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OPTIMIZATION OF PRODUCT PROCESSING MODES IN MODELING AND PROGRAMMING OF MACHINING ON MACHINE TOOLS WITH PROGRAM CONTROL

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ОПТИМІЗАЦІЯ РЕЖИМІВ ОБРОБКИ ВИРОБІВ ПРИ МОДЕЛЮВАННІ ТА ПРОГРАМУВАННІ МЕХАНІЧНОЇ ОБРОБКИ НА ВЕРСТАТАХ З ПРОГРАМНИМ КЕРУВАННЯМ

Purpose. To solve a scientific and technical problem related to the technological support of high-performance machining of a cast iron part by optimizing and controlling its machinability with a hard-alloy tool on multi-axis CNC machines using CAD-CAM systems.

The methods. The methodological basis of the work is a systematic approach and analysis of the study of the object of research, based on the use of: numerical and graphical-analytical research methods in order to establish a systematic relationship between turning parameters and the properties of the material being processed, tool geometry and its stability, parameters of cutting modes with the corresponding indication in the control program for the CNC machine.

Findings. Numerical research results have been obtained for a scientifically based approach to solving the technical problem of high-performance turning of cast iron parts on multi-axis machining centers, which contains a set of adjusted methods and algorithms for predicting their machinability with ensuring the reliability of hard alloy cutting tools. The results obtained were compared with known works related to the study of machining processes of various grades of steels, alloys, and cast irons, the assessment of the reliability of cutting tools, the accuracy and roughness of the machined surface, and the results of measurements of cutting force parameters. The maximum relative error of the calculations did not exceed 6-8%.

The originality. Establishment of a complete and systematic connection of machining parameters with the properties of the processed material, tool geometry and design and technological factors of the part for the calculation of an optimized automated production technology. In the mathematical and statistical processing of experimental data, which made it possible for the first time to obtain complex dependencies in a form convenient for calculation and analysis, which give a clear picture of the effect of each parameter of the turning process on its energy and time indicators when compiling a rational technology for machining a part of complex geometric shape in a CAM system.

Practical implementation. It consists in selecting and justifying the optimal geometric parameters of cutting tools and equipment, establishing the nature of the influence of the conditions of turning cast iron on the main process parameters - machining time and operating parameters depending on the hardness of the part material and tool material. Practical recommendations are given on the optimal use of CAD-CAM systems, adjustment of process results and operating parameters to obtain optimal results at the stage of production preparation.

Keywords: *turning, machine, cast iron, tool material, technology, stability, cutting tool, cutting modes, CAD, CAM.*

Introduction. Today, it is already impossible to produce modern complex equipment, which requires high accuracy without computer automation. The sharp growth of computerization in production and in everyday life is happening all over the world. The implementation of computer and telecommunication technologies increases the efficiency and productivity of labor.

Nowadays, the rapid development of computer-aided design (CAD) systems is observed in such fields as aircraft, automobile construction, heavy engineering, architecture, construction, oil and gas industry, cartography, geo-information systems, as well as in the production of consumer goods, such as household electrical appliances. [1, 2]. CAD in mechanical engineering is used to carry out design and technological works, including works on technological preparation of production. Development of drawings, three-dimensional modeling of products and assembly process, design of auxiliary equipment, for example dies and moulds, drawing up technological documentation and control programs (CP) for machines with computer numerical control (CNC), database compilation is done using CAD.

Modern CAD and CAM systems are used for end-to-end computer-aided design, technological preparation, analysis and production in mechanical engineering, as well as for electronic management of technical documentation.

CAM systems were set up and now have become widespread. However, unfortunately, the first developers of such systems were specialists in programming, projective geometry and metalworking in the last turn. Consequently, such systems brilliantly solve the tasks of designing shape-generating movements for making surfaces of any level of complexity, but they do not take into account that such a surface is formed on the machine tool as a result of cutting process, which has force, temperature disturbance, tool wear, etc.

However, a situation arose when there were opportunities to control the cutting process in a wide range on the part of equipment, at the same time such opportunities are ignored or simply not used on the part of CAM. Such a contradiction is the driving force behind the further development of cutting metalworking and the theory of cutting [3].

Work purpose and task statement. We will consider optimal control to be such an influence on the cutting process that ensures maximum productivity (minimum cost) at any time if all conditions of limitations are met. In this sense, the optimization task is single-criteria and can be solved by classical methods of nonlinear programming, in other words, optimal control actions can be uniquely identified. Typically, the control influences mean longitudinal feed on workpiece turnover and cutting speed and the depth of cutting is considered to be the main disturbance. Thus, theoretically, for given turning conditions, there are such constant values of longitudinal feed per workpiece turnover and cutting speed that lead to maximum productivity. However, in practice, none of its parameters remains constant during any cutting process. This is determined by the continuous change of both external disturbances and the characteristics of the technological processing system (TPS) [4].

It is necessary to continuously determine new optimal values of control influences and apply them on the cutting process in order to maintain initial characteristics

of the process at the optimal level at each moment of time. Thus, optimal control should be permanent, take into account variable cutting conditions and be carried out automatically. Industrial control systems that manage feed, cutting speed and sometimes depth of cut are most suitable for meeting such requirements [4, 5].

Regarding the practical application of the optimization process. It is necessary to analyze the draft of the researched workpiece and the material from which it is planned to be manufactured. It is also needed to analyze the part design for fabricability according to qualitative and quantitative indicators and to provide a description of the production facility.

It is necessary to make three-dimensional model in the CAD system that will serve as a digital standard for its further mechanical processing in the CAM system and calculation of the control program for the CNC machine tool.

The obtained results of optimized cutting modes during turning should be input to the interface of a specialized engineering program and obtain the optimal control program (NC file) for the CNC machine tool.

The main part. The main difficulties in the implementation of optimal management using closed industrial control system (ICS) are due to the principal impossibility of creating productivity or cost measuring device to use it as a feedback sensor. Therefore, it is possible to optimally control cutting process based only on the assessment of auxiliary parameters related to the necessary optimality criterion of the corresponding a priori mathematical model.

Optimal control, which is implemented by software, is the most rational in modern CAM systems of technological production preparation. In general, various approaches based on indirect allowance measurement, temperature of the cutting zone, rates of tool wear [1, 2] are used to evaluate disturbances and obtain information about the actual progress of the cutting process in ICS of optimal control. The method that evaluates the process based on the current section value of the allowance layer that is cut off is the closest to the proposed ICS.

Thus, the software of the ICS of optimal control should have the following structure (Fig. 1).

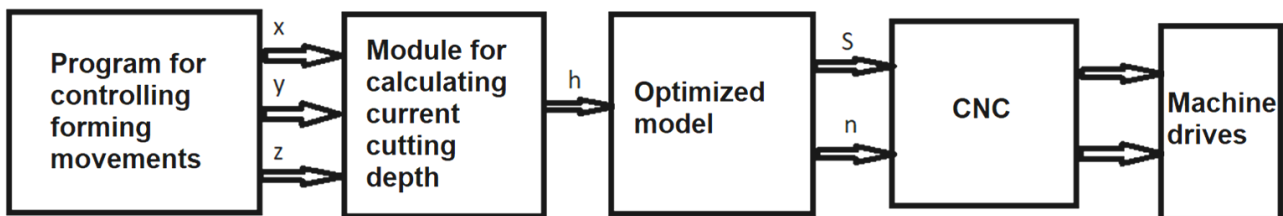


Fig. 1. The structure of the ICS of optimal control

Primary information about the progress of the cutting process, in addition to the constants that are entered earlier, is obtained from the calculation module of the current cutting depth, which is connected to the program for controlling shape-generating movements. Next, the optimal values of the control influences (for example, feed and cutting speed) are determined according to the optimization mathematical model of the cutting process. The values calculated in this way are sent

to the software control module, which produces commands for the corresponding drives of the machine.

In this way, the main such ISC of cutting process optimization is its optimization mathematical model, which relates the optimization criterion to the controlling influences of feed and cutting speed. The controlling influence that ensures maximum productivity or minimum cost subject to absolute compliance with the requirements of limitations on the processing quality are found as a result of solving the optimization task. Criterion of the maximum intensity of allowance removal is applied depending on the results of technical and economic analysis in addition to traditional optimization criteria (productivity and cost). Sometimes the task of achieving maximum productivity or minimum cost at given values of tool life is set in production.

The development of a mathematical model of the cutting process is the most important stage of creating an optimization algorithm. With a traditional, classic approach the mathematical model is built in the form of a system of equations and inequalities, which express the relationships between the controlling influences, limitations and accepted optimality criteria based on the classical dependencies of cutting theory [5, 6].

The cutting mode will be optimal with such a combination of feed and cutting speed, when the main technological time is minimal for the case of processing by longitudinal turning in one pass with a constant depth of cut, which is equal to the machining allowance (ideal case). Such an optimal solution is found by looking for such integral values of the control influences (feed S and spindle rotation frequency n) while satisfying all the limitations that deliver the minimum of the optimality criterion of technological time t_0 . Thus, for the case of longitudinal turning, the optimization mathematical model can be expressed by the following system of equations and inequalities. The relationship between controls S and n and the period T of the tool life, which determine its cutting ability, is obtained according to the dependence known from the theory of cutting:

$$v = \frac{\pi D n}{1000} = \frac{C_v k_v}{T^m H^{x_v} S^{y_v}}$$

$$\text{from where } n S^{y_v} = \frac{318 C_v k_v}{D T^m H^{x_v}}, \quad (1)$$

where, v – cutting speed, m/min; π – constant value 3.14; n – rotation frequency, rpm; H – cutting depth, mm; T – period of the tool life, min; S – feed mm/rev, m , v , x , y – correction coefficients for the material, cutting forces, processing modes.

Since all the dependencies that make up the mathematical model are empirical, it should not forget about the dimensions of the physical quantities included in them. Usually, these dimensions do not correspond to CI-dimensions.

In the mathematical model (1), it is necessary to take into account the known from the practice of processing by turning, depending on the stability of the cutter not only on the workpiece and tool material but also on the geometric parameters of the cutting part of the cutter in the plan. Influence of the main and auxiliary angles in the

plan of the cutter is displayed by known [7] dependencies for the permissible cutting speed:

$$v = \frac{C_\varphi}{\varphi_{ih}}, \quad v_1 = \frac{C_{\varphi_1}}{\varphi_{ih1}}.$$

Such dependencies are included in the mathematical model of the cutting process, and their influence on the limitations (1) is carried out due to the coefficient k_v , the value of which is calculated according to specific processing conditions. The next limitation is in the cutting force N_p , kW:

$$N_p = \frac{P_z \pi D n}{1000 \cdot 6 \cdot 10^4} = \frac{C_p h^{x_p} S^{y_p} k_p \pi D n}{6 \cdot 10^7} \leq N_{cm} \eta,$$

from where

$$n S^{y_p} \leq \frac{1,91 \cdot 10^7 N_{cm} \eta}{C_p h^{x_p} k_p D}, \quad (2)$$

where N_{cm} – effective machine capacity in kW; η – coefficient of performance; C_p, k_p, x_p, y_p – coefficients and indicators of the empirical dependence of the cutting force on the processing mode and conditions.

The feed allowed by the required roughness of processing, can be determined by the deterministic component of the roughness profile of the machined surface, which, in turn, is determined by the geometric dependencies of the waviness formation of the workpiece surface layer for each of the four possible profiles [7].

Block scheme of research algorithm

To solve such a problem, it is expedient to use a numerical method, which is built on the interactive principle of approximation with a given step to the solution according to the algorithm, the block scheme of which is presented in Figure 2.

Such cases are determined by the ratio between the geometric parameters of cutter tip in the plan (main angle φ , auxiliary angle φ_1 in the plan and the radius r of the cutter tip rounding in the plan) and feed S against the workpiece.

When $\varphi < \arcsin(S/2r)$ and $\varphi_1 < \arcsin(S/2r)$ the profile protrusion is formed by the intersection of the main and auxiliary cutting blades of the tool, when $\varphi > \arcsin(S/2r)$ and $\varphi_1 < \arcsin(S/2r)$ the profile protrusion is formed by the intersection of the auxiliary cutting blade and radius part of the tool top, when $\varphi < \arcsin(S/2r)$ and $\varphi_1 > \arcsin(S/2r)$ the profile protrusion is formed by the intersection of the main cutting blade and radius part of the tool top, when $\varphi < \arcsin(S/2r)$ and $\varphi_1 < \arcsin(S/2r)$ the profile protrusion is formed by the intersection only the radius parts of the tool tops. Thus, the condition for determining the permissible (by roughness) feed includes the feed itself, which makes it impossible to obtain the corresponding analytical dependence [1].

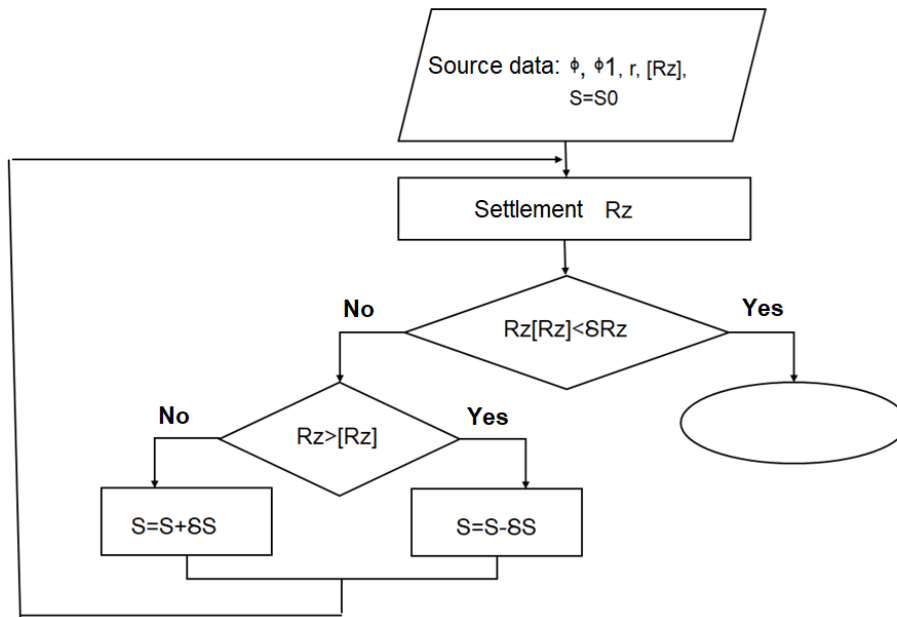


Fig. 2. Block scheme of the algorithm

The following limitations, that is superimposed on the longitudinal feed, is chosen from the stiffness strength conditions of the TPS. For example, feeding with maximum force, which is provided by the machine feed drive can be calculated according to the following dependence:

$$[S_p]_{add} = \left(\frac{2P_n}{C_p h^{Xp} k_p} \right)^{\frac{1}{Y_p}}.$$

The allowable feed is selected as the smallest of the feeds that are calculated based on the tool strength $[S_l]_{add}$ or by the traction force of the machine feed mechanism $[S_p]_{add}$:

$$S \leq \min\{[S_p]_{add}, [S_l]_{add}\} \quad (3)$$

Design limitations which are determined by the capabilities of the metal-cutting machine:

range of longitudinal feeds:

$$S_{min} \leq S \leq S_{max}, \quad (4)$$

range of spindle rotation frequencies:

$$n_{min} \leq n \leq n_{max}. \quad (5)$$

It is accepted as an evaluative function based on the criterion of maximum productivity

$$f = nS \rightarrow \max, \quad (6)$$

because at the same time the main processing time $t_0 = L/n \rightarrow \min$ (where L – processing length).

The obtained mathematical model (3) – (6) forms the core of the application program "Turning optimization" [1], which we will use to optimize cutting modes during turning.

Optimization of cutting modes during turning

An application program [1] is used to carry out the work, the interface is presented in Figure 3. Instructions and explanations for working with the program are contained in the program itself and appear on the monitor screen when the "Help" button is pressed.

All the calculated limits forming the area D of permissible values of spindle rotation frequency and feed, which corresponds to the output data of the machine presented on the interface and the cutting process appear in the graphic window of the interface after program activation, entering the data according to the option and pressing the button "Apply data". This area is formed by the intersection of the following constraints in Figure 3: 1 – minimum feed, 3 – minimum spindle rotation frequency, 5 – minimum feed on the surface roughness, 7 – tool life limitations, 8 – machine capacity limitations. Line 9 displays the optimization function for maximum productivity and satisfies the dependence (6).

Line 9 appears in the graphical window of the interface and is moved in it by the mouse intersection. To determine the optimal coordinates of the scope of permissible values, it is necessary to move the mouse so that the line of maximum productivity was tangent to the top of the scope of permissible values that is the furthest from the origin and the mouse intersection coincided with this top.

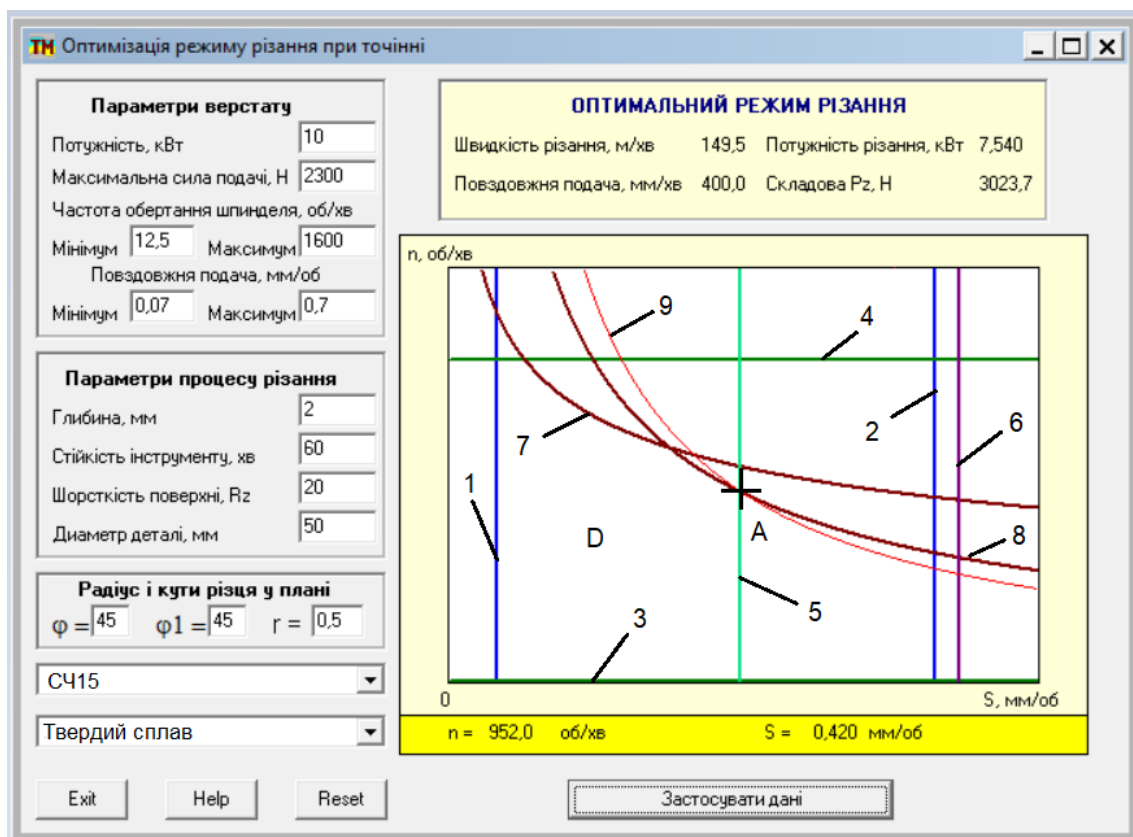


Fig. 3. The interface of the application program for optimizing cutting modes

The optimal values of the cutting mode appear in the interface after pressing the left mouse button, while holding its intersection at the top of the scope of permissible values. The following components of the cutting mode and its main characteristics are determined: spindle rotation frequency (952 rpm), feed per revolution (0.42 mm/rev), cutting speed (149.5 m/min), longitudinal feed (400 mm /min), cutting force (7.54 kW), which is the cutting force P_z (3023.7 N).

We pay attention to the fact that according to the accepted criterion of optimality - maximum productivity – its value can be conveniently estimated directly by the value of the longitudinal feed.

The research progress for the initial data, which is indicated in the windows of the main interface of the program in Figure 3, is presented below as an example of work performance.

It is necessary to create a table of experimental data by determining the range and step of the change in the cutting depth (table 1) in order to complete experimental studies on the first three tasks that are performed in the cutting depth function, before activating the application program. Figure 4 presents the D area state of permissible values of the spindle speed and longitudinal feed during experimental research according to the data in table 1.

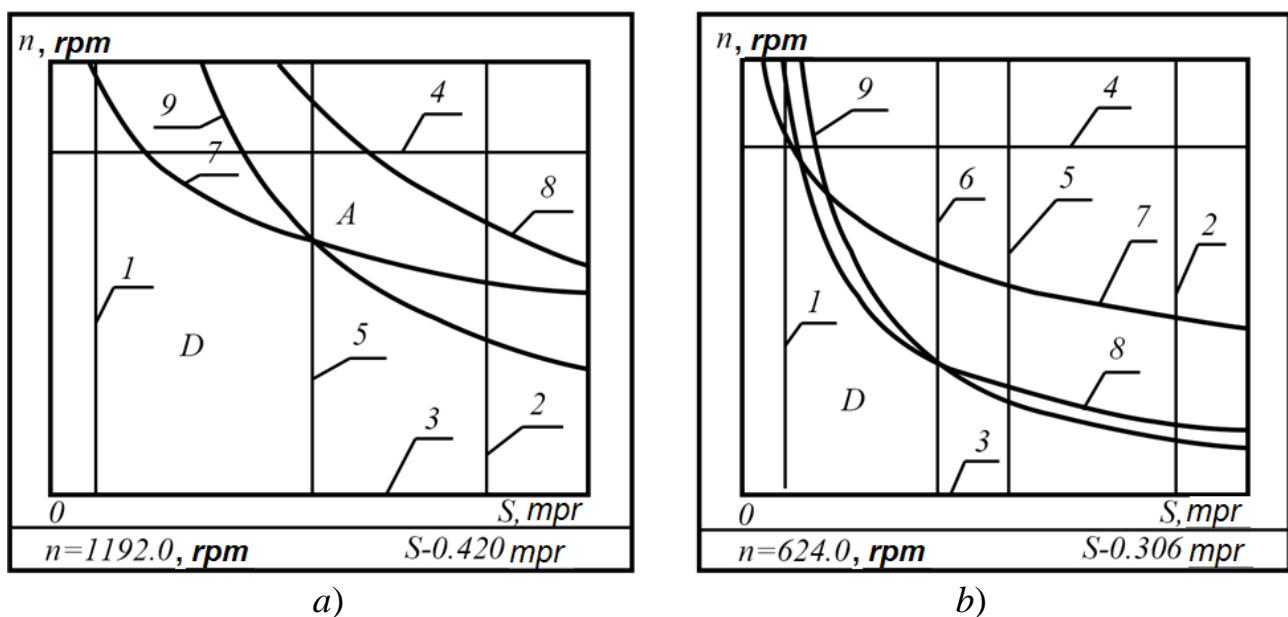


Fig. 4. The results of determining the optimal cutting mode: *a* – at the cutting depth 1 mm ($n = 1192.0$ rpm; $S = 0.420$ mpr); *b* – at the cutting depth 4 mm ($n = 624.0$ rpm; $S = 0.300$ mpr).

The same designations as in Figure 4 are used here: lines 1 and 2 – limitations on minimum and maximum feed, lines 3 and 4 – limitations on the minimum and maximum spindle rotation frequency, line 5 – limitation of feed on the given roughness, line 6 – feed limitation by the admissible force of the machine tool feed mechanism, line 7 – tool life limitations, line 8 – machine capacity limitations. Line 9 displays the optimization function for maximum productivity. It can be seen that with a change of the cutting depth, the top A of the scope of permissible values which corre-

sponds to the optimal (in terms of productivity) cutting mode, is formed by the intersection of various limitations. Thus, at a cutting depth of 1 mm, this top is formed by limitations on tool life and necessary surface roughness, and at a depth of 4 mm, the top is formed by limitations on cutting force and the maximum permissible feed drive force. The obtained experimental data that determine the optimal cutting mode for different values of the cutting depth H are presented in table 2. Graphs of the corresponding dependence, presented in Figure 5, were built based on experimental data using the Excel package.

Table 1

Experimental data for one technological transition

№	H, mm	n_{rev} , rpm	S_{rev} , mm/rev	N_{cut} , kW	P_z , N	S_{min} , mm/min	v , m/min
1	0.5	1320	0.420	2.80	810	554	207
2	1.0	1192	0.420	4.88	1565	501	187
3	1.5	1120	0.420	6.75	2301	470	176
4	2.0	952	0.418	7.50	3011	389	150
5	2.5	768	0.418	7.48	3722	321	121
6	3.0	648	0.418	7.51	4426	271	232
7	3.5	624	0.362	7.51	4600	226	112
8	4.0	624	0.306	7.52	4603	191	112

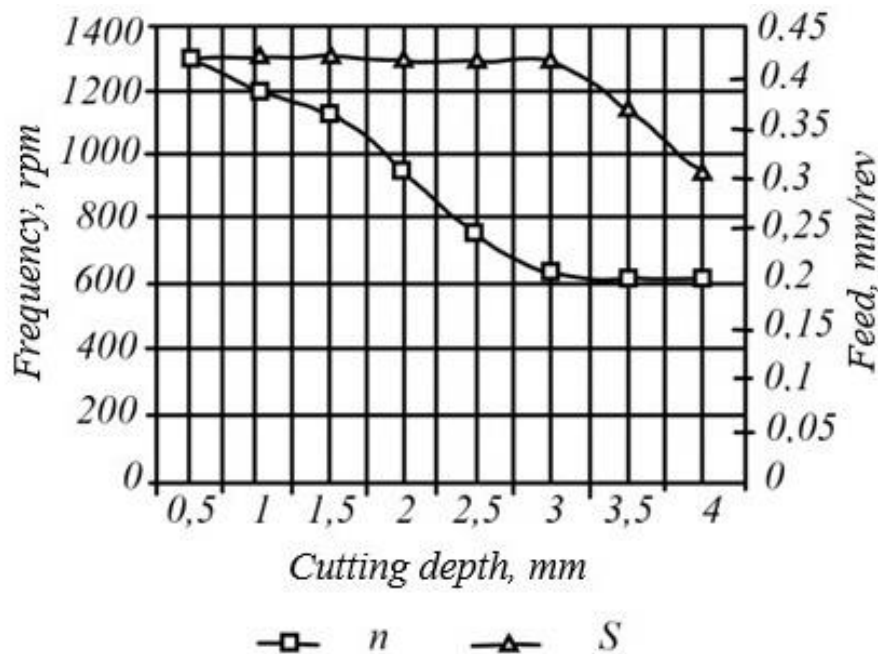


Fig. 5. Experimental dependencies of the optimal cutting mode from the cutting depth

The analysis of the obtained experimental results (Fig. 5) shows that the law of optimal control has two zones:

1) optimal processing up to a cutting depth of 3 mm occurs with a constant feed to the workpiece, but the rotation frequency decreases almost according to a linear dependence;

2) optimal processing with a depth that exceeds 3 mm is performed with a constant rotation frequency of the workpiece, but the longitudinal feed also decreases almost according to a linear dependence;

During the experiments it can be seen that the optimal point of the phase plane n - S is mainly formed by three limitations: stability, force and roughness. Up to a cutting depth of 3 mm, the main limitation imposed on the feed is the limitation of the required roughness of the treated surface. When the cutting depth increases, the fourth limitation comes into effect – by machine feed force.

Such numerical values of cutting modes calculations were also obtained with the classical analytical method of correction in relation to the geometry of the cutting tool, material and parameters of the part [7–9], the relative error of the calculations did not exceed 6–8%. This means that the model is verifiable for the adequacy of the results of the mechanical processing modes in relation to our part "Right bearing cage" and its geometric parameters.

Further we consistently repeat the procedure of changing the input data for each technological transition during turning (transverse, longitudinal, boring, groove turning and cutting). The obtained results are entered in the table 2 where we adjust the cutting modes for each turning case.

Table 2

Optimized cutting modes of turning operations on a CNC machine tool

Operation name	Depth, mm	Feed, mm/rev (mm/cutter tooth)	Speed, m/min
Radial turning	-	0.427	228
External turning (draft)	3.0	0.418	232
External turning (finishing)	0.85	0.162	267
Boring (draft)	2.25	0.281	188
Boring (finishing)	0.25	0.143	241
Internal groove turning	1.15	0.182	215
Workpiece cutting off	-	0.221	194

Note. Value of cutting modes during milling, drilling and rifling were not optimized, but were chosen as a weighted average from the range of modes recommended by the manufacturer and taking into account the passport ranges of the processing mode of the CNC machine

Practical implementation of the obtained results in CAD-CAM systems

It is necessary to study the parameters of the part, make appropriate conclusions about linear, diametrical and tolerance sizes in the drawing in order to qualitatively and correctly approach the assembly of the automated manufacturing process. It is necessary to analyze from the drawing technical requirements for the part, roughness and quality of processing surfaces. Also we need to analyze chemical composition and mechanical properties of the part material, provide a general description of the research object and carry out a qualitative analysis of fabricability of part design. At the end of the chapter the part need to be model in three-dimensional form in the Autodesk PowerShape CAD-system by size according to the drawing. The part "Bearing cage" (Fig. 6), that was selected for the example, is part of the gear shift transmission of the tractor. The shaft in rolling bearing rotates in the middle of the part. The cage remains stationary after installation in the case.

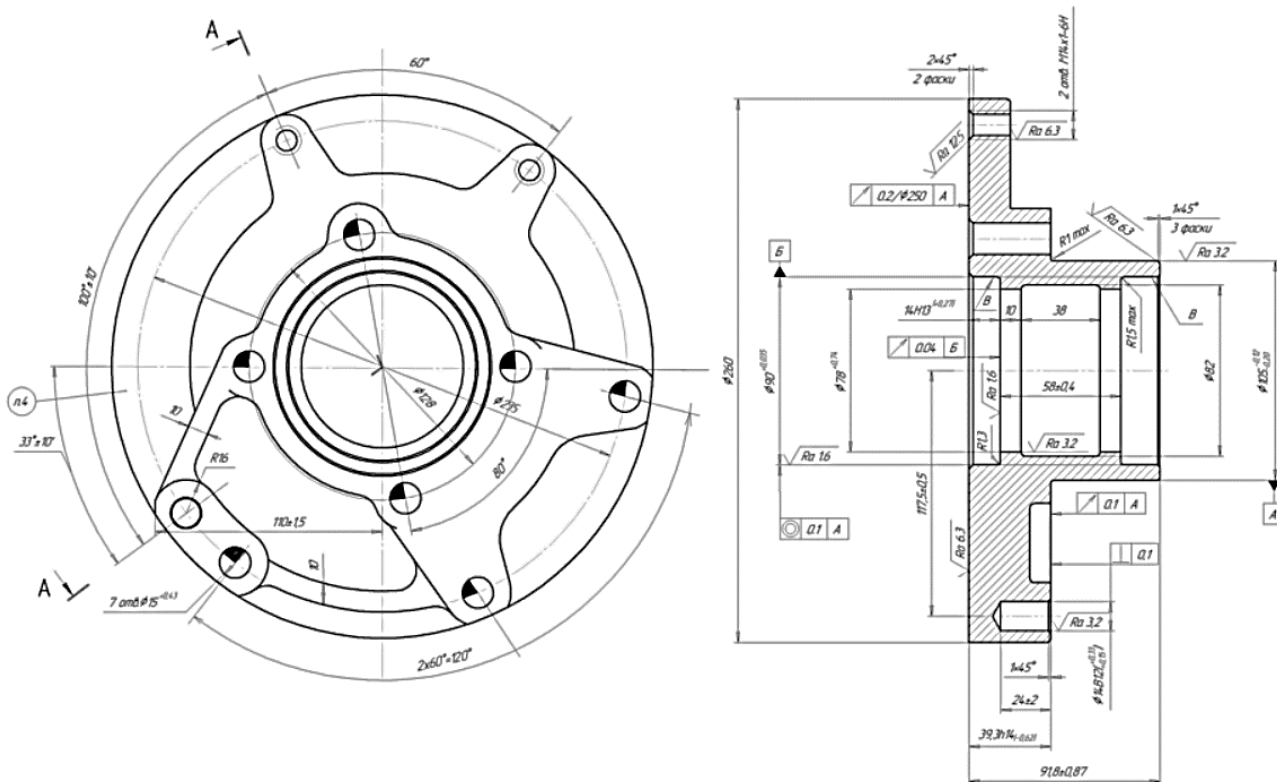


Fig. 6. Part sketch "Bearing cage"

Making a three-dimensional model of a part in the Autodesk PowerShape program

Autodesk PowerShape is easy to learn and use CAD system that combines the capabilities of surface, solid and facet 3D modeling. It has effective functionality for reverse engineering and recovery of damaged imported data [6–8].

We use this program to make a three-dimensional model of the part "Bearing cage". With the help of simple lines, simple geometric shapes and curves of the PowerShape interface, we create an object step by step in terms of sizes and proportions, in scale, perfectly similar to the one on the drawing, which is a technical task for us.

The created model of the part is presented in Figure 7

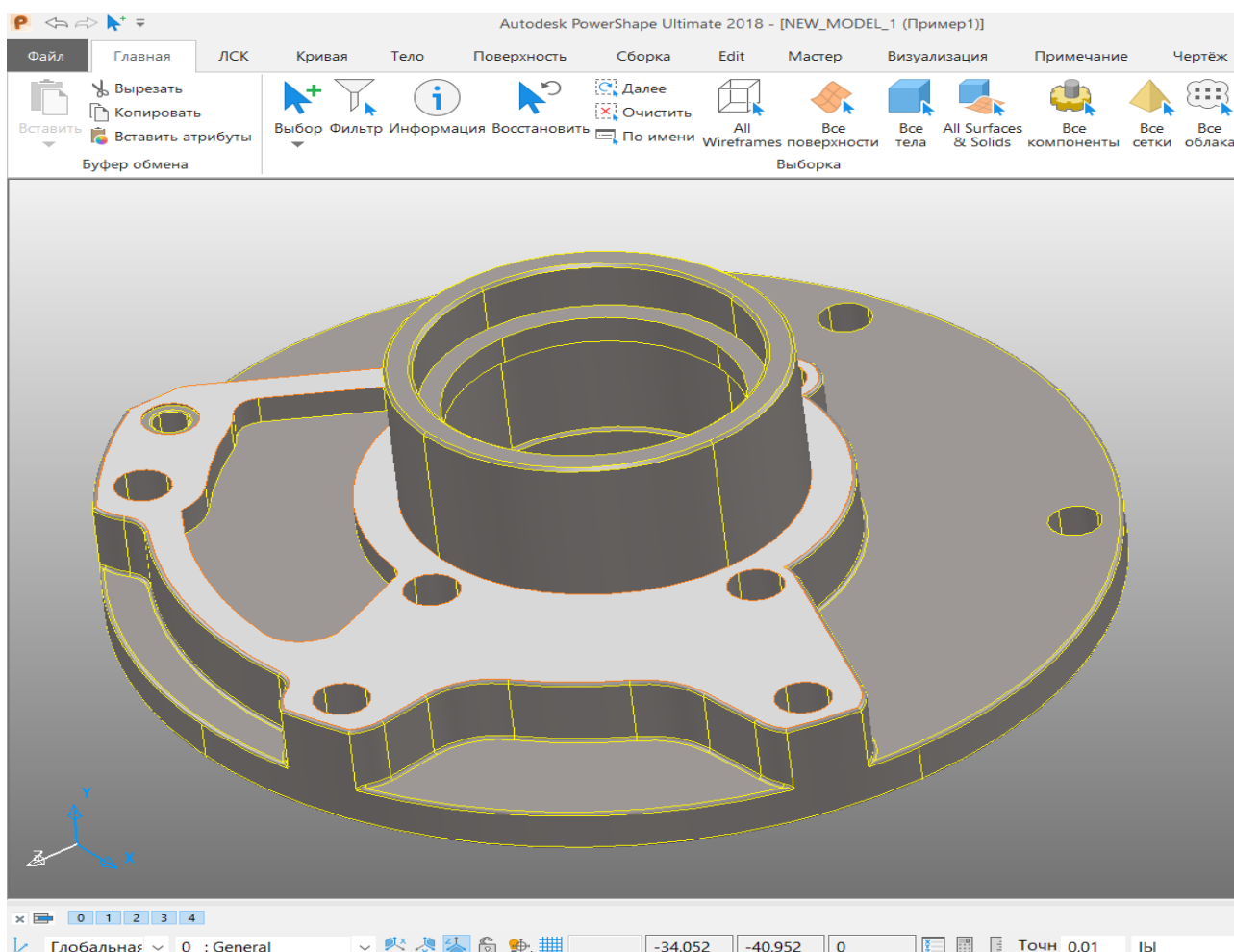


Fig. 7. A three-dimensional model in the Autodesk PowerShape program

The method of making of automated processing technology in CAM system

It is necessary to perform a certain sequence of operations in order to make the correct automated technology of mechanical processing on a CNC machine under the conditions of using CAD-CAM systems:

- create a three-dimensional model based on a drawing or sketch (technical task) in the selected CAD system;
- calculate and create a three-dimensional model of the workpiece or use the functionality of the selected CAM system and calculate it from simple geometric shapes;
- choose a logical and correct sequence of the part processing route (PPR), taking into account its geometry, requirements for accuracy and quality, material, equipment, modes and conditions of part processing;
- select the necessary software-controlled equipment, progressive cutting tool, facilities and assign cutting modes according to the ISO standard guides;
- choose a CAM system and make the optimal sequence of operations (technological transitions) in it using numerical calculations and mode parameters obtained and described in the list above;
- visualize in 3D mode and on the machine completed process of mechanical processing of the part, provide clarifications or reactions in technology parameters;

- make a control program for a multi-coordinated machine tool with CNC after completing the technology adjustment, using the CAM system;
- save the NC file of the control program in the appropriate format and the technology project in the CAM system for further correction and transfer of information to the CNC equipment.

We import the part model and the interface of the FeatureCAM program, assign the workpiece sizes, that were calculated in the previous section, set the local coordinate frame of the part, select in the database the existing post-processor of the machine and the three-dimensional hybrid model of the MAZAK Integrex 200-IV S machine, get the following view of a computer experiment on preparation for technology automation, Fig. 8.

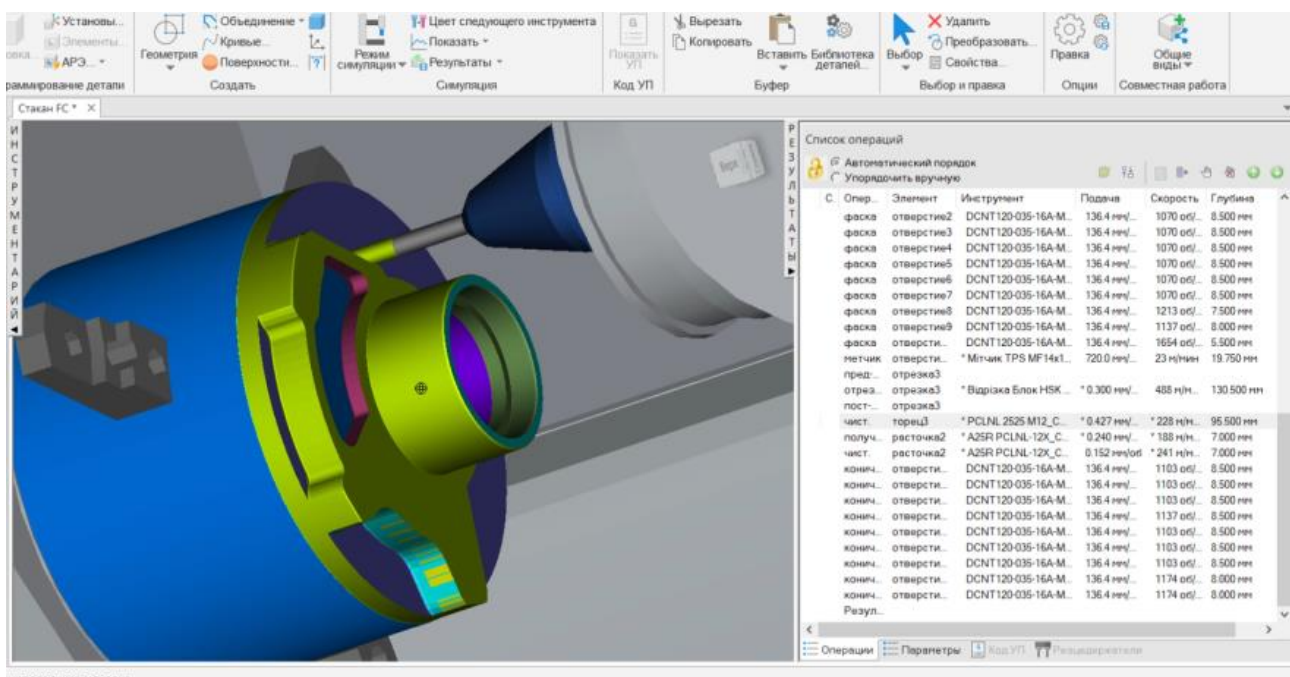


Fig. 8. The project preparation for automation of the FeatureCAM interface

Consistently, according to the PPR of tables 1 and 2 assign the appropriate processing operations, choosing the appropriate options from the program interface: "Turning", "Radial turning", "Boring", "Milling", "Drilling", "Workpiece cutting off".

At the last stage of programming mechanical operations, using the features of the FeatureCAM program, we create a control program (CP) for a CNC machine and save it in *.txt format. A fragment of the CP from the interface for the machine is shown in Fig. 9.

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Код УП
P1: baxis_head

ОПример1 ( УСТАНОВ1 )
( СТАКАН FC 1-9-2023 )
( MAZAK INTEGRGX -IV S MATRIX CONTROL )

( SET G30 P3 SAFE TOOL CHANGE/PIVOT LOCATION WITH MACHINE M6 PARAMETER )
#150=0 ( ENTER DISTANCE FROM SUB ORIGIN TO MAIN ORIGIN. USED TO SHIFT ORIGIN FOR WORKING ON SUB )
#151=0 ( ENTER C ANGLE OFFSET BETWEEN SUB AND MAIN. USED TO SHIFT SUB C POSITION )
#155=0 ( ENTER FINE ADJUSTMENT FOR SUB SPINDLE TRANSFER )

IF [#150 EQ 0] GOTO 9999
#152=[#150+#9101]
#153=[#151+#9102]

N60 ( MAIN SPINDLE, TURNING )
N65 ( FINISH FACE ТОРЕЦІ )
N70 G00 G18 G21 G40 G80 G99
N75 G30 P3 U0. V0.
N80 G30 P3 W0.
N85 M901 ( MAIN SPINDLE )
N90 M202 ( MAIN TURN MODE )
N95 T001.01 T002 M06 ( PCLNR2525-M12_CNMG120408NR_IC5010 )
N100 G30 P3 U0. W0.
N105 G50 S2500 R1
N110 G97 S582 M04
N115 M248
N120 G53.5
N125 G00 Z3.0
N130 X267.0
N135 G96 S488
N140 X269.0 Z-0.95
N145 G01 X-1.6 F0.152
N150 X3.774 Z1.737

N155 ( MAIN SPINDLE, TURNING )
N160 ( FINISH FACE ТОРЕЦІ )
N165 G50 S2500
N170 G96 S488
N175 G00 X269.0 Z1.737
    
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Fig. 9. Fragment of the control program for Mazak Integrex 200-IV S

Exactly from the table 2 we take the adjusted cutting modes and enter them into the settings of each technological transition (operation) of mechanical processing in the interface of the FeatureCAM program (Fig. 10).

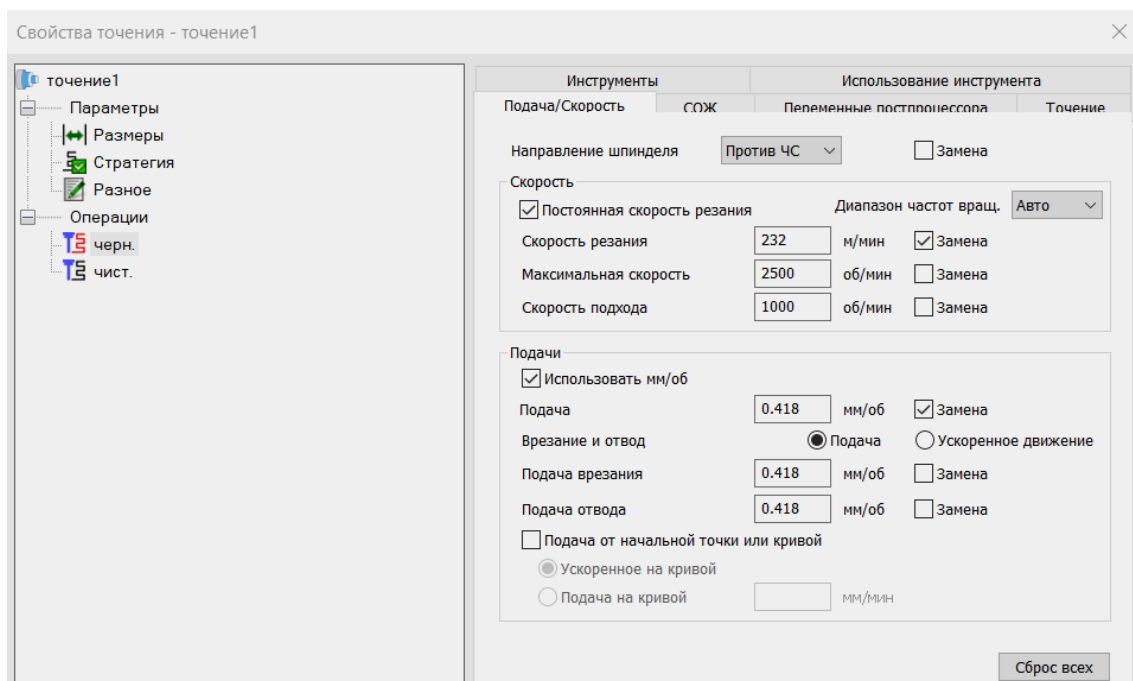


Fig. 10. The interface of the FeatureCAM program with optimized modes

Conclusions.

1. The obtained numerical research results are used for a scientifically based approach in solving the technical problem of part turning made from pig iron on multi-axle processing centers containing a set of adjusted methods and algorithms for predicting their machinability with ensuring the reliability of a cutting tool made of hard alloys. The obtained results were compared with well-known works related to the research of machining process of various steel grades, alloys and pig iron, evaluation of the reliability of cutting tools, accuracy and roughness of the machined surface, and the results of measurements of cutting force parameters. The maximum relative error of calculations did not exceed 5-8%.

2. The complete system connection of the processing parameters with the properties of the processed material, the tool geometry, tool material and design and technological factors of the part on the calculation of the optimized turning technology is substantiated and established.

3. The performed method significantly simplifies the cumbersome analytical calculations by classical methods with a lot of correction coefficients and takes into account the modern geometry of tools, cutting indicators and modes in relation to a specific part. Moreover it can be adapted to other types of parts, such as rotation bodies of various production branches.

4. Analyzed design features of the part, material and the general characteristics of the research object is provided, also a qualitative analysis of the manufacturability of the part design was performed. The three-dimensional model is qualitatively made in the CAD system.

5. The optimal technology of mechanical processing of the part was developed. An advanced cutting tool of the ISO standard was applied, equipment for a modern multi-purpose CNC machine tool. The software implementation and computer experiment based on automated technology of mechanical processing are implemented in the Autodesk FeatureCAM program.

6. Practical recommendations on optimal use of CAD-CAM systems are provided, as well as adjustment of technology results and mode parameters to obtain optimal results at the production preparation stage.

7. Completed research allows to simulate absolutely all turned works due to the use of computer programs in conditions of production shortage of full-scale experiments and distance learning; is also enables to individualize the learning process and increase the efficiency of the pupil's or student's independent work; makes it possible to conduct research in such areas of changing parameters that are impossible or dangerous to implement on real expensive equipment.

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АНОТАЦІЯ

Мета. Розв'язання науково-технічної задачі, пов'язаної з технологічним забезпеченням високопродуктивної механічної обробки деталі з чавуна шляхом оптимізації та управління її оброблюваністю інструментом з твердих сплавів на багатоцільових верстатах з ЧПК, за умов використання САД-САМ систем.

Методика. Методологічною основою роботи є системний підхід та аналіз вивчення об'єкта досліджень, що ґрунтується на використанні: чисельного та графо-аналітичному методах дослідження з метою встановлення системного зв'язку параметрів точіння з властивостями оброблюваного матеріалу, геометрією інструменту та його стійкістю, параметрами режимів різання з відповідним зазначенням до керуючої програми для верстата з ЧПК.

Результати. Одержані чисельні результати досліджень для науково-обґрунтованого підходу у розв'язанні технічної задачі високопродуктивної токарної обробки деталей з чавуну на багатовісних обробних центрах, що містить сукупність скорегованих методик та алгоритмів для прогнозування їхньої оброблюваності із забезпеченням надійності різального інструменту з твердих сплавів. Отримані результати порівнювалися з відомими роботами, пов'язаними з дослідженнями процесів механічного оброблення різних марок сталей, сплавів та чавунів, оцінкою надійності ріжучих інструментів, точності та шорсткості обробленої поверхні, результатами вимірювань силових параметрів різання. Максимальна відносна похибка розрахунків не перевищувала 6-8%.

Наукова новизна. Встановлення повного і системного зв'язку параметрів оброблення з властивостями оброблюваного матеріалу, геометрією інструменту і конструкторсько-технологічних чинників деталі на розрахунок оптимізованої технології автоматизованого виробництва. У математико-статистичному опрацюванні експериментальних даних, що дало змогу вперше одержати комплексні залежності в зручному для розрахунку й аналізу вигляді, які дають наочне уявлення про вплив кожного параметра процесу точіння на його енергетичні та часові показники при складанні раціональної технології механічної обробки деталі складної геометричної форми в САМ системі.

Практична значимість. Полягає у виборі й обґрунтуванні оптимальних геометричних параметрах різальних інструментів та оснащення, установленні характеру впливу умов токарної обробки чавунів на основні показники процесу – час механічної обробки та режимні показники в залежності від твердості матеріалу деталі і інструментального матеріалу. Надані практичні рекомендації щодо оптимального використання CAD-CAM систем, коригування результатів технології та режимних параметрів для отримання оптимальних результатів на стадії підготовки виробництва.

Ключові слова: *точіння, верстат, чавун, інструментальний матеріал, технологія, стійкість, різучий інструмент, режими різання, CAD, CAM.*