Визначення умов зменшення собівартості виготовлення деталей машин

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Определение условий уменьшения себестоимости изготовления деталей машин

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Determination of conditions necessary to reduce cost price of machine details producing

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Запропоновано новий теоретичний підхід до визначення умов зменшення собівартості механічної обробки деталей машин, заснований на встановленні функціональних взаємозв'язків між основними статтями витрат. Аналітично встановлено, що собівартість обробки залежно від продуктивності обробки має екстремум (мінімум), обумовлений ступенем зношування різального інструменту. Це дозволило визначити оптимальні умови механічної обробки за критерієм найменшої собівартості. На прикладі алмазного шліфування аналітично визначені основні умови зменшення собівартості обробки, які полягають в підтримці на робочій поверхні шліфувального круга оптимального ріжучого рельєфу, що забезпечує високу ріжучу здатність круга й підвищення продуктивності обробки. Доведено переважний вплив безрозмірного коефіцієнта, що визначає ступінь затуплення алмазного зерна, на собівартість обробки. Знання цього коефіцієнта дозволяє науково обґрунтовано підійти до порівняння різних варіантів шліфування й вибору найкращого за критерієм найменшої собівартості обробки.

Ключові слова: собівартість обробки, основний технологічний час обробки, алмазне шліфування, ціна інструмента

Предложен новый теоретический подход к определению условий уменьшения себестоимости механической обработки деталей машин, основанный на установлении функциональных взаимосвязей между основными статьями затрат. Аналитически установлено, что себестоимость обработки в зависимости от производительности обработки имеет экстремум (минимум), обусловленный степенью износа режущего инструмента. Это позволило определить оптимальные условия механической обработки по критерию наименьшей себестоимости. На примере алмазного шлифования аналитически определены основные условия уменьшения себестоимости обработки, состоящие в поддержании на рабочей поверхности шлифовального круга оптимального режущего рельефа, обеспечивающего высокую режущую способность круга и повышение производительности обработки. Доказано преобладающее влияние безразмерного коэффициента, определяющего степень затупления алмазного зерна, на себестоимость обработки. Знание этого коэффициента позволяет научно обоснованно подойти к сравнению различных вариантов шлифования и выбору наилучшего по критерию наименьшей себестоимости обработки.

Ключевые слова: себестоимость обработки, основное технологическое время обработки, алмазное шлифование, цена инструмента

A new theoretical method under review, which is used to determine conditions of reducing of machining cost price, is based on functional interconnection between the major heads of expenditure. Due to analyses the cost price of machining, depending on production efficiency has its extremum (minimum) specified by the cutting tool wear rate. This enabled us to determine the optimal conditions of machining in the criterion of the least cost price. By way of example of diamond grinding were determined new conditions necessary for machining cost price reducing. They are maintenance of the optimal cutting relief of grinding wheel working face, that ensures its fast cutting capability and increasing of product efficiency. The influence of *dimensionless coefficient that determines the dulling degree of a single-point diamond on machining cost price is demonstrated. Knowing this coefficient it is possible to compare different variants of grinding in a scientifically grounded way and chose the best one in the criterion of the least machining cost price.*

Key words: machining cost price, the prime machining process time, diamond grinding, and tooling price

In market economy conditions the question of cost price decreasing of machine details becomes extremely important, as long as it is connected with the production of competitive machine-building production. As we know it is possible to decrease the cost of machine details production using the up-to-date, efficient, highly-performing and energy-efficient technologies, equipment and tools, which provide the increasing of labor production. However, the intractable problem of optimal route-operational technology determination to produce the specific detail according to the criterion of the least cost price arises. Traditionally this task is settled under structurally-oriented optimization with the usage of empirical dependence for machining cost price calculating. For this purpose the technologist or planning engineer grounding on his experience sets intuitively several variants of workflow, describes them mathematically and choses among them the most efficient one in the cost price criterion. However, this method gives no guarantee in choosing the optimal variant as it may not be one of the examined variants [1; 2].

To choose the optimal method of machining in a scientifically grounded way the theoretical (analytical) approach to fix the task of structurally-parametric optimization should be taken. This approach adds up to analytical describing of machining cost price and determination of conditions for its decreasing [3; 4]. This makes it possible to use the potential of hi-tech, equipment and tools to the utmost extent.

The goal of the work is to find theoretical basis for conditions that enable to decrease the cost price of machine details and to develop the practical recommendations for increasing the economic efficiency of manufacturing.

Taking into account the three main items of expenses the cost price C is calculated according to the scheme below:

$$C = n_1 \cdot t_H \cdot S_1 \cdot k + n_2 \cdot C_o + S_2 \cdot W \cdot t_H , \qquad (1)$$

where n_1, n_2 is the number of machined details and supplied tools, pcs;

$t_H = Z \cdot t_0$ is the time allowance necessary to machine one detail, h;

t_0 is the prime process time necessary to machine one detail, h;

Z is the coefficient that considers the length of idle time in performing one detail towards the prime time ($Z > 1$);

S_1 is the worker's tariff rate, UAH/h;

k is the coefficient, that includes all possible charges (taxes) imposed upon the worker's salary;

C_o is the cost of one tool, UAH;

S_2 is the cost of an energy unit, UAH;

W is the supplied power of manufacturing process, W.

The equation (1) includes 3 main heads of expenditure connected with the worker's salary, cost of the tools, and energy supplied while working at the lathe.

As follows from the equation, it is possible to decrease the machining cost price through decreasing the parameters t_H, n_2, C_o, W. It is common knowledge that parameters t_H and n_2 are connected with each other through the machining conditions (i.e. cutting conditions, tools characteristics etc.). That is why it is necessary to know the functional relations between t_H and n_2 parameters, calculated in an analytical or empirical way, to ground the ways for decreasing the cost price of machining conditions C. These relations usually are not taken into account during calculation, only certain variants of proceeding for quite specific values of t_H, and n_2. As a result specific decisions usually taken leave much to be desired. To get the optimal general solution it is important to know functional relations between the first and the second summand of the equation (1), neglecting the third one because of its infinitesimality. In other words, it is necessary to subordinate the economic formula of machining cost price C to the technological regularity in the form of functional relation between t_H and n_2, i.e. to unite economist's and technologist's knowledge. This attitude gives completely new possibilities in designing technological process and technological preparation of manufacturing.

For example, substituting in the given equation the formula for taking-off of the used instruments n_2 expressed in terms of t_H is determined the extremum (minimum) of machining cost price C and optimal values of the t_H and n_2 parameters that carry it out. This enables us to compare the various technological schemes of machining on the different equipment, cutting conditions, cutter characteristics, ground the conditions for decreasing the t_H, n_2, and C_o parameters on the equal basis (This can be done through using the wear-resistant coating of the tools, hi-tech of machining, new tools design etc.).

Basing on this fact let's determine the optimum parameters of machining in the criterion of the least cost price in respect of diamond grinding, which is one of the most effective methods used to increase quality and production efficiency as well as to decrease the production expenses.

Let's transform the equation (1) taking into account the following ratios:

$$t_0 = \frac{V_0}{Q}; \quad V = n_1 \cdot V_0; \quad T = \frac{h}{V_w}; \quad V_w = \frac{Q_w}{\pi \cdot D_d \cdot B}; \quad q = \frac{Q_w \cdot \rho_a \cdot \alpha}{Q \cdot \rho_M},$$

where V_0 is the size of the material, which is removed from one detail, m^3;

Q is the production efficiency, m^3/sec;

V is the cumulative material size, which is removed from n_1 details, m^3;

h is the thickness of diamond cover of the wheel, m;

B, D_d is the width of the working body and the diameter of the wheel, m;

Q_w is the size of the diamond cover of the wheel, which is worn out per unit time, m^3/sec;

q is specific consumption of diamond, kilo/kilo;

ρ_a, ρ_M are diamond and proceeded material density, kilo/ m^3;

α is the coefficient that considers the size taken by diamond powder in the total size of diamond covering of the wheel.

Neglecting the third summand in the equation (1) due to its infinitesimality, we get after transformation:

$$C = V\left(\frac{A_1}{Q} + \frac{C_o}{V_{diamond}} \cdot \frac{\rho_M}{\rho_a \cdot \alpha} \cdot q\right)_1 , \tag{2}$$

where $V_{diamond} = B \cdot h \cdot \pi \cdot D_d$ is the size of diamondiferous covering of the wheel, m³;

$A_1 = S_1 \cdot Z \cdot k$.

Product of parameters $V_{diamond} \cdot \rho_a \cdot \alpha = m_a$ determines the weight of single-point diamonds, and the ratio $C_o / m_a = C_{o1}$ − the value of a unit of mass of diamond powder. It has been found experimentally that there is a functional linkage between the variables Q and q: $q = \beta \cdot Q^m$, where β and m are parameters found experimentally (fig. 1a). Considering everything mentioned above the equation (2) is described as

$$C = V \cdot \left(\frac{A_1}{Q} + C_{o1} \cdot \rho_M \cdot \beta \cdot Q^m\right). \tag{3}$$

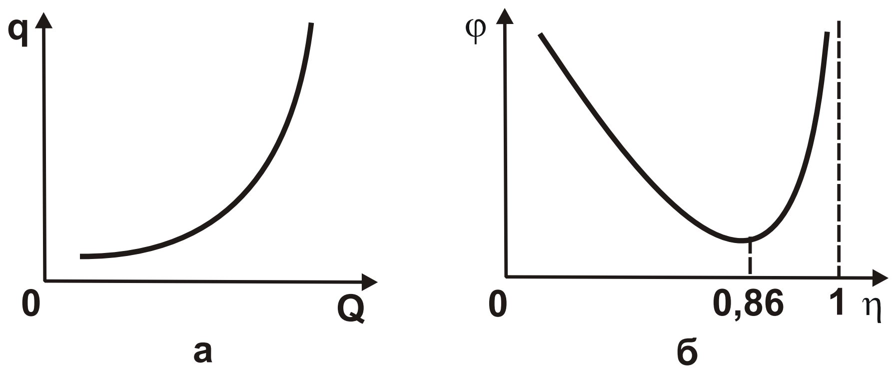

Fig. 1. **Function of q from Q (a) and of φ from η (б)**

As we can see, the machining cost price C with the changing of production efficiency alters according to extremum function. Differentiating function

C by the variable Q and equating it the first derivative to null, we determine the extremum value Q_{ex}:

$$Q_{ex} = \left(\frac{A_1}{C_{o1} \cdot \rho_M \cdot \beta \cdot m} \right)^{\frac{1}{m}}. \qquad (4)$$

In conditions m ≥ 2 the second derivative C''_Q in the extremum point is positive, i.e. has the minimum of machining cost price C.

Basing on the equation (4), it is possible increase Q_{ex} through increasing $A_1 = S_1 \cdot Z \cdot k$ and decreasing the C_{o1}, ρ_M, β, and m parameters. In this case the parameters C_{o1}, β, and m are determined by durability and endurance of single-point diamonds. Hence, the characteristics of single-point diamonds affect Q_{ex} and machining cost price ambiguously.

It is necessary to mention that capabilities of optimization problem solving that bases on the experimentally determined equation $q = f(Q)$ are quite limited, as the equation(4) does not include the parameters of grinding conditions, characteristics of the wheel and detail. Tacking this into account, let's analyze the machining cost price with the help of analytical equation $q = f(Q)$ [5]:

$$q = \frac{\rho_a \cdot \alpha \cdot HV}{\rho_m \cdot c \cdot P_y \cdot a \cdot \eta^3} \cdot \sqrt{\frac{\pi \cdot tg\gamma \cdot \sigma_{comp} \cdot HV}{(1-\eta)}}, \qquad (5)$$

where σ_{comp}, HV is the compression resistance and material hardness, N/m^2;

$P_y = F_y / a \cdot B$ is the standard pressure, N/m^2;

a is the cross-sectional thickness of the being machined sample, m;

γ is a half of an angle at the top of the grain;

η is the dimensionless coefficient that correlates in the interval 0 … 1 and determines the speed of grain dulling (for "sharp" grain $\eta \to 0$, for dull grain $\eta \to 1$);

c is a coefficient, which characterizes grain endurance, N/m^3.

According to the equation given above the specific consumption of the diamond q obeys the extremum function (fig. 1b), where $\varphi = \eta^{-3} \cdot (1-\eta)^{-0,5}$. If η = 0 and η = 1 the specific consumption of the diamond goes to infinity. The minimum of the function φ is reached when η = 0,86. Production efficiency is determined by the equation [5]:

$$Q = \frac{2 \cdot V_d \cdot F_y \cdot (1-\eta)}{\pi \cdot tg\gamma \cdot HV}. \qquad (6)$$

If $\eta \rightarrow 1$ (i.e. while grinding with dull grains), we get Q → 0. Let's substitute equations (5) and (6) into (3):

$$C = V\left[\frac{\pi \cdot tg\gamma \cdot HV \cdot A_1}{2 \cdot V_d \cdot F_y \cdot (1-\eta)} + \frac{C_{o1} \cdot \rho_a \cdot \alpha \cdot HV}{c \cdot P_y \cdot a \cdot \eta^3} \cdot \sqrt{\frac{\pi \cdot tg\gamma \cdot \sigma_{comp} \cdot HV}{(1-\eta)}}\right]. \qquad (7)$$

When the coefficient η increases, same happens to the first summand, but the second one decreases (considering in the fig. 2 only the left part of the function $\varphi - \eta$).

If η = 0 the second summand goes to infinity. Hence, while η is increasing the machining cost price C will be firstly decreasing from infinity to some definite level (minimum C), and then increase. The minimum of machining cost price is reached when η < 0,86. To determine the extremum value η let's take the first derivative from the machining cost price C upon η and the formula we get equate with null:

$$\frac{(3-3{,}5 \cdot \eta) \cdot (1-\eta)^{0,5}}{\eta^4} = \frac{A_1 \cdot c}{2 \cdot V_d \cdot C_{o1} \cdot \rho_{a\cdot} \cdot \alpha \cdot B} \cdot \sqrt{\frac{\pi \cdot tg\gamma}{\sigma_{comp} \cdot HV}}. \qquad (8)$$

The equation (9) includes two variables F_y and V_d. With their increasing C_{min} is definitely decreasing (in case η = const), and the product efficiency is increasing. Hence, the decreasing of machining cost price C_{min} is caused by increasing of productivity Q. But the limits of C_{min} decreasing and Q increasing are limited. The obtained results of the research were used at the leading machine-building enterprises of Ukraine to upgrade the technological process of details machining on the basis of the usage of highly-effective diamond grinding.

Summing up the results of the research, following conclusions can be made:

1. The work deals with the new theoretical method of determining the conditions that enable to decrease the machining cost price of details. The method is based on finding the functional linkages between the major heads of expenditure, that are connected with the worker's salary, tools value and energy supplied while working at the lathe.

2. According to performed calculations the cost price of machining depending on the efficiency has its extremum (minium), which is conditioned by the tool wear rate. This made it possible to determine the optimum conditions for machining in the criterion of the least productivity.

3. By way of example of diamond grinding there were determined new conditions necessary for machining cost price reducing. This is maintenance of the optimal cutting relief of grinding wheel working face, that ensures its fast cutting capability and increasing of product efficiency.

Taking into account the prevailing influence of dimensionless coefficient η on the machining cost price C. It is necessary to find experimentally the value of this coefficient for different grinding wheels in the following research. This will make it possible to compare different variants of grinding in the scientifically-grounded way and choose the best one in the criterion of the least machining cost price.

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