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MODEL OF AN INTERACTION OF AN ABRASIVE PARTICLES STREAM WITH MICROROUGHNESSES OF A WORKPIECE

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Abstract: *It is necessary to control processing productivity and quality of the received surface at jet abrasive processing. The model of interaction of an abrasive particles stream with microroughnesses of a detail is for this purpose necessary. The paper shows several mechanisms of the destruction of the part surface roughnesses. The calculating scheme of interaction of the abrasive particles flow and roughnesses in the form of pyramids with a square base is given. The mathematical model in which parameters for processing quality management are defined is presented. The directions of particles blows with a pyramids sides are defined; frequency and force of blows of particles depending on processing parameters are also given.*
Key words: *abrasive particle, microroughness, jet-abrasive treatment*

1. INTRODUCTION

A jet-abrasive treatment of parts surfaces has a high performance, manageability and simplicity of manufacturing equipment. However, for its using not only in the rough, but also in finishing operations, it is necessary to run an overall study of physical phenomena and laws of the interaction process of the abrasive particles flow with the machined workpiece microroughnesses. In particular, it is necessary to work out a model of this process.

Before describing the proposed model of the interaction of the workpiece surface with flying in a stream abrasive particles, it is necessary to make a decidion about the nature of the interaction and to determine the geometry of parts roughness.

2. INFORMATION

Studies by using the method of electron microscopy of surfaces treated with the gas and water jet streams show that the nature of material removal can be considered as the action of several mechanisms of destruction. They are:

– microcutting when the focused jet of abrasive particles acts as an edge tool and removes chip from the part surface;
– brittle fracture that occurs due to repeated impact activity of abrasive particles (in the machining of poor-plastic and fragile materials);
– microplastic deformation of the same areas of the machined surface with a gradual superposition of microprofile projections on each other and receiving the surface with lower roughness;
– fracture of the workpiece surface by hydromolecular jet action with the penetration of fluid particles in the micro-cracks under the pressure of the jet stream.

The second and third processes can be considered as the most universal and popular and therefore they form the basis of the proposed model.

The actual shape of the part surface roughnesses cannot be strictly mathematically described because of the large variety of pre-treatment methods, used instruments and the trajectories of their motion on the workpiece surface, as well as the properties of machined materials. In the fundamental works on the theory of friction the part surface microprofile is described with relatively simple geometric shapes. For example, D. Moore (Moor, 1978) offers to describe them with cubic, square pyramidal, or hemispherical surfaces. Provolotsky A.E. (Provolotsky, 1989), Isupov M.G. (Isupov, 2005) and Spiridonov N.V. (Spiridonov & Yasev, 2009) in solving similar problems also offer a hemispherical or spherical profile. A pyramidal profile with a square base can be assumed as closest one to the actual surface of the pre-machined parts. It allows us to treat the above mentioned two mechanisms of destruction with the same degree of complexity. However, neither these authors nor the others present a model of the interaction of the abrasive particles with microroughnesses of a pyramidal shape.

A graphic model of interaction of the abrasive particles flow with such microroughnesses is shown in Fig. 1. Surface microroughnesses are presented in the form of arranged in rows pyramids with square base, whose faces are located upstream of abrasive particles.

Flux abrasive particle are simulated by spheres whose sizes and values of physical and mechanical properties of the material are random variables. These parameters are in accordance with the percentage of large (5%), fine (30%) and basic (65%) fractions of abrasive material. Of course, the real abrasive particles have an irregular complex shape without its repeatability in individual grains.

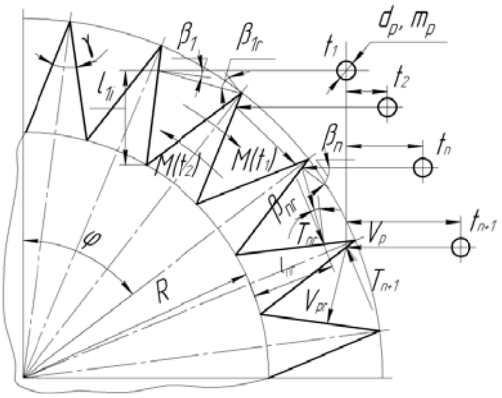

Fig. 1. Design diagram for modeling of the interaction of the abrasive particles flow with part

In the first approximation a two or tree-component abrasive jet is assumed as a one-component stream of non-interacting abrasive particles. In addition, a priori we assume that in 95% of cases there is no simultaneous power action on any of the microprofile pyramids by direct and reflected or neighboring particles of flying abrasive. I.e. there is a process of alternating shock loads on the part from the abrasive particles on each of the pyramids with the creation of alternating cyclic stresses. Under the action of these stresses there is either a destruction of pyramids or their deformation with overlay on each other. These processes decrease the height of workpiece microroughnesses. In the first case it happens with the material removal, and in the second case without it. That can improve the physical properties of the part surface due to the appearing of a thin strained layer.

Abrasive particle we will present in the form of absolutely elastic sphere. A pyramid material we will consider also absolutely elastic. Analyzing the design scheme shown in Fig. 1 and assuming that the reflection angle of the particle from a pyramid side equals to the incidence angle, from the geometrical construction the equations are obtained:

$$\beta_n = \varphi - \gamma/2, \beta_{nr} = \beta_n - \gamma \quad (1)$$

Of course, not all of the abrasive particles impact strictly on the top of each asperities of a pyramidal shape. In the upper part of the flow, in fact, the majority of particles strikes at a short distance from the top of the pyramid, being cut off by the underlying pyramid. In the lower part of the flow, if we consider the distribution law of the particles impact on the face of the pyramid to be symmetrical, the largest number of strikes will occur at a distance from the tip equal to the height of a pyramid minus the maximum size of the particles. Therefore, it is assumed that the most likely point of contact of straightflying particles with a face of the pyramid lies at a distance from the base of the pyramid which is equal

$$l_{1i} = K_1(\Delta R\cos(\gamma/2)) \quad (2)$$

where ΔR is height of microroughnesses (of pyramid), K_1=0,8÷0,9 – is an empirical coefficient.

Coordinate of the collision point of the reflected particles with a face of the pyramid is defined analytically from geometric constructions:

$$l_{nr} = l_{1i}[\cos\gamma + \sin\gamma/\tan(\pi/2 - \gamma + \beta_n)] \quad (3)$$

The shown collision will occur only if:

$$\Delta R\cos(\gamma/2) \geq l_{nr} \geq d_p/2$$

otherwise the particle either flies past the top of the pyramid, or stops in the cavity between adjacent pyramids.

The physical processes that characterize the impact dynamics of the reduced to the sphere abrasive particles with the brink of a pyramid microroughnesses from the classical physics point of view (analogically with Makhanko, 1993) were analized. Using the law of Hertz's and defining objects as linearly elastic, the expressions for the determination of normal to the pyramid axis forces of direct and indirect impacts are obtained:

$$T_i = n^{2/5}\left(1.25 m_p V_p^2 \varepsilon_p \cos^2\beta_i\right)^{3/5}\cos(\gamma/2) \quad (4)$$

$$T_r = n^{2/5}\left(1.25 m_p V_p^2 \varepsilon_p \cos^2\beta_r\right)^{3/5}\cos(\gamma/2) \quad (5)$$

where $n = \frac{0.75\sqrt{d_p/2}(E_1+E_2)}{(1-\nu_1^2)+(1-\nu_2^2)}$; $E_{1,2}$, $\nu_{1,2}$ are respectively modulus of elasticity (Young's modulus) and Poisson's ratios of workpiece and abrasive materials; ε_p=0,8..0,9 is a loss ratio of reflected particle velocity due to loss of energy for heating during impact.

From the known values of strength and arm the bending moments $M(t_1)$ and $M(t_2)$ (Fig. 1) are found. They act on the same pyramid at different points in time.

Let's define the repetition frequency of the direct impact of particles on the brink of a single pyramid. To do this, we express the number of particles n_p in a small volume of flow equal to the product of the projection at ground level a^2 (the direction of flow) and a distance x (from the nozzle end to the part surface) in terms of density ρ_p distribution in the stream of particles of known mass m_p:

$$n_p = \rho_p a^2 x\cos^2\varphi/m_p \quad (6)$$

Assuming that the workpiece is at a distance not exceeding the length of the initial segment, where the flow velocity on its axis does not change, the travel time of the volume will be equal:

$$\tau = x/\left(V_p - wR\cos\varphi\right) \quad (7)$$

where w – is angular velocity of the details.

Having divided the expression (6) and (7), a repetition frequency of attacks on any of the pyramids pin, located in the zone of the jet, is received:

$$f = \rho_p a^2\cos^2\varphi\left(V_p - wR\cos\varphi\right)\overline{\varepsilon}_\varphi/m_p \quad (8)$$

where $\overline{\varepsilon}_\varphi = 1 - \cos\varphi$ – is function that accounts the decrease repetition of rate shocks on the pyramid, located in the upper part of the interaction zone due to partial overlapping of their neighboring pyramid from the bottom.

3. CONCLUSION

Thus, model parameters with the help of which it is possible to operate productivity of jet abrasive processing and quality of the received surface are defined.

A model of the interaction of the abrasive particle flow with workpiece microroughnesses in the form of single pyramidal projections is presented for the first time. Its purpose is to determine the intensity of the destruction of the surface layer of part, depending on the flow regimes of the abrasive jet, the properties and geometry of parts, as well as the properties of abrasive.

Using the basic tenets (principles) of the theory of strength of materials, analytical findings confirmed that during the processing by abrasive jet before the classic micro-cutting, there are regimes that are characterized by cyclic fatigue failure of microroughnesses tops.

The implementation and refinement of the model is straightforward, checking its adequacy, as well as solving with its help the problem of the pyramidal asperities destruction (for brittle materials parts) and plastic deformation (for viscous materials) under the action of cyclic loads will be also examined in future.

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