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OPTIMIZATION OF THE PROCESS OF PROCESSING HOLES WITH A TOOL ASSEMBLY REAMER

Currently, scientific and technological progress is associated with the increasing importance of manufacturing technology in the creation of new products.

The constant increase in the range of manufactured products, shortening the time for changing production facilities, increasing the complexity of part designs, and increasing the requirements for accuracy and surface quality implies an increase in the volume of blade processing operations, among which hole processing operations occupy a particularly prominent place.

This article is devoted to optimizing machining operations to ensure that the finished part is of the required quality at a minimum cost of processing. The effectiveness and expediency of the widespread use of scientifically based optimization methods for the analysis and processing of information, in particular, for the research and optimization of various technological processes of metalworking, is shown.

An increase in the efficiency of the hole processing process with a chisel assembly with a rigid attachment without vertex teeth was achieved using a mathematical model solved graphically. Technical limitations have been selected and calculated, and a graphical representation of the machining process with a chisel assembly with without vertex teeth for structural steel (Steel 45) has been constructed. Optimal modes (rotation speed and feed rate) of hole processing have been determined, taking into account all technological, structural, organizational and production conditions.

Keywords: reamer, cutting, strength, precision, rigidity, roughness, feed, rotation speed.

Introduction

The stability of the quality indicators of mechanical engineering products depends crucially on the rational design of technological processes. The optimally selected technology makes it possible to ensure high product performance and economic efficiency of production [1; 2].

Experimental studies conducted by the authors [3] have shown that in terms of high efficiency of the final deployment operation, increased accuracy and durability of the tool, and reduced roughness of the machined parts, the best results are provided by a new design of a combined cutting tool – a chisel assembly with rigid attachment without vertex teeth.

Optimization of technological processes and cutting modes, in particular, is based on a mathematical model, and to establish it, technical limitations are identified, which determine the described process to the greatest extent, and an evaluation function (optimality criterion) [4; 5].

The choice of certain technical limitations depends on the type of processing and is determined by specific conditions of a technological, structural, organizational and production nature. The most important technical limitations are:

– cutting capabilities of the tool, determined by its durability;

– the power of the main motion drive motor;

– the lowest and highest cutting speed (spindle speed) and feed allowed by the kinematics of the machine;

– the strength and rigidity of the cutting tool;

– processing accuracy;

– roughness of the treated surface.

When optimizing for two parameters (n – rotation speed and S – feed), the minimum cost is usually used as an evaluation function. Technical limitations are based on known dependencies. Bringing all technical constraints to a linear form and representing them as a system of inequalities in combination with an evaluation function provides a mathematical model of the metal cutting process [6]. The determination of optimal cutting modes (rotation speed and feed) using the constructed mathematical model can be performed analytically or graphically.

Materials and methods. Limitation 1. Cutting capabilities of the tool. Establishes a relationship between the cutting speed, determined by the accepted durability of the tool, its geometry, cutting depth, feed and mechanical properties of the processed material, on the one hand, and the cutting speed, determined by the kinematics of the machine, on the other [7].

The cutting speed is determined by the formula [8]:

$$V = \frac{C_v D^q}{T^m t^x s^y} K_v \tag{1}$$

where C_v – is a constant coefficient characterizing the standard processing conditions, C_v = 10.6 (structural carbon steel $\sigma_в$ =750 MPa material of the cutting part T15K6 [8, p. 383];

D – is the diameter of the workpiece, D = 45 mm;

T – is the accepted durability of the tool, T = 90 min [8, p. 384];

Kv – is a correction factor that takes into account the actual cutting conditions.

$$K_v = K_{mv} K_{uv} K_{lv} K_{\lambda p.кр.}, \tag{2}$$

where $К_{mv}$ – is the coefficient that takes into account the properties of the processed material, 1.08 [8, pp. 358–359];

$К_{иv}$ – is a coefficient that takes into account the properties of the tool material, $К_{иv}$ = 1.0 [8, p. 361];

$К_{lv}$ – is a coefficient that takes into account the depth of deployment [8, p. 385];

q, x, y, m – are exponents of degrees or variables in the cutting speed formula, q = 0.3; x = 0.2;y = 0.65;m = 0.4 [8, p. 383].

$К_{λр.кр.}$ – is a coefficient that takes into account the angle of inclination of the cutting edge of the chisel assembly, $К_{λр.кр.}$ = 1.5.

$$K_v = 1{,}08 \cdot 1{,}0 \cdot 1{,}0 \cdot 1{,}5 = 1{,}62$$

On the other hand, the cutting speed is determined by the kinematics of the machine according to the dependence:

$$V = \frac{\pi D n}{1000} \tag{3}$$

By equating the right-hand sides of formulas (2) and (3) and making transformations, we obtain the expression of the first technical constraint in the form of inequality:

$$n S^{0,65} \leq \frac{318 \cdot 10{,}6 \cdot 45^{0,3} \cdot 1{,}62}{45 \cdot 90^{0,4} \cdot 0{,}5^{0,2}} \tag{4}$$

To select the optimal values of cutting modes using linear programming methods, all technical limitations and the evaluation function are reduced to a linear form by logarithm. So, the expression after logarithmization will have the form:

$$\ln n + \ln S = \ln \frac{318 \cdot 10{,}6 \cdot 45^{0,3} \cdot 1{,}62}{45 \cdot 90^{0,4} \cdot 0{,}5^{0,2}} \tag{5}$$

We introduce the notation x_1 = lnn; x_2 = ln(100S) (in the notation x2, the feed S is multiplied by 100 to avoid obtaining negative values of the logarithms).

$$b_1 = \ln \frac{318 \cdot 10{,}6 \cdot 45^{0,3} \cdot 1{,}62}{45 \cdot 90^{0,4} \cdot 0{,}5^{0,2}} \cdot 100^{0,65}$$

From here we get the first technical constraint in linear form

$$x_1 + 0{,}65 x_2 \leq b_1$$

$$b_1 = \ln(72{,}16 \cdot 100^{0,65}) = 7{,}27. \tag{6}$$

Limitation 2. The power of the electric motor of the main movement of the machine. This limitation establishes the relationship between the effective power spent on the cutting process and the power of the electric drive of the main movement of the machine [7, p. 311]. The effective power spent on the cutting process is determined by the formula [8, p. 371]:

$$N_{eff} = \frac{P_z V}{102 \cdot 60}, \tag{7}$$

where P_z – is the cutting force, which according to [8, p. 371] is defined as:

$$P_z = C_{p_z} t^{x_{P_z}} S^{y_{P_z}} V^{n_{P_z}} k_P \tag{8}$$

Given the necessary conditions for the cutting process, the following inequality can be obtained:

$$N_{eff} \le N_n \eta \text{ ,(9)}$$

where Nn – is the power of the electric motor of the main drive of the machine, kW;

η – is the efficiency of the kinematic circuit from the electric motor to the tool.

By equating the right-hand sides of expressions (6) and (9), we obtain the second technical constraint in the form of inequality:

$$n^{n_{P_z}+1} S^{y_{P_z}} \le \frac{6120(10^3)^{n_{P_z}+1} N\eta}{C_{P_z} t^{x_{P_z}} D^{n_{P_z}+1} \pi^{n_{P_z}+1} k_P}, \tag{10}$$

where the values of the coefficients are selected from [8, p. 372]: CPz = 300; xPz = 1,0; yPz = 0,75; nPz = -0,15.

The value of the refining coefficient for cutting force:

$$k_P = k_{mp} \cdot k_{\varphi p} \cdot k_{\gamma p} \cdot k_{\lambda p} \cdot k_{rp} \cdot k_{\lambda p.\kappa p} = 0,938 \cdot 1,08 \cdot 1,0 \cdot 1,0 \cdot 1,0 \cdot 1,5 = 1,52$$

For the 2A135 machine, the electric motor power is N=4.0 kW, n = 0.81 [9]. Then:

$$n^{0,85} S^{0,75} \le \frac{6120(10^3)^{0,85} \cdot 4 \cdot 0,81}{300 \cdot 0,5^{1,0} \cdot 45^{0,85} \cdot \pi^{0,85} \cdot 1,52}$$

After reducing to a linear form and introducing the notation, we obtain:

$$0,85x_1 + 0,75x_2 \le b_2, \tag{11}$$

where $b_2 = \ln(124,33 \cdot 100^{0,75}) = 8,28$.

Limitations 3 and 4. The lowest and highest allowable cutting speeds. These limits establish the relationship between the calculated cutting speed and the kinematics of the machine at a minimum and maximum. They are written as follows [7, p. 311]:

$$n \geq n_{mach.min} \tag{12}$$

$$n \leq n_{mach.max} \tag{13}$$

For the 2A135 machine, the rotation speed is $n_{mach.min} = 68$ min^{-1}, $n_{mach.max} = 1100$ min^{-1}. Then:

$$x_1 \geq b_3, \tag{14}$$

where $b_3 = \ln 68 = 4{,}22$.

$$x_1 \leq b_4, \tag{15}$$

where $b_4 = \ln 1100 = 7{,}00$.

Limitations 5 and 6. The smallest and largest allowed feeds. These restrictions, similar to the previous two, establish the relationship between the calculated feed and the feed allowed by the minimum kinematics of the machine [7, p. 312]:

$$s \geq s_{mach.min} \tag{16}$$

and to the maximum

$$s \leq s_{mach.max} \tag{17}$$

For the 2A135 machine, the rotation speed $s_{mach.min} = 0.12$ mm/rpm (8.16 mm/min), $s_{mach.max} = 1.6$ mm/rpm (256 mm/min) [9]. Then:

$$x_2 \geq b_5, \tag{18}$$

where $b_5 = \ln 8{,}16 = 2{,}1$.

$$x_2 \leq b_6, \tag{19}$$

where $b_6 = \ln 256 = 5{,}55$.

Other technical limitations are defined in the same way:

Limitation 7. The strength of the cutting tool. Establishes the relationship between the calculated values of cutting speed and feed with acceptable strength.

Limitation 8. Rigidity of the cutting tool. Establishes the relationship between the calculated values of cutting speed and feed with the permissible stiffness of the cutting tool.

Limitation 9. Rigidity of the workpiece. Establishes the relationship between the calculated values of the cutting speed and feed with the permissible ones.

Limitation 10. Required surface roughness. Establishes the relationship between the calculated cutting and feeding speeds providing the required roughness.

All the obtained technical limitations 1–10 form a mathematical model of the cutting process of the cutter assembly in an analytical form. In addition to the technical limitations presented in the form of a system of inequalities, the model includes the evaluation function f0:

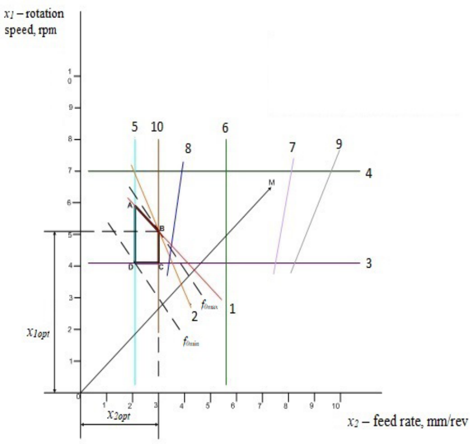
$$\begin{cases} x_1 + 0{,}65x_2 \le 7{,}27 \\ 0{,}85x_1 + 0{,}75x_2 \le 8{,}28 \\ x_1 \ge 4{,}22 \\ x_1 \le 7{,}00 \\ x_2 \ge 2{,}1 \\ x_2 \le 5{,}55 \\ -0{,}15x_1 + 0{,}75x_2 \le 4{,}99 \\ -0{,}15x_1 + 0{,}75x_2 \le 1{,}89 \\ -0{,}3x_1 + 0{,}6x_2 \le 15{,}06 \\ x_2 \le 3{,}02 \\ f_0 = (x_1 + x_2)_{\max} \end{cases}$$

It is known that the extreme value of the evaluation function (for a decision polygon) is provided for x_1 and x_2 located at a point lying on one of the boundary lines or their intersection. Therefore, the task of finding the optimal values of x_{1opt} and x_{2opt} is reduced to sequentially calculating the coordinates of all possible points of intersection of boundary lines and then determining for them the largest sum $f_0 = (x_1 + x_2)_{max}$. After determining the coordinates of x_{1opt} and x_{2opt}, optimal cutting modes can be calculated. To solve a problem given by a system of linear equations and inequalities, the method of complete enumeration of points forming a polygon of possible solutions is usually used. The points of intersection of the lines are determined in pairs and the coordinates of these points are substituted into the inequalities of the system. A point whose coordinates satisfy all straight lines without exception (checking for compatibility of the system of equations) and at the same time the sum of whose coordinates ($x_1 + x_2$) is the largest, and will be the optimum point.

Results and discussion

This problem is solved by the graphical method, where each technical constraint is represented by a boundary line that defines a half-plane where it is possible for a system of inequalities to overlap. The boundary lines intersect to form a polygon of ABCD solutions (Figure 1), within which any point satisfies all inequalities without exception.

The estimated function $f_0 = x_1 + x_2$ is represented by a straight line perpendicular to the maximization vector M at an angle of 45° to the axes x_1 and x_2.



1 – limitation 1; 2 – limitation 2; 3 and 4 – limitations 3 and 4; 5 and 6 – limitations 5 and 6; 7 – limitation 7; 8 – limitation 8; 9 – limitation 9; 10 – limitation 10

Figure 1 – Graphical representation of the mathematical model [10]

At point D, where the line of the evaluation function touches the polygon of solutions, the function takes the minimum value of f_{0min}, and at point B – the maximum value of f_{0max}. The coordinates of this point are the optimal values x_{1opt}= 5,08 and $_{x2opt}$= 3,02.

After determining the coordinates of x1opt and x2opt, optimal hole processing modes were calculated with a chisel assembly with rigid mounting without vertex teeth teeth for structural steel (Steel 45):

- rotation speed

$$n_{opt} = \exp(x_{1opt}) = \exp(5{,}08) = 160 \text{ rpm}$$

- supply

$$s_{opt} = \exp(x_{2opt}) / 100 = \exp(3{,}02) / 100 = 0{,}2 \text{ mm/rev}$$

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Conclusions

Thus, it can be concluded that optimizing the process of processing holes with a chisel assembly with a rigid attachment without vertex teeth using the above mathematical modeling technique can be recommended for predicting cutting conditions.

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ОПТИМИЗАЦИЯ ПРОЦЕССА ОБРАБОТКИ ОТВЕРСТИЙ РЕЗЦОВОЙ СБОРНОЙ РАЗВЁРТКОЙ

В настоящее время научно-технический прогресс связан с усилением значения технологии производства при создании новых изделий.

Постоянное увеличение номенклатуры выпускаемых изделий, сокращение сроков смены объектов производства, усложнение конструкций деталей, повышение требований к точности и качеству поверхности предполагает увеличение объема операций лезвийной обработки, среди которых операции по обработке отверстий занимают особо заметное место.

Данная статья посвящена оптимизации операций механической обработки, гарантирующих получение готовой детали требуемого качества при минимальной стоимости обработки. Показана эффективность и целесообразность широкого применения научно-обоснованных методов оптимизации для анализа и обработки информации, в частности, для исследования и оптимизации различных технологических процессов обработки металлов.

Повышение эффективности процесса обработки отверстий резцовой сборной развёрткой с жёстким креплением безвершинных зубьев достигнуто с *помощью математической модели, решенной графическим методом. Выбраны и рассчитаны технические ограничения, построено графическое изображение процесса обработки резцовой сборной развёрткой с безвершинными зубьями для конструкционной стали (Сталь 45). Определены оптимальные режимы (частота вращения и подача) обработки отверстий с учетом всех условий технологического, конструкционного и организационно-производственного характера.*

Ключевые слова: развёртка, резание, прочность, точность, жёсткость, шероховатость, подача, частота вращения.

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КЕСКІШ ҚҰРАМА ҰҢҒЫЛАҒЫШПЕН ТЕСІКТЕРДІ ӨҢДЕУ ПРОЦЕСІН ОҢТАЙЛАНДЫРУ

Қазіргі уақытта ғылыми-техникалық прогресс жаңа өнімдерді жасау кезінде өндіріс технологиясының маңыздылығын арттырумен байланысты.

Шығарылатын бұйымдар номенклатурасының ұдайы ұлғаюы, өндіріс объектілерін ауыстыру мерзімдерінің қысқаруы, бөлшектердің конструкцияларының күрделенуі, бетінің дәлдігі мен сапасына қойылатын талаптардың артуы пышақты өңдеу операцияларының көлемін ұлғайтуды көздейді, олардың ішінде тесіктерді өңдеу операциялары ерекше орын алады.

Бұл мақала өңдеудің минималды құнымен қажетті сапаның дайын бөлігін алуға кепілдік беретін өңдеу операцияларын оңтайландыруға арналған. Ақпаратты талдау және өңдеу үшін, атап айтқанда, металдарды өңдеудің әртүрлі технологиялық процестерін зерттеу және оңтайландыру үшін ғылыми негізделген оңтайландыру әдістерін кеңінен қолданудың тиімділігі мен орындылығы көрсетілген.

Графикалық әдіспен шешілген математикалық модельдің көмегімен шыңсыз тістерді қатты бекітетін кескіш құрастырмалы ұңғылағышпен тесіктерді өңдеу процесінің тиімділігін арттыруға қол жеткізілді. Техникалық шектеулер таңдалды және есептелді, құрылымдық болатқа арналған шыңсыз тістері бар кескіш құрама ұңғылағышпен өңдеу процесінің графикалық бейнесі салынды (45 болат). Технологиялық, құрылымдық және ұйымдастырушылық-өндірістік сипаттағы барлық жағдайларды ескере отырып, тесіктерді Өңдеудің оңтайлы режимдері (айналу жиілігі және беру) анықталды.

Кілтті сөздер: ұңғылағыш, кесу, беріктік, дәлдік, қаттылық, кедір-бұдыр, беру, айналу жиілігі.

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