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THEORETICAL STUDIES OF THE DYNAMIC CHARACTERISTICS OF THE INTERNAL LAPPING PROCESS

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Abstract. In the article dynamic characteristics of lapping process were analyzed and the main parameters of the process were determined. The influencing degree of technological parameters to the forming of the surface and the processing was determined. It was given construction of the head of the new lubrication projected for the processing of the internal cylindrical surfaces, scheme of the lapping operation and graphic description of the forces influencing the process. The relations between axial, radial and tangential organizers of shear force to provide the pressure to the surface and their joint influencing effect were evaluated. The relevant geometric and mathematical dependences were obtained on the basis of the dynamic analysis.

Keywords: abrasive sand, lapping process, friction coefficient, dynamic characteristics, shear force

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ТЕОРЕТИЧЕСКОЕ ИССЛЕДОВАНИЕ ДИНАМИЧЕСКИХ ХАРАКТЕРИСТИК ПРОЦЕССА ПРИТИРКИ ПРИ ОБРАБОТКЕ ВНУТРЕННИХ ПОВЕРХНОСТЕЙ

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Аннотация. В статье анализируются характеристики процесса притирки и определяются основные параметры процесса. Установлена степень влияния технологических параметров на формирование поверхности и обработку. Приведена конструкция головки новой системы смазки, предназначенной для обработки внутренних цилиндрических поверхностей, схема процесса притирки и графическое изображение сил, влияющих на процесс. Оценены взаимоотношения между осевыми, радиальными и тангенциальными составляющими усилия сдвига для обеспечения давления на поверхность и их совместного влияния. Соответствующие геометрические и математические зависимости были получены на основе динамического анализа.

Ключевые слова: абразивный песок, процесс притирки, коэффициент трения, динамические характеристики, усилие сдвига.

Для цитирования

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Introduction

By increasing the accuracy and quality indicators of the machine details, increasing their reliability and durability is one of the most actual issues of modern mechanical engineering. Multiple studies show that the machines with the completely same construction often have completely different reliability. This is related to the difference in the technological processes in their preparation. The mentioned reason necessitates the management of the exploitation parameters by technological methods. This necessity reflects itself in the processing of the machine details of higher accuracy (Гафаров, 2001).

Thus, learning of the processes and technological legitimacy allows us to describe the general view of the forming process of the final quality indicators of the processed surfaces more completely and exactly, to improve the processing, as well as to provide the required quality for the surface increasing the reliability and durability of the machines and mechanisms (Масловский, 1971).

The application of the new advanced processes of the finish technological operations allows us to provide the surface quality and high accuracy of the processed surfaces of the machine parts. Increasing requirements for the increasing level of the durability, stability, anticorrosion and anti-abrasion resistance, fatigue strength of the parts, as well as improving the accuracy of the machines and mechanisms, their reliability and durability necessitates the use of advanced processing methods. One of such methods is the technological process of lapping (Орлов, 1998).

The difficulty of the process of removing the thin material layer from the surface layer is in the implementation of the process with free abrasive, as well as under the influence of the multiple functional and random factors. One of such factors is the difference of the geometric form of the abrasives-cutting sands and their ability to move freely (Ящерицын 1996). Mutual meeting of the abrasive sands changing their position freely during the processing with the surface becomes complicated, as well as makes difficult to learn the influence of the different parameters of lapping to the quality and accuracy of the processed surface (Попов, 1971).

Depending on the characteristics of the processing method and lapping, the sizes of the lubrication head is determined approximately and it is given rotating and forward-back - combined working movement in respect of the processed surface. These movements influence directly the intensity and removal characteristics of the metal layer, creates spiral crossing lines on the surface so that influence the durability of the detail according to the exploitation condition (**Figure 1**). The particles can slip, roll or slip-roll during the finishing process. The movement characteristics of particles are influenced significantly by the difference of the composition of the sands and the homogeneity of their forms. The authors relate the efficiency of the process with the probability of the loading of the abrasive to the working surface of the lapping tool in the studies of (Ковалев, 1967) and (Крагельский, 1962). The formula of $B = \frac{T_s S_s}{T_{det.} S_{det.}} R_s R_{k.k}$ was offered by authors for evaluation of this probability, where T_s and $T_{det.}$ is the consistency of lapping tool and detail material accordingly, S_s and $S_{det.}$ is the contact area of the sand with lapping tool and detail, R_s relative wetting coefficient with lapping tool and lubrication material of the detail, $R_{k.k}$-relative unevenness coefficient of the lapping tool and detail surface. In case of B<1, the probability of loading of the abrasive particle to the lapping tool, in case of B>1, the probability of loading of the abrasive particle to the detail becomes real.

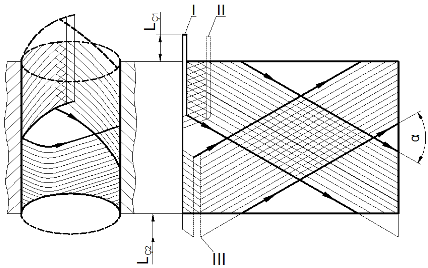

Fig. 1. Movement scheme of abrasive sand and its trace on the surface: I, II. III – consecutive edge positions of lubrication head, Lç1 and Lç2- accordingly exit sizes of the lubrication from the detail

Рис. 1. Схема движения частиц абразивного песка и их след на поверхности: I, II, III – последовательные краевые положения смазки, Lç1 и Lç2 соответственно размеры на выходе после смазки детали

It was determined that h/p ratio can be used to evaluate the interaction of the particle with the detail surface, where h is sinking depth of the particle, p – roundness radius of the particle. It was mentioned in studies of (Маслов, 1992) and (Макаров, 1996) that the ratio of h-sinking depth scratching the metal to its peak p-roundness radius can be accepted as a parameter determining the deformation characteristic of surface layer. The process is elastic deformation in case of h/p<0.02, plastic deformation in case of 0.02<h/p<0.5, cutting of the metal in case of h/p>0.5 (**Figure 2**). The distribution of the random probability (γ=h/ρ) should be found to determine the occurrence probability of plastic and elastic deformation of microvolumes of metal with abrasive particles, as well as the probability of occurrence of micro-cutting. During the exploitation period of an internal cylindrical surface of the machine details working dynamically, the physical-mechanical indicators decrease by losing its quality gradually. For the purpose of increasing the durability of the details working under the complex pressure-temperature condition and having stochastic characteristic of abrasion, it is necessary to conduct the analysis of the production condition, especially dynamic and kinematic analyses. A production process with lapping consists of mutual cutting of the detail and lapping tool loaded with abrasive particles (Орлов, 1971 and Орлов, 1972).

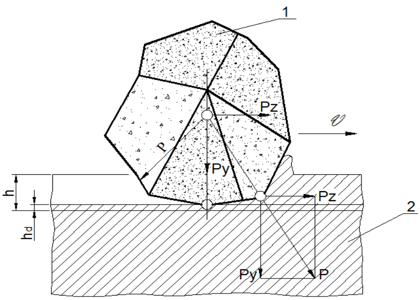

Fig. 2. Entering and movement scheme of sharp part of abrasive sand (1) to detail (2) under the pressure
Рис. 2. Схема поступления и движения острого участка абразивного песка (1) на деталь (2) под давлением

During the processing of the detail, the particle carries out the cutting process by leaning to the lapping tool, but in case the resistance to shear force is not sufficient, the process of the removal of the particle from the said surface can happen. Particle hanging between the lapping tool and detail surfaces cannot carry out the cutting process as particle not touching to other by adhering one of the surfaces. Therefore, the particle being in contact with the surface of the lapping tool and detail influence them with the same force and the cutting process is going on the account of pressure formed in cutting-scratching zone (Ящерицын, Зайцев, 1972) and (Ящерицын 1979).

The results of the experimental studies show that the change of shear force in the lapping process is a non-linear characteristic not depending on the speed of the organizers and value of the pressure. One of the main reasons is movement of the abrasive particles for the acceleration along with the processed surface of the detail. Being related to the microrelief of detail surface and complex movement legitimacy of the detail on the surface of a lapping surface tool, the working of the abrasive particles is going in their irregular movement during the lapping process according to constantly changing cutting and deformation conditions (Swan, 1999). Regardless of such complex progressing of the lapping process, the influence of shear force of granularity of lapping pastes is subject to the certain legitimacy. It was determined that the value of the organizers of shear force decreases monotonously by increasing the granularity of lapping forces. It was known that as a result of increasing of interspace between a detail and a lapping tool in the area of removal of the metal in the lapping process, unevenness in removal of the material along with the axle of the detail decreases. Disruption of the contact of the friction element, decrease of special pressure and decrease of the restoration intensity of the form errors naturally are related to the abrasion of the lapping tool (Matsinada, 1986 and Lishtenberger, 1995).

Abrasion of the lapping tools in the production process causes the change of the characteristic of force influences of their surfaces to the detail from abrasive layer, to change of the real contact areas of the detail and lapping tool and indirectly uneven distribution of intensity of the metal removal in separate points of surface layer of the detail and change of its profile.

It was determined by the experiments that the relation between geometrical parameters as diameter and cone in the detail before and after the lapping is of statistic characteristic, not depending on the form of the lapping tool. Relative high values of the correlation coefficients between geometric parameters of details before and after the lapping show the influence of the relations greatly determined sufficiently, conditioned physically by the technological factors heritage for the mentioned parameters (Pursche 1995).

It was approved that instability of processing of the internal cylindrical surface of the detail and joint influence of the multiple factors during the lapping cause to the occurrence of the form errors. In most cases the form errors of the details during the processing with lapping exceed the limit given to the diameter of the detail. Therefore, substantiated selection of the parameters of the lapping process to provide the high accuracy of the details is of significant importance in the learning of the occurrence legitimacy of the form errors (Bozina, 2006).

The empirical studies in the influence of the different lapping regimes to the occurrence of the form errors of the detail showed that none of the main parameters of the technological process influence directly the occurrence of these errors. However, the studied limit of the regimes allows us to select the lapping conditions and more purposeful regimes helping to the decrease of the form errors during the processing.

After the lapping the quality of the upper surface layer is dependent on the influencing characteristic of the used abrasive sands in the paste to the lubrication and surface layer material. Depending on the applied working condition, abrasive sands usually work under the micro-cutting or periodic micro-percussive mutual influencing condition during the uninterrupted contact of the detail and lubrication surfaces (www.dislib.net).

As it is known that the exploitation characteristics of the detail are influenced mostly by the preparation accuracy of them, bumpiness of the working surfaces, remaining intensity occurred in the upper surface layer and difference of the certain metal layer. Furthermore, the structure and a chemical composition of an upper surface layer can be different from the structure and a chemical composition of the core part. If there is complex influence of mechanical operations and occurrence of heating at significant degree in the cutting zone, separate chemical elements on the formed surface can be burned and chemical weakening (being stagnant) can be in a very thin layer of the metal surface, so that the exploitation characteristics of the surface decrease (www.dissercart.com and www.dissertation.com).

Exploitation characteristics of the detail surfaces are usually carried out by considering an optimal condition of their processing. If in such case it is chosen unsatisfactory regime in the formation of the upper surface layer, then no matter how accurate the detail is processed, they will have lower-degree physical-mechanical characteristics and consecutively decrease of the exploitation period will be observed. Thus, micro-hardness and remaining intensity towards to the internal depth from the upper surface of the processed detail will change significantly; it is possible to get the most different results depending on the processing conditions in clean and final operations of lapping.

As it is shown from the abovementioned, quality parameters of the surface depend on multiple interactive factors such as bumpiness, remaining intensity and beating and they form exploitation qualities of the machine details complexly. It was determined by the study of the influence of different technological factors to lapping process done with new methods that each parameters of the quality of upper surface layer does not allow separately to provide the required exploitation indicators of the surface layer of the machine details (www.globalsecurity.org). In this regard, for the purpose of the provision of the required quality indicators, the necessity of the complex study of the technological opportunities of the lapping process occurs.

The result of the experiments shows that plastic deformation in lower pressure is observed only in cutting of end parts of roughness of the surface. After that the intensity of the process decreases, cutting area grows and the value of the special pressure for subsequent plastic deformation is not sufficient. Consecutively, the opportunities of the lapping process decreases so that it leads to the increase of the value of Ra (www.hydratech-industries.com).

Theoretical modeling

As bumpiness decreases, the contact of abrasive sands with the surface increases significantly and at the end of the process main parts of these sands become tiny. In such condition, higher contact pressure shall be provided for the continuation of the lapping process in the next process.

There is allowed value of the special pressure in each regime of the removal process of the material from the upper surface layer by new method of the lapping operation, its increase leads to the increase of the bumpiness of the surface. The mentioned case can be resulted in increase of lapping strength, increase of the temperature in the cutting area and holding the soft material of the upper surface with abrasive sands strongly.

1. It was determined in the studies that increase of the special pressure from 25 to 100 kPa increases the removal of metal from the surface gradually, in the next increase the cutting intensity of the tool decreases so that causes the decrease of the metal removals (www.mashin.ru/eshop/journals/vestnik-mashinostroeniya). Decrease of the special pressure to the certain limit causes to filling of the lapping surface with paste fully or partially, after that the evenness process for the height of some sands begins.

The kinematic analyses of the processing scheme with the lapping shows that cutting process is characterized by the joint influence of the axial-P_x, radial-P_y and tangential-P_z organizers of shear force and each of these forces is directed into three directions (Ox, Oy and Oz).

Principal scheme of the lubrication head for the processing of eth internal cylindrical surfaces is shown in **figure 3**, here 1-processed detail, 2-lubrication, 3-bow. External bows maintain the completeness of the lapping tool by creating always the force forwards to the centre from the external surface of the lubrication, internal bows press the lapping tool into the internal surface of the detail and are assigned to provide the pressure to the processed surface. The lubrication head does both forward-back and rotating movements.

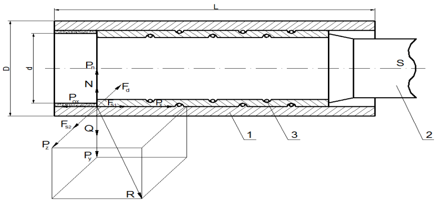

Fig. 3. Schematic description of the forces pressuring to the lapping process: 1 – detail; 2 – lubrication; 3 – bows

Рис. 3. Схематическое изображение действующих сил во время притирки: 1 – деталь; 2 – смазка; 3 – прогибы

Compile up the equations of the balance system of the shear forces occurred during the processing with lapping:

$$\begin{cases} P_x + F_{s1} - P_{ox} = 0 \\ P_y + Q - N - P_n = 0, \\ P_z - F_d + F_{s2} = 0 \end{cases} \quad (1)$$

where P_x– axial cutting force, N;

F_{s1} – friction force occurred in the forward-back movement of the lubrication, N;

P_{ox} – axial force, N;

P_y– radial shear force, N;

Q – sum of the forces occurred by the bows directed from the detail centre, N;

N – sum of the forces occurred by the bows directed to the detail centre, N;

P_n – normal reaction force, N;

P_z – the tangential component of the cutting force, N;

F_d – force characterizing the rotating movement of the detail, N;

F_{s2} – friction force occurred in the rotating movement of the lubrication, N.

Friction force occurred in the forward-back movement of the lubrication (F_{s1}) is determined by the following expression:

$$F_{s1} = \mu \cdot P_{xt} \cdot \chi, \quad (2)$$

where μ – friction coefficient;

P_{xt} – special pressure, N/mm^2;

χ – meeting area of the lubrication and detail, mm^2.

Axial force (P_{ox}) is determined through the following formula:

$$P_{ox} = m_s \frac{dS_{uz}}{dT}, \quad (3)$$

where m_s – mass of the lubrication, kg;

S_{uz} – longitudinal gait, mm/sec;

T – time, sec.

Q – N–forces difference is determined by the following expression:

$$Q - N = (C_1 - C_2)\frac{S_i}{2}, \quad (4)$$

where C_1 and C_2 – accordingly firmness of the internal and external bows, N/mm;

S_i – distance between the ends of the rings in *i*-condition, mm.

It is described the different conditions of the lapping process in **Figure 4**. According to the scheme, radial dislocation of the lubrication elements is $\frac{1}{2}S_i$. Then, it can be expressed as following according to the lapping scheme:

$$\sin\varphi_i = \frac{S_i}{2r_i} \text{ or } S_i = 2r_i \cdot \sin\varphi_i, \quad (5)$$

where r_i – changed radiuses depending on the abrasion of external surface for the lubrication, mm;

φ_i – dislocation angle of the elastic lubrication elements during the abrasion, rad.

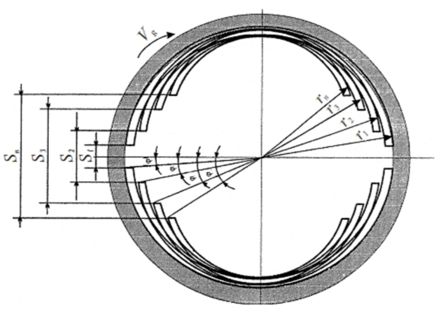

Fig. 4. Different conditions of the lapping process

Рис. 4. Различные условия процесса притирки

Considering expression (5) in expression (4), finally the following expression can be obtained for the forces difference (Q-N):

$$Q - N = (C_1 - C_2)\cdot\frac{2r_i\cdot\sin\varphi_i}{2}$$

or $Q - N = (C_1 - C_2)\cdot r_i\cdot\sin\varphi_i$. (6)

Normal reaction force of the lapped surface of the detail is determined by the following formula:

$$P_n = P_{xt}\cdot\chi, \quad (7)$$

where $P_{x.t}$ – special pressure, N/mm^2;

χ – meeting area of the lubrication with detail, mm^2.

F_d force characterizing the rotating movement of the detail is expressed by the following formula:

$$F_d = m_{\det}\cdot\frac{d^2\varphi}{dT^2}, \quad (8)$$

where $m_{\det}$ – mass of the detail, kg;

φ – angle dislocation of the detail, rad.

Friction force occurred in the rotating movement of the lubrication (F_{s2}) is determined by the following formula:

$$F_{s2} = \mu\cdot P_{xt}\cdot l\cdot\frac{\pi r}{180^\circ}\phi, \quad (9)$$

where l – length of lapped surface, mm;

$\frac{\pi r}{180^\circ}\varphi$ – the length of the arc of contact, mm.

Considering expressions (2), (3), (6), (7), (8) and (9) in expression (1), the following system is obtained:

$$\begin{cases} P_x + \mu\cdot P_{xt}\cdot\chi - m_s\frac{dS_{uz}}{dT} = 0; \\ P_y + (C_1 - C_2)\cdot r_i\cdot\sin\phi_i - P_{xt}\cdot\chi = 0; \\ P_z - m_{\det}\cdot\frac{d^2\phi}{dT^2} + \mu\cdot P_{xt}\cdot l\cdot\frac{\pi r}{180^\circ}\phi = 0. \end{cases} \quad (10)$$

In **Figure 5** it is given graphical description of the forces influencing the lapping process normally and axially. As it is shown in the graphic, the sum of the forces occurred by the bows directed to the centre of the detail-N and normal reaction force P_n is in the same direction, the sum of the forces occurred by the bows directed from the centre of the detail-Q is in the opposite direction. As well as friction force occurred in the forward-back movement of lubrication - F_{s1} is directed into the opposite direction in respect of P_{ox} – axial force. Upon Figure 5, it can be written:

$$P_{ox} + Q + F_{s1} - N - P_n = 0 \quad (11)$$

or

$$m_s\frac{dS_{uz}}{dT} + (C_1 - C_2)\cdot r_i\cdot\sin\varphi_i + $$
$$+\mu\cdot P_{xt}\cdot\chi - P_{xt}\cdot\chi = 0. \quad (12)$$

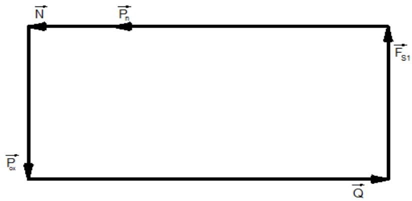

Fig. 5.Graphical determination of forces influencing lapping process

Рис. 5. Графическое изображение сил, действующих на процесс притирки

If we exclude $P_{x.t}$ – in expression (12) out of the brackets, we will get:

$$m_s\frac{dS_{uz}}{dT} + (C_1 - C_2)\cdot r_i\cdot\sin\varphi_i + $$
$$+P_{xt}(\mu\chi - \chi) = 0. \quad (13)$$

It can be determined the value of the special pressure from expression (13) by the following formula:

$$P_{xt} = \frac{m_s\frac{dS_{uz}}{dT} + (C_1 - C_2)\cdot r_i\cdot\sin\varphi_i}{\chi(1-\mu)}. \quad (14)$$

If expression (14) in its place in system equation of (10), we can get the following final expressions for axial, radial, tangential shear forces:

$$P_x = m_s\frac{dS_{uz}}{dT} - $$
$$-\frac{m_s\frac{dS_{uz}}{dT} + (C_1 - C_2)\cdot r_i\cdot\sin\phi_i}{(1-\mu)}\cdot\mu; \quad (15)$$

$$P_y = \frac{m_s \dfrac{dS_{uz}}{dT} + (C_1 - C_2)\cdot r_i \cdot \sin\varphi_i}{(1-\mu)} - \\ -(C_1 - C_2)\cdot r_i \cdot \sin\varphi_i; \quad (16)$$

$$P_z = m_{\det}\frac{d^2\phi}{dT^2} - \\ -\frac{m_s \dfrac{dS_{uz}}{dT} + (C_1 - C_2)\cdot r_i \cdot \sin\phi_i}{\chi(1-\mu)}\cdot \mu \cdot l \cdot \frac{\pi r}{180^\circ}\phi. \quad (17)$$

Thus, R (substitute of general shear forces) can be determined as the following through P_x, P_y and P_z organizer forces:

$$R = \sqrt{P_x^2 + P_y^2 + P_z^2}\,. \quad (18)$$

In general, P_x force is directed horizontally and calculated to determine gait movement, P_y force is directed to perpendicularly to the axle of the detail and is calculated to determine the firmness of technological system (DTAP), P_z force is directed to main movement and is calculated to determine the torque moment.

Empirically, it was determined that P_x– axial, P_y– radial and P_z– tangential shear forces are changed in the ratio of $P_z^2 : P_y^2 : P_x^2$ = 1 : 0.40 : 0.25 for the given processing condition.In case of the change of the factors such as cutting regime elements, physical-mechanical indicators of the detail, geometrical parameters of lubrication head, this ratio will be changed at certain level [18, 20]. Considering this dependence in (18):

$$R = \sqrt{P_z^2 + (0{,}40P_z)^2 + (0{,}25P_z)^2} \approx 1{,}12P_z\,. \quad (19)$$

Conclusion

Thus, it is necessary to determine the optimal values of the organizers of shear force to obtain the surface having required accuracy and quality. A cutting process is characterized by the joint influence of axial – P_x, radial – P_y and tangential – P_z in the processing with the lapping. Obtained analytic expressions can be realized in the subsequent experimental research and used in the engineering calculations of the technological process of the processing with lapping.

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