CONDITIONS OF REDUCED COST FOR MACHINE-BUILDING PRODUCTS

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Abstract: *The mathematical model for the cost of processing of machine parts was developed and the conditions for its reduction were determined. Analytically established the existence of a minimum of the cost of processing which achieved at high cutting speeds in terms of using modern high-performance cutting tools with wear-resistant coatings and high-speed machining centers with CNC. This opens up wide possibilities for the effective application in practice of high-performance high-speed processing and, on this basis, for reduction in the cost of machine-building products. It is shown that the optimal durability of the cutting tool which determines the minimum cost of processing depends only on the economic parameters. This indicates the need to solve technological problems associated with the mechanical treatment of machine parts through the use of economic methods. The specific practical recommendations for the improvement of engineering technology are given.*

Keywords: processing cost, machining performance, cutting tool, tool durability, cutting speed, metal-cutting machine.

1. INTRODUCTION

At present mechanical treatment of machine parts there are widely used the modern metal-cutting machines with CNC machining center type and advanced prefabricated carbide and ceramic cutting blade tools with wear-resistant coatings that implement the conditions of high-speed cutting and can significantly improve the performance and quality of processing, reduce its complexity. At the same time, as practical experience shows, through the high cost of these machines and cutting tools from the leading machine tool companies of the world, the cost of processing increases dramatically, and the use of new high-speed processing technologies in some cases becomes economically inexpedient [1-4]. Therefore, to solve the problem of efficient mechanical treatment in production of machine parts, it is important to determine the conditions for reducing the cost of processing, which determines, mainly, the cost of engineering products. This will allow a scientifically sound approach to the choice of rational cutting conditions and characteristics of progressive blade tools for processing of machine parts on modern high-speed CNC machines. In this regard, new mathematical models of the cost of machining were developed and the conditions for its significant reduction were determined.

2. ANALYTICAL RESEARCH

The analysis of manufacturing cost of machine-building products at machine-building enterprises in Ukraine showed that the largest are cost items related to the wages of production workers and the cost of raw materials, which average up to 25%. Therefore, to reduce the cost of engineering products can, first of all, through an increase in labor productivity with the use of more advanced technologies, equipment and tools. An important role is played by the tool. As the analysis of the financial and economic activities of numerous machine-building enterprises has shown, the cost item associated with the consumption of tools amounts to 3-5% of the cost of manufacturing the product. Moreover, this percentage does not actually change when using new modern tools that are offered by leading foreign machine-tool companies and which are 10-100 times more expensive than domestic tools. This is due to the fact that their performance is proportional to the increase in price. However, the use of these tools allows to increase labor productivity, which naturally leads to a reduction in the item of expenses associated with the wages of workers and the solution of the problem of reducing the cost of manufacturing engineering products.

It is shown in [5, 6] that the reduction in the price of the cutting tool by 20% corresponds to a decrease in the cost of the product by only 0.6%. An increase of 2 times the service life of the cutting tool also leads to a slight decrease in the cost of the product, by only 1.5%. The increase in processing performance due to the use of a more advanced tool by 20% leads to a reduction in the cost of the product by 15%. Consequently, a reduction in the cost of a product from the use of a more progressive tool occurs due to a reduction in the cost item associated with the workers' wages, as a result of an increase in labor productivity. Therefore, theoretical analysis of the conditions for cost reduction and increase in processing productivity is an extremely important task. Taking into joint account two variable cost items related to the worker’s wages and tools, C:

$$C = N \cdot t_0 \cdot S_w \cdot k + N \cdot \frac{t_0}{T} \cdot Z, \tag{1}$$

where N − the number of workpieces; t_0 − main processing time, min; S_w − working rate, UAH / min; k − coefficient taking into account the various charges on the tariff rate of the worker; $T = n \cdot t_0$ – tool life, min; n − number of parts after machining by the same tool; Z − tool price, UAH.

Technological processing time t_0 and durability of the cutting tool for longitudinal turning [7]: $t_0 = i \cdot \frac{l}{S_1} = \frac{\pi \cdot D_{det} \cdot R_s \cdot l}{V \cdot t \cdot S}$; $T = \frac{C_4}{V^{m_1} \cdot t^q \cdot S^p}$, where $i = R_s / t$ − the number of longitudinal moves of the instrument; R_S – removable stock, m; t – cutting depth, m; l − tool stroke length, m; $S_1 = V \cdot S / (\pi \cdot D_{det})$ − longitudinal feed speed, m/min; V – cutting speed, m/min; S – feed, m/r.; D_{det} − part diameter, m; C_4, m_1, q, p − constants for specific processing conditions.

After transformation dependence (1) takes the form:

$$C = \vartheta_\Sigma \cdot \left(\frac{S_w \cdot k}{V \cdot t \cdot S} + \frac{Z}{C_4} \cdot \frac{V^{m_1 - 1}}{t^{1-q} \cdot S^{1-p}} \right), \tag{2}$$

where $\vartheta_\Sigma = \pi \cdot D_{det} \cdot R_s \cdot l \cdot N$ − total volume of material removed from all N parts, m^3.

As can be seen, the cost of processing C continuously decreases with an increase in the parameters of the cutting mode t and S, and varies by extreme dependence with increasing cutting speed V. Extreme values V and C determined by the necessary condition of the extremum $C'_V = 0$:

$$V_{ext} = \left[\frac{S_w \cdot k \cdot C_4}{(m_1 - 1) \cdot Z \cdot t^q \cdot S^p} \right]^{\frac{1}{m_1}}. \tag{3}$$

The second derivative C''_V at the point of extremum is a positive value, therefore there is a minimum of the function $C = f(V)$, Fig. 1:

$$C_{ext} = \vartheta_\Sigma \cdot m_1 \cdot \left(\frac{S_w \cdot k}{m_1 - 1} \right)^{1 - \frac{1}{m_1}} \cdot \left(\frac{Z}{C_4} \right)^{\frac{1}{m_1}} \cdot \frac{1}{t^{1 - \frac{q}{m_1}} \cdot S^{1 - \frac{p}{m_1}}}. \tag{4}$$

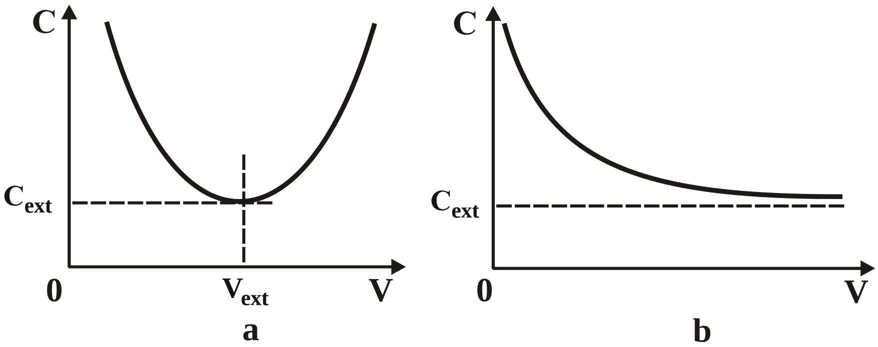

Fig. 1. *Dependence* C *on* V *when* $m_1 > 1$ *(a) and* $m_1 = 1$ *(b)*

From dependencies (3) and (4) it follows that with the point of view of providing the specified cost of processing C_{ext} (Fig. 1a) increase in cutting speed V_{ext} limited. Consequently, the use of high-speed cutting requires a "shift" of the extremum point in the region of large values V_{ext}, what can be achieved on the basis of dependence (3), by reducing the price of the tool Z and increasing its strength properties, generally defined by the parameter C_4. However, this will not lead to a noticeable increase in V_{ext} even with a significant change in these parameters, because they are in relationship (3) with a degree less than one, because $m_1 > 1$. A much greater effect in this case can be achieved by reducing the parameter $m_1 \to 1$. Then, based on the dependence (3), the extreme value of cutting speed $V_{ext} \to \infty$, and the cost of processing C_{ext}, described by dependence (4), taking into account $m_1 > p > q$, takes the form:

$$C_{ext} = \frac{\vartheta_\Sigma \cdot Z}{C_4 \cdot S \cdot t}. \tag{5}$$

Dependence (1) after transformations under $m_1 \to 1$ takes the form:

$$C = \frac{\vartheta_\Sigma \cdot S_w \cdot k}{V \cdot S \cdot t} + \frac{\vartheta_\Sigma \cdot Z}{C_4 \cdot S \cdot t}. \tag{6}$$

As can be seen, processing cost C continuously decreases with increasing of cutting speed V, asymptotically approaching to the value C_{ext} (Fig. 1b), determined by dependency (5). Therefore, processing cost C remains almost unchanged after exceeding of a certain value V, whereas processing performance $Q = V \cdot t \cdot S$ unlimited increases, that in fact predetermines the effect of high-speed processing. Thus, the implementation of the condition $m_1 \to 1$ opens up new technological possibilities for mechanical processing, with a multiple increase in productivity without increasing of processing cost.

From a physical point of view, the case $m_1 = 1$ means that the durability of the cutting tool does not depend on the cutting speed V, those temperature is not a factor in tool wear. Depreciation occurs mainly from the action of the mechanical factor. This situation can occur when cutting with diamond tools, which provide intensive heat removal from the cutting zone and a significant reduction in cutting temperature. As a result, the tool during processing is actually in a cold state, which naturally contributes to its durability. Consequently, the durability of the cutting tool mainly determines the level of processing cost C. Elimination of the predominant role of the temperature factor in the formation of an indicator of tool life is the main condition for reducing the cost of processing and a theoretically unlimited increase in cutting speed V_{ext}, which allows high-speed processing on modern high-speed CNC machines. Therefore, the use of high-speed CNC machines (n = 20,000 rpm and more) should be considered as necessary condition for the implementation of high-speed processing, and the use of cutting tools of high durability, for which $m_1 \to 1$, as sufficient condition. One example of the implementation of this condition may be the use of carbide tools with wear-resistant plasma coatings that retain their performance properties at high cutting temperatures.

Processing performance Q_{ext} and tool life T at the minimum point of the function C determined by dependencies:

$$Q_{ext} = \left(\frac{C_4 \cdot S_w \cdot k}{(m_1 - 1) \cdot Z} \right)^{\frac{1}{m_1}} \cdot t^{1 - \frac{q}{m_1}} \cdot S^{1 - \frac{p}{m_1}}; \tag{7}$$

$$T = \frac{(m_1 - 1) \cdot Z}{S_w \cdot k}. \tag{8}$$

It is possible to reduce the cost of processing C while increasing processing performance Q_{ext} by means of increase the parameters t and S, as well as decrease V_{ext} according to dependency (3). Optimum tool life T does not depend on the parameters of cutting conditions, but is determined by economic parameters S_w, k, Z. Since the parameters S_w and k affect the cost of processing C and tool life T, then there is no one-to-one connection between C and T. Parameter Z may vary within larger limits than parameters S_w and k. On this basis, it is possible to reduce parameters C and T by reducing of parameter Z, those work cost-effectively with the lowest possible values of parameter T. Reduction of parameter Z leads to increased parameters Q and V_{ext}. Insofar as $q < p$, then the depth of cut t in dependence (7) is included with a greater degree than feed S. In this connection, it is advisable, first of all, to increase the cutting depth t to the value of the removed allowance R_s, those to make processing for one pass of the tool.

Dependence (4) with use (7) takes the form:

$$C_{ext} = \vartheta_{\Sigma} \cdot \frac{S_w \cdot k}{Q_{ext}} \cdot \frac{m_1}{(m_1 - 1)}. \tag{9}$$

In essence, the second term (2) is expressed in dependence (9) through the first term (2). Value C_{ext}, derived from (9), is always $m_1/(m_1 - 1)$ times larger than the first term in dependence (2), which varies in the range of 2 ... 1.1 with an increase in m_1 from 2 to 10. A decrease in the cost of processing C_{ext} may be associated with an increase in Q_{ext} by increasing the parameters t, S and decrease Z, according to dependency (7). This indicates the need to solve technical problems in determining the best options for machining in production of parts using economic methods [8].

The analysis of the cost of processing allows to determine the savings on the wages of machine workers and the consumption of the cutting tool, which, on the basis of (1), is expressed:

$$\Delta C = C_N - C_B = N \cdot \left(t_{0_N} - t_{0_B}\right) \cdot S_w \cdot k + N \cdot \left(\frac{t_{0_N} \cdot Z_N}{T_N} - \frac{t_{0_B} \cdot Z_B}{T_B} \right). \tag{10}$$

Parameters C_B, t_{0_B}, T_B, Z_B in (10) determine the basic processing option, and the parameters C_N, t_{0_N}, T_N, Z_N relate to the new processing option. As can be seen, the value ΔC the greater the greater the difference $\left(t_{0_N} - t_{0_B}\right)$ and the second term of dependence (10), which expresses a complex ambiguous relationship between its parameters. This is due to the extreme nature of the mathematical relationship (1). If values C_B and C_N belong to the left branch of dependence (Fig. 1b), then there will be an unambiguous increase in ΔC in the transition from the basic to the new treatment option. If values C_B and C_N belong to different branches of dependence (Fig. 1a), then the values ΔC can take both positive and negative values. In the latter case, saving ΔC will not be reached.

Given the ambiguity of decisions based on dependency (10), an assessment of the savings ΔC under consideration of the two options should be made on the basis of a comparison of the minima of the cost of processing in accordance with dependence (9). In this case, the value C_{ext} uniquely determined by processing performance Q_{ext}, that simplifies the solution of optimization problems. Obviously, the more Q_{ext}, the less C_{ext}. Consequently, Q_{ext} increases and C_{ext} decreases with increasing cutting speed V_{ext}. According to (3), it is possible increasing cutting speed V_{ext}, first of all, by increasing the parameter C_4 (i.e. due the durability of the cutting tool) and a decrease in the price of the tool Z.

Cutting speed V_{ext}, and accordingly Q_{ext}, C_{ext} remain unchanged with a proportional increase in parameters C_4 and Z, and at first glance it may seem that the effect of processing will not be achieved. However, it should be borne in mind that the increase in C_4 implies a decrease in the dimensionless parameter $m_1 \to 1$ (due to increased physical and mechanical properties of tool material), and this leads to an unlimited increase in cutting speed V_{ext}, according to (3), and reducing the cost of processing C to C_{ext} (Fig. 1b). As shown above, this pattern is the basis of high-speed machining of machine parts, providing significant savings from reducing the wages of the machine worker and the consumption of the cutting tool. Thus, the scientific approach to choosing the optimal variant of machining and the acquired machine with numerical program control is economically justified.

3. CONCLUSION

A theoretical analysis for the cost of processing of machine parts is carried out and the conditions for its reduction are determined. It is proved the existence of a minimum of the cost of processing from an increase in cutting speed, which takes the lowest values when using modern high-performance cutting tools with wear-resistant coatings and high-speed metal-cutting machines with numerical control of the "machining center" type. The effectiveness of the use of high-performance high-speed processing in terms of reducing the cost of engineering products is shown. Concrete practical recommendations for the improvement of engineering technology are given.

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