducted research, the following main conclusions can be drawn:

– a decrease in the degree of damping of the medium can be achieved by increasing the amplitude of oscillations of the reservoir;

– for vibrating machines intended for finishing operations, and therefore operating at small amplitudes, the most acceptable, as experiments have shown, should be considered reservoirs with a bottom radius of no more than 200 mm.

6. Conclusions

All the described experimental studies and their results form the basis for calculating the design parameters of vibration machines and designing technological processes for grinding and polishing operations for vibration finishing and grinding of parts of various types of metalworking industries.

Also, over the decades, the described developments have been successfully implemented at enterprises in various branches of mechanical engineering and instrument making, which indicates their high scientific level and practical relevance, which ensured the expansion of the fleet of modern metalworking machines and finishing and grinding technologies aimed at the process of effective mechanization of manual labor.

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ВИЗНАЧЕННЯ РОЗМІРІВ ГРАНУЛ СЕРЕДОВИЩА У ТЕХНОЛОГІЇ ОБРОБКИ ВІЛЬНИМИ АБРАЗИВАМИ ТА РОЗМІРІВ РЕЗЕРВУАРА ВЕРСТАТА ДЛЯ ВІБРАЦІЙНОЇ ОБРОБКИ ДЕТАЛЕЙ

Анотація. *Відзначено, що процес вібраційної обробки деталей здійснюється відносним переміщенням і взаємним тиском циркулюючих в резервуарі, що коливається, гранул середовища та оброблюваних деталей. Зазначається, що видалення дефектів з поверхні деталі здійснюється процесами мікрорізання та пружнопластичного деформування. Вказано, що попри ефективність вібраційної обробки її можливості обмежені виконанням найпростіших операцій та недостатньо вивчені. Ефективність вібраційної обробки залежить від низки факторів, серед яких значну роль грають розміри гранул середовища та розміри резервуара верстата. Для визначення зазначених факторів розглянуто кінематику процесу оздоблювально-зачищувальної обробки, бралося до уваги спільне переміщення гранули середовища та оброблюваної деталі. Так само враховувався зйом мікростружки по всій довжині оброблюваної поверхні за один період коливання резервуара верстата і демпфуючі властивості матеріалу робочого середовища. Встановлено, що залежно від форми оброблюваної деталі, її положення та напрямки руху в резервуарі кут зустрічі з гранулами може змінюватись від 0 до 90º. У зв'язку з цим розглянуті випадки зустрічі гранул з оброблюваними деталями. Встановлено, що несприятливий випадок зустрічі відбувається під прямим кутом їхнього зіткнення. Зроблено висновок, що зйом мікростружки з поверхні деталей теоретично зворотно пропорційний розміру гранул середовища. Визначено, що підвищення демпфування середовища, викликане зменшенням розмірів гранул, можна компенсувати збільшенням амплітуди коливань резервуара і застосуванням гранул з великою питомою вагою. Вибір розміру гранул також обмежується умовами їх доступу до поверхонь, що обробляються, при цьому дотримуються умови виключення можливості заклинювання гранул. Експериментально підтверджено, що найкращим виявився резервуар «U» – подібної форми поперечного перерізу через відсутність у ньому застійних зон. Дано методику досліджень визначення оптимальних розмірів перерізу резервуара. Встановлено, що зі збільшенням перерізів резервуара продуктивність верстата знижуватиметься. Інтенсифікація процесу збільшенням амплітуди неприйнятна, оскільки це викликає появу на оброблюваних поверхнях глибоких дефектів. Для підвищення ефективності обробки необхідно збільшувати об'єм резервуара шляхом його подовження, а не збільшення перерізу.*

Ключові слова: *віброобробка; гранульоване середовище; фізико - технологічні параметри; кут зіткнення; резервуар; продуктивність віброобробки.*