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NEW DESIGN OF COMBINED ELECTRIC MACHINES TO INCREASE THE EFFICIENCY OF PROCESSING COMPOSITE MATERIALS

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ABSTRACT

The paper presents an original solution to the actual problem of increasing the efficiency of the drilling of composite materials of the carbonic group through the use of coupled electric rotary type machines whose combination of movements allows to obtain controlled rotary-reciprocating motion of the instrument. By creating cyclic low frequency load of the cutting zone, it is possible to improve the efficiency and quality of processing, without destroying the composite.

INTRODUCTION

Contemporary mechanical engineering is characterized by sharp modern machinery, in particular, aircraft and rocket science, nuclear industry, characterized by steady growth in the use of products made of composite materials, primarily on the basis of glass and carbon fibers. Such materials possess a complex of unique physical and mechanical properties, high strength, resistance in aggressive environments, and the ability to maintain mechanical properties in various conditions, including at elevated operating temperatures.

Usually all composite materials from the point of view of their final processing are considered to be difficult to process. But the biggest problems accompany the processing of products from carbon-carbon materials [1,8]. This material has a 2D or 3D structure, along with high strength, fragility, abrasive activity and low thermal conductivity, prone to chips and bundles in shock loads.

The complexity of the treatment consists in the fact that the polymer composite materials (PCM) are a combination of high-strength fibers with a matrix. The matrix provides a monolithic composite, fixes the shape of the product and the relative position of the reinforcing fibers, distributes the operating external voltages by volume of the composite, providing a uniform loading of the fibers and its redistribution in the destruction of the part of reinforcing fibers. Epoxy and polyamide resins are used as matrix.

When cutting composites, its components react differently to the action of the cutting edge, resulting in a possible violation of the structure of the material [2]. On the other hand, the tool itself undergoes a significant impact: its edges quickly wear out, changing the scheme of force [3]. In most cases, the quality of the surface layer when machining is directly determined by the scheme of reinforcement of the material, its composition. Researchers from leading countries of the world are working to improve the cutting tool to ensure its quality.

However increasing the processing efficiency may be affected due to changing the working conditions of the tool, in particular, diamond-bearing, ensuring such a dynamic contact of grains of diamond with the material, in which rational conditions of microscope will be maintained for a long time. From works [4–6] it is known that the synergy of worker movements can significantly intensify the processes of destruction of material, and the application of genetic and morphological analysis methods of electromechanical systems allows the selection of a set of new technical solutions to ensure these conditions.

EXPOSITION

The purpose of the work is to develop and economically substantiate a new technical solution for the effective drilling of carbon fibers by diamond-shaped tubular drills.

The analysis of publications reflecting the study of the processing of composites, in particular, V. I. Drozhzhin, M. V. Veresub, O. F. Salenko, N. Griffits, G. Irwin, A. Ewance, B. Louwin, etc., proves that the main mechanism of formation of new surfaces under mechanical influence is the process of formation of chips, which is connected with the multiplicities of origin and development of microdefects, which lead to cracks in the body of the material being processed at the macro level.

The power drill pattern of a tubular drill is similar to the load when cutting materials only on the microscopic level of process consideration, that is, when a single abrasive grain is an elementary cutting wedge. However, in addition to the tangential loads of the cutting zone, the latter perceives a significant axial load, as a result of which the

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most dangerous defect is the bundle between the adjacent layers of reinforcement perpendicular to the direction of the force.

Thus, it can be concluded that the drilling of loose composite materials (in particular, carbon-carbon group) will be accompanied by the active development of defects in adhesion and cohesive nature, fiber removal and increased strength when decreasing the cutting capacity of the diamond-bearing layer. This requires consideration of material behavior at micro and macro levels.

Let such an element be a cylindrical body of diameter dv, on which surface is the layer of carbon dioxide s_{pv}, and the layer of the cavity s_{pp} (Fig. 1).

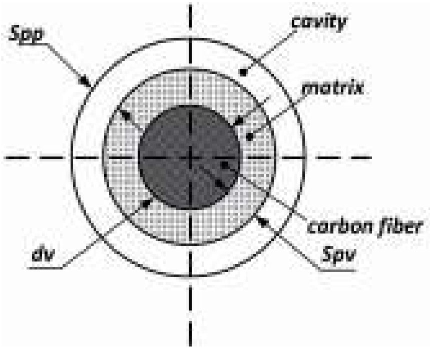


Fig. 1. Initial Structural Element (ISE) and its geometric characteristics

These layers can be characterized as follows: cylindrical body diameter dv consists of a set of carbon single directed fibers, an intermediate layer of thickness s_{pv} – isotropic pyrocarbon, the layer s_{pp} – a conventionally hollow layer with separate multi-directional oriented fibers.

If we take into account that for the infinitely small parallelepiped deformating the components of the deformation tensor are defined as

$$\varepsilon_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial v_j} + \frac{\partial u_j}{\partial x_i}\right), \quad i, j = 1,2,3$$

u_2, u_3 – projections of complete displacements on the axis x_1, x_2, x_3, then the Hooke's law for an isotropic body will have the form:

$$\begin{aligned} \varepsilon_{11} &= \frac{1}{E}\left[\sigma_{11} - \mu(\sigma_{22} + \sigma_{33})\right], & j_{12} &= \frac{\sigma_{12}}{G}; \\ \varepsilon_{22} &= \frac{1}{E}\left[\sigma_{22} - \mu(\sigma_{11} + \sigma_{33})\right], & j_{23} &= \frac{\sigma_{23}}{G}; \\ \varepsilon_{33} &= \frac{1}{E}\left[\sigma_{33} - \mu(\sigma_{22} + \sigma_{11})\right], & j_{31} &= \frac{\sigma_{31}}{G}. \end{aligned} \qquad (1)$$

where E – is the elastic modulus of the material, G – is the displacement module, and μ – is the Poisson coefficient, moreover $G = \frac{E}{2(1+\mu)}$.

With its motion, the grain is abrasive interaction with each component of the ISE. However, the condition of the operation of individual grains on the end and on the side surface is different.

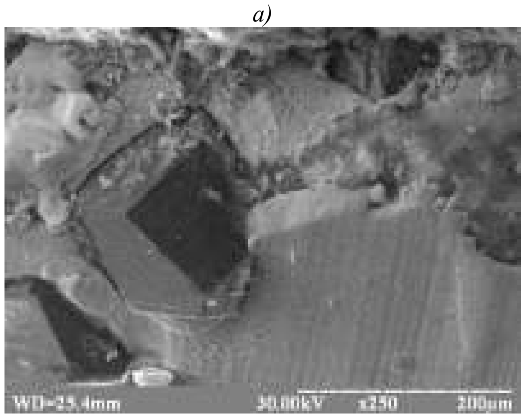
The surface surface (grain Z_3), which can be presented at the macro level in the form of a discontinuous surface layer, takes the load from individual grains with the cavity t_p defined as $t_p=d_v/2+s_{pp}+s_{vv}$. Such interaction can be represented as a jump-like deepening of a conical indenter (diamond) under the influence of the axial P_z at a depth h, resulting in a grinding with a grinding angle β, after which the tangential force P_y is applied. In the beginning, the slider of the indenter along the creature cone is brought up under the action of the component t until the time when the force is sufficient to destroy the layer with h_1 depth. In this case, the indenter overcomes the friction between the chips and the main material. The value of sliding indenter is determined by the radius of rounding of the single grain. The interaction of diamond grains with the surface of the treated material with respect to the depth of the hollow h to the radius of rounding of the cutting edge ρ of less than 0.01 is characterized by elastic extraction of the material, that is, the absence of its removal.

For the estimation of the expected size of the sludge particles, the geometric parameters of the ISE (Fig. 2a) and the individual cutting grain (Fig. 2b) have been determined on the received micro and microelectronic photo of the samples.

The analysis of the results of calculations proves that an increase in the applied axial force will cause an appropriate increase in the stresses on the contact surface and the splitting of individual fibers and their conglomerates will occur. Excessive stresses exceeding 40 MPa greatly increases the size of the sludge particles; and based on the physical model of surface formation with single grain we can conclude that the surface roughness will grow. These results are reflected in [2].

The effect of orientation of fibers on fractional slime is not significant within the stresses of 15–40 MPa; orientation of fibers at angles approaching π/4 leads to a decrease in the fractionality of the sludge by 20...35%. Significant influence on the size of the particles of the slime is the frequency of oscillations of the working tool.

a)



b)

Fig. 2. Micro- and microelectronic photo-structures of the carbon-carbon composite of spatial weaving (a) and the surface of a diamond-shaped tubular drill (b)

Overlapping of the corresponding vibrations on the working tool (due to cyclic linear feed) greatly increases the drilling efficiency. To provide this movement (supply with oscillatory displacement of the ends), a technical solution is proposed for a power drive with connected electric machines [4, 8].

The schematic diagram of the device – the spindle node is shown in Fig. 3. The assembly consists of a housing 1, which, on the one hand, with the possibility of longitudinal motion along the central axis, mounted a pin 2, fixed from the possible rotation of the pin 3, which is in contact with the rectilinear guide groove 4, located on the housing 1.

The moving stroke 7 of the main motion electric motor with a winding of 7 is mounted on the moving pin 2 with the terminals for supplying the voltage 6 so that the axes of the piston 2 and the windings 5 coincide. In the inner cavity of the pencil 2, a motionless stator 5 of the flow feeder with a winding 7a with terminals for supplying voltage 8, inside of which a rotor 9 is installed, is fixedly connected to the spindle 10, made in the form of a shaft, one of the ends of which has a flange for fastening the tool 11, and on the other end a screw surface 12 is provided. To provide a rotational motion, the spindle 10 is mounted on the thrust-radial supports (bearings) 13 and 14, mounted in the pin 2.

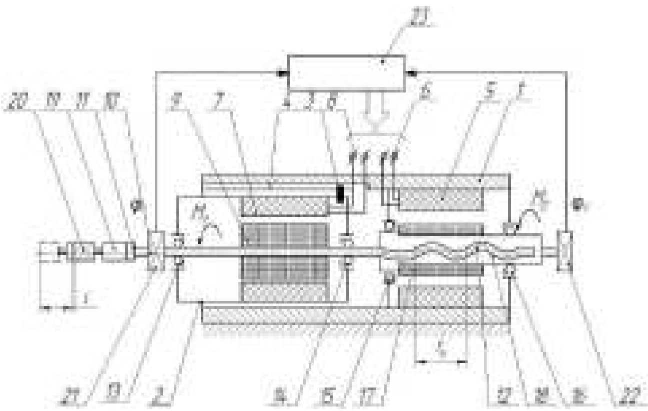


Fig. 3. Principle diagram of the power head

Concentrically to the stator 7 in the radial tensile pins 15 and 16 mounted in the body 1, a rotor 17 is located fixedly connected to the nut 18, with the axis of the rotors 17 and 9 and, accordingly, the spindle 10 and the nuts 18 coincide, and the screw surface 12 of the spindle 10 is connected to the screw surface of the nut 18, forming a mobile screw-nut type with it.

The flange 19 is mounted on the flange 11, in which the tool 20 is secured. With the output end of the spindle 10 and the end of the nut 18, the sensors of the angles of turns 21 and 22 are connected, which, in turn, are connected to the control system 23 and control the angles the rotation φ_1 of the spindle 10 and φ_2 of the coupling 18. The control system 23 is connected to the output circuits with terminals 6 and 8, and together with the sensors of angular positions 21 and 22 forms a closed electromechanical circuit.

Such a combination of a housing with a movable spindle and a clamping device, a veneer located in the front of the body, a stator of an electric main machine, a spindle with a distributed winding, fixed inside the vane, a rotor rigidly connected to the spindle, and an electric drive in the form of an additional stator An electric machine coupled to the body and mounted in a coil of the spindle and the rotor, which interacts through the "screw-nut" connection with the spool, makes it possible to perform the flow of motion in the event of a difference in angular velocity Awning two rotors, which is controlled by the appropriate control system. In this case, the coaxial performance of the electric drive frees the spindle and allows you to balance the feedstock during drilling; the absence of extra gear and other gear increases the accuracy and stability of the system.

For verification of the formulated provisions, the simulation, fabrication and testing of combined electric machines, performed on the principle of stepping motors, was carried out. The system of differential equations is given below.

$$J_R \frac{d^2\varphi_1}{dt^2} = M_e^I - M_k - M_{01} - C_1(\varphi_n - \varphi_1) - b_1\left(\frac{d\varphi_n}{dt} - \frac{d\varphi_1}{dt}\right)$$

$$J_0 \frac{d^2\varphi_n}{dt^2} = C_1(\varphi_n - \varphi_1) - b_1\left(\frac{d\varphi_n}{dt} - \frac{d\varphi_2}{dt}\right) - M_{fr} - C_1(\varphi_2 - \varphi_n) - b_2\left(\frac{d\varphi_2}{dt} - \frac{d\varphi_n}{dt}\right)$$

$$J_2 \frac{d^2\varphi_2}{dt^2} = M_e^{II} - M_{02} + C_2(\varphi_2 - \varphi_n) - b_2\left(\frac{d\varphi_2}{dt} - \frac{d\varphi_n}{dt}\right)$$

$$\frac{d\varphi_1}{dt} = \omega_1; \quad \frac{d\varphi_2}{dt} = \omega_2; \qquad (3)$$

$$m_1 \frac{d^2 Z}{dt^2} = -P_z + C_3 k(\varphi_2 - \varphi_1) - b_3 k\left(\frac{d\varphi_2}{dt} - \frac{d\varphi_1}{dt}\right); \quad \frac{dz}{dt} = v_z$$

where φ_1, φ_n, φ_2 – respectively the absolute angles of rotation of the spindle, coupling, and rotor of the second electric machine and the moment of inertial damper; C_1, C_2, C_3, b_1, b_2, b_3 – dynamic coefficients of the mathematical model; M_{fr} – moment of friction, M_k – the moment of the kinematic chain between the motor shaft and the coupling; M_{01}, M_{02} – the total torque of the nut resistance; M_e – the moment of electromagnetic forces acting on the rotor.

The electromagnetic processes in the motors were described by known regularities, which are not given here due to the limited volume.

By simulating the work of connected electric machines, control pulses were set so that at corresponding rotation of the output end of the spindle ϕ_i and linear axial feed θ_i, and with a fixed base on the surface of the treatment, corresponding loads appeared in accordance with Fig. 4.

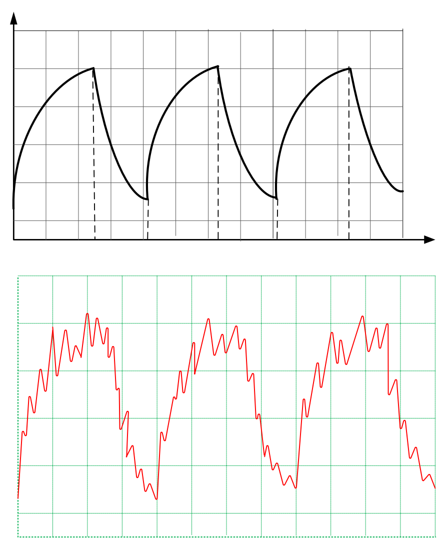


Fig. 4. Cyclically variable load of the working tool during drilling

Since, in the process of drilling a material, which is long fiber reinforcing carbon fiber and pyro carbonate layers, it is converted into fine particle dust of sufficiently small fractionality. Divided into a gap between the formed surface of the treatment and protruding diamond grains, the dust under the action of a number of forces begins to move. In this case, the adhesive properties, aerodynamic, contact interaction between the particles and the surface, as well as the inertial forces are manifested. The dust particles stick to the surface, changing the height of the abrasive grain leaving and changing the spot of the dynamic contact between the tool and the material being processed.

A detailed physical description of the phenomena in the cutting zone allowed to perform the mathematical modeling of dust formation and to obtain the regularities of the change in the intensity of the dusting of I_i (and, accordingly, the concentration of dust particles in the K_i) in the gap between the tool base and the surface to be processed. Comparison of controlled indicators has proven that a more stable and long-lasting treatment with a low frequency (up to 50 Hz) fluctuations and a certain law of motion of the end of the instrument.

Since the proposed solution for the application of two connected electric machines allows to perform modulated control over a wide frequency range and provide various forms of oscillations, a model of the device was made and a test of processing of carbonaceous materials was performed. As a result of checking the quality of the edge (Fig. 5), the application of the proposed device allows practically eliminating the appearance of bundles, pulling out the fibers, and damaging the matrix adjacent to the zone of the drill zone.

Fig. 5. The quality of the hole processing ∅3.0 mm in the material VKU-25

To solve the issues of rational conditions for processing, an experiment plan [7] was implemented to find appropriate regression equations to determine the functional conditionality of the parameter R_z by the most effective factors: the angle of stacking of fibers relative to the direction of drilling α , the diameter of the fibers d_v , the speed of the abrasive particles V_a and the magnitude of the stress in the material σ . The polynominal model is derived on the basis of the quad right-factor rotatable planning of the second order.

Statistical processing of the experimental allows to write the following equation:

$$\begin{aligned} R_z &= 6,28537-0,659889\alpha+35,5631d_V+ \\ &+0,755159V_a-0,318388\sigma+0,00468889\alpha^2+ \\ &+0,133704\alpha d_V+0,0159259\alpha V_a+0,0068\alpha\sigma- \\ &-15,2917d_V^2-0,0166667dV_a+ \\ &+0,309048d\sigma-0,0693556V_a^2+ \\ &+0,0235238V_a\sigma-0,000804082\sigma^2 \end{aligned} \tag{4}$$

The adequacy of the models is confirmed by the high determination coefficient R^2 , equal to 91.2%.

CONCLUSION

The process of diamond drilling by means of tubular drillings of composite plastics on the basis of carbon fibers is explored. It is shown that in order to improve the process efficiency, it is necessary to impose on the working too additional movements that activate shredding of chips and ensure its active removal from the processing zone.

To implement the proposed concept of processing, a fundamentally new technical device – a power head with connected electric rotary type machines – has been developed. This solution allows to generate in a motor-spindles imposed on a working feed the periodic oscillation with variable load amplitude.

Will be study the influence of the stochastic properties of the processing process as a loading on the proposed electric machine, in particular, the system's reaction rate for perturbation during the drilling process of composite material.

The test drilling on the material VKU-25 is given, the proposed regression equations for determining the rational conditions for the processing.

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