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Technological Assurance Of The Milling Process Of Prismatic Channels In Heat Exchange Aluminum Alloys

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Abstract. **When milling prismatic grooves in aluminum alloy products, the technological parameters of the process must ensure the specified accuracy and processing performance. This guarantees the maximum heat exchange properties of the surfaces of the processed parts, critical for applications where efficient thermal management is essential. Enhancing these properties can significantly impact the operational efficiency of systems in aerospace, automotive, and electronics industries.**

Articles on the interrelationship of cutting modes and technological and energy parameters of the milling process of prismatic channels in aluminum alloys is an actual task. Its practical implementation will guarantee the improvement of various facilities for transferring and releasing thermal energy. This research could lead to advancements in heat sink design and more effective cooling strategies in high-performance engineering applications, where optimal heat dissipation is vital for maintaining system stability and prolonging lifespan.

Keywords: aluminum alloy products, milling process, technological assurance

I. INTRODUCTION

To establish the relationship between the parameters of the cutting mode and the cutting force, systematic experimental studies were conducted utilizing a rigorous methodological approach. These studies aimed to identify optimal settings that would maximize both the efficiency and precision of the milling process. Measurements were meticulously taken to ensure reliable and reproducible results, providing a robust basis for analysis.

As a criterion for optimization of the process of milling channels in aluminum alloys, the value of the components of the cutting forces P_b were taken; P_p; energy losses and the quality of treated surfaces, assessed visually. These metrics served as indicators of both the mechanical effectiveness and the energy efficiency of the milling operations. The experiments were carried out on a Universal Milling Machine FU320, a choice driven by its widespread use in industrial applications, which allows for greater generalization of the findings.

This comprehensive experimental framework not only facilitates a deeper understanding of the dynamics involved in milling aluminum alloys but also enhances the predictive capability regarding the outcomes of varying cutting parameters. The results of these studies are expected to contribute significantly to the body of knowledge in machining science, particularly in the optimization of process parameters that affect both operational cost and material performance.

A dynamometer UDM-600 is installed on the table of the machine with an aluminum alloy workpiece attached to it. The experiments were carried out without the use of lubricating-cooling fluid (LCF) under the following conditions: $\alpha=10'$; $\gamma=6'$; $\alpha_p=1mm$; $\alpha_g=2mm$. The tool material is U8A steel and is mounted on a knife head. The cutting speed varies from 44 to 352 t/min [7].

The nature of the change of the components of the cutting force F: - F_{Cp}, F_{Pp}, F_f depending on the change of the cutting speed V_c when milling flat surfaces in aluminum workpieces with short-angle cutting correspond to those when processing with traditional methods. Cutting forces decrease with increasing cutting speed [3]. When processing such materials, the contact area on the front surface of the knife is very large, and this leads to a large chip thickness and a large cutting force.

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When milling channels, with an increase in the cutting speed, the component forces P_p and P_c decrease, which is shown in Fig.1. As the cutting speed increases, the temperature in the cutting zone increases, the coefficient of friction of the chip on the front surface decreases, which leads to a decrease in the components of the cutting forces P_p and P_c. The component force P_p with increasing cutting speed practically does not change, and the friction force between the back and the processed surface due to the change in the friction coefficient changes insignificantly [4, 5].

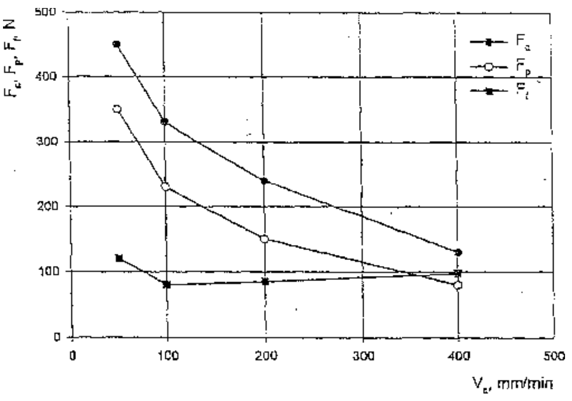


Fig. 1. Dependence of cutting force on speed

II. MATERIALS AND METHODS

The processing of flat aluminum parts is expedient to be carried out with high cutting speeds, contributing to the reduction of the friction coefficient, respectively the cutting force and increasing the quality of the processed channels and their strength.

To determine the influence of the longitudinal feed on the cutting forces *P_e, P_p, and P_p, a* number of experiments were conducted. The cutting speed is constant *(V_c = 44 m/min^{-1})*, and the feed varies in a range from *44* to *137,5 mm/min (1,0-3,125mm/min^{-1}).*

With an increase in feed from 1 to 3,125mm/min^{-1}, the cutting force P_a increases (fig. 2), which is explained by an increase in the cutting area in proportion to the feed.

The slight increase in the P_p force is explained by the insignificant increase in the friction force and the contact area of the chip with the front surface of the tool. The force P_p remains practically constant.

When the pitch of the ribs is less than 1 mm, the chip is obtained with a small thickness and is in poor adhesion to the substrate. Machining ribs with such a step is difficult, since the tool must have a minimum sharpening angle, and this leads to a decrease in its strength and to an increase in the cost of its manufacture [4, 5].

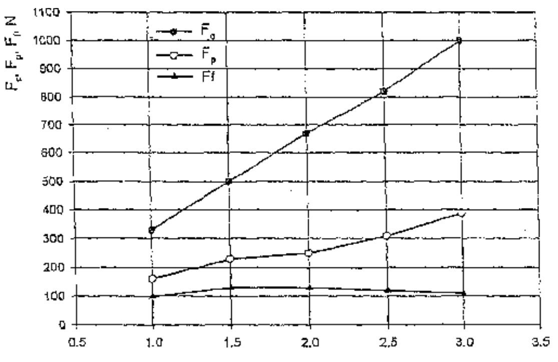


Fig. 2. Dependence of the cutting force on the feed

Increasing the pitch of the channels by more than 2 mm leads to an increase in the thickness of the sheared layer of material, the area of contact of the chip with the front surface of the tool increases, and therefore this leads to an increase in the frictional force, which significantly increases the components of the force of cutting P_e and P_p.

When determining the influence of the depth of cut on the components P_e and P_p of the cutting force (fig. 3), it was found that they increase as the thickness of the cut layer and, accordingly, its area increase. The value of P_p is insignificantly affected by the change in the depth of cut.

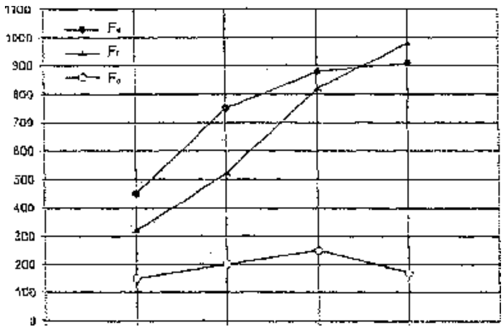


Fig. 3. Dependence of the cutting force on the cutting depth

When evaluating the energy losses in the different processing modes, a methodology [2] was used, according to which, during milling, the cutting speed V_c, the cutting force F_c and the power P_t are determined according to the dependencies [1]:

$$V_c = \frac{C_v \times D^q}{T^m \times a^x \times f_z^y \times a_c^u \times z^p} \times K_v, \text{ m/min;} \quad (1)$$

$$F_c = \frac{10 \times C_p \times a_p^x \times f_z^y \times a_c^u \times z}{D^q \times n^w} \times K_{mp}, \text{ N;} \quad (2)$$

$$N_c = \frac{F_c \times V_c}{1020 \times 60}, \text{ kW} \quad (3)$$

Where: α_p is axial cutting depth, mm; f_z – tooth feed, mm; α_r – radial depth of cut; D – cutter diameter, mm; z – number of teeth; C_v, $C_{p,x,y,u,p,q,w}$ – correction coefficients and exponents; K_v, K_{mp} - coefficients considering the working conditions.

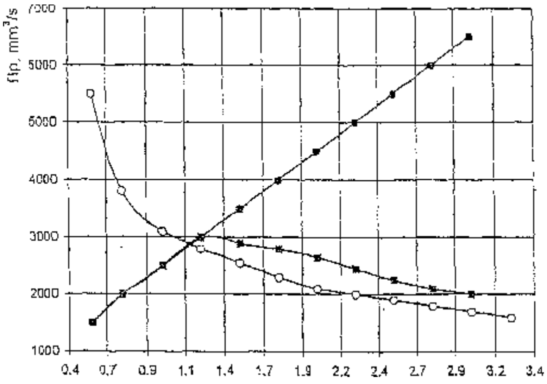
The productivity of the milling process P_p is calculated according to the formula [6]:

$$P_p = \frac{Q}{60 \times T} \qquad (4)$$

Where: Q is the volume of the cut layer, mm^3; T - time for processing the part, min.

III. RESULTS AND DISCUSSION

The results of the calculations of the productivity when milling aluminum alloys in different cutting modes are shown in fig. 4. The analysis of the graphs shows that the performance of chamfering with cutting modes determined by the traditional methodology is lower at small cutting depths, compared to those determined by the proposed methodology. This is explained by the incomplete power load of the feed translation of the machine when milling with modes determined according to the traditional methodology, when the feed and speed are determined by a set cutting depth. In order to increase the productivity of the milling process of aluminum alloys, it is suggested to initially set the maximum feed in accordance with the prescribed quality of the processed surface, and then, taking into account the power of the feed translation of the machine, calculate the depth and speed of cutting.



- traditional methodology; —O— developed methodology; —я— a traditional methodology accounting for equipment

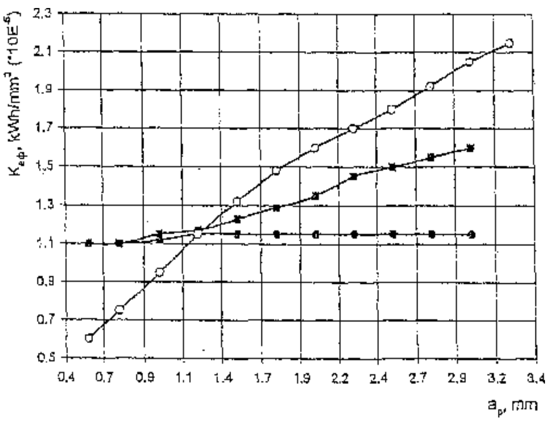
Fig. 4. Milling performance in different cutting mode

To estimate the level of energy consumption when milling aluminum alloys with different cutting modes, the individual energy consumption coefficient K_{ef} (kWh/m^3) [6] is used, the value of which is determined by the formula:

$$K_{ef} = \frac{P_t \times T}{60 \times Q} \qquad (5)$$

where P_t is the cutting power, kW; Q — volume of removed material, mm^3; T - time for processing the part in min.

The results of the calculation of the coefficient of the individual energy consumption of the milling process of aluminum alloys in different cutting modes are presented in Fig.5.



- traditional methodology; —O— developed methodology; —я— a traditional methodology accounting for equipment

Fig. 5. Energy losses during milling

The analysis of the graphs shows that the energy loss of the feed translation of the main movement of milling aluminum blanks with cutting modes determined in a traditional way are significantly lower than those proposed by the current methodology when loading the technological equipment at partial power [4]. At the same time, it should be noted that when calculating the cutting modes according to the proposed methodology, the technological equipment works at full power.

IV. CONCLUSION

Experimental studies have shown that when milling channels in flat aluminum alloys, the process should be carried out at a cutting speed of over 400 mm/min, a feed of 1 mm/min^{-1} and a depth of cut of over 1.5 mm.

In this case, the components of the cutting force either decrease or increase slightly, and the channels are milled with high productivity, good adhesion to the base, and ribbing of the surface with parameters that ensure high heat exchange characteristics. This improves the efficiency of the process and leads to better technical results under the existing machine parameters.

The comparative analysis of the methodology for setting cutting modes during milling shows that in terms of productivity and energy consumption, processing with the cutting modes proposed by the current methodology is more preferable when removing small allowances with large feeds. This opens up new opportunities for optimizing production processes and can contribute to increasing the overall economic efficiency of enterprises.

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