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Increasing the capabilities of machining attachments by means of ferromagnetic liquids

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Abstract. The article is devoted to application of ferromagnetic liquids in machining attachments of technical process for producing machine components. Application of such liquids allows to simplify equipment and decrease its cost, to increase accuracy of workpieces treatment by elimination of additional processing of workpieces base surfaces. It is proposed to set the workpiece not on supports of machine-tools but on the layer of rheological liquid hardened in outer magnetic field. At the same time contact pressure of rheological medium on side surface provides slip resistance caused by the forces appearing during treatment. The article contains calculated dependences for definition of forces holding the workpiece on machine table, being fully or partially submerged into ferromagnetic medium during mechanical processing. Criterion for applicability of ferromagnetic liquid at workpiece setting during treatment is proposed. On the ground of achieved per samples experimental verification of formulated statements and calculated dependences the authors worked out recommendations for selection of rheological media in liquid state for workpiece setting and holding taking into account frequent changes of working objects. Development and running of such machining attachments is efficient in modern industry that is characterized by low serial production and wide assortment of produced goods during finishing mechanical, electrical and combined work, where scientifically grounded application of ferromagnetic liquids increases production profitability by 1,5-2 times.

1 Introduction

Modern industry is characterized by low serial production, wide assortment of produced goods, and consequently by a great deal of quite difficult machining attachments including the appliances for installation and work holding. It is known that the cost of machining attachments may amount to 90 % of production prime cost. That is why design and manufacture of such appliances exercise significant influence over production cost of goods manufacture. For reduction of expenses on preproduction it is effectually to use multi-operated equipment instead of special tools.

2 Relevance. Scientific significance of the question

In machine-building we use different types of machining attachments: magnetic, cryogenic, etc. However there are some severe restrictions in this sphere. Accurate location reference surfaces, workpieces and fixturing components made of magnetic alloys, powerful magnetic elements are required for magnetic catch mechanisms. For frozen liquids (based on water) you need accurate bases, powerful energy-consuming refrigerating systems, complex modernization of equipment for accumulation, feed, and regeneration of the liquid, etc.

The analysis of performed tasks allowed to make preliminary conclusions that it is possible to use setting in ferromagnetic liquid for different types of treatment. Analytical models and correspondences for cutting forces definition available in literature, can be used for design of machining attachments based on rheological media. However it is necessary to estimate the forces adequative for reliable and accurate workpiece positioning and prove the possibility of magnetic liquid use in typical production methods of high-variety manufacturing [1-5].

Manufacture transition to the system of individual orders required scientific substantiation of rheological media use for simplification and cheapening of machining attachments, increasing workpiece accuracy, deletion of additional treatment of workpiece reference surfaces. Their application accelerated conversion and initiation of competitive products (including cost attractiveness) what is relevant to machine-building.

3 Setting of the problem

The research task is development of flexible method of workpieces setting and justification of field for its

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rational application with the use of ferromagnetic liquids properties and managing their state by outer magnetic field for creating bases without production of specialized supports.

Our research of workpiece setting in rheological liquid was based on operational hypothesis according to which change of magnetic field operating upon rheological medium allows to reach viscosity value providing permanent position of work area relative to the tool, appliance, or basic components of equipment [7]. At the same time the provided holding force is suitable for achievement of accurate and reliable workpiece position at the finishing stage of treatment. Development of this hypothesis allowed to create new treatment methods and means for their materialization [7-12].

4 The theoretical part

Conceptually new approach involves setting workpiece on the layer of ferromagnetic liquid hardened in outer field instead of machine-tool supports. Contact pressure of rheological medium on side surface provides slip resistance during processing [7, 13].

The scheme showing method of workpiece positioning in rheological medium is given in Fig. 1.

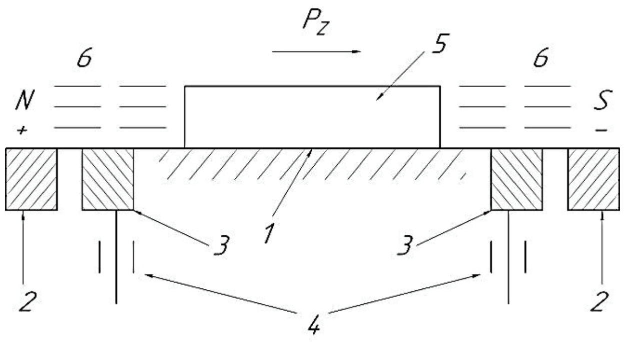

Fig. 1. Scheme of workpiece positioning on magnetic table: 1 – magnetic table; 2 и 3 – magnets; 4 – controllers of magnetic field force; 5 – workpiece; 6 – rheological ferromagnetic liquid

For the workpiece holding on the table it is necessary to create the force (F_H) of standard pressure on table surface determining the stability of position for the workpiece basic parts and pillars with magnetic liquid at complete submergence of the workpiece or its parts into the rheological medium.

$$F_H = (\mu_0 m_z \Delta H) S_e, \quad (1)$$

where μ_0 – coefficient of magnetic inductivity in vacuum (μ_0=4π·10-7 H/m); m_z – magnetic moment of particle; ΔH – gradient of magnetic intensity, kA/m; S_e – workpiece surface area (plane view).

Resistance of the force of workpiece treatment during cutting (F_C) will be composed of the constituent (F_T) for friction of contact areas, pressed by the workpiece mass (m) and friction at standard influence of F_H, but also of the resistance (F_e) of thick ferromagnetic liquid in the field of magnetic influence on it, taking into account the surface area (S_b) of workpiece part, contacting with rheological liquid by the side opposite to the influence of cutting force (Fig. 2).

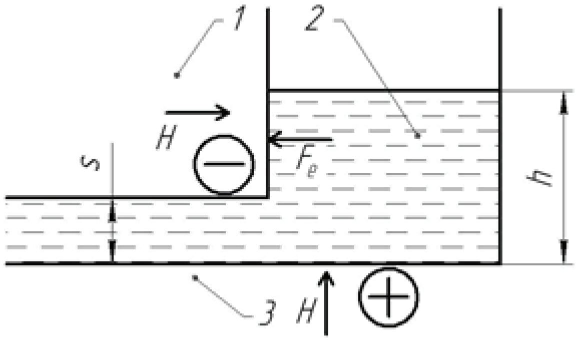

Fig. 2. The forces acting on the workpiece on the machine table: 1 – workpiece; 2 – rheological ferromagnetic liquid; 3 – machine table

$$F_C = F_T + F_e > K_P F_z, \quad (2)$$

where F_z – treatment force; K_P – coefficient considering dynamic and other impacts on workpiece during processing.

Frictional force of contact areas:

$$F_T = K_T(F_H + F_d), \quad (3)$$

where F_d – pressing force of worpiece mass (m); K_T – surfaces friction coefficient.

$$F_T = K_T(\mu_0 m_z \Delta H S_e + gm). \quad (4)$$

Friction force (F_e) of thick medium (ferromagnetic liquid) depends on its density. Density may be taken equal to the force at the beginning of elastic material (rheological medium) flowing. This force can be found by means of maximum tangential stress τ_{max}:

$$F_e = \tau_{max} / S_b, \quad (5)$$

where $\tau_{max} = \{1 - \mu\}\{1 - \tau arctg[1/\tau] - 3/[4(1+\tau^2)]\}/2$; μ – medium viscosity (for ferromagnetic liquid); $\tau = z/(2l)$; z – clearance between surfaces of contact bodies (maximum viscosity layer thickness); l – workpiece width.

Subsequently

$$\tau_{max} = 0{,}31 F_0 (\text{Hertz's task solution}), \quad (6)$$

$$F_e = F_H(S_b) = \mu_0 m_z \Delta H S_b, \quad (7)$$

$$F_C = K_T \mu_0 m_z \Delta H S_e + K_T gm + \mu_0 m_z \Delta H S_b = \\ = \mu_0 m_z \Delta H (K_T S_e + S_b) + K_T gm. \quad (8)$$

Criterion for applicability of ferromagnetic liquid for work setting during its treatment:

$$\Delta\rho' V g H \le kT, \quad (9)$$

where $\Delta\rho'$ – difference in material density of particles and base (liquid); V – particle volume; g – gravitation constant near the ground; H – magnetic liquid layer height; kT – thermal-motion energy of particles (k – Boltzmann's constant; T – temperature of magnetic liquid).

At the known contact surface area of workpiece with the table S_e minimum requirement for layer height of magnetic liquid (H_{min}) at workpiece width l and length l_g.

$$F_C = \mu_0 m_z \Delta H(K_T l l_g + lH) + K_T g \rho_{wp} l l_g H, \quad (10)$$

where ρ_{wp} – density of workpiece material.

Whence H_{min} is determined by numerical methods.

Workpiece stability criterion:

$$H_{min} \le H_{wp}, \quad (11)$$

where H_{wp} – height of workpiece.

5 Practical significance

Experimental verification for formulated statements and calculated dependences was achieved per samples [6]. Research results also led to definition of optimum concentration of magnetic phase in rheological liquid with setting workpieces made of different materials. For magnetic materials we recommend the rheological media based on machine grease of high viscosity with 20 % part concentration by volume, this increases holding force as compared to traditional fixation on magnetic table: 41-56 % in shear and 20-36 % under separation. For non-magnetic parts specific holding forces determined with the help of experimental plant are approximately (3-3,5)·10^5 N/m^2 in shear and (4-6)·10^4 N/m^2 under separation. The rated workpiece holding forces were tested on plain grinder at treatment under standard conditions. With due consideration of reserve coefficient the necessary forces were provided, the setting base was maintained. We proved the availability of non-magnetic workpiece holding forces to be approximately (12-15)·10^5 N/m^2 in shear and (2-3)·10^5 N/m^2 under separation.

Application of the research results allowed to speed up of the industrial technological cycle in operating high-variety manufacturing due to labour intensity reduction at pre-operation of workpieces setting bases and in some cases due to removal of grippers and reduction in expenditures on machining attachments production. Moreover a number of fixtures and tools having adaptive interaction with rheological medium were created, they allowed to simplify and cheapen their construction, reduce the costs of storing and check out of machining attachments.

6 Conclusions

The research of methods for workpiece setting and holding in rheological liquid allowed to work out scientifically grounded recommendations for the reasonable field of rheological liquid application in high-variety manufacture, their use is desirable when receiving high accuracy surfaces on rough workpiece bases during finishing work, particularly in operations with physicotechnical processes.

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