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ANALYTICAL DETERMINATION OF THE TIME OF HANDLING PROCESS OF POLYMERIC PARTS IN A MACHINE WITH A COMPLEX MOVEMENT OF WORKING CONTAINER

Purpose. *An analytical determination of the main technological parameters of polishing small polymer parts with a free abrasive in the form of granules in containers that perform a complex spatial movement, determination of the time of handling process of polymeric details in a machine with a complex movement of working container*

Methodology. *An analytical research was conducted of the processing of small polymeric parts by abrasive in the form of free granules in a machine whose working capacities performs a complex spatial movement to determine rational polishing conditions.*

Results. *On the basis of the conducted analytical research of the processing of small polymer parts in a machine with a complex spatial motion of a working container, mathematical dependencies were obtained that enable to predict the technological result at the design stage. It has been analytically established that in a container with proportional greater geometric parameters processing will take less time.*

Scientific novelty. *The regularities of the influence of the geometric parameters of the working container, which performs the complex spatial motion and the modes of motion of a friable working medium, are determined on the intensity of the process of polishing small polymer parts by abrasive in the form of free granules.*

Practical significance. *The mathematical dependences are obtained for the calculation of the processing time and instructions for realization of the corresponding mode of movement of a friable working medium, which provide intensive polishing of small polymer parts with a free abrasive in the form of granules, are obtained in a machine whose working capacities performs a complex spatial movement.*

Keywords: *polishing, working container, free abrasive in the form of granules, polymeric units.*

Introduction. Formation of a large number of small polymer parts of various industries, including fittings of light industry, is caused by mechanical processing or casting. After that, the surface of the products has significant microniness and lack of gloss. Such parts are subjected to finishing, the essence of which is grinding and polishing their surface with a free abrasive in the form of granules, usually in the middle of the rotational container [1, 2] or in the capacities of vibrating machines [3]. These operations take up to 80% of the technological time [4]. Such processing in machines whose working capacities perform low-performance rotary motion [5] require a lot of time.

Setting problem. Reducing the processing time can be due to the intensification of polishing processes of polymeric products with a free abrasive in the form of granules using equipment in which the working container performs a complex spatial movement, due to the fact that the working environment in the processing process moves very rapidly.

However, to date, there are practically no guidelines for the processing of fine polymeric parts (grinding, polishing) with a free abrasive in the form of granules in a machine which working container is complicated by spatial motion [6], there is no scientifically substantiated information about the time required to perform the relevant technological operations.

Thus, the definition of the time required to perform the relevant technological operations, as well as the prediction of technological result at the design stage in the execution of the relevant technological operations, is an urgent task to date.

Results of the study. Intensification of polishing processes of polymeric products by free abrasive in the form of granules can occur in the course of increasing the friction path *S*, which passes a part in the middle of the working container for a complete cycle of processing. In turn, the path of friction passed will depend on the geometric parameters of the working container. It is known [7] that the main displacement, which performs a particle in the middle of the working container, is its displacement along the x-axis of the cylindrical container. In one full rotation ofcontainer there are two such movements along its axis x, with each change in the direction of displacement the particle stops near one of the ends of the container. The actual total displacement of the particle along the capacitive axis will be somewhat reduced due to the fact that a portion of the free volume of the container will fill the friable working environmentAccording to the work presented in [7], the trajectories of moving the particle in the working container, found that the actual friction path that passes the particle (product) in one revolution of the driving shaft of the machine is approximately equal to three distances $l_Ц$ between opposite ends of the container:

$$S = 3l_Ц. \tag{1}$$

The friction path that the product passes over the entire processing process:

$$S = 3l_Ц q, \tag{2}$$

where q − number of revolutions carried out by the driving shaft for the entire period of processing.

In turn, the number of revolutions that executed the leading shaft for the entire period of processing can be determined as follows:

$$q = nt60, \tag{3}$$

where n − number of revolutions carried out by the driving shaft, rpm; t − time of treatment period, hours. Switch from the angular velocity *ω[rad/s]* to the rotational speed *n[rpm]* by the known formula [8]:

$$n = \frac{30\omega}{\pi}. \tag{4}$$

Substituting expression (3) in the formula (2) and obtain:

$$S = 180 l_Ц nt. \tag{5}$$

Thus, according to expression (5), a friction path passing through the part in the middle of the working tank, which performs a complex spatial movement for the corresponding period of processing, can be established.

In addition to the friction path that the part is passed, the force influence of the abrasive components on these parts should also be taken into account, which will occure in the force of slip friction between the surface of the machined parts and abrasive material with a volume limited by a large surface of this part and its height of the bulk mass to this area.

In the process of operation of the machine, the modulus and the vector of the friction-slip force between the product and the abrasive will respectively change. However, the force of friction-slip will occur only when there is a movement of the abrasive material on the surface of the part. To simplify the theoretical hypothesis, we will arbitrarily assume that the immobilized part is located under the moving layer of the abrasive, which slides on the surface of the workpiece, which, in turn, is at a certain angle to the horizontal plane.

If you observe the movement of a loose working mass in relation to the product through the transparent walls of the working container of the experimental stand with the dimensional parameters corresponding to the mass ratio of $n=1,0$ when filling by 40%, then it becomes clear that the greatest movement of the abrasive on the surface of the workpiece is at that moment , when she, moving from one end of the container to the opposite, stops, and then, on its surface, an array of abrasive, which slides on it, pours out. It is visually established that for a working container of an experimental stand, the bulk height of the abrasive is approximately equal to the radius of the end of the container. The calculation scheme for determining the force influence of the abrasive array on the machined surface of the part is shown in Fig.1.

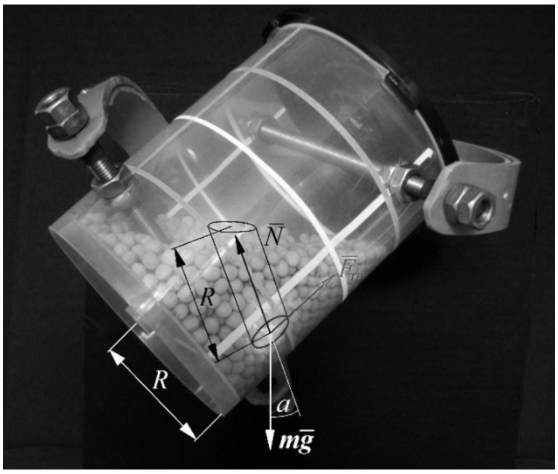

Fig. 1. **Design scheme for determining the force influence of the abrasive array on the treated surface of the part in the middle of the working container of the test stand**

However, the assertion that, for example, in a working tank with a volume of 0,3 m^3 (300 liters) relative to the conditionally stationary surface of the workpiece will move a bulk array of approximately 0,3 m height, since this is the radius of the end face will have a container of 0.3 m^3 (300 liters). The situation described above, may be valid only for working capacities with a relatively small volume. It is known [9] that the height of the moving layer of a bulk solid that moves along the surface of the immovable part of the friable medium does not exceed 0.1 m. We will use these guidelines for our own analytical research.

Thus, in determining the friction-slip force we will assume that when moving the abrasive material on the surface of the part, the bulk height of such an abrasive coating is approximately equal to the radius of the end of the working container, but not more than 0.1 m, since, in excess of this height, the displacement of the abrasive on the treated surface will be practically absent or minimized.

We will then write down the law of Amonton-Coulon to determine the dynamic force of friction-slip that will occur between the processed surface of the part and the abrasive array:

$$F_{TP} = fN, \tag{6}$$

where: f − slip friction coefficient, which should be taken for the interaction between the materials of the parts and the abrasive between them; N − the strength of the support`s normal reaction.

The strength of the support`s normal reaction N is defind as:

$$N = mg\cos\alpha, \tag{7}$$

where: m − mass of abrasive material of a corresponding volume, which creates pressure on the surface of the part, g − free fall acceleration, α − angle of inclination to the horizon of the treated.

In the process of polishing the parts occupy a variety of positions relative to the walls of the container and the horizontal plane, therefore the angle of inclination α is constantly changing and, as a rule, different from zero degrees. However, taking into account that the maximum angle of inclination of the axis of the working container of the basic design of the machine to the horizontal plane is 54 °, and also, that it is precisely at such a position of the working container that the greatest relative displacement of the abrasive on the surface of the workpiece is realized, we will accept the value of the angle α equal to 54.

We substitute expression (7) into equation (6):

$$F_{TP} = fmg\cos 54^{\circ}. \tag{8}$$

Thus, we can conclude that the proportional change in geometric parameters of the working container at the same time will change the following parameters: The distance traveled through the product in the middle of the container (friction path) S and the friction force F_{TP}. Therefore, consider these parameters in the complex, as a work of frictional force A_{Fmp}:

$$A_{F_{TP}} = F_{TP}S. \tag{9}$$

We substitute the equation (9) for expressions (5) and (8):

$$A_{F_{TP}} = 180\, fmg\cos 54^{\circ}\, l_{Ц}nt. \tag{10}$$

y expression (10) one can determine the work of frictional force A_{Fmp} between the part and the abrasive material. In order to determine the time required for the processing of parts in the working container of another size with the corresponding angular velocity of the drive shaft, we shall express from the formula (10) the value t:

$$t = \frac{A_{F_{TP}}}{180\, fmg\cos 54 l_{Ц} n},\ \text{[hour]} \tag{11}$$

In order to determine the work of the frictional force A_{Fmp} between the part and the abrasive material that needs to be performed in order to allow the surface of the part to be processed, an additional experimental study of the polishing of the surface of the parts in the middle of the working container of the experimental installation, the essence of which is to achieve the required value of the roughness parameter of the part`ssurface corresponding to the processed sample. After that, taking into account the most important parameters, according to expression (11), it is possible to determine the time spent on performing the polishing operations.

Then, based on the results and conditions of the experiment [10], we will check the correctness of the stated theoretical dependencies. We will record in general terms the equation obtained by using the Microsoft Excel-2016 equation obtained as a result of the approximation of experimental data describing the dependence of the roughness change on the R_a or R_{max} parameter from the time of processing under the exponential law:

$$R_x = R_0 e^{-xt}, \tag{12}$$

where: R_x − the value of the roughness of the surface of the part with the corresponding parameter, µm; R_0 − the value of the roughness of the surface of the rough part with the corresponding parameter, µm; e − exponent; t − processing time, hour; x − dimensionless coefficient characterizing the intensity of the curve decay. We will express from the equation (12) the processing time and get a logarithmic dependence:

$$t = \frac{\ln\left(R_0 / R_x\right)}{x}. \tag{13}$$

By expression (13), it is possible to set the time required to achieve the corresponding value of the roughness parameter of the surface of the buttons, when processed in a working container with the corresponding geometric parameters. However, such an equation with the corresponding value of x can be obtained only after an experimental study of processing in a container with specific geometric parameters. To verify the validity of the theoretical dependencies, determine the work of frictional force between the surface of the button with a diameter of 28 mm and the abrasive material necessary for the surface of the part to be processed in the middle of the container at $n=1,54$, substituting all the necessary data in expression (10).

Taking into account the lack of information in the reference books, the coefficient of friction slipping f on the ceramic surface of the abrasive was determined experimentally on the moist surface of the polyester button, which was 0.2.

The mass of the abrasive material m of the corresponding volume, which creates the pressure on the surface of the product, will be determined as the multiplication number of the conventional volume, which is limited to the processed surface of the button and the height of the bulk mass that acts on this surface, multiplied by the bulk density of the abrasive material:

$$m = \pi r^2 h \cdot 1500, \tag{14}$$

where: r − radius of the processed surface of the button, m; h - height of the bulk mass, acting on the area of the treated surface, m; *1500* - bulk density of abrasive material kg / m^3.

Since it has been previously established that the height of the bulk mass is equal to the radius of the butt end of the vessel, but does not exceed 0.1 m, and the working container at n = *1.54*, used in this experiment has a diameter equal to 0.2 m, then $h=h_{рє}$. We substitute into the equation (14):

$$m = \pi r^2 r_{РЄ} \cdot 1500. \tag{15}$$

Now we substitute equation (15) for expression (10):

$$A_{F_{TP}} = 27 \cdot 10^4 \, f \pi r^2 r_{РЄ} g \cos 54^\circ \, l_Ц n t, \tag{16}$$

where: f=0.2; r=0,014m; $r_{PЄ}$ = 0.1m; $l_{Ц}$ = 0.26 m; n = 28 rpm; time t = *32* h is taken according to the processing time in which the curve of the roughness change curve by the parameter R_a for buttons with a diameter of 28 mm, formed by approximation, reaches the value of the roughness of the surface of the processed button. We substitute all values in equation (16). As a result, the calculated value of the force of friction will be *4467J.*

Thus, in order to achieve a complete surface treatment of a button 28 mm in diameter, which occurs in the middle of the working tank at $n = 1.54$, it is necessary that the frictional force between the button and the abrasive material is approximately equivalent to *4467J*. Assume that the same value of the friction force is necessary for processing a button with a diameter of 28 mm in working container with any proportionally altered geometric parameters. Consequently, we define the time required to handle a button with a diameter of 28 mm with less geometric parameters $n = 1,0$. To do this, from equation (9) we will express the friction path S, which product goes through the entire processing process:

$$S = \frac{A_{F_{TP}}}{F_{TP}}. \tag{17}$$

Determine the frictional force F_{TP} between the button and the abrasive material that occurs when processing in a working container with a scale factor $n = 1.0$, substituting all the necessary data in expression (8), while: slip friction coefficient f=0.2; the mass of the abrasive material m of the corresponding volume, which creates pressure on the surface of the button with a diameter of 28 mm when processed in a working tank with $n = 1.0$, according to the calculation of expression (16), will be: $m = 0.057kg$. The friction path S, calculated by the expression (17) will be: S=68724m.

Next, according to expression (11), we define the time required for processing buttons with a diameter of 28 mm in the working container at $n = 1.0$. According to the calculation for (11), the processing time will be at least $t = 64.2$ *h*. Compare the analytically defined time with the experimental one [10]. After substituting the data into equation (13), it was experimentally established the time taken to handle the buttons with a diameter of 28 mm in a working container with smaller geometric parameters ($n = 1.0$), which would be 69.2 hours, which is 7.8% more from the theoretically established time. Such a discrepancy can be explained by the fact that, firstly, when deducing theoretical dependencies, a large number of simplifications were adopted concerning the very, extremely complex in its essence, the process of processing parts by abrasive in the form of free granules. Second, because a significant number of factors that influence the change in the processing time can not be simultaneously taken into account in the deduced theoretical dependence.

In addition, when using a machine with a flexible working container to perform grinding or polishing operations on the surface of the parts and simultaneously reducing power consumption, it is not necessary to simultaneously process two or more types of parts, including buttons, with distinct geometric parameters. It is recommended that only one type of detail be processed in one machine.

Conclusions:

1. The influence of geometric parameters of the working container on the intensity and quality of processing of small polymer parts is investigated. The mathematical dependencies of the

time spent on polishing small polymer parts from the angular velocity of the drive shaft of the machine and the dimensional parameters of the working container are obtained.

2. It is established that in order to perform technological operations of polishing small polymer parts, the equipment in which the working container performs a complex spatial movement is much more efficient than the equipment with a rotating drum. The processing time of the buttons in a machine with a complex movement of the working container may be less than one and a half times during processing in a rotary drum machine.

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АНАЛІТИЧНЕ ВИЗНАЧЕННЯ ЧАСУ ОБРОБКИ ДРІБНИХ ПОЛІМЕРНИХ ДЕТАЛЕЙ В МАШИНІ ЗІ СКЛАДНИМ ПРОСТОРОВИМ РУХОМ РОБОЧОЇ ЄМКОСТІ

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Мета. *Аналітичне визначення основних технологічних параметрів полірування дрібних полімерних деталей вільним абразивом у вигляді гранул у ємкостях, що виконують складний просторовий рух, визначення часу обробки дрібних полімерних деталей в машині зі складним просторовим рухом робочої ємкості*

Методика. *Проведено аналітичне дослідження процесу обробки дрібних полімерних деталей абразивом у вигляді вільних гранул в машині, робоча ємкості якої виконує складний просторовий рух, для визначення раціональних умов полірування.*

Результати. *На основі проведеного аналітичного дослідження процесу обробки дрібних полімерних деталей в машині зі складним просторовим рухом робочої ємкості отримано математичні залежності, що дають можливість прогнозувати технологічний результат на стадії проектування, отримано математичні вирази, що дозволяють розрахувати необхідний час виконання технологічної операції полірування полімерних деталей. Аналітично встановлено, що в робочій ємкості, яка має пропорційно більші геометричні параметри, процес обробки деталей займатиме менше часу.*

Наукова новизна. *Встановлені закономірності впливу геометричних параметрів робочої ємкості, що виконує складний просторовий рух та режимів руху сипкого робочого середовища на інтенсивність процесу полірування дрібних полімерних деталей абразивом у вигляді вільних гранул, встановлений взаємозв’язок між шляхом тертя, який проходить деталь в середині ємкості та необхідним її часом обробки.*

Практична значимість. *Отримані математичні залежності для розрахунку часу обробки та настанови щодо реалізації відповідного режиму руху сипкого робочого середовища, що забезпечують інтенсивне полірування дрібних полімерних деталей вільним абразивом у вигляді гранул в машині робоча ємкості якої виконує складний просторовий рух.*

Ключові слова: *полірування, робоча ємкість, вільний абразив у вигляді гранул, дрібні полімерні деталі.*

АНАЛИТИЧЕСКОЕ ОПРЕДЕЛЕНИЕ ВРЕМЕНИ ОБРАБОТКИ МЕЛКИХ ПОЛИМЕРНЫХ ДЕТАЛЕЙ В МАШИНЕ СО СЛОЖНОЙ ПРОСТРАНСТВЕННОЙ ПОДВИЖНЫМ РАБОЧИМ ЕМКОСТИ

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Цель. *Аналитическое определение основных технологических параметров полирования мелких полимерных деталей свободным абразивом в виде гранул в емкостях, выполняющих сложное пространственное движение, определение времени обработки мелких полимерных деталей в машине со сложным пространственным движением рабочей емкости.*

Методика. *Проведено аналитическое исследование процесса обработки мелких полимерных деталей абразивом в виде свободных гранул в машине, рабочая емкость которой выполняет сложное пространственное движение, для определения рациональных условий полирования.*

Результаты. *На основе проведенного аналитического исследования процесса обработки мелких полимерных деталей в машине со сложным пространственным движением рабочей емкости получены математические зависимости, позволяющие прогнозировать технологический результат на стадии проектирования, получены математические выражения, позволяющие рассчитать необходимое время выполнения технологической операции полировки полимерных деталей. Аналитически установлено, что в емкости, которая имеет пропорционально большие геометрические параметры, процесс обработки будет занимать меньше времени.*

Научная новизна. *Установлены закономерности влияния геометрических параметров рабочей емкости, выполняющей сложное пространственное движение и режимов движения сыпучей рабочей среды на интенсивность процесса полирования мелких полимерных деталей абразивом в виде свободных гранул.*

Практическая значимость. *Полученные математические зависимости для расчета времени обработки и установки по реализации соответствующего режима движения сыпучего рабочей среды, обеспечивающие интенсивное полирование мелких полимерных деталей свободным абразивом в виде гранул в машине, рабочая емкость которой выполняет сложное пространственное движение.*

Ключевые слова: *полирование, рабочая емкость, свободный абразив в виде гранул, полимерные детали.*