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Perspective Drilling Methods, Non-Technological Holees in Polymeric Composite Materials

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Abstract

The article discusses the issues of improving productivity and quality when drilling non-technological holes in polymer composite materials. Systematization of non-technological holes was carried out, promising methods of drilling with varying cutting modes when inserting and entering the drill were developed and introduced into production, as well as a method of grinding outgoing chips and removing it and the cutting zone. A mathematical model of the influence of drilling modes and methods on the accuracy and quality of holes is obtained. The algorithm of the proposed drilling methods for machine tools with programmed control has been compiled. A method has been developed for determining the degree of loosening of holes after drilling PCM.

Keywords: Non-technological holes, polymer composite materials, chip crushing, chip removal, drilling, quality, accuracy, resistance, drilling methods, cutting, loosening modes, pneumatic drilling device.

INTRODUCTION

In recent years, the share of polymer composite materials (PCM), which have high physical, mechanical and operational characteristics, has been growing rapidly in industry. Their application allows to obtain products with properties that even traditional materials do not possess.

Composite materials with a polymer matrix based on carbon or carbon fiber are widely used in mechanical engineering. This material is characterized by high strength, elasticity and low density.

PCMs are fundamentally different in structural structure, in the nature of achieving the required mechanical properties and production technology, which significantly complicates the choice of methods for connecting these materials to each other. The connection by the method of installing fasteners in the machined holes of the products, from the above materials, in most cases is the only possible way to assemble them into the structure.

The analysis of literature data shows that the accuracy of the hole obtained by drilling is affected by the main technological parameters of the process, namely: cutting speed and feed, and a number of additional process parameters: lubrication, cooling, the mechanism of crushing and chip removal. The presence of lubrication and cooling improves the surface quality and accuracy of the holes and allows you to increase the cutting conditions in order to increase productivity. Chip removal, excluding its packing in the hole, also improves surface quality and hole accuracy. The most important, from the point of view of optimizing the process of drilling holes, are the cutting speed and feed, they will be considered as the main factors. [1,2]

Due to the lack of evidence-based recommendations for choosing a drilling method and cutting modes, the productivity of the cutting process is not high, the durability period of tools, in particular drills, is also quite low. The quality of the hole during drilling, due to delamination at the entrance and exit of the drill, the packaging of the outgoing chips is very poor. The most acutely indicated features are manifested in the processing of drilling of non-technological holes in parts made of polymer composite materials. [7]

The search for ways to increase productivity and improve quality when drilling non-technological holes in PCM, as well as the development of specific evidence-based recommendations on the method and technology of drilling are currently an urgent task.

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Figure 1 shows the most typical types of non-technological holes for drilling in RMB and the existing methods for processing recommendations.

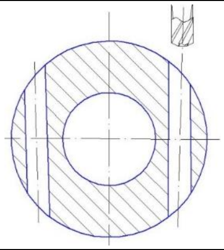
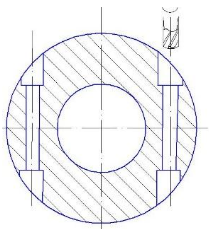
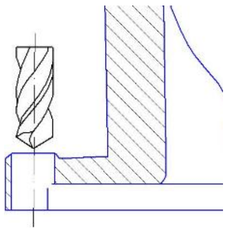
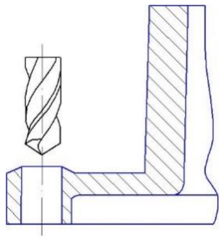
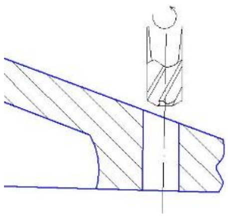
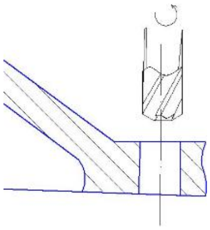
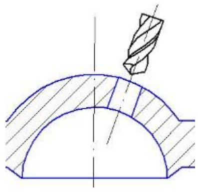
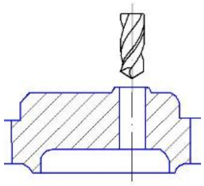
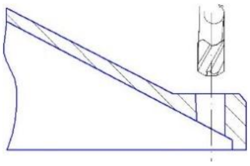
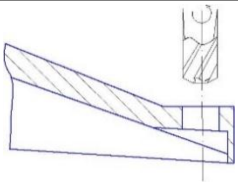
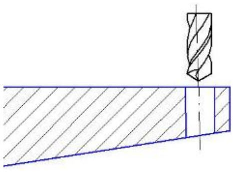
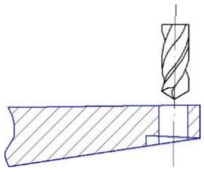
Non-technological holes	**Recommended drilling methods**	**Non-technological holes**	**Recommended drilling methods**
1	**2**	**1**	**2**
			
			
			

Fig. 1. Types of non-technological holes in parts made from PCM and recommended drilling methods

As can be seen from Fig. 1. the drilling process of non-technological holes is complicated due to the drift of the drill during cutting into the inclined and spherical surfaces of the part, which leads to a bending of the working part of the drill, which contributes to a sharp deterioration in the accuracy and quality of the holes, reducing the tool life.

Diameter errors (size and shape errors) of the hole in the PCM are most clearly manifested at the tool inlet. At the output of the tool, diameter errors are usually less. The reason for this kind of defects is usually an additional removal of material from the walls of the PCM hole at the drilling stage. Chip during the drilling process moves from bottom to top along the chip groove of the drill. Since the PCM polymer matrix has low hardness, the movement of the chips leads to undesirable "indentation and adhesion" of the material to the walls of the hole. Most often, this leads to hole shape errors with reduced quality.

Defects caused by the PCM texture arise due to inconsistent chip formation conditions due to the anisotropic structure of the material. The occurrence of tearing of fibers and microprofile defects is a consequence of the action of cutting mechanisms. Defects at the exit of the tool from the hole are the result of the development of the fracture process in the area of the top of the drill when it leaves the PCM. The uncut fibers are the remnants of the PCM filler fiber remaining along the edge of the hole from the outlet side of the tool. Their formation is due to the orientation of the filler fibers in this area with respect to the velocity vector of the cutting edge so that the moving cutting edge does not cut them, but crushes them. As a result, the remains of uncut wrinkled fibers are bent over the edge of the hole in the feed direction, and after the end of the cutting process, they partially restore their original shape. Defects at the outlet of the tool are caused by "peeling" of the material due to insufficient interlayer adhesion of the filler layers.

At present, for the implementation of the process of drilling non-technological holes, it is necessary to manufacture special devices, use conductive bushings. They also carry out preliminary preparation, perform an additional operation, which, of course, significantly increases the cost of the product. This problem is most acute when the drill leaves the cutting zone. Since it is impossible to use the special devices discussed above used when cutting a drill.

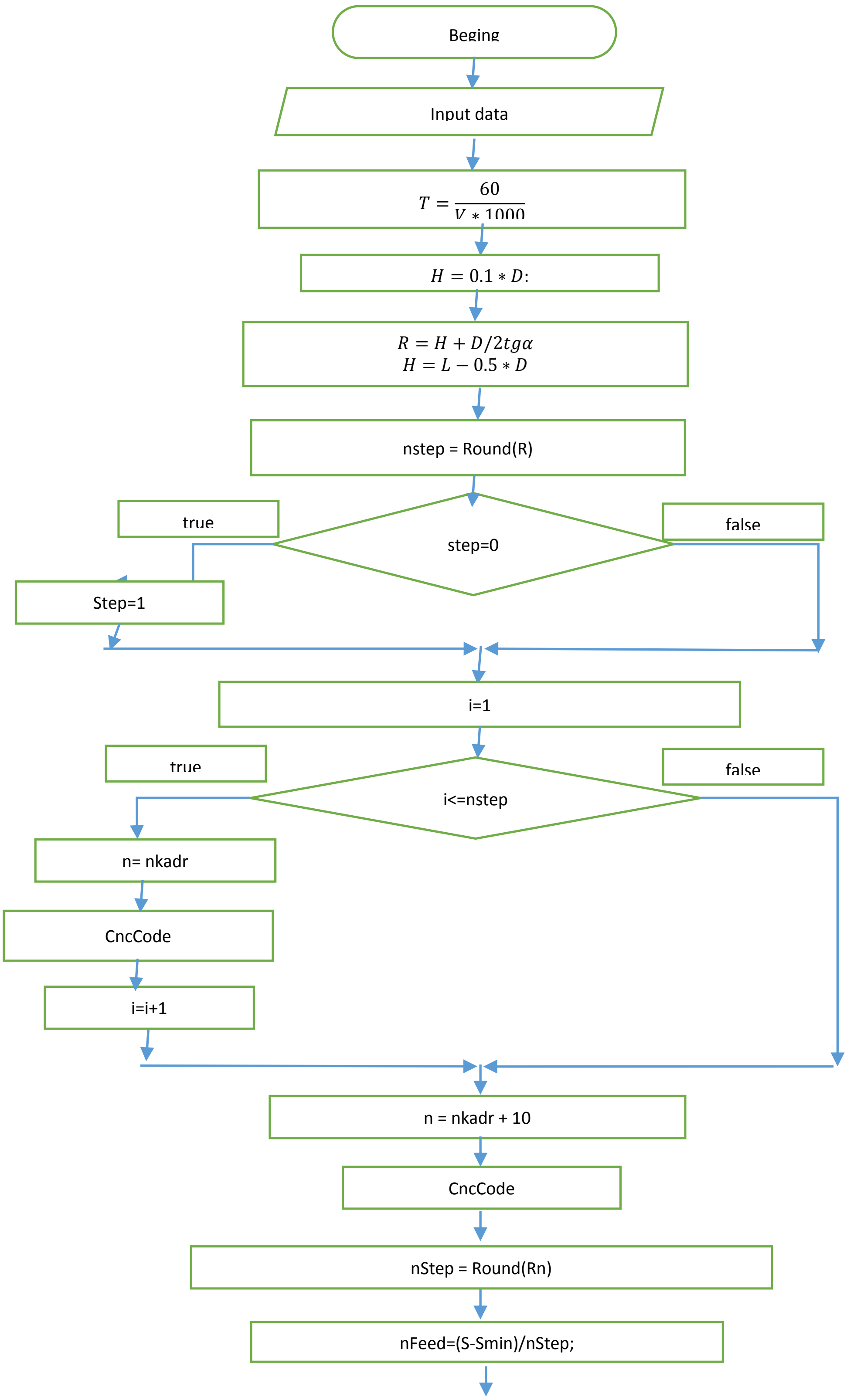
In addition, the disadvantages of the known methods of drilling is also the low quality of the machined holes, the presence of chips and loosening of polymer composite materials, especially in the exit zone of the drill, the low resistance of the drill.

METHODS IMPROVEMENT PERFORMANCE AND DRILLING QUALITY PCM

As noted above, PCM drilling is the most difficult task due to the processing conditions that cause various requirements for cutting conditions and cutting tools.

The introduction of new methods for processing holes, the rational choice of cutting tools and cutting modes contribute to achieving the required quality of the holes, minimizing their cost, increasing the accuracy of the holes made of carbon fiber.

We have proposed a method for drilling non-technological holes according to which, the drill is informed of rotation and axial movement with adjustable feed and cutting speed when plunging, drilling a hole and the drill exit from the cutting zone. (fig. 3) [3]



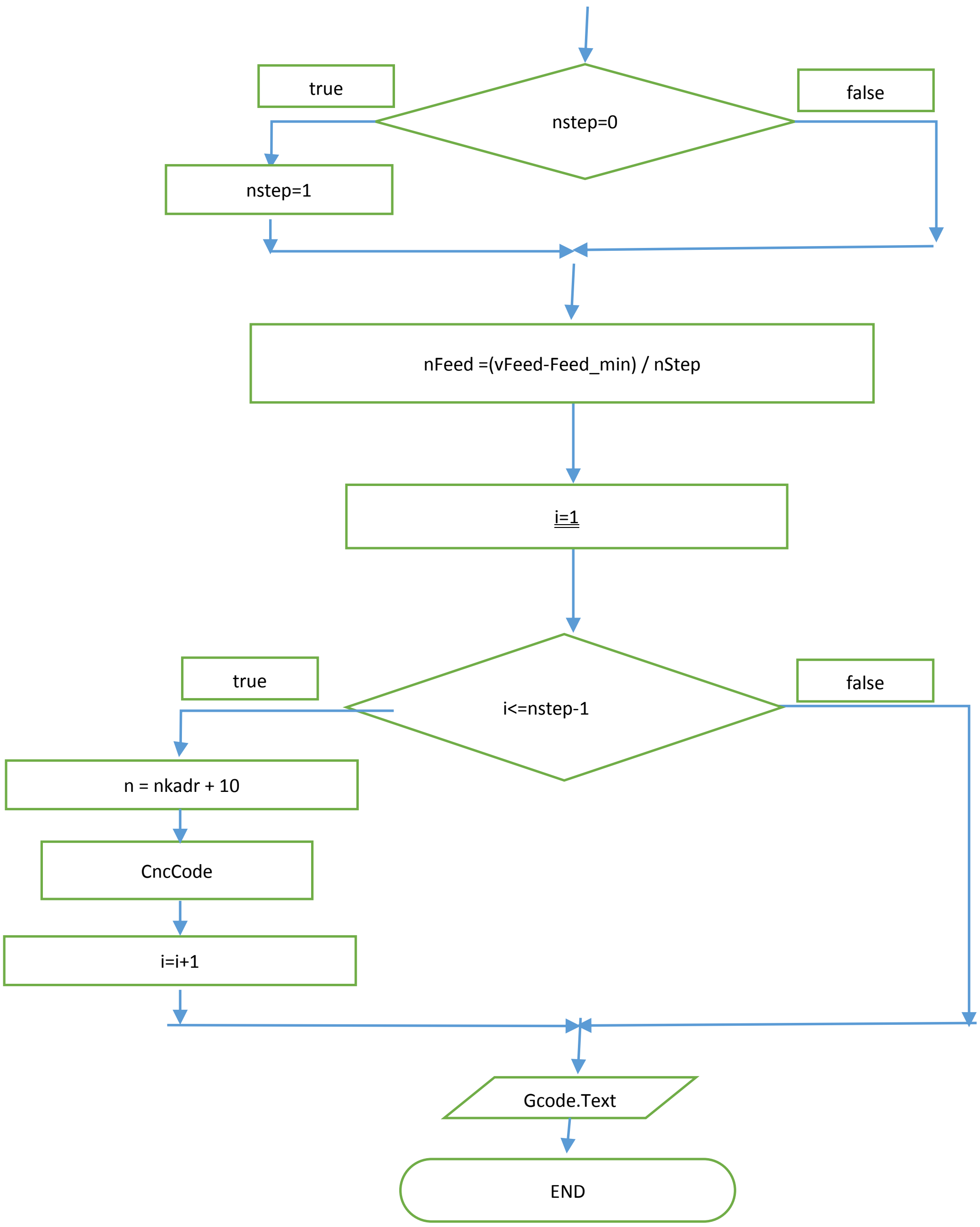


Fig. 2. Flow chart for drilling non-technological holes with variable feed.

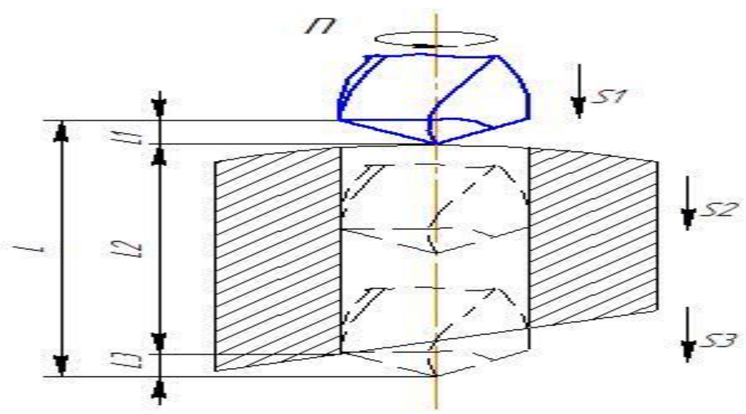


Fig. 3. Recommendations a method for drilling non-technological holes with variable feed.

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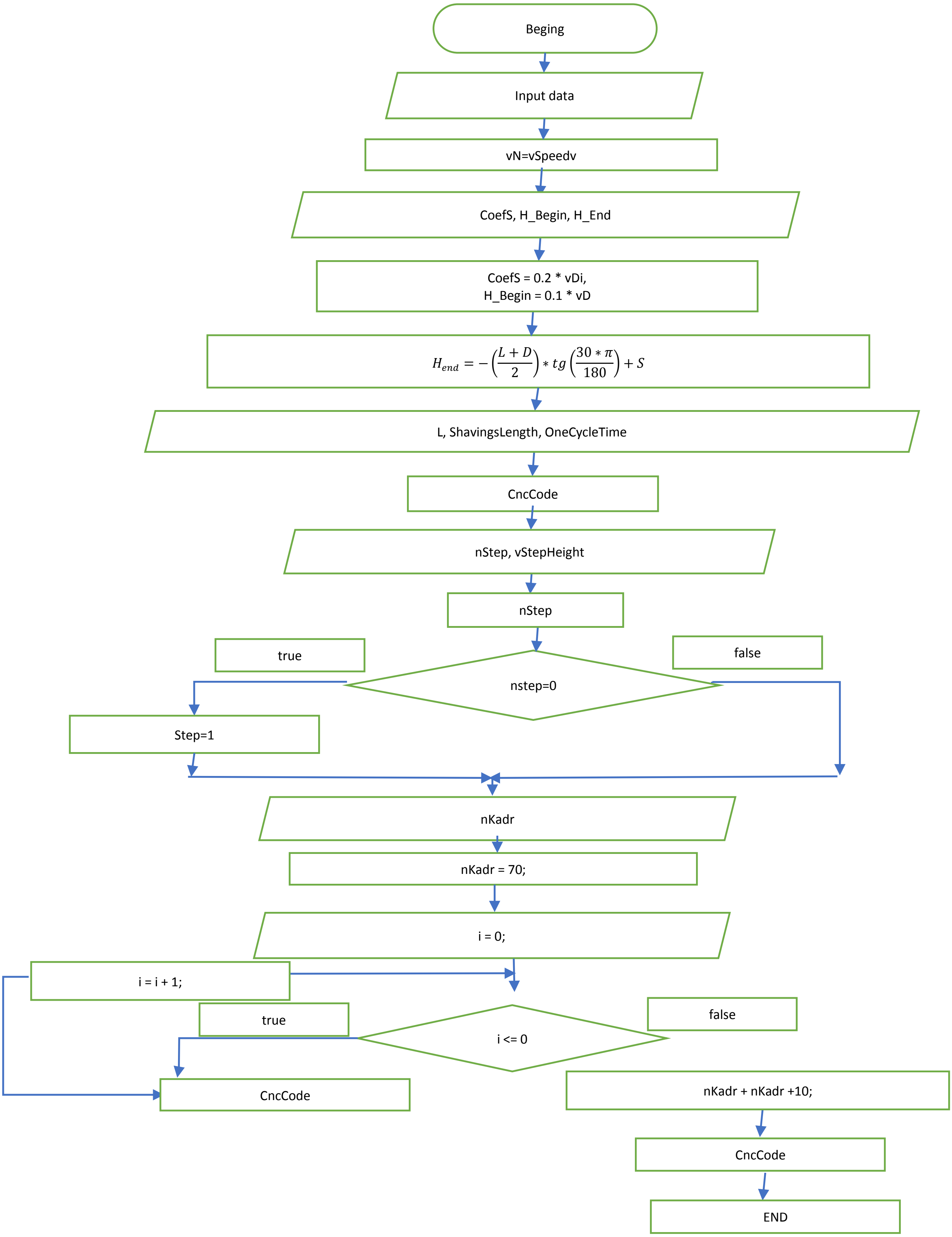

Figure 4. The block diagram of the method for producing chips with a predetermined length when drilling on machines with programmed control. [4]

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The proposed method is carried out in the following sequence. The drill rotates and axially moves, and during drilling, after a quick approach to the drill during insertion, the cutting speed and the feed rate of the drill change. After the cutting part of the drill enters the cutting zone, the feed and cutting speed are automatically adjusted in accordance with the recommendations for PCM drilling. Further, when the drill leaves the cutting zone, the feed rate and cutting speed are automatically adjusted again.

In order to prevent jamming of the falling and pressed chips from the cutting zone during the drilling process, it is proposed to periodically stop the axial feed of the drill for crushing them, which will lead to separation into small parts of the chips, preventing jamming of the falling chips between the tool and the hole, and prevents pressed chips (Fig. 4) [3,4].

This method of drilling polymer composite materials consists in the fact that the drill is informed of rotation and axial movement with a periodic stop of the axial movement of the drill for at least one revolution of the drill, which makes it possible to stabilize the dynamic characteristics of the processing process and improve the quality of the holes being machined by crushing chips, exceptions from pressing during chip removal along the grooves of the drill, improvement of chip removal, especially when processing on automatic lines.

The effectiveness of the proposed method of drilling, in comparison with known analogues, was evaluated by the quality of the machined holes and the resistance of the drill. In addition, when processing products by known methods in the areas of the drill exit from the workpiece, even chips and loosening were visually detected.

The hole drilling operation was performed under the following processing modes: V=0.125 m/s, S=0.2 mm/rev; V=0.125 m/s, S=0.6 mm/rev; V=0.2 m/s, S=0.2 mm/rev; V=0.2 m/s, S=0.6 mm/rev. The existing technology provides for the modes V=0.12 m/s, S=0.1 mm/rev with a periodic output of the drill to remove chips. In the processing process, the nature of chip formation and the degree of its packaging were determined. After the drilling process was completed using the microscope, the dimensions of the bundles were determined as the maximum damaged diameter relative to the nominal diameter of the holes. The resulting defect sizes were, compared with the size of the delaminations in the conventional drilling method. The surface roughness of the machined hole was, determined by the contact method using a profilometer. The wear of the drill was, assessed after completion of processing the entire series of holes using an instrumental microscope.

According to the test results, it was found that the application of the proposed drilling method with periodic tool stopping due to better crushing and evacuation of the chips from the cutting zone and reducing the degree of its packing allows reducing delamination sizes to 0.3-0.6 mm against 1.05-1.3 mm with the existing drilling method. The roughness is, reduced from Ra 7-8.5 microns to Ra 5.5-6.2 microns.

Thus, when processing with a periodic stop of the axial movement of the drill, these types of defects are absent, which provides an increase in the resistance of the drill and the achievement of the quality of the machined holes.

Further tests consisted in sequential processing of through holes at fixed cutting conditions v=0.15 m/min, s=0.050 mm/rev. The purpose of the tests was to compare drilling methods in terms of durability and quality of the resulting holes.

The hole diameters were measured in one central section. The graph (Fig. 5) shows the deviations of the diameters of the holes from the diameter of the drill.

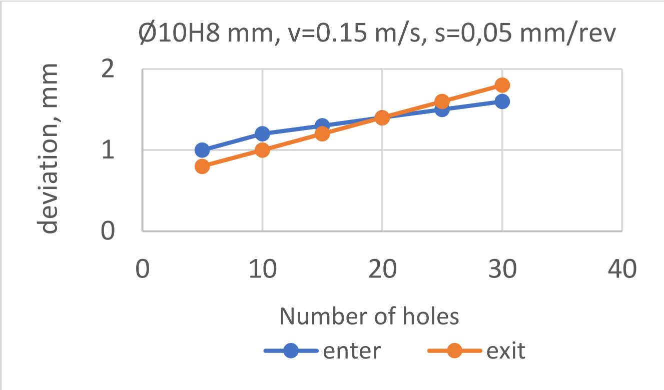

Figure 5 - Effect of the number of drilled holes on the deviationThe degree of conformity of the diameters of the holes to the established tolerance was estimated by comparison. The target value corresponds to a rejection probability of 0.27%. To calculate the sigma level, we used the tolerance for the manufacture of holes adjusted by the tolerance for the manufacture of the tool and its wear. The adjusted tolerance Δ_{dev} was 30 mkm.

Statistical data on the diameters of the holes obtained by different methods of drilling are summarized in table 1.

Table 1 Hole Diameter Statistics

Drill	**Number of machined holes**	**The average deviation of the diameters of the holes, mm**	**Standard deviation δ, mm**
Existing method	10	D_c+0.016	0.0035
	20	D_c+0.015	0.008
	30	D_c+0.014	0.0086
The proposed method	10	D_c+0.009	0.005
	20	D_c+0.008	0.006
	30	D_c+0.007	0.007

According to the results of experimental tests with the existing method for drilling 30 holes, the diameter of the holes is stable at the level of reject less than 0.27%. The range of variation in hole diameters is 26 µm, with a maximum permissible value of 30 µm, which corresponds to the processing of holes of the 9th accuracy class.

The proposed method with a resistance of 20 holes had a range of variation of diameters of 32 µm, which is suitable for processing holes of the 10th accuracy class.

The hole roughness parameter Ra was measured using a profilometer. Graphs reflecting the change in the roughness of the walls of the number of machined holes are shown in the figures.

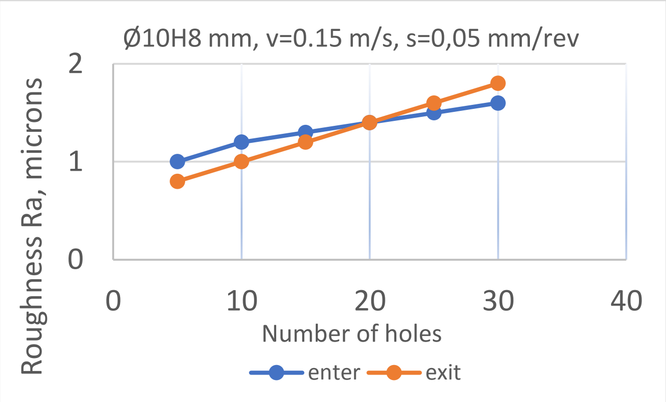

Figure 6 - Effect of the number of drilled holes on the roughness

We will evaluate the degree of conformity of the roughness to the established tolerance by comparing the average values for different tool life (10, 20, 30 holes). An additional assessment parameter will be the maximum roughness value.

The statistical data on the roughness of the holes are summarized in Table 2. The average roughness in the PCM is Ra3.64, the maximum value of Ra is 4.98 among the 30 machined holes.

Table 2 Roughness Statistics

Drill	Number of machined holes	Ra, mkm	
		Medium	Maximum
Existing method	10	2,6	2,56
	20	3,1	3,38
	30	3,96	4,68
The proposed method	10	3,05	4,05
	20	2,55	3,86
	30	2,7	2,35

The proposed drilling method provides the best roughness in PCM.

Due to the lack of physical and mathematical regularities of the processes occurring in aerodynamic devices for removing chips along the groove of the drill, further research has been carried out in stages.

At the first stage of the study, the regularity of the functioning of aerodynamic flows in the chosen design scheme was determined and the interaction of the flow with the freely placed shavings was considered. At the second stage of the research, the possible variants of the devices were considered and the basic variant was chosen for solving a specific problem. It should be noted that the theoretical dependences obtained in the first stage should be acceptable for the analyzed options.

The consistent implementation of these steps will allow us to develop non-driven automatic aerodynamic devices.

Before proceeding to the theoretical descriptions of the processes in the calculation scheme, we consider the phenomena that occur during the operation of an aerodynamic action device.

The analysis carried out in the course of the study showed that the aerodynamic phenomena that create forces primarily affect the nature of the flow of chip removal. In the process of considering the aerodynamic forces of the flow acting, we are faced with a peculiar task, which is located at the junction of solid mechanics and aerodynamics.

An analytical description of such a problem is possible only in the case if we have a solution of the equations of gas dynamics in a region with a variable boundary [6].

Significant difficulties are also presented by the determination of the aerodynamic forces of the flow acting on the chips.

Without experimental data, it is practically impossible to obtain the required dependences of the functioning of aerodynamic action devices.

For theoretical studies of the processes inside the aerodynamic action device in order to determine the dependences of the rotational air flows and their interaction with the chips, we will take as the basis the calculation scheme shown in Fig. 7

An analysis of the known developments showed that a potential method for solving the removal of the chip problem from the cutting zone is to use the energy of swirling flows.

If the developed vortex device is installed vertically, the lower end is closed, and loose products are placed inside, we will get a device where, in the process of functioning of the latter, movement in the circumferential and axial directions is carried out only with the help of compressed air energy (Fig. 7).

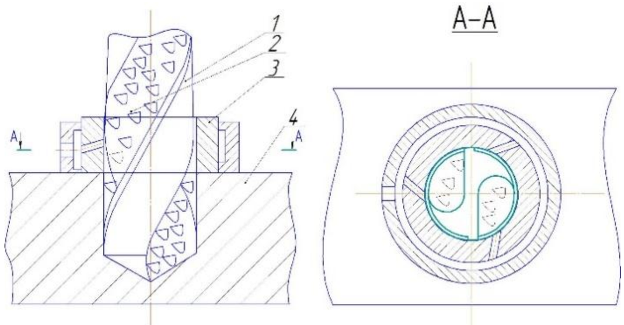

Fig. 7. The design scheme of the device aerodynamic action

1-drill, 2-shavings, 3-hole device, 4-part (RMB)

The principle of operation of this device is as follows: compressed air, entering the cylindrical pipe through tangential nozzles, acquires rotational and axial motion. As a result of the interaction of the rotating stream with a freely located chip in the groove of the drill, which begins to rotate at a speed proportional to the air flow. The presence of axial flow velocities directed to the exit creates an axial force for moving the chips along the axis of the drill along the groove without any mechanical drive mechanisms.

Compressed air through tangential nozzles enters the holes and interacts with the freely placed chips. In this case, the energy of the rotating flow is divided into two components: axial and peripheral speed. The axial component moves the chips along the axis of the hole and the circumferential component rotates with a frequency proportional to air flow [6].

As is known, a stationary rotary flow moving in a hollow cylinder can be determined at each point in space by its following main parameters: pressure, velocity components (district $\overline{V}_\tau$, axial $\overline{V}_z$, radial $\overline{V}_r$) and flux density ρ.

We make a number of simplifying assumptions.:

a) peripheral speed distribution $\overline{V}_\tau$ the flow in the nozzle section of a vortex tube is described by the law of a free vortex;

в) steady-state gas flow in is accepted isentropic.

In accordance with the assumptions made, the peripheral flow rate $\overline{V}_r$ represented as a constant in the range.

$R - r = r_s$

At $\overline{V}_\tau$ in the range under consideration is determined mainly by the velocity of the outflow of air from the nozzle openings, i.e. assume that with $R_\omega \leq r < r_s$,

$$V_\tau = V_c \,.$$

Given the assumptions, the original system of equations has the form:

Navier-Stokes equation of motion

$$V_\tau \frac{\partial V_\tau}{\partial r} - \frac{V_\tau^{\,2}}{r} = \frac{1}{\rho} \cdot \frac{\partial p}{\partial r} \qquad (1)$$

Neglecting the axial velocity of movement, which affects only the perfection of the energy exchange process and taking into account that in the zone of separation of the vortices it is equal to zero and the interaction of the chip with the flow occurs only in the zone of the free vortex, from the equations of motion (1), which in our case will take the form

$$\frac{V_\tau^2}{r} + \frac{1}{\rho} \cdot \frac{dP}{dr} = 0 \qquad (2)$$

and expressions (2), we can determine the distribution of static pressure in a free vortex

$$P = P_1 \left[1 - \frac{K-1}{2} M^2 \left(\frac{1}{r^2} - 1 \right) \right]^{\frac{K}{K-1}} \qquad (3)$$

where M is the Mach number at the periphery of the free vortex,

$$M = \frac{V_\tau}{a} \,;$$

P_1 – static pressure at the periphery of a free vortex in the nozzle section is equal to P_1=(0,55÷0,60) P_c;

R – current radius in the considered section;

K – adiabatic coefficient (for air K=1,2);

$a = \sqrt{q \cdot K \cdot R \cdot T_r}$ – critical flow rate equal to local flow velocity;

V_c – air velocity from nozzle openings;

q – gas constant; T_r – section flow temperature R - r.

With a known value of static pressure in the selected section, the corresponding flow density is found taking into account the equation of state of the gas and the adiabaticity of the flow and is expressed as:

$$\rho = \frac{P_1}{q \cdot R_r \cdot T} \left[1 - \frac{K-1}{2} \cdot \frac{V_\tau}{\sqrt{q \cdot K \cdot R \cdot T_r}} \left(\frac{1}{r^2} - 1 \right) \right]^{\frac{K}{K-1}} \qquad (4)$$

(4)

In accordance with the assumptions made, the peripheral speed is represented as a constant in the gap range R - r. In the selected calculation scheme, the number of nozzles is three, therefore, it can be assumed that the speed in the considered range R - r is determined mainly by the velocity of air flowing out of the holes - nozzles.

The rate of air flow from the holes - nozzles is equal to:

$$V_C = \sqrt{\frac{K}{K-1} \cdot q \cdot R_r \cdot T_{вых} \left[1 - \left(\frac{P_{вых}}{P_{вх}} \right)^{\frac{K}{K\ 1}} \right]} \qquad (5)$$

where P_{out} - outlet pressure;

P_{int} – vortex inlet pressure.

Subject to assumptions, the peripheral velocity in the nozzle section in the considered range can be represented as:

$$V_\tau = \frac{V_c \cdot R}{r} \,. \qquad (6)$$

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In view of the fact that the constant in R-r expression (2) is accepted, we can write

$$V_\tau = \frac{\sqrt{\frac{K-1}{K} q R_r T_{вых} \left[1 - \left(\frac{P_{вых}}{P_{вх}}\right)^{\frac{K-1}{K}}\right] R}}{r} \quad (7)$$

An analysis of the obtained dependences shows that to find a vortex tube in a specific nozzle section, it is necessary to set not only the pneumatic flow parameters, but also the design parameters of the device.

The effectiveness of the proposed method of drilling, in comparison with known methods is evaluated by the quality of the machined holes and the durability of the drill.

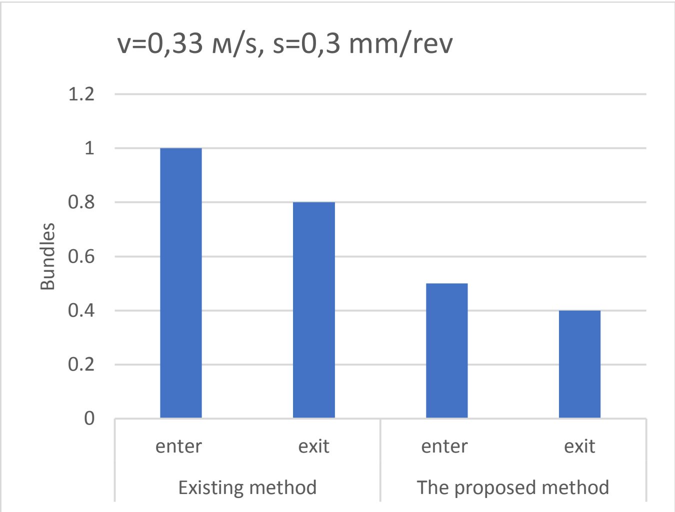

Fig. 9. Bundle Intervals

The results of the studies showed that when processing non-technological holes with an adjustable feed and cutting speed, depending on the drilling process, chips and rafting are not observed, the quality of the machined holes, the drill resistance increased

CONCLUSION

1. Based on theoretical and experimental studies of the patterns of chip formation and its impact on quality indicators when drilling PCM non-technological holes, processing methods are proposed that provide a significant reduction in defects, an increase in quality parameters, productivity and lower production costs.

2. As a result of experimental studies of the chip formation and chip packing process, a method for regulating the feed at the entrance and exit of the drill from the cutting zone is proposed, which allows to improve the quality of the holes in parts made of polymer composite materials.

3. A method has been developed and proposed for producing chips with a predetermined length when drilling for machines with programmed control, which is achieved by the fact that the drill is informed of rotation with a periodic stop of the axial movement of the drill for one revolution. Designed and introduced into production, a pneumatic-vortex unit for withdrawing descending crushed chips from the cutting zone during drilling.

4. According to the results of theoretical and experimental studies, the problem of increasing productivity, surface quality and hole accuracy by using the proposed drilling methods has been solved. The use of precision and high-quality drilling technology in composite materials with changes in cutting conditions depending on the position of the drill has improved the accuracy and quality of the holes. The technology for crushing drainage chips allowed to increase productivity by 20%, the use of a plant for removing outgoing crushed chips from the cutting zone made it possible to improve the quality of holes and increase drilling productivity by 20%. The annual economic effect is an increase in labor productivity by 1.4 times. The relevant acts of testing and implementation at the enterprise of the Republic of Uzbekistan are available.

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