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MANUFACTURING ENGINEERING AND AUTOMATED PROCESSES

МАШИНОБУДУВАННЯ, АВТОМАТИЗАЦІЯ ВИРОБНИЦТВА ТА ПРОЦЕСИ МЕХАНІЧНОЇ ОБРОБКИ

UDC 621.9

INCREASE THE PRODUCTIVITY OF HARD-ALLOY TOOLS FOR HEAVY MACHINE TOOLS BY PROCESSING IMPULSE MAGNETIC FIELD

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Summary*. The work is devoted to the creation and implementation of a cutting tool made of carbide material with increased operational properties. The reinforced tool is reliable and durable. Increasing the efficiency of the cutting tool for cutting carbides for heavy machine tools is performed by processing pulsed magnetic field. It has been established that processing by a pulsed magnetic field contributes to the durability and durability of tool material during roughing cutting.*

Key words*: hardening, hard alloy, heavy duty machine, tool, impulse magnetic field processing (IMFP), cutting modes, performance.*

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Statement of the problem. The efficiency increase and development of heavy machinery is possible on the basis of the equipment operation intensification, the introduction of advanced technological processes, automation and mechanization on the basis of the implementation of the latest achievements in science and technology.

Solving these tasks in metalworking requires the creation and implementation of high-performance carbide cutting tool with increased operational properties having high reliability and durability. The «tool-part» system is one that is defined as extreme loaded − conditions of its operation are high temperatures and ultrahigh static and cyclic contact loads. «Extreme» of such a system increases while machining on heavy machine tools, the essential features of which are the large dimensions of machined parts (cylinders, shafts, rods, bandages up to 24000 mm and more with diameter up to 5000 mm, weighing up to 250 tons); large depth of cutting (15...20 mm) and feed (up to 3 mm); high cost billets; long cutting way; high production costs associated with the cost of unique equipment; uneven allowances [1]. Increasing the tool resources while machining on heavy duty machines is extremely important due to the considerable cost of heavy machines and the need to reduce idle time when replacing the tool, as well as the high cost of the hard-alloy tool itself.

Analysis of the availabe investigations. Analysis of the tool failures during machining on heavy machine tools shows that along with the tool failure due to wear, up to 80% of failures result in brittle fracture of the cutting part of the hard-alloy plate, which manifests itself in the cutting edges microchipping and cutting part shearing [1]. This is due to the fact that the large values of the cut thickness cause the increase in size and range of tension stress action on the front tool surface, while the structural bending strength differs substantially from that obtained on standard samples and depends on the grains and porosity of the hard alloys, the content of cobalt, and the surface condition of the cutting plate. Analysis of the tool failures also revealed the heterogeneity of the degree of degradation of various sections of variable plates of cutters and mills characteristic for heavy machine tools.

Analysis of various methods for improving the physical and mechanical properties of hard alloy tools prove that the application of these methods allows to increase the tool wear resistance, but does not allow to reduce costs significantly. In many cases, these methods are uneconomical and inappropriate due to the loss of other valuable properties, particularly the material strength or toughness. Therefore, the development of new progressive methods of strengthening the cutting tool is the first task to increase the metalworking tool life.

Trends of solving the problem of lengthening the resource of tools for heavy machinery are to provide surface and bulk strength [4, 5]. Ways of obtaining tool materials with the complex of necessary under the conditions of processing on heavy machine tools characteristics is processing technology by impulse magnetic field [2, 3]. The histogram is constructed In accordance with the methodology for calculating production costs and production efficiency (Fig. 1).

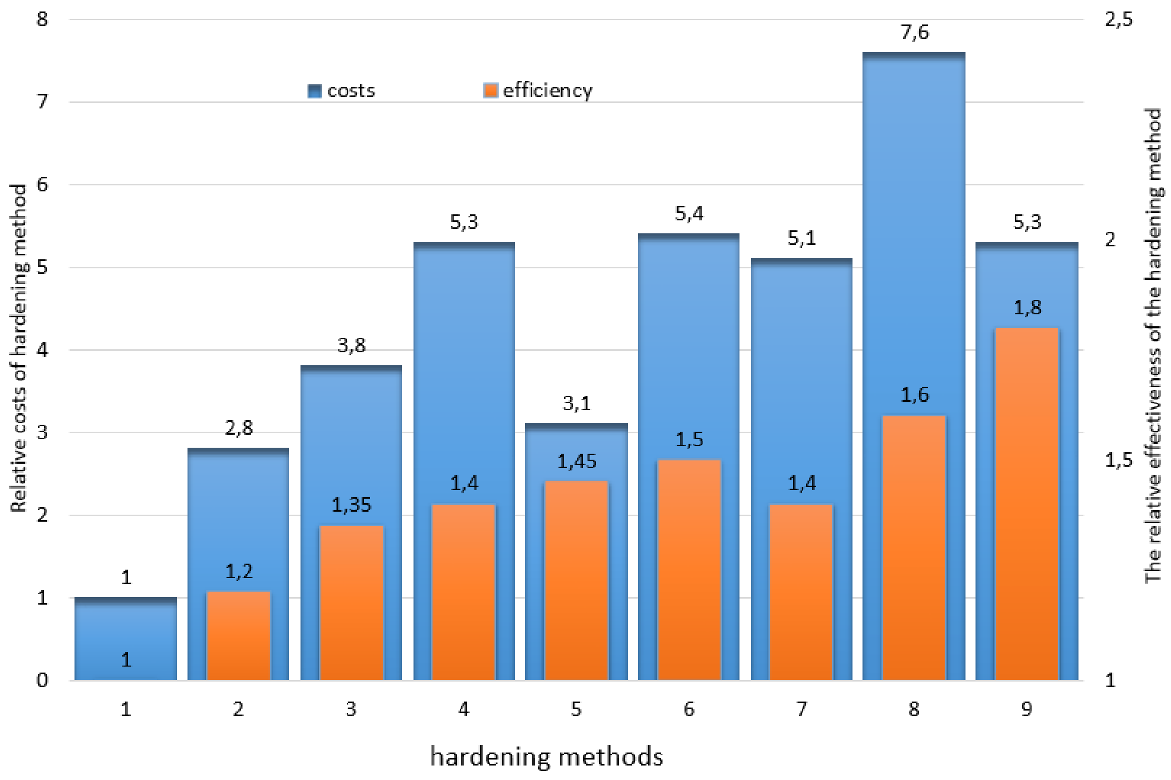

Figure 1. Histogram of dependence of costs and production efficiency on methods of strengthening cutting tools made of hard alloy hard alloy to destination K20 (ISO classification):
1 – constructive methods; 2 – reinforcement by mechanical defamation;
3 – application of wear-resistant coatings; 4 – pulsed laser processing;
5 – plasma-arc reinforcement; 6 – radiation strengthening; 7 – ion doping;
8 – surface laser reinforcement; 9 – processing by a pulsed magnetic field

As can be seen from Figure 1, the best combination of cost and production efficiency is observed in the impulse magnetic field processing method. High efficiency is due to the volume character of the strengthening [4, 5].

The objective of the paper is to increase the operational resource, reliability, durability and wear resistance of hard-alloy cutting tool due to impulse magnetic field processing (IMFP).

Statement of the problem. To accomplish this objective, the following tasks were solved:

- to investigate the wear resistance of hard-alloy cutting tools after IMFP by means of forced testing methods and cutting process modeling;
- to determine the mechanism for changing the properties of hard-alloy under the action of magnetic impulse processing;
- to identify the main factors influencing the change of the hard-alloy wear resistance under the action of magnetic impulse processing;
- to investigate the influence of the impulse magnetic field processing on the efficiency of hard-alloy cutting tools under production conditions;
- to determine the impact of strengthening on productivity, operation cost and instrumental costs;
- to investigate the interconnection of IMFP parameters, the parameters of the machining process and the efficiency of production.

Research methodology. The increase of the working capacity of the hard-alloy cutting tool for heavy machines is carried out in this paper by the impulse magnetic field processing at the installation consisting of the impulse generator with the power supply and inductor. The impulse generator and power supply are made in the form of a separate electric rack. The inductor is connected to the generator by cable.

Technical characteristics of the generator are given in Table 1. The technological parameter of the control unit is the operating voltage of the installation (discharge voltage of the capacitor the chains of magnetic field pulse generation), displayed by a special device on the front of the generator block.

Table 1

Technical characteristics of the complex for IMFP

Complex parameter	Parameter value
Range of magnetic strength field EMBED Equation.3, A / m	$0{,}2\cdot10^5 – 2{,}2\cdot10^5$
Operating voltage	100–900 V
Inductor inductivity	225 μH
Frequency of impulses passing EMBED Equation.3, Hz	1–10
Impulse duration EMBED Equation.3, ms	60

Investigation of the stability of hard-alloy cutting tools after IMFP was carried out using forced test methods that allow to shorten the test time, the cost of tool and workable material. Method of stepwise increase of cutting modes (feed and cutting speed) make it possible to realize the principle of extrapolation by load (gradual increase in the load on the strength and speed of wear of the instrumental material).

The tools testing by the method of stepwise increase in cutting speed was to determine the cutting speed at which the wear reached the standard blinding criterion. Dependence of the tool wear rate *Vu* on the cutting speed *V* were derived. It was found that at lower cutting speeds the wear rate for tools after the IMFP strengthening were 2 − 2,3 times lower in comparison with non-strengthened tools. With further increase in the cutting speed, the wear rate increases.

Testing of instruments by the stepwise increase in feed was to determine the supply, the achievement of which causes the cutter cutting part fracture. These tests showed the increase in the marginal feedrate of $1.5 - 2.2$ times for instruments after IMFP. Were there comparable to unbreakable tools. With a further increase in the speed of cutting, the wear rate increases. Instruments test by a stepwise increase in feed was to determine the supply, the achievement of which causes the destruction of the cutting part of the cutter. These tests showed $1.5 - 2.2$ times increase in the limit feed rate for instruments after IMFP. Instrument tests were also carried out by the method of continuous increase of the cutting speed (the final sharpening method). The forced tests showed that after IMFP strengthening, the instruments have higher stability in the areas of low cutting speeds and high feedings, that is, at rough metal processing [6].

The IMFP influence on physical and mechanical factors determining the cutting ability of hard alloys during roughing were also considered. The strength and abrasive wear resistance of hard alloys to destination K20, K30, P30, P10 (ISO classification) were investigated using simulation methods. At the same time, it was taken into account that during roughing by hard-alloy cutting tools large loads were acting, which due to the low strength of the hard alloy, result in the cutting tool wedge fracture. The tool surfaces are subjected to various workpiece abrasive inclusions, and, therefore, abrasive wear became decisive.

It was determined that IMFP contributes to 1,2 times increase of hard alloy material strength and to the reduction of its strength variation coefficient by 2 times. For hard-alloy cutting tools after IMFP strengthening the increase of abrasion wear resistance in $1{,}3 - 1{,}4$ times and the decrease of its variation coefficient in $1{,}8 - 2{,}3$ times are characteristic. The use of simulation methods made it possible to determine the influence of hardening modes on hard alloy wear resistance.

The IMFP influence on the physical and mechanical factors determining the cutting ability of hard alloys during roughing was considered. The strength and abrasive wear resistance of hard alloys to destination K20, K30, P30, P10 (ISO classification) was investigated by means of simulation methods. It was taken into account that during roughing the hard-alloy cutting tools on heavy machine tools there are large loads that due to the low hard-alloy strength result in the cutting tool wedge fracture. In this case, the surface of the tool is exposed to various abrasive workpiece inclusions, and, consequently, from all types of wear the abrasive wear is defining one.

In order to evaluate the strength of the instrument cutting part, the samples were tested under the console bending. The samples were made according to the shape of the corresponding geometric form of the cutting tool made of hard alloys. The samples loading was carried out on the testing machine in the direction of action by the main component of the cutting force *Pz*. It is well known that in rough processing, the probability of the tool fragile fracture directly depends on the thickness of the cut layer, so the ratio of the fracture load to the contact area was taken as the criterion of strength.

The tests results (Fig. 2) showed that the strength of the material after IMFP increased by 1.12 times, and when processed on the inductor number 2 (with increased power) – $1.14 - 1.22$ times. For the samples after IMFP, the coefficient of strength variation reduced by 1.2 times.

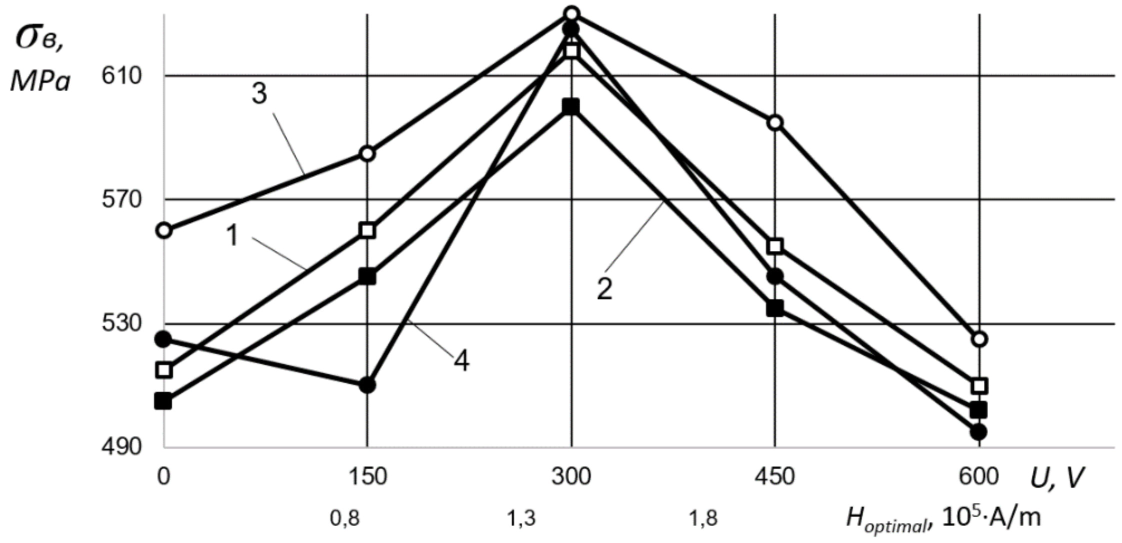

Figure 2. Dependence of the strength on the console bend after IMFP on the inductor number 2:
1 – P30; 2 – P10; 3 – K30; 4 – K20 (ISO classification)

The same results (Fig. 3) were obtained during the tests under the concentrated load action on the sample located on two supports. The bending strength value increased by 1,2 times and the coefficient of strength variation decreased by 2 times.

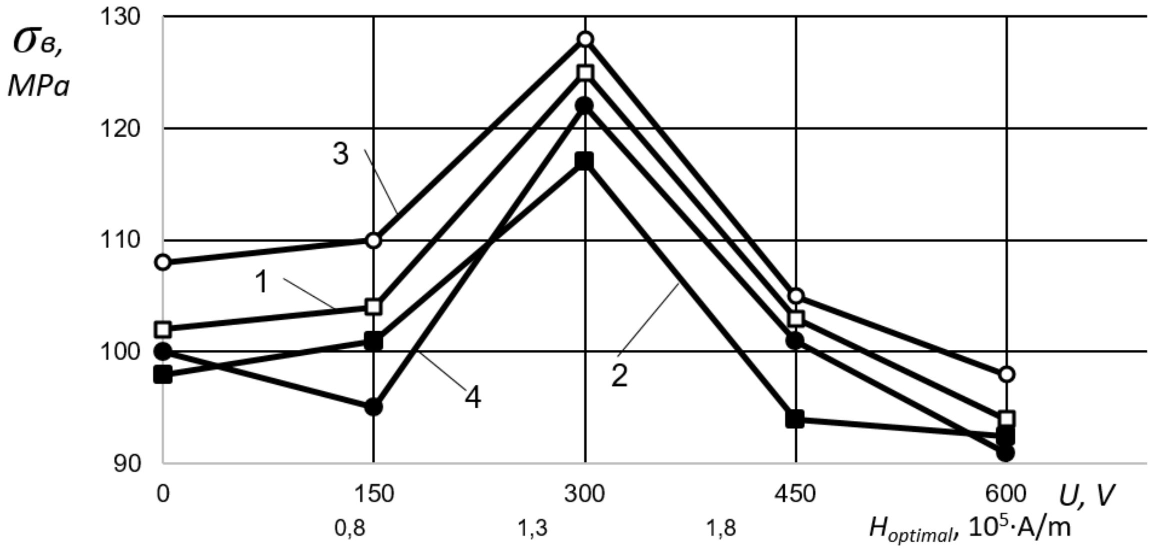

Figure 3. Dependence of flexural strength under the action of a concentrated load:
1 – P30; 2 – P10; 3 – K30; 4 – K20 (ISO classification)

The resistance of the tool materials K20, K30, P30, P10 (ISO classification) to abrasive wear was investigated. Test results (Fig. 4) showed that for samples after IMFP there is 1,3 − 1,4 times decrease in the wear value and 1,5 times decrease in the coefficient of wear variation.

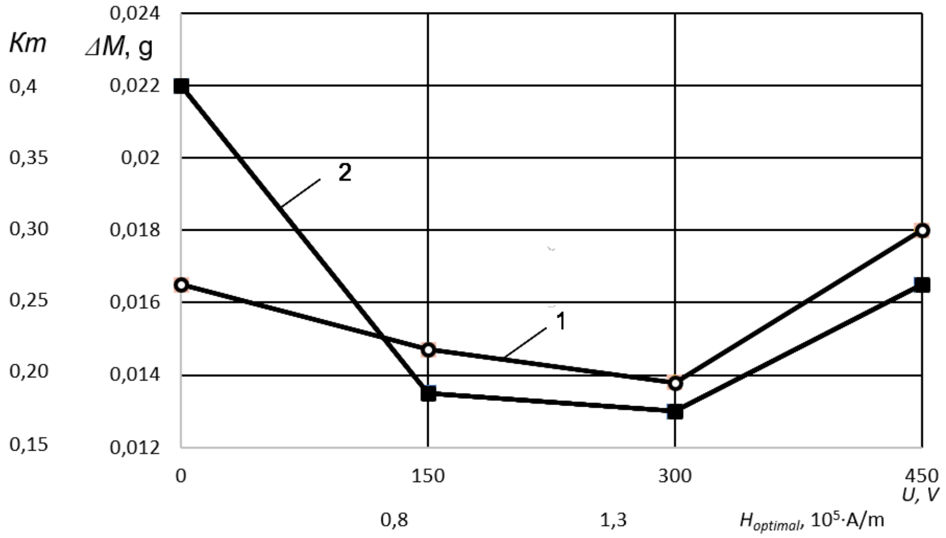

Figure 4. Influence of IMFP on abrasive wear of hard alloy K20 (ISO classification):
1 − coefficient of variation of wear; 2 − the average value of wear

The carried out tests made it possible to find optimal strengthening modes and set the impulse frequency where the strongest effect occur.

Thus, due to the tests results we established that IMFP allowed to increase the characteristics of the material strength, as well as the homogeneity and the degree of uniform distribution of defects by the body volume.

The production tests of the strengthened instruments under PJSC NKMZ conditions were carried out. The ability evaluation was carried out according to the following indices: average stability of tools *T*, coefficient of wear resistance variation K_T, gamma resistance percentage T_γ, stability distribution density *f (T)*, failure rate *λ (T)*, probability of failure-free operation *P (T)*.

The tests results showed that for hard alloy tools after IMFP, the average wear resistance of tools increased 1.2 − 2.0 times, and the coefficient of wear resistance variation decreased in 1.3 − 3.1 times, which confirms previously obtained experimental results. Gamma resistance increased more significantly. So with 0.9 probability this increase occurs in 1.7 − 2.8 times indicating the relevance of using these tools on heavy duty CNC machines, when the part length requires significant stability period.

The efficiency evaluation of metal processing by cutting was carried out by the target functions characterizing the productivity *Q*, cost *C* and instrumental costs *S* depending on the tool stability and cutting modes. The influence of the tool stability dispersion was also taken into account in these functions.

The evaluation of the efficiency of metal processing by cutting allowed to determine the increase in the optimum stability of cutting tools reinforced by IMFP in 1,4 − 2,5 times, as well as to give practical recommendations for determining the optimal feed.

Using the results of production tests, based on the principles of the system approach, the relationship between the mechanical processing parameters and the production process efficiency while using IMFP was presented.

After evaluation of the correlation relations by means of the full factor experiment of 2^4 type, the dependence of the productivity of machining by the cutters strengthened by IMFP was determined from the dominant factors: magnetic field intensity *H*, hard alloy strength boundary $\sigma_в$, cobalt content in the hard alloy *Co*, impulse frequency *f*, having practical implementation:

$$Q = (-22{,}728 + 0{,}094H + 2{,}869\,Co + 4{,}7717\,\sigma_в + 3{,}43\,f + +0{,}003\,f\,H\,Co - 0{,}0144\,H\,\sigma_в - 0{,}7787f\,\sigma_в - 0{,}5983Co\,\sigma_в - 0{,}0892Hf - 0{,}4846fCo + 0{,}0112\,H\,\mathrm{f}Co + 0{,}0973fCo\,\sigma_в + +0{,}006HCo\sigma_в + 0{,}0209\,Hf\,\sigma_в - 0{,}0026HfCo\,\sigma_в) \cdot 10^6$$

Conclusions. The effect of volume strengthening with the impulse magnetic field processing of the hard-alloy cutting tool designed for rough processing on heavy machine tools is established.

The hard-alloy cutting tools tests proved that processing by the impulsed magnetic field contributes to increasing the durability and wear resistance of the tool material during roughing, that is, in the range of small cutting speeds and large feedings.

Tests of hard alloy samples with console bending showed that the tools subjected to IMFP have 1,2 − 1,22 times increased strength, as well as higher homogeneity and uniformity of the defects distribution according to the body volume.

Investigations on abrasive wear demonstrated that after processing by impulsed magnetic field, the abrasive wear resistance of hard-alloy tools rose in 1,3 − 1,4 times and the wear variation coefficient was reduced by 1,5 times.

The use of simulation techniques made it possible to determine the optimal modes and conditions for strengthening, depending on hard-alloy type and geometric parameters of the tool.

The use of IMFP allows to optimize the cutting modes based on processing performance, operation cost and instrumental costs. It is determined that under difficult cutting conditions it is reasonable to optimize the cutting mode by the feed size, taking into account the tools stability dispersion. The application of the hard-alloy tools processing by impulsed magnetic field contributes to the optimal feed value increase in 1,2 − 1,3 times with productivity increase in 1,1 − 1,2 times.

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УДК 621.9

ПІДВИЩЕННЯ ПРОДУКТИВНОСТІ ТВЕРДОСПЛАВНИХ ІНСТРУМЕНТІВ ДЛЯ ВАЖКИХ ВЕРСТАТІВ ШЛЯХОМ ОБРОБКИ ІМПУЛЬСНИМ МАГНІТНИМ ПОЛЕМ

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Резюме. *Робота присвячена створенню й упровадженню твердосплавного різального інструменту з підвищеними експлуатаційними властивостями, який має високу надійність і довговічність. Підвищення ресурсу інструменту при обробленні на важких верстатах є надзвичайно важливим внаслідок значної вартості важких верстатів і необхідністю скоротити час простою при заміні інструменту, а також великою вартістю самого твердосплавного інструменту. Аналіз різних методів підвищення фізико-механічних властивостей твердосплавних інструментальних матеріалів показав, що застосування цих методів, хоча і дозволяє домогтися збільшення зносостійкості інструменту, але не дає можливості суттєво знизити витрати. Підвищення працездатності твердосплавного різального інструменту для важких верстатів здійснюється за рахунок обробки імпульсним магнітним полем. Встановлено, що обробка імпульсним магнітним полем сприяє підвищенню міцності й зносостійкості інструментального матеріалу при незначних витратах. Випробування зразків з твердого сплаву при консольному вигині показали, що зміцнені інструменти мають підвищені міцності, а також вищу однорідність і рівномірність розподілу дефектів за обсягом тіла. Дослідження на абразивне зношування показали, що після обробки імпульсним магнітним полем підвищується абразивна зносостійкість твердосплавних інструментів і зменшується коефіцієнт варіації. Використання методів моделювання дозволило встановити оптимальні режими й умови зміцнення залежно від марки твердого сплаву і геометричних параметрів інструменту.*

Застосування ОІМП дозволяє оптимізувати режими різання за продуктивністю обробки, собівартістю операції та інструментальними витратами. Встановлено, що при важких умовах різання доцільно оптимізувати режим різання по величині подачі з урахуванням розсіювання стійкості інструментів. Застосування обробки імпульсним магнітним полем твердосплавних інструментів сприяє підвищенню величини оптимальної подачі в 1,2 − 1,3 раза, при підвищенні продуктивності − 1,1 − 1,2 раз.

Ключові слова: *зміцнення, твердий сплав, важкий верстат, інструмент, обробка імпульсним магнітним полем, режими різання, продуктивність.*

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