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Faculty: "Mechanical Engineering and Instrumentation"
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Study of the Parameters of the Turning Process when Working with Quick-Change Toolholders

AUTOREFERAT

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DOCTOR

Field of higher education:**5. Technical science**
Professional field: **5.1. Mechanical Engineering**
Scientific specialty: **Cutting materials and cutting tools**

Research supervisor
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The dissertation was discussed and directed for official defense at a meeting of the Extended Department Council of the Department of Mechanical Engineering and Technologies at the Faculty of Mechanical Engineering and Instrumentation of the Technical University - Gabrovo, held on 04.07.2025.

The dissertation work contains 113 pages and an appendix. The scientific content is presented in an introduction, 4 chapters and a conclusion and includes 59 figures, 16 tables and 1 appendix. 138 literary sources are cited. The numbering of the figures, tables and formulas in the abstract is in accordance with that in the dissertation.

The development/research of the dissertation work was/are carried out in the Department of Mechanical Engineering and Technologies at the Faculty of Mechanical Engineering and Instrumentation of the Technical University - Gabrovo and in the company "ADTECH" EOOD, Gabrovo.

The official defense of the dissertation will take place on .... at .... h. in the Conference Hall, Rectorate building of the Technical University - Gabrovo.

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GENERAL CHARACTERISTICS OF THE DISSERTATION

Relevance of the problem

In recent years, specialized machines for performing a given technological operation in a number of workshops have given way to multifunctional machining centers, which allow the sequential and even simultaneous execution of various processes, such as milling, drilling, turning, boring, grinding, polishing with one clamping and on one installation. Modern CNC machines are equipped with automated magazines with over 100 tools, the change of which must occur literally in seconds.

In addition to the functional tooling of the equipment, many new developments are being reported in the tooling equipment - materials, geometries and coatings. The use of diamond-tipped tools significantly improves the final surface quality and accuracy of CNC-machined parts, especially when working with hard and difficult-to-machine metals such as stainless steel and titanium. Many innovations are also observed in new generation lubricants and coolants, which optimize processing by reducing heat generation and wear, and in addition contribute to higher quality of the final product. Among the most key factors for market growth in the segment are innovations in mechanical engineering, which include, in addition to innovations in design and programming software, innovative solutions in the technological equipment of machines (cutting and auxiliary tools and fixtures). In this regard, the current development proposes an innovative design of a universal tool holder, through which to improve the efficiency of the technological process when processing rotary parts on Swiss-type CNC lathes.

Purpose and goals of the dissertation work

The aim of the dissertation is to optimize the cutting mode when turning on CNC machines with an innovative design of a quick-change toolholder.

To achieve the set goal, it is necessary to solve the following main tasks:

1. To develop a quick-change toolholder for CNC turning machines.
2. To conduct a comparative study of the parameters (average roughness - Ra and durability) of the CNC turning process when machining with a monolithic toolholder and with the created innovative quick-change toolholder.
3. To study the influence of the lubricating and cooling fluid supplied through the body of the innovative quick-change toolholder on the average roughness of the machined surfaces.
4. To optimize the cutting conditions in CNC turning when using the innovative quick-change toolholder.

Research methods

The research presented in the work has been carried out using modern and adequate methods and technical means for solving the tasks set. Methods for modeling, statistical processing and analysis of experimental results, planning of experiments and optimization using specialized software have been applied.

Scientific novelty

The scientific novelty is concluded in:

- Development of an innovative design of a quick-change tool holder;
- Construction of graphical dependencies of comparative studies of the average roughness of the machined surfaces and the durability of the tool when turning with a standard (monolithic) holder and with the created innovative design of a quick-change holder.

➢ Construction of mathematical models for the influence of cutting speed and feed on the average roughness and durability of the cutting insert when using the innovative design of a tool holder.

Applicability

➢ Based on the developed innovative design of a quick-change tool holder, tools have been manufactured and industrial tests have been carried out on the machining of bearing rings.

➢ The optimal combinations of cutting speed and feed have been determined, which result in minimum average roughness and maximum tool life.

Approbation of the dissertation work

The dissertation work was reported and discussed at an extended meeting of the Department of Mechanical Engineering and Technologies at the Technical University of Gabrovo.

Stages of the dissertation work were discussed and published in:

- International Scientific Symposium “Metrology and Metrology Assurance“, 2022 and 2023;
- Journal "Automation of Discrete Manufacturing" 2023;

Structure and volume of the dissertation work

The dissertation work consists of: table of contents, accepted notations and abbreviations, introduction, 4 chapters, conclusion, classification of contributions, list of publications on the dissertation, used literature and appendix, in a total volume of 124 pages, which contain text, formulas, 59 figures and graphs and 16 tables.

The literature includes 80 titles (articles, reports, books, textbooks, dissertations, reference books and catalogs, standards) and 58 Internet sites. Of the literary sources, 47 are in Latin.

CONTENTS OF THE DISSERTATION WORK

Chapter One: Turning on CNC Machines – State of the Problem and Analysis of Existing Technological Solution

The introduction in recent years of the requirements of "Industry 4.0" and "Industry 5.0" for ensuring a high-quality product in mechanical engineering, necessitates the need for continuous improvement of the technical and organizational level of companies. This is achieved through the introduction of modern production and technological systems based on international standards, and in particular ISO 9000.

Increasing the productivity and flexibility of technological processes is achieved through the use of modern CNC machines, machining centers and flexible production modules, which can be combined into flexible automated production systems, as well as through the application of tooling equipment (a complex of cutting and auxiliary tools), which provides:

➢ *reducing the loss of time for setting up and changing the cutting tool by simplifying the tool mounting elements and creating quick-change tools, as well as mechanisms that provide automatic change of the cutting tool during idle;*

➢ *reducing the loss of time for adjusting the cutting tool on the machine, which is achieved by creating cutting tools with adjustable dimensions outside the machine;*

➢ *reducing unplanned downtime of the equipment by using devices signaling extreme wear and breakage of the cutting tool, as well as devices for kinematic chip crushing*

To solve the problems related to the quality of machining on CNC metalworking machines, it is important to ensure the accuracy and stability of technological processes, which largely depends on the type of cutting and auxiliary tools used.

Cutting tools for CNC metalworking machines must meet the following requirements:

➢ *stable cutting properties;*

➢ *good chip formation and removal;*

➢ *ensuring the specified accuracy;*

- *universality when using standard machined surfaces from different parts on different machine models;*
- *quick changeability when re-setting for another machined part or after wear;*
- *possibility of pre-setting the size outside the machine, etc.*

Auxiliary tools must meet the following requirements;

- *their nomenclature and value should be reduced to an economically justified minimum;*
- *the installation of cutting tools to them should ensure the necessary accuracy and stability;*
- *if necessary, they should provide the possibility of adjusting the position of the cutting edges of the tool;*
- *they should be convenient for service and technological for manufacturing*.

The variety of methods for optimizing the turning process on CNC machine tools is mainly divided into two main groups - conventional and unconventional.

The parameters influencing the optimization of the turning process form four main groups - cutting tool properties, machine tool parameters, material properties and cutting conditions. The most common input variables in process optimization are cutting speed and feed rate.

From the literature data provided, it can be seen that both standard and quick-change holders of different designs are used when working on CNC lathes. There are a number of studies on the accuracy and roughness of the machined surfaces, the durability of the cutting tool, the productivity and cost of the turning process, implemented with various cutting and auxiliary tools. However, there are no comparative studies on the parameters of the turning process when using standard and quick-change holders, as well as recommendations for choosing a holder for tools for processing materials with different physical and mechanical properties.

Chapter Two: Designing a Quick-Change Holder

2.1. Quick-change tool holders for CNC lathes

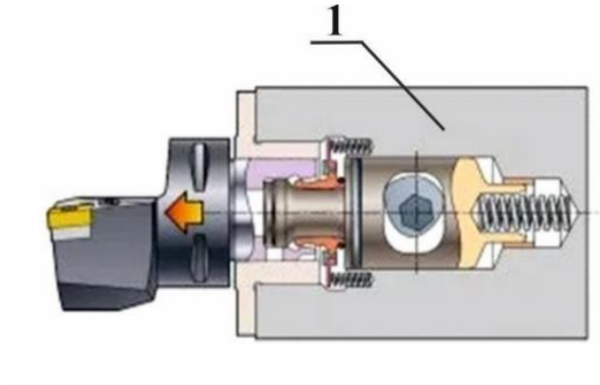
When selecting an auxiliary tool, one should look for a reduction in machine downtime. Quick-change tool holders reduce the time for setting up and changing tools, which leads to a significant increase in the time for effective use of the machines**.**

From the information in the literature, it is established that the main part of the tooling equipment of CNC lathes is the tool holder. In recent years, new designs of quick-change holders for metal-cutting tools have entered practice. With these quick-change tool systems, the use of the machine can be significantly increased by reducing the time spent on measuring, setting up and changing tools.

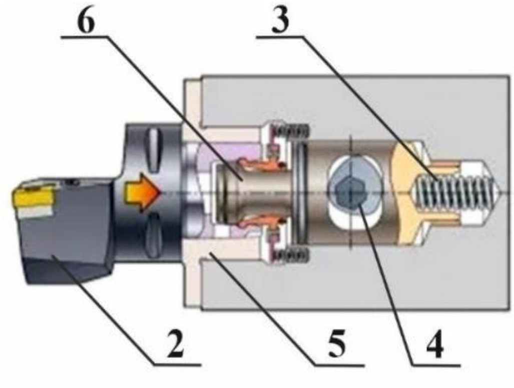
Currently, leading companies in the supply and design of modular quick-change tool holders are: Kennemetal, Widia krupp, Sandvik Coromant Capto, Valter, Hainz Kaizer, etc.

Coromant Capto® is a modular quick-change tool system - fig. 2.1, which maximizes machine utilization and cutting efficiency. Its advantages are:

- *Segment collet clamping – The camshaft-driven linkage is used both to lock the segment collet-clamped joint and to push the cutting head out. Manual locking and unlocking of the tool block requires only a turn – Fig. 2.1 c. The self-locking cam mechanism prevents the tool from loosening during machining;*
- *Repeatability - The high-precision, self-centering design of the linkage provides repeatable accuracy (±2 µm) in the x, y, and z axes for the same cutting head in the same holder. This allows pre-setting off-machine for large batches of parts or to use a tool magazine during batch changes, eliminating the need for measuring operations, achieving faster start-up and less rejects*



a.



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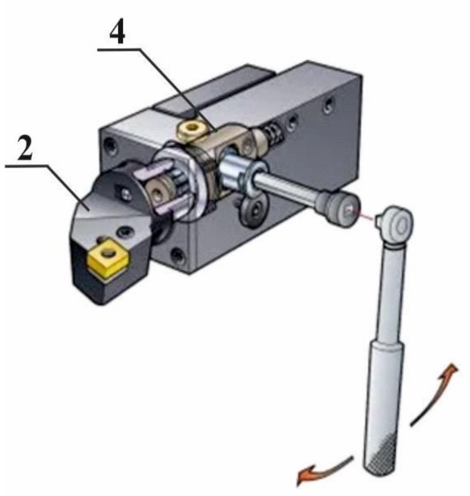


c.

Fig. 2.1. Tool change diagram when using the Coromant Capto® system [122]:
a – automatic removal of the tool block;
b – automatic clamping of the tool block;
c – manual change of the tool block.
1 – tool holder body;
2 – tool block;
3 – spring; 4 – screw connection;
5 – sleeve; 6 - adapter

- *Increased stability - Stability is characterized by the transmitted torque. The main properties that provide excellent stability are:*
  - ✓ Face and cone contact: withstands bending moments and ensures positioning accuracy;
  - ✓ Polygonal connection: the large contact area allows torque transmission without additional parts such as pins or keys. In this case, the load is distributed evenly regardless of direction, and the self-centering of the polygonal profile guarantees the exact position of the cutting edge relative to the height of the axis of the machining centers;
  - ✓ High clamping force: Clamping with a segmented collet generates a high clamping force, providing an interference fit and contact in two planes, which increases the resistance to bending moments generated during cutting.

The presented Coromant Capto quick-change tool systems can be used on all types of machines: multi-spindle lathes, machining centers, etc. The company's quick-change holders are available in six sizes to suit any application: C3-C10, with flange diameters of 32, 40, 50, 63, 80 and 100 mm.

Internal coolant ensures that the full potential of the machine is used with optimized tools and maximum chip control. The increased number of tool positions with two-position tool blocks allows the block to be used for machining external and internal surfaces.

Fig. 2.2 shows a new design of a quick-change holder, built from modular elements with a clamping mechanism (ISCAR Patent WO 2013/018087 A3) [104]. The modular part of the holder includes two main modules: rear - pos. 1 and front - pos. 4. Their connection is carried out by spherical surfaces with four convex and four concave points. A spring 2 is placed in the hole of the body 1, and the connecting element 3 is attached to the hole of the cutter head 4 by means of a screw connection.

A carbide plate (pos. 5) is attached to the cutting head in a socket (pos. 6) by means of a screw connection. The cutter head is fixed to the holder body by means of a screw connection 7, implemented in the hole of the holder 8.

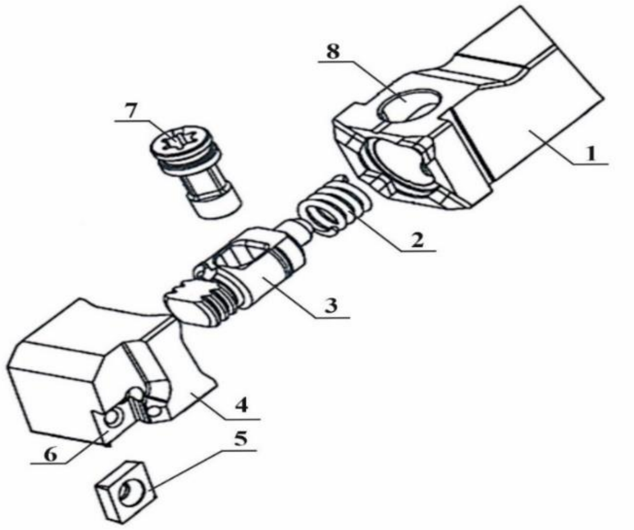


Fig. 2.2. Scheme of quick-change toolholder ISCAR WO [104]

Along with the advantages of this design, there is also a significant drawback - the system is complex and multi-component. Over time, the spring loses its elasticity, which leads to a violation of the working properties of the holder. This makes the practical application of the design effective only in the turning process.

Quick-change toolholders from the SCHNEIDER system - Fig. 2.3, have found relatively wide distribution in practice [135]. They are based on clamping by a stop screw at an angle to the main axis of the tool and the holder.

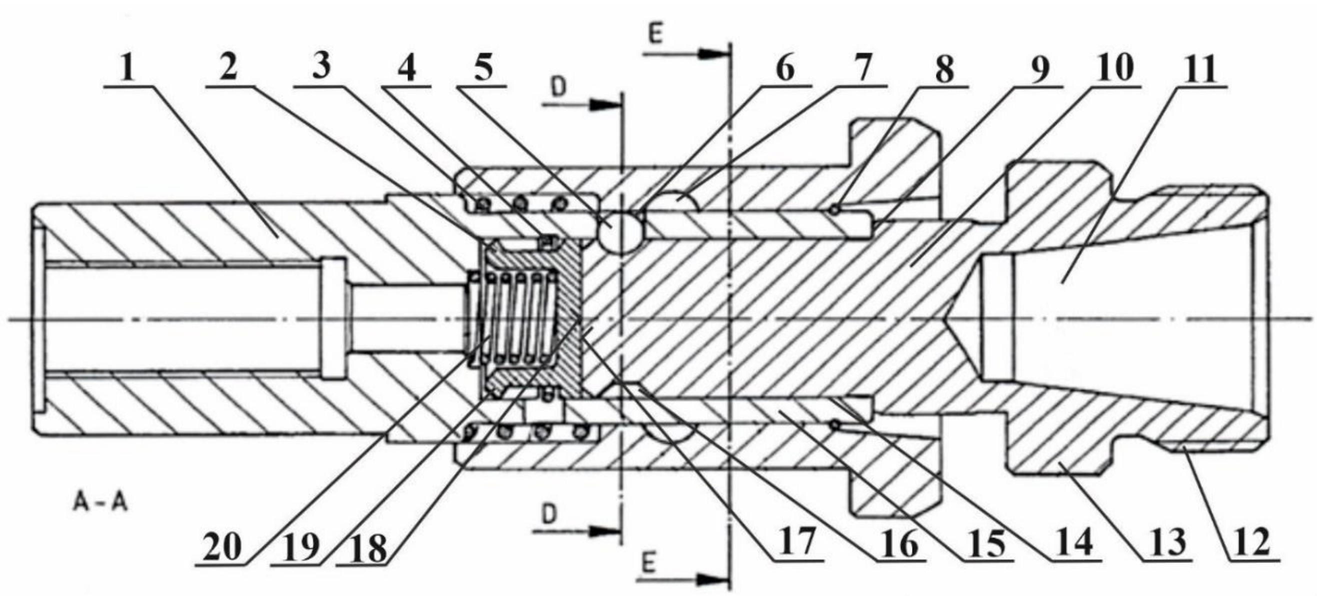


Fig.2.3. Schematic of a quick-change tool holder SCHNEIDER [135]
1 – housing; 2 – bushing; 3 – outer spring; 4 – "O" ring;
5 – stop screw; 6 – lubrication hole; 7 – outer sleeve;
8 – connecting cone adapter; 9- contact surface; 10 – adapter body; 11 – cone connecting tool;
12 – connecting thread; 13- working part of the adapter;14 – connecting sleeve; 15 – transition sleeve; 16 – locking channel; 17, 18 – contact surfaces; 19 – spring; 20 – seal.

At the smallest size of the holder, with a screw M5 and a tightening torque of 3 Nm, stable operation of the cutting edge is ensured. This tightening has two disadvantages;

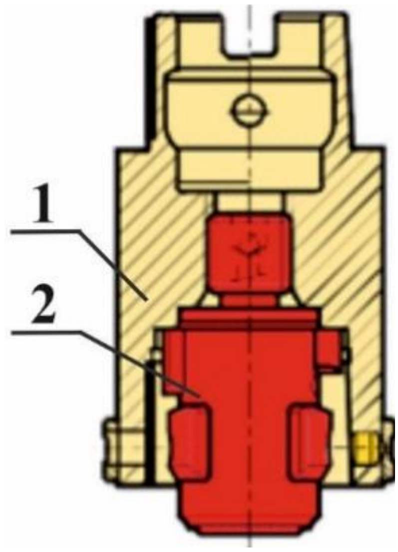
- *the tightening force is not symmetrical to the main axis, which is why the screw is located on the most favorable side;*
- *at the required tightening force, the screw M5 is significantly loaded, which necessitates the use of high-strength materials.*

This variant of a quick-change holder is applicable only for tools with a rotary shank shape or for the drilling, countersinking and milling processes.

The main disadvantage of the design is its excessive complexity, which leads to a high cost of the final product and the impossibility of directly supplying coolant to the cutting zone.

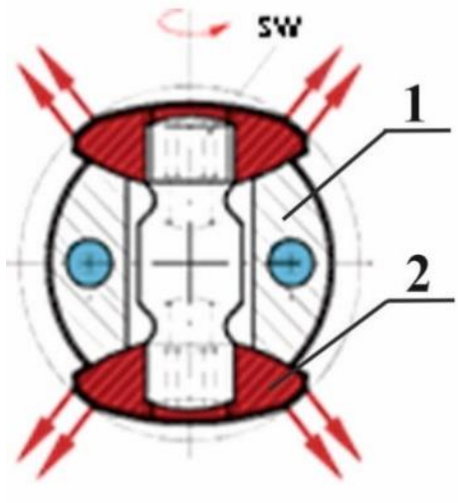
Fig. 2.4 shows a diagram of a cassette with four-point clamping of quick-change tools, in which the clamping force is transmitted in a perpendicular direction through a conical surface – Fig. 2.5.

The clamping force is provided by two jaws with chamfers on the contact side. The jaws move radially on the cartridge from a core, on which on one side there is a left-hand thread, and on the other - a right-hand one. When unscrewing and screwing the core, the jaws move apart (tightening) and come together (loosening). This clamping is symmetrical to the main axis. The required tightening torque for a M5 screw for the smallest size of the machining tool is two times smaller - 1.5 Nm, compared to the system presented in Fig. 2.3.



a.

Fig.2.4. Quick-change holder with four-point clamping 1 – holder; 2 – adapter [88]



b.

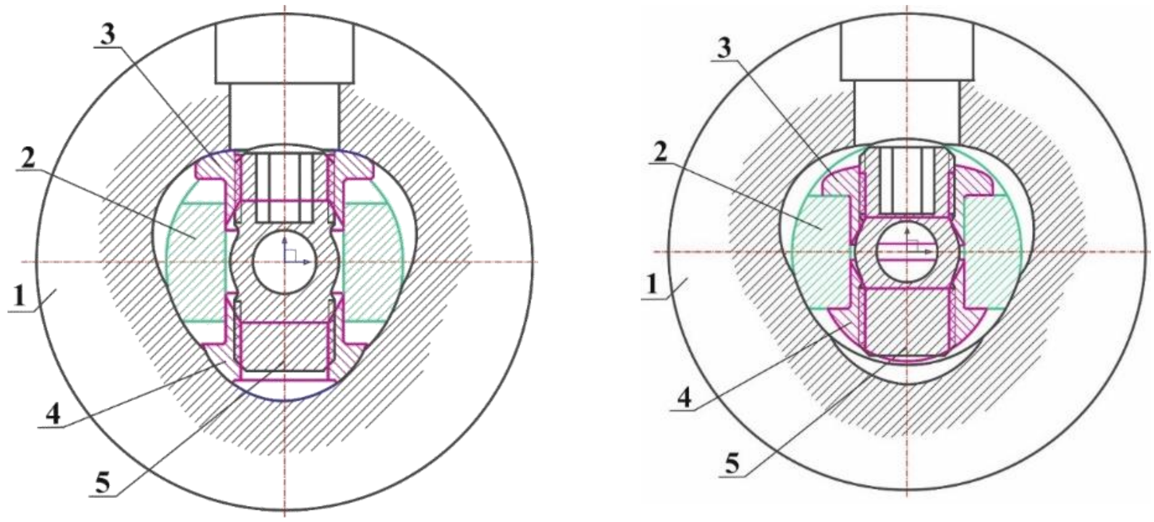
Fig.2.5. Scheme of four-point clamping: 1 – body; 2 – jaws [88]

A disadvantage of 4-point clamping is that in order to ensure uniform force at the 4 points, it is imperative that there is some clearance between the guides, the threads of the core and the jaws. If the design does not provide for clearances, then high precision in manufacturing the elements of the assembled unit is necessary to ensure a relatively uniform distribution of the clamping force.

2.2. Innovative design for quick-change holder

The schemes of quick-change holders for CNC lathes considered in section 2.1 have one main drawback - they are characterized by a very complex design and complex manufacturing. In most of the proposed options, there is no possibility of supplying coolant to the cutting zone. All this leads to a higher cost, and hence to a high price of the final product.

Based on the accumulated information, a new innovative system of a clamping mechanism for quick-change fastening of metal-cutting tools has been developed. – Fig. 2.6.

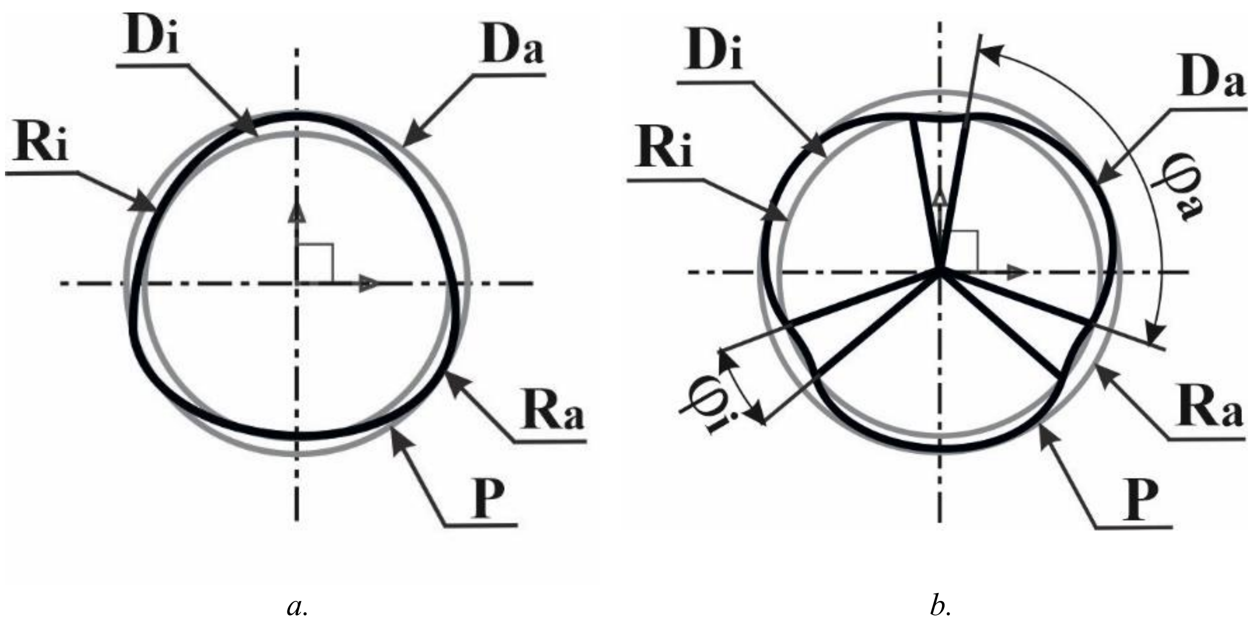


a. *b.*

Fig. 2.6. Scheme of a clamping mechanism for quick-change fastening of metal-cutting tools:
a – in the clamped position (working position); b – with retracted stops for tool change
1 – tool modular head; 2 – internal carrier;
3 – stop with two support radius surfaces;
4 – stop with one support radius surface; 5 – core.

It is based on the known systems with a polygonal profile, presented in EP0294348 [106]. The system includes a holder, in the base face of which a stepped hole with a cylindrical and profile section and a modular head is formed.

In the innovative design, the modular head is connected to the holder, with the step-shaped connecting element of the modular head being mounted with a clearance in a step opening of the holder, so that the cylindrical section of the step-connecting element is located in the cylindrical section of the step opening, and the profile section of the step-connecting element is located in the profile section of the step opening. The shape of the profile section of the holder corresponds to the shape of the profile section of the modular head. It has the shape of a concave polygonal cone, and the profile section of the modular head has the shape of a convex polygonal cone. Each of the profile sections has conical surfaces with three outer radii Ra and three inner radii Ri – Fig. 2.7.



a. *b.*

Fig. 2.7. Diagram of the shaft profile (a) and the hole (b) of the clamping deviceo

The cross-section of each of the profile sections, respectively of the holder and the modular head, has a polygonal profile type "Capto" according to ISO 26623:2014, with the design basis of the polygonal profile being according to DIN 32711. The contact surface, which bears the torque load, provides resistance to crushing, but the arm of application of the resultant torque force is shorter, which leads to increased torsional stress.

The developed clamping mechanism for quick-change tool attachment – Fig. 2.6, includes a tool modular head 1, in which a central hole is formed with three concave radius surfaces, located at 120 ° intervals. An internal carrier 2 is placed in the central hole with cutouts formed therein for mounting stops. At one end of the carrier 2, a stop 3 with two support radius surfaces is mounted and opposite it - a second stop 4 with one support radius surface. The length of the recesses from the central hole corresponds to the length of the stops 3 and 4. The stop 3 on the back side has a formed chamfer and has an internal right-hand thread, and on the back side of the second stop 4 a chamfer is formed and has an internal left-hand thread, whereby the stops 3 and 4 are installed on a core 5 placed in the central hole of the tool module head 1. On the core 5 on one side there is formed an external right-hand thread, corresponding to the thread of the stop 3 with the two support radius surfaces, and on the other side there is formed an external left-hand thread, corresponding to the thread of the second stop 4 with one support radius surface, and on the side of the right-hand thread of the core 5 there is a front internal hexagonal hole for a corresponding tightening key.

During machining of metal workpieces, the clamping mechanism for quick-change tool clamping is subjected to cutting forces of different directions and magnitudes. They cause reactions that are transmitted to its attachment and, in particular, to its clamping mechanism. In the developed clamping mechanism, the clamping force is transmitted in a perpendicular direction through a conical surface, but the clamping force is applied at three axisymmetric points. The formation of this clamping at three points is achieved thanks to the presence of the two stops 3 and 4. The stop 3 has two support radii, and the second opposing stop 4 has one support radius, through which the clamping force is applied at three points and is distributed evenly relative to the central axis of the tool modular head 1.

The developed innovative system for quick-change tool attachment is implemented in a tool system, which is presented in a 3D image in Fig. 2.8 ÷ 2.10. It includes a holder 1 and a modular head 3.

- *The holder 1 has a surrounding surface and a base face, and in the base face a stepped opening 2 with a cylindrical section 2.1 and a profile section 2.2 is formed - Fig.2.9.b.*
- *The modular head 3 has a surrounding surface, a working surface and a base face, in which a stepped connecting element 4 with a cylindrical section 4.1 and a profile section 4.2 is formed on the base face - Fig.2.9.a.*

The modular head is connected to the holder 1, with the stepped connecting element 4 of the modular head 3 being mounted with a clearance in the stepped opening 2 of the holder. In particular, the cylindrical section 4.1 of the stepped connecting element 4 is located in the cylindrical section 2.1 of the stepped opening 2, and the profile section 4.2 of the stepped connecting element 4 is located in the profile section 2.2 of the stepped opening 2.

The profile section 2.2 of the holder 1 has the shape of a concave epitrochoidal cone, and the profile section 4.2 of the modular head 3 has the shape of a convex epitrochoidal cone. The shape of the profile section 2.2 of the holder 1 corresponds to the shape of the profile section 4.2 of the modular head 3. The shape of the cross-section of each of the profile sections 2.2, 4.2, respectively of the holder 1 and the modular head 3, is a cloverleaf type (Fig. 2.7.b). The profile sections 2.2, 4.2 in turn have conical surfaces (three convex and three concave) with three outer radii Ra and three inner radii Ri. The outer radii Ra are larger than the inner radii Ri, with the inner radii Ri having a smaller central angle φi compared to the central angle φa of the outer radii Ra – Fig. 2.7.b.

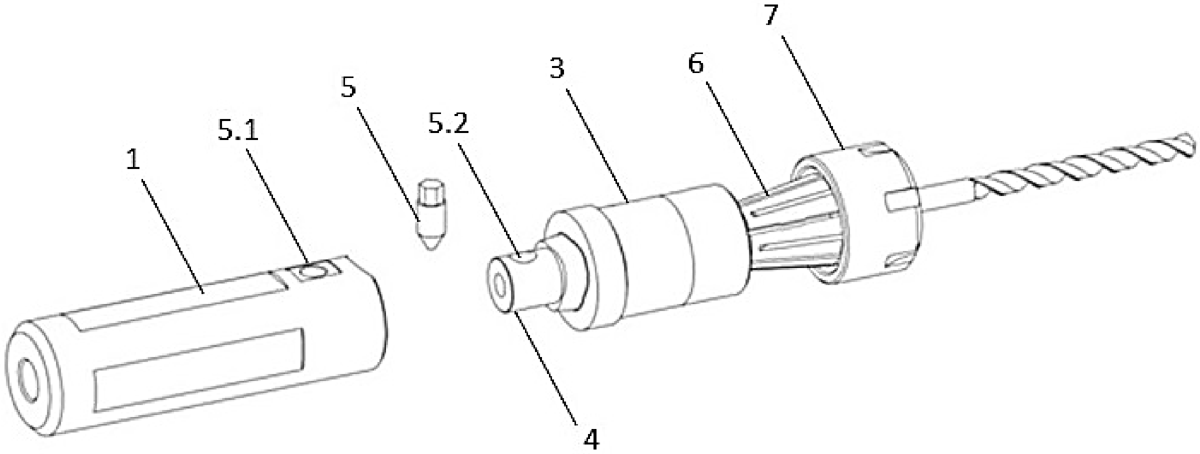


Fig.2.8. Scheme of the innovative solution for a tool module
1 – holder; 3 – modular head;4 – stepped connecting element of the modular head;
5 – stop screw; 5.1 and 5.2 – holes for the stop screw; 6 – collet;7 – connecting nut

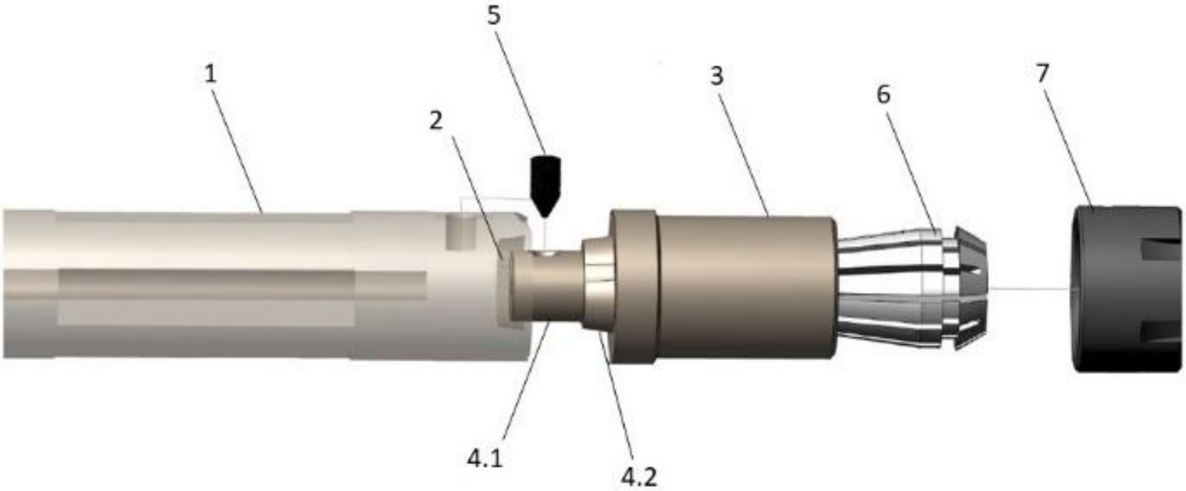
A through threaded hole 5.1 is formed in the surrounding surface of the holder 1 for placing a locking screw 5 with a conical tip, which has the possibility of being tightened in an additional conical hole 5.2, formed in the cylindrical section 4.1 of the stepped connecting element 4.

Two variants of the system for quick-change tool fastening have been developed, differing in the shape of the holder and the modular head. In the first variant - Fig. 2.9 a, the holder 1 and the modular head 3 have a cylindrical shape. A conical hole is formed in the working surface of the modular head 3, which has the possibility of attaching a collet 6. On the surrounding surface of the modular head 3, from the working surface, a cylindrical metric thread is formed, which allows for tightening a nut 7. In the second variant of the system for quick-change tool fastening - Fig. 2.10, the holder 1 and the modular head 3 have a prismatic shape. The working surface of the modular head 3 is shaped so that it is possible to attach a turning tool.

The analysis and comparison between the presented innovative technical solution of a system for quick-change tool clamping and the known systems with a polygonal profile, such as the one presented in EP0294348 [106], show that they are made of a material with the same strength properties and hardness after heat treatment and have comparable overall dimensions. The resistance under the influence of the torque is borne by three radii of the profile, as the generator along these radii has the same slope, which makes the conical surfaces of the two clamping systems similar.

The innovative quick-change tool clamping system developed differs significantly from standard polygonal profile systems, which is a result of the way the modular head is attached to the holder:

- *With the polygonal profile, the contact surface that bears the torque load is larger, which provides greater resistance to crushing, but the arm of application of the torque force is shorter. This leads to higher torsional stresses. With the epitrochoidal profile, the contact surface is smaller. This leads to lower resistance to crushing, but the torque load is smaller, since the arm of application of the torque is larger.*
- *The size of the contact spot between the tool module and the holder largely depends on the clearance between the conical surfaces of the module head and the conical surfaces of the holder. This clearance is mandatory for the connection to be quick-changeable while ensuring self-centering. In order to be precise, the assembly of the polygonal profile requires higher accuracy of execution (g6/H6). This in turn leads to high requirements for the mutual arrangement of the conical surfaces for*



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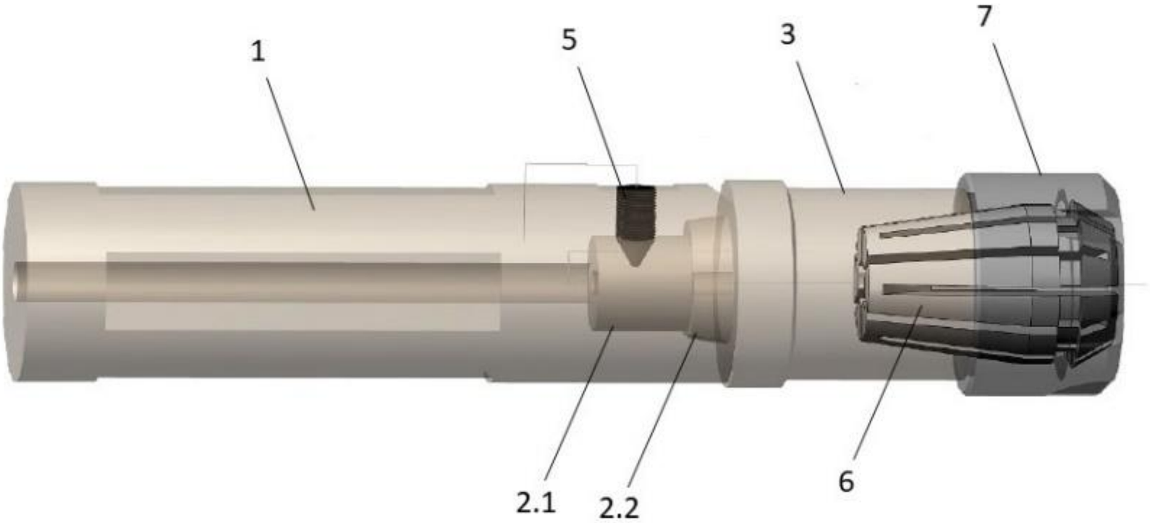

b.

Fig.2.9. 3D model of the proposed innovative quick-change holder system in the cylindrical shape of the holder and the modular head
a – in the process of joining; b – in the working position with a mounted connecting screw;
1 – holder; 2 – foot-shaped hole of the holder;
2.1. – profile section of the connecting element of the modular head;
2.2 – profile section of the holder; 3 – modular head;
4 – foot-shaped connecting element of the modular head;
4.1 – cylindrical section of the connecting head;
4.2 – profile section of the connecting head;
5 – stop screw; 6 – collet; 7 – connecting nut;
8 – channel for supplying lubricating and cooling liquid.

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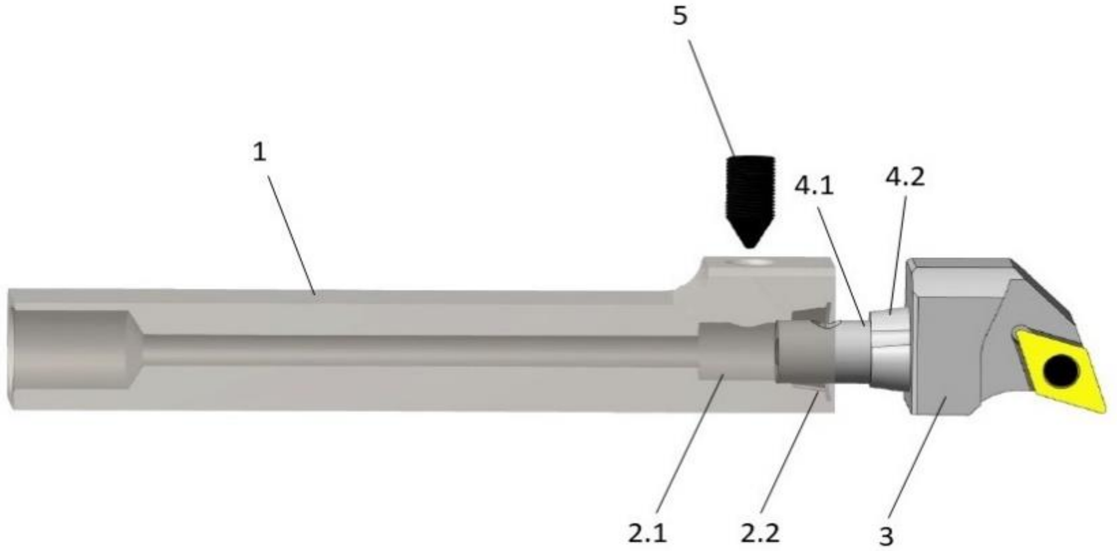
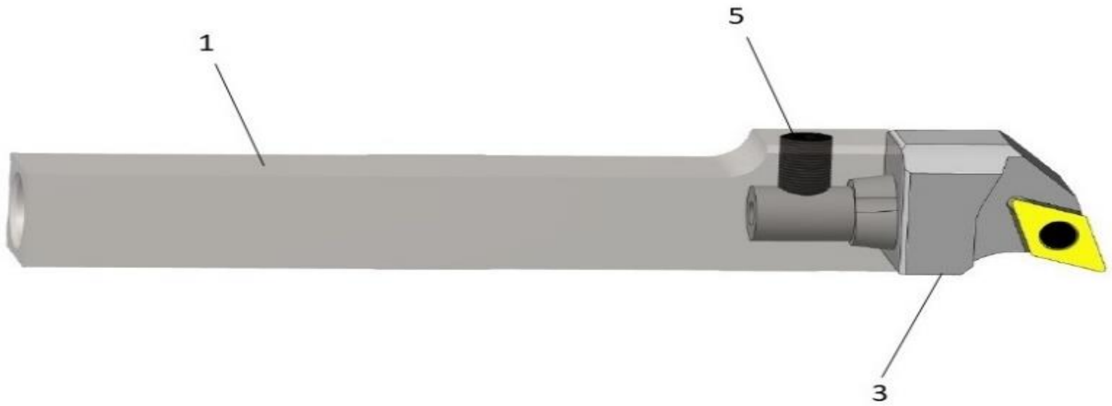


a.



b.

Fig. 2.10. 3D model of the proposed innovative quick-change holder system with a prismatic shape of the holder and the modular head
a – in the process of joining;b – in the working position with a mounted connecting screw;
1 – holder; 2 – foot-shaped hole of the holder;
2.1. – profile section of the connecting element of the modular head;
2.2 – profile section of the holder; 3 – modular head;
4 – foot-shaped connecting element of the modular head;
4.1 – cylindrical section of the connecting head;
4.2 – profile section of the connecting head;
5 – stop screw; 6 – collet; 7 – connecting nut;
8 – channel for supplying lubricating and cooling liquid.

each element of the fastening system. The absence of convex connecting cones in the epitrochoidal profile is a technological advantage. The concave conical surfaces do not require precise contact between the module head and the holder, i.e. this gives greater freedom in the accuracy of execution and the ability to ensure a good contact spot even in an assembly with a clearance (g6/H7).

- *The greatest technological advantage of the epitrochoidal profile is that the mutual arrangement of the conical surfaces is specified only between three axisymmetric cones, and not between six, as is the case with the polygonal profile.*

2.3. Practical implementation of the development

The developed quick-change tool clamping system can be used to clamp tools with both rotary and prismatic coupling parts.

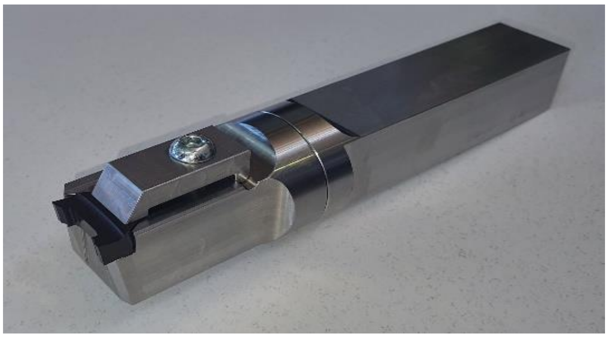
When attaching instruments with a cylindrical shank, the cylindrical section 4.1 of the modular head 3 enters the cylindrical section 2.1 with a corresponding diameter in the holder 1. This achieves alignment of the main axes of the modular head 3 and the holder 1. The convex epitrochoidal cone of the modular head 3 is oriented in the concave epitrochoidal cone of the holder 1 so that the through threaded hole 5.1 is coaxial with the additional conical hole 5.2, which allows for tightening with a locking screw 5 with a conical tip. Tightening the conical locking screw 5 leads to pressing the base face of the modular head 3 against the base face of the holder 1. This ensures the frontal basing of the modular head 3 against the holder 1. A cutting tool with a cylindrical shank is pre-mounted in the modular head 3, clamped to it by means of the collet 6 and the nut 7. This can be done outside the working area of the machine. The collet 6 together with the nut 7 fits into the conical hole of the working surface of the modular head 3. It has an external cylindrical metric thread, onto which the nut 7 is screwed. When a drill, countersink, milling cutter or other tool with a cylindrical shank with a diameter corresponding to the collet 6 is placed in the hole of the collet 6, by tightening the nut 7 it is fixed firmly to the modular head 3. According to the diameter of the cylindrical shanks of the tools, the corresponding collet 6 is selected. The conical dimensions of the collet 6 are the same for one size of modular head 3.

The modular head 3, the collet 6, the nut 7 and the machining tool form a so-called tool module. The tool module is attached to the machine tool holder 1 in the working area by means of a quick-change attachment. The holder 1 is firmly and immovably attached to a standard support of the metalworking machine. The tool module enters the stepped connection element 4 into the stepped opening 2 of the holder 1, so that the epitrochoidal conical profile section 4.2 of the modular head 3 is based on the epitrochoidal conical profile section of the holder 1. In this way, the loading torque is absorbed by the outer radii Ra of the epitrochoidal profile. The conical tip of the stop screw 5, when it enters the additional conical hole 5.2 of the modular head 3, ensures pressing of the base face of the modular head 3 against the base face of the holder 1. This means that the assembly of the two conical epitrochoidal profiles has a clearance, which excludes wedging.

In the other exemplary embodiment – Fig. 2.10, the fastening of turning tools with replaceable carbide inserts of different shapes is presented. The turning tool is fastened in a standard way through a bed to the working surface of the modular head 3. In order to achieve the correct orientation of the modular head 3 to a holder with a prismatic shape 1, it is necessary that the cylindrical section 4.1 of the modular head 3 enters the cylindrical section 2.1 with a corresponding diameter in the holder 1. The alignment of the cylindrical section 4.1 of the modular head 3 and the cylindrical section 2.1 with the corresponding diameter in the holder 1 ensures the coincidence of the main axes during assembly. The epitrochoidal convex cone of the profile section 4.2 of the stepped connecting element 4 of the modular head 3 is oriented in the epitrochoidal concave cone of the profile section 2.2 of the stepped opening 2 of the holder 1, so that tightening with a locking screw 5 is possible. Tightening by means of the locking screw 5 leads to the base face of the modular head 3 being pulled towards the base face of the holder 1. This ensures the frontal alignment of the modular head 3 with the holder 1.

Depending on the shape and angles of the turning tools, different modular heads have been developed. The modular head 3 is mounted on a prismatic holder that is stationary relative to the machine in the following way:

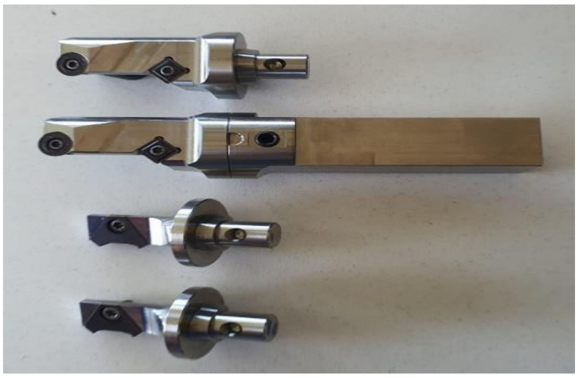
- *The prismatic holder or a group of similar holders are mounted stationary on a support attached to the base surfaces of the support in the machining area of the machine.*
- *The base face of the holder is strictly perpendicular to the walls of the surrounding prismatic surface of its body. Since there is a technological radius between the convex epitrochoidal conical profile and the base face, a cylindrical relief is made in the base face of the holder. As a result, a tight fit of the two faces is ensured. The profile section 2.2 with the epitrochoidal profile of the stepped hole 2 of the holder and the centering hole in the holder are strictly coaxial, with the larger outer radii Ra taking priority. The same requirement is observed for the convex epitrochoidal conical profile of the profile section 4.2 of the stepped connecting element 4 of the modular head 3, where the larger outer radii Ra also take priority.*
- *The modular head ensures precise orientation of the cutting edge of the turning tool (most often a cermet insert) relative to the prismatic holder, and therefore also relative to the base surfaces of the machine support.*
- *The fitted base faces ensure the position of the cutting edge tip relative to the machine coordinate system.*
- *The epitrochoidal profile of the quick-change tool clamping system ensures unambiguous orientation of different modular heads 3 to the corresponding prismatic holders.*



a.

b.

c.



d.

Fig.2.11. Sets of quick-change holders and tool blocks for turning on CNC metalworking machines, made on the basis of the developed innovative design:
a – general view of a quick-change holder;
b – holder with a tool block for external cylindrical turning;
c – combined holder for face turning and boring holes;
d - quick-change holder with a set of replaceable tool blocks.

Based on the innovative solution, sets of quick-change holders with tool modules for processing various surfaces in turning operations on CNC metalworking machines have been manufactured, presented in Fig. 2.11.

2.4. Conclusions

Based on the results obtained from the conducted research, the following more important conclusions can be formulated:

1. It has been established that at present the most practical application is found in the quick-change modules of Sandvik Capto (Coromant Capto). The main advantages of the system over the others considered are:
   - *flexibility through broad modularity;*
   - *high stability and precision;*
   - *minimal tool nomenclature;*
   - *reduced setup time.*
2. The considered designs of existing quick-change holders have major disadvantages related to:
   - complex multi-component systems;
   - the need for high accuracy in manufacturing the elements;
   - in most designs there is no possibility of supplying coolant to the cutting area.
3. Based on the identified shortcomings of existing quick-change holder designs, an innovative system for quick-change tool mounting with an epitrochoidal profile of the contact surface of the holder and the modular head has been developed, which can be used to mount tools with a rotary and prismatic coupling part.
4. The developed innovative system is characterized by a stable design, allowing for quick readjustment of CNC lathes when manufacturing small batches of parts (when using standard holders, this is associated with high time costs).
5. The developed innovative proposal is characterized by the following features:
   - *allows high torque transmission;*
   - *high bending strength;*
   - *fast or automated cutting tool change;*
   - *possibility of using new cooling technology through fixed nozzles for process reliability even at low coolant pressure;*
   - *possibility of internal coolant supply from the machine to the tip of the cutting edge;*
   - *balance and alignment;*
   - *self-centering, etc.*
6. The use of the new system will lead to a reduction in the cost of manufactured products and an increase in the competitiveness of companies.

Chapter Three: Study of the parameters of the turning process using a standard and quick-change holder

3.1. Research tasks

The tasks to be solved in the research process are:

- *To conduct comparative studies of the average roughness of the machined surfaces and the durability of the cutting tool when turning with a standard (monolithic) holder and with the innovative quick-change holder design created.*
- *To study the influence of the types of lubricating and cooling fluids on the accuracy of the machined surfaces when turning with the innovative quick-change holder design created.*
- *To monitor the economic efficiency of the implementation of quick-change holders in real production conditions.*

3.2.Equipment, materials, methods

The turning process was implemented on a CNC turning center, model GOODWAY SW-20. – Fig.3.1.

The Swiss turning center of the GOODWAY SW series provides up to 9-axis control and 4-axis coordinate movement, which is of high productivity by using a high-speed built-in spindle, a complete tool system – Fig.3.2. and a flexible design of a hybrid guide bushing.

Fig.3.1. General view of a Swiss-type CNC turning center model GOODWAY SW-20 [136]

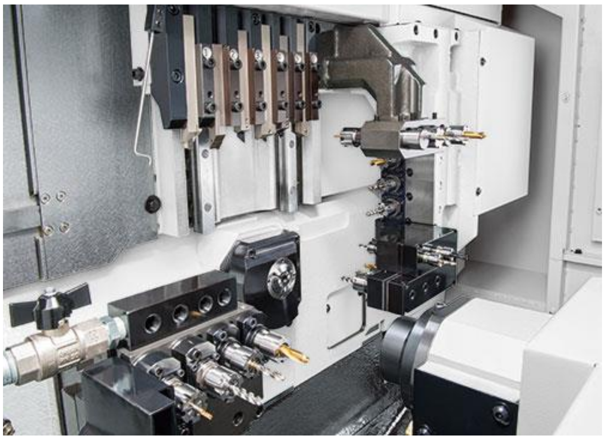


Fig.3.2. The GOODWAY SW-20 instrument system [136]

Tools with replaceable metal-ceramic carbide inserts VCMT 110302 (ISO 1832) are used, mounted in a standard holder SDJCL-1212G-11 (ISO 5608) and in the original design of a quick-change holder - Fig. 3.3.

a.

b.

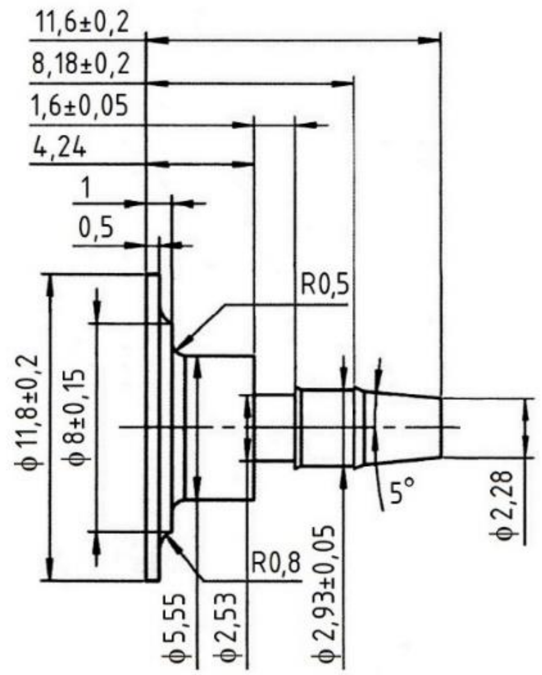
c.

Fig.3.3. Innovative tool system:
a – quick-change tool holder; b – holder and tool block; c – holder with tool block

Experimental studies on the influence of the type of tool holder on the average roughness - Ra of the machined surfaces were carried out when manufacturing a series of parts - Fig. 3.4, from alloy steel 42CrMoS4 (1.7227) [22] with a hardness of 33-35 HRC and a chemical composition according to table 3.1.

Table 3.1. Chemical composition of 42CrMoS4 (1, 7227) EN 10277-5-2008

Chemical elements, %								
	C	Si	Mn	P	S	Cr	Mo	Fe
min	0,38	0,02	0,60	-	0,02	0,90	0,15	до
max	0,45	0,04	0,90	0,025	0,04	1,20	0,30	100%



a.

b.

Fig.3.4. Drawing of the manufactured part – a and finished products – b

When determining the influence of the cooling medium on the roughness of the machined surfaces, two types of cooling and lubricating fluids were used – ECOCOOL MACH 40 [110] and VASCO 6000 [138].

The holders used in the studies ensure constant geometry of the tool:

- *front angle –* $\gamma = -5$ *°;*
- *rear angle –* $\alpha = 0.7$ *°;*
- *main setting angle – kr = 93 °;*
- *auxiliary setting angle -* $kr^1 = 32$ *°;*
- *tool tip radius - rε.= 0.2 mm.*

The turning process was carried out with the following parameters of the cutting mode:

- cutting speed Vc = 150 m/min;
- feed f = 0.05 mm/rev;
- cutting depth ap = 0.02 mm.

When assessing the roughness of surfaces according to the current standards ISO 4287; ISO 12085 (BDS 728-79), the arithmetic mean deviation from the profile – Ra was studied.

The measurements were carried out on the front surface of the machined parts (Ø 11.8±0.2) with a TESA Rugosurf 20 profiler. As a parameter for assessing the quality of the machined surfaces in this particular case, the roughness measured by the criterion, Ra, µm - Fig. 3.5.

Fig.3.5.Scheme of roughness measurement by criterion, Ra, µm.

In order to compare the experimental results obtained for the average roughness of the machined surfaces from the two experiments, conducted with a standard and a quick-change holder, a comparative statistical analysis was performed. It includes testing two statistical hypotheses:

- *equality of variances of two random variables;*
- *equality of mathematical expectations of two random variables.*

The calculations of the statistical hypotheses were performed in accordance with the methodology presented in [1], in the following sequence:

1. The arithmetic mean values of the average roughness of the machined surfaces when turning with a standard and quick-change holder are determined in accordance with dependencies 3.1 and 3.2.

$$\bar{R}a_i = \frac{\sum_{u=1}^{n} \bar{R}a_{iu}}{n} \tag{3.1}$$

$$\bar{R}a_{iu} = \frac{\sum_{j=1}^{p} Ra_{iuj}}{p} \tag{3.2}$$

where: p = 3 - number of measurements in each trial.

2. The statistical estimates of the variances of the average roughness of the studied surfaces are determined for each experiment according to 3.3 and 3.4.

$$S_i^2 = \frac{\sum_{u=1}^{n} S_{iu}^2}{n} \tag{3.3}$$

$$S_{iu}^2 = \frac{1}{p-1} \sum_{j=1}^{p} \left(Ra_{iuj} - \bar{R}a_{iu} \right)^2 \tag{3.4}$$

The estimates of the variances S_i^2 are determined after checking their homogeneity - S_{in}^2, according to the Cochrane criterion. The variances are homogeneous if the condition is met - 3.5.

$$\hat{G}_i = \frac{S^2_{iu,\max}}{\sum_{u=1}^{n} S^2_{iu}} \le G_{\alpha,k_1,k_2} \qquad (3.5)$$

where: Gi - empirical value of the Cochran test;

$G(\alpha, k_1,k_2)$ - Cochran quantile, determined at a significance level of - $\alpha = 0.05$ and the number of degrees of freedom $k_1 = p – 1$ and $k_2 = n$.

3. The hypothesis of equality of roughness variances in both experiments was tested. To verify the hypothesis, Fisher's exact test was used, the empirical value of which was determined in accordance with the relation 3.6:

$$\hat{F} = \frac{s_1^2}{s_2^2} = 1.7548\,. \qquad (3.6)$$

4. The hypothesis of equality of mathematical expectations of the roughness of the treated surfaces in both experiments was tested. To verify the hypothesis, the Student's t-test was used, the empirical value of which was determined in accordance with dependencies 3.7 and 3.8:

$$\hat{t} = \frac{\left|\overline{R}a_1 - \overline{R}a_2\right|}{s}\sqrt{\frac{n_1 n_2}{n_1 + n_2}} = 0.7283 \qquad (3.7)$$

$$s = \sqrt{\frac{s_1^2(n_1-1)+s_2^2(n_2-1)}{n_1+n_2-2}} = 0.4038 \qquad (3.8)$$

3.3.Comparative analysis of the treated surfaces

Two separate experiments were conducted to determine the average roughness of machined surfaces at constant values of the cutting mode elements, respectively for turning with a standard and quick-change toolholder. In each of the experiments, three large samples with a volume of 900 machined parts were made, on which the Ra values were measured.

Each of the large samples is divided into groups of the same number of parts, the number of which (n) corresponds to the number of tests in each sample (n = 20).

The measured values for Ra (Raij = 1,2 - respectively when using a standard and quick-change holder; i = 1÷n - test number; j = 1, 2, 3 - sample number) are presented in tables 3.2 and 3.3, and their graphical interpretation - in Fig. 3.6.

The determined values of the statistical estimates of the variances S12 and S22 for the roughness obtained when processing with a standard and quick-change holder, as well as the checks for uniformity of the variances according to the Cochrane test for the two experiments are presented in tables 3.2. and 3.3 (columns 6 and 7) , respectively.

After comparing the empirical value of the Fisher criterion – F, with the Fisher quantile ($F_{\alpha, k1,k2} = F_{0.05, 40.40} = 1.51$) it was found that, $\dot{F} > F_{0.05, 40.40}$, i.e. the dispersion of the roughness of the machined surfaces when using a standard holder is greater than when using a quick-change holder.

After comparing the empirical value of the Student's criterion - ṫ, with the Student's quantile ($t_{\alpha,k} = t_{0.05, 38} = 1.684$) it was found that $\dot{t} < t$ (0.7283<1.684), i.e. the average values of the roughness of the treated surfaces in the two experiments do not differ.

Table 3.2. Experimental results with a standard tool holder

Measurement No., N	Roughness – Ra $_{1\div n}$, μm			Average value, Ra_2, μm	Standard deviation, S_{2u}	Dispersion, S_{1u}^2
	Ra_{11}	Ra_{12}	Ra_{13}			
10	0,80	0.75	0.80	0.783	0.0289	0.00083
30	0.90	0.72	0.70	0.773	0.1102	0.01213
50	1.01	0.81	0.76	0.860	0.1323	0.01750
100	1.18	0.83	1.12	1.043	0.1872	0.03503
150	1.25	0.76	1.13	1.047	0.2554	0.06523
200	1.22	0.86	1.25	1.110	0.2170	0.04710
250	1.20	0.98	1.10	1.093	0.1102	0.01213
300	1.39	0.97	1.16	1.173	0.2103	0.04423
350	1.21	1.36	1.05	1.207	0.1550	0.02403
400	1.35	1.29	0.95	1.197	0.2157	0.04653
450	0.88	1.10	1.13	1.037	0.1365	0.01863
500	0.78	1.39	1.18	1.117	0.3099	0.09603
550	1.36	1.25	1.64	1.417	0.2011	0.04043
600	1.29	1.34	1.22	1.283	0.0603	0.00363
650	1.25	1.42	1.56	1.410	0.1552	0.02410
700	1.39	1.18	1.39	1.320	0.1212	0.01470
750	1.25	1.12	1.45	1.273	0.1662	0.02763
800	1.34	1.22	1.46	1.340	0.1200	0.01440
850	1.65	1.32	1.66	1.543	0.1935	0.03743
900	1.78	2.10	1.77	1.883	0.1877	0.03523

Ra_1 = 1,196 μm
S_1 dispersions are uniform according to the condition:
G_1= 0,156 < G_T(α= 0,05; k_1 = 2; k_2 = 20) = 0,2705;
S_1^2 = 0,03085

Table 3.3. Experimental results with quick-change toolholder

Measurement No., N	Roughness – Ra $_{1\div n}$, μm			Average value, Ra_2, μm	Standard deviation, S_{2u}	Dispersion, S_{2u}^2
	Ra_{21}	Ra_{22}	Ra_{23}			
10	0.80	0.76	0.80	0.787	0.0231	0.00053
30	1.10	0.77	0.70	0.857	0.2136	0.04563
50	1.01	0.81	0.77	0.863	0.1286	0.01653
100	1.18	0.82	1.12	1.040	0.1929	0.03720
150	1.16	0.76	1.13	1.017	0.2228	0.04963
200	1.22	0.85	1.11	1.060	0.1900	0.03610
250	1.20	0.98	1.18	1.120	0.1217	0.01480
300	1.05	0.97	1.10	1.040	0.0656	0.00430
350	1.01	1.10	1.01	1.040	0.0520	0.00270
400	0.89	0.85	0.81	0.850	0.0400	0.00160
450	0.98	0.87	0.87	0.907	0.0635	0.00403
500	0.82	0.88	0.85	0.850	0.0300	0.00090
550	1.10	0.91	1.01	1.007	0.0950	0.00903
600	1.12	1.12	1.12	1.120	0.0000	0.00000
650	1.25	1.32	1.13	1.233	0.0961	0.00923
700	1.39	1.18	1.41	1.327	0.1274	0.01623
750	1.25	1.12	1.45	1.273	0.1662	0.02763
800	1.24	1.22	1.48	1.313	0.1447	0.02093
850	1.55	1.32	1.57	1.480	0.1389	0.01930
900	1.78	2.1	1.77	1.883	0.1877	0.03523

Ra_2 = 1,103 μm
S_2 dispersions are uniform according to the condition:
G_2= 0,1412< G_T(α= 0,05; k_1 = 2; k_2 = 20) = 0,2705
S_2^2 = 0,01758

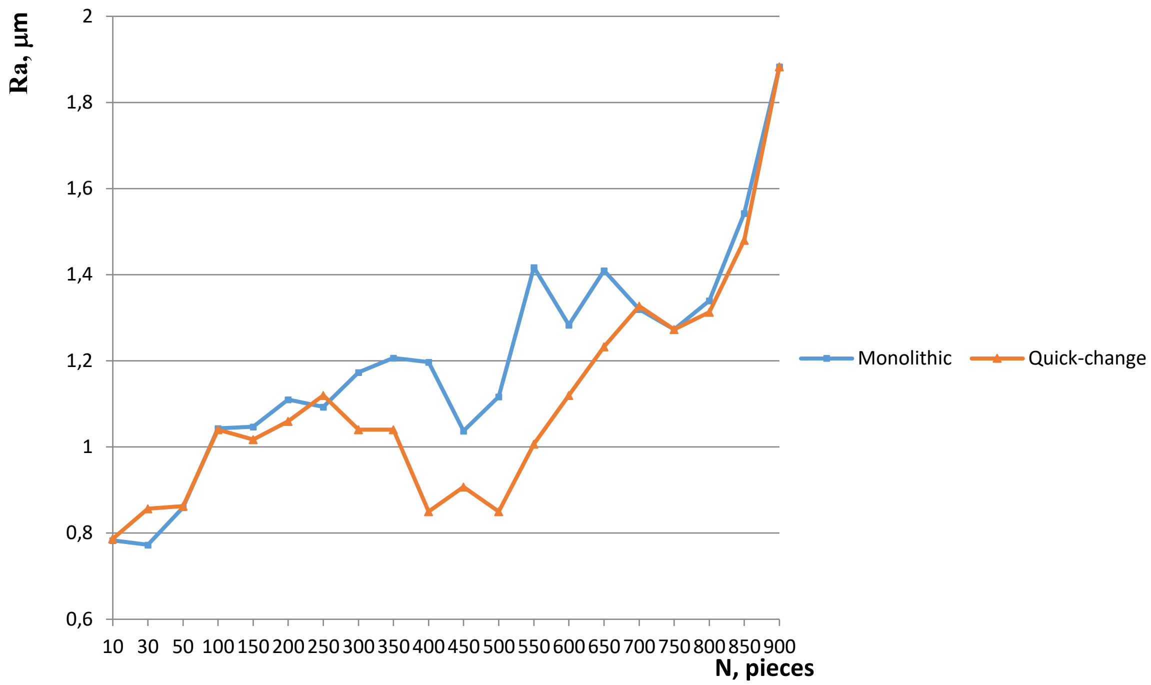


Fig.3.6. Roughness of machined surfaces when turning with a monolithic and quick-change holder.

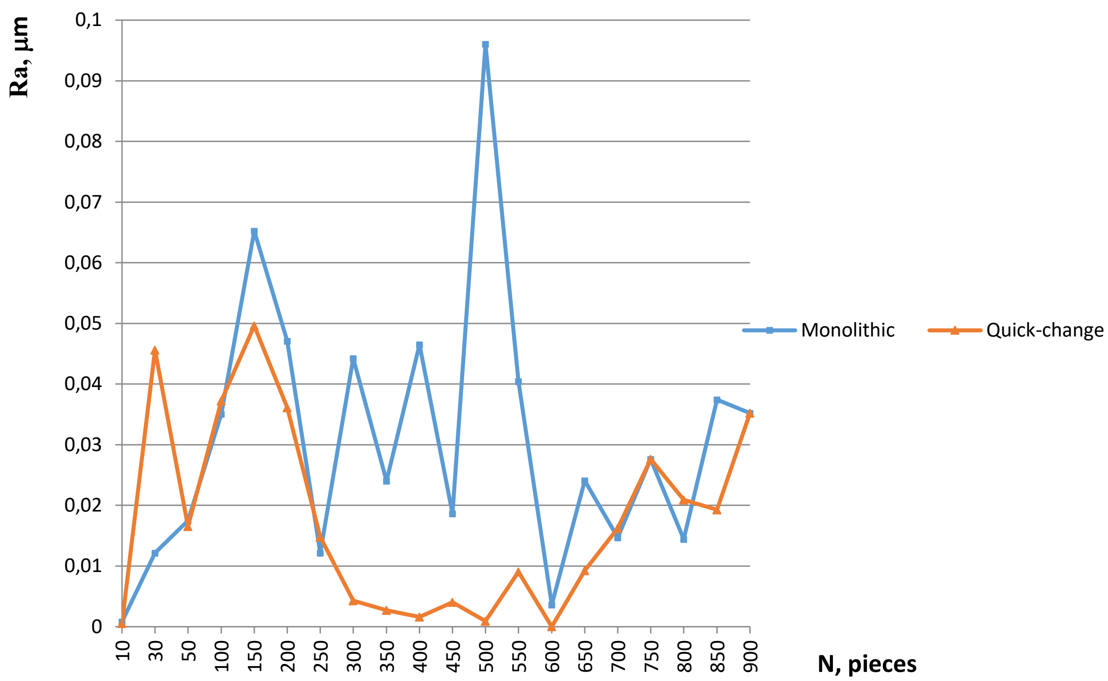


Fig.3.7. Evaluation of the roughness dispersion of machined surfaces during turning with a monolithic and quick-change holder

The statistical analysis shows that in the two experiments, conducted with a standard and a quick-change holder, comparable values of the average roughness of the machined surfaces are obtained, but the dispersion of the roughness - Fig. 3.7, when turning with a quick-change holder is smaller than that when using a monolithic holder. This is evidence of greater stability of the technological process when using a quick-change holder and is a prerequisite for obtaining higher quality of the machined surfaces.

The conducted studies have found the following advantages in machining parts using a quick-change holder***:***

- *less roughness when machining sample parts;*
- *greater tool life, determined by the technological criterion of wear Rak = 1.4 μm - T_2 = 920 pieces when working with a quick-change holder (T_1 = 880 pieces when working with a monolithic holder)*
- *much less time for changing worn metal-ceramic hard alloy inserts (t_2 = 30 s) compared to the time for changing inserts with a monolithic holder (t_1 = 20 min), as a result of which 81 more parts were produced using the quick-change holder for the same machining time.*
- *less time for equipment setup (40 times compared to using a standard holder) - determined when processing a batch of 20,000 parts and the time for manufacturing one part is 43 s.*

3.4. Influence of the type of coolant in turning with a quick-change holder

One of the main advantages of the quick-change holder is the possibility of delivering a lubricant-coolant to the cutting zone through its body. This necessitates a more thorough study of the influence of the type of lubricant-coolant on the quality of the machined surfaces.

The statistical analysis of the influence of cooling on accuracy was made based on measurements of the controlled dimensions of the part – Fig.3.1 (diameter D=11.8±0.2 mm and length L=11.6±0.2 mm) in batches of 3300 pieces.

Two series of experimental studies were conducted to determine the influence of the type of lubricating and cooling fluids (LUF) on the accuracy of dimensions and cutting speed.

To determine the influence of the cooling medium on the accuracy of the machined parts, two brands of lubricating and cooling fluids were used - ECOCOOL MACH 40 and Vasco 6000. The experimental results obtained for the controlled dimensions using two types of lubricating and cooling fluids are presented in Table 3.4, and their graphical interpretation - in Fig. 3.8 and 3.9.

When comparing the obtained values for the controlled parameters in table 3.4, it is found that when using the VASCO 6000 coolant, the deviations from the set tolerances are more numerous. This requires a change in the operating modes and a reduction in the cutting speed. In this regard, when applying this coolant-lubricant, experimental studies were conducted at two cutting speeds - Vc = 150 m/min and Vc = 125 m/min, with the values of the cutting depth and feed being constant - ap = 0.02 mm and f = 0.05 mm/rev. The experimental results are presented in table 3.5 and fig. 3.10.

In order to compare the results for the accuracy of the controlled dimensions when using two types of coolant - table 3.5 and at two different cutting speeds - table 3.6, a statistical analysis was performed, which included testing two statistical hypotheses - for the equality of the variances of two random variables and for the equality of the mathematical expectations of two random variables.

The verification of the statistical hypotheses was carried out in the following sequence:

1. The arithmetic mean values of the controlled dimensions were determined using the ECOCOOL MACH 40 and Vasco 6000 brands of lubricant-coolant (D_1 and L_1, respectively; D_2 and L_2 - table 3.4) and at cutting speeds Vc = 150 m/min and Vc = 125 m/min and applying the Vasco 6000 lubricant-coolant (D_2 and L_2, respectively; D_3 and L_3 - table 3.5).

2. The statistical estimates of the dispersions of D and L of the studied surfaces for each experiment - S_{D1}^2, S_{D2}^2, S_{D3}^2, S_{L1}^2, S_{L2}^2, and S_{DL}^2 - table 3.6.

Table 3.4. Experimental results for the accuracy of machined dimensions when cooled with ECOCOOL MACH 40 and VASCO 6000

Part No.	Type of cooling medium			
	ECOCOOL MACH 40		VASCO 6000	
	D_1, mm	L_1, mm	D_2, mm	L_2, mm
1	11,58	11,36	12,11	11,36
10	11,62	11,41	11,89	11,41
20	11,68	11,43	11,85	11,41
100	11,66	11,42	11,68	11,65
300	11,71	11,44	11,87	11,58
500	11,70	11,42	11,80	11,53
600	11,72	11,46	11,72	11,71
700	11,71	11,45	11,58	11,65
800	11,75	11,43	11,61	11,71
900	11,74	11,45	11,66	11,67
1000	11,81	11,47	11,65	11,47
1100	11,76	11,51	11,68	11,51
1200	11,78	11,53	11,81	11,71
1300	11,80	11,51	11,80	11,66
1400	11,78	11,54	11,72	11,60
1500	11,79	11,55	11,68	11,55
1600	11,83	11,56	11,75	11,45
1700	11,81	11,57	11,84	11,59
1800	11,87	11,53	11,85	11,53
1900	11,88	11,58	11,97	11,71
2000	11,85	11,60	11,85	11,67
2100	11,89	11,61	11,86	11,61
2200	11,86	11,59	11,88	11,59
2300	11,85	11,59	11,87	11,55
2400	11,89	11,62	11,23	11,62
2500	11,86	11,63	11,85	11,69
2600	11,91	11,64	11,96	11,61
2700	11,88	11,61	11,96	11,76
2800	11,87	11,70	11,94	11,65
2900	11,93	11,76	11,95	11,76
3000	11,90	11,81	11,90	11,82
3100	11,88	11,42	11,98	11,49
3200	11,91	11,44	12,01	11,66
3300	12,20	11,41	11,35	11,79

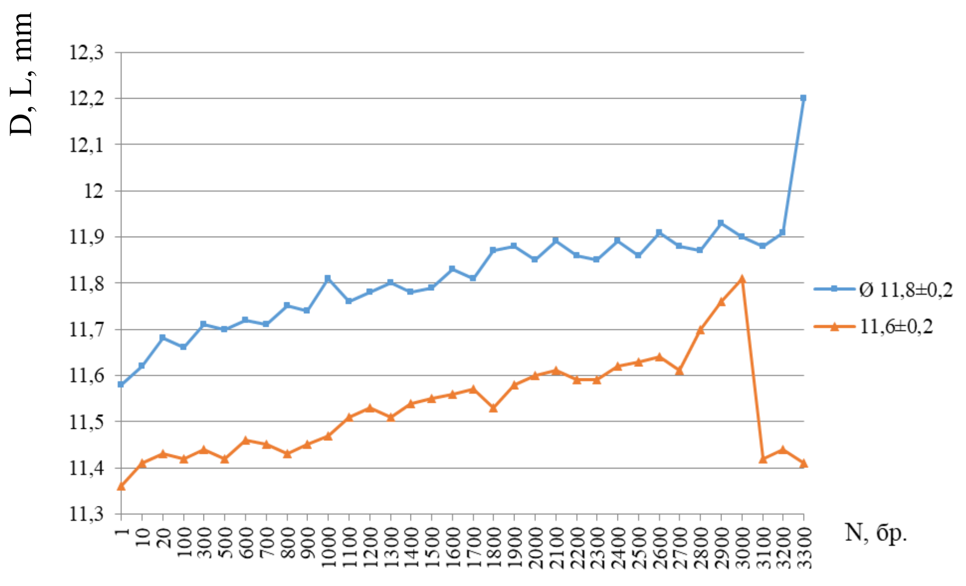


Fig.3.8. Measurements of controlled dimensions when machining with ECOCOOL MACH 40 coolant and cutting speed Vc = 150 m/min.

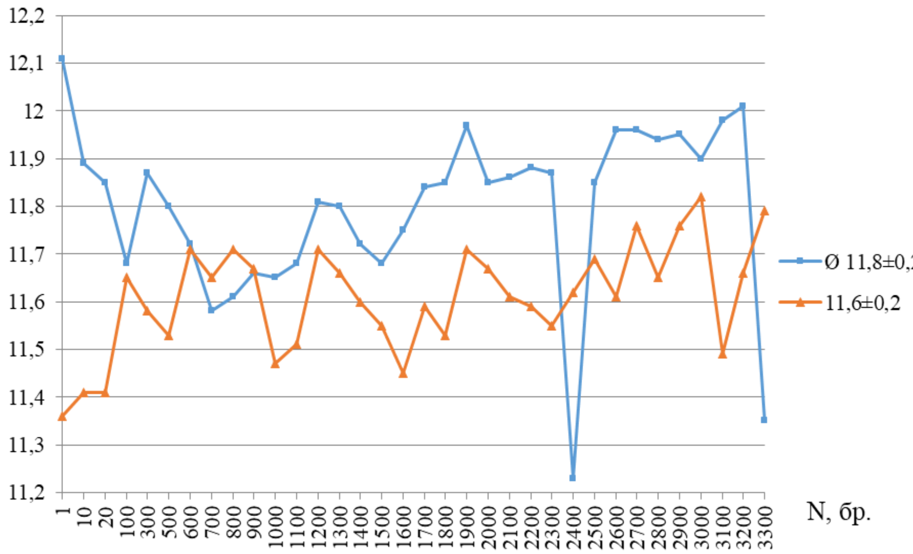


Fig.3.9. Measurements of controlled dimensions when machining with Vasco 6000 coolant and cutting speed Vc = 150 m/min

Table 3.5. Experimental results for the accuracy of machined dimensions when cooling with VASCO 6000 at different cutting speeds.

Part No.	Cutting speed			
	Vc = 150 m/min		Vc = 125 m/min	
	D_2, mm	L_2, mm	D_3, mm	L_3, mm
1	12,11	11,36	12,15	11,36
10	11,89	11,41	11,89	11,41
20	11,85	11,41	11,85	11,41
100	11,68	11,65	11,68	11,65
300	11,87	11,58	11,87	11,58
500	11,80	11,53	11,8	11,53
600	11,72	11,71	11,72	11,71
700	11,58	11,65	11,63	11,65
800	11,61	11,71	11,61	11,71
900	11,66	11,67	11,66	11,67
1000	11,65	11,47	11,65	11,47
1100	11,68	11,51	11,68	11,51
1200	11,81	11,71	11,81	11,71
1300	11,80	11,66	11,8	11,66
1400	11,72	11,60	11,72	11,6
1500	11,68	11,55	11,68	11,55
1600	11,75	11,45	11,75	11,58
1700	11,84	11,59	11,84	11,59
1800	11,85	11,53	11,85	11,53
1900	11,97	11,71	11,97	11,71
2000	11,85	11,67	11,85	11,67
2100	11,86	11,61	11,86	11,61
2200	11,88	11,59	11,88	11,59
2300	11,87	11,55	11,87	11,55
2400	11,23	11,62	11,23	11,62
2500	11,85	11,69	11,85	11,69
2600	11,96	11,61	11,96	11,61
2700	11,96	11,76	11,96	11,76
2800	11,94	11,65	11,94	11,65
2900	11,95	11,76	11,95	11,76
3000	11,90	11,82	11,9	11,82
3100	11,98	11,49	11,98	11,49
3200	12,01	11,66	12,01	11,66
3300	11,35	11,79	11,35	11,79

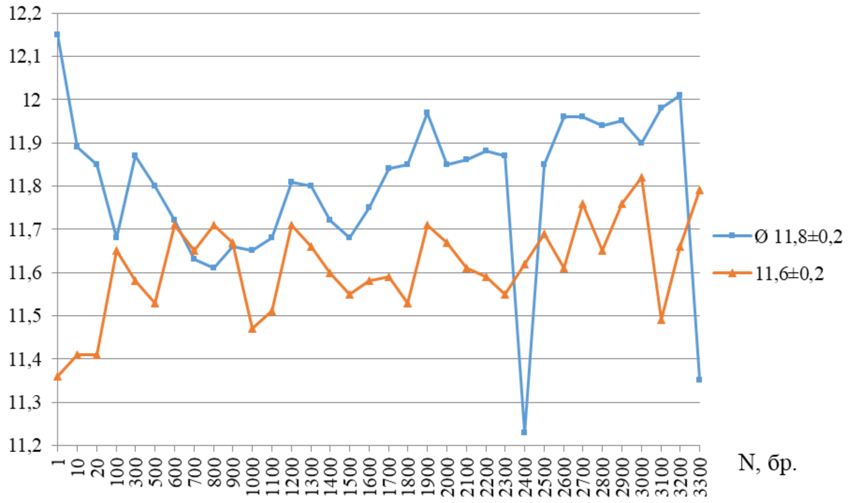


Fig.3.10. Measurements of controlled dimensions during machining with a coolant, brand Vasco 6000, and a cutting speed Vc = 125 m/min

Table 3.6. Statistical analysis of experimental results

Statistical criteria	Controlled dimensions					
	Diameter D=11.8±0.2 mm			Length L=11.6±0.2 mm		
Average values	D_1	D_2	D_3	L_1	L_2	L_3
	11.814	11.797	11.800	11.531	11.610	11.614
Dispersion	S_{D1}^2	S_{D2}^2	S_{D3}^2	S_{L1}^2	S_{L2}^2	S_{L3}^2
	0.0127	0.0320	0.0322	0.0113	0.0127	0.0119
Standard deviation	S_{D1}	S_{D2}	S_{D3}	S_{L1}	S_{L2}	S_{L3}
	0.1127	0.1789	0.1795	0.1063	0.1127	0.1092
Overall estimated variance	S_{D1-2}		S_{D2-3}	S_{L1-2}		S_{L2-3}
	0.1495		0.1792	0.1095		0.1109
Note: *The values S_{D1-2}, SD_{2-3}, S_{L1-2} and S_{L2-3} are average estimates of the population variances in the experiments conducted*						

3. The hypothesis of equality of variances of the controlled dimensions D and L was verified using the Fisher criterion, the empirical values of which were determined in accordance with the dependencies:

- *when using two lubricating coolants – 3.9;*
- *when processing with different cutting speeds – 3.10.*

$$\hat{F}_{D_{1-2}} = \frac{S_{D1}^2}{S_{D2}^2} = 0.397$$

$$\hat{F}_{L_{1-2}} = \frac{S_{L1}^2}{S_{L2}^2} = 0.889 \qquad (3.9)$$

$$\hat{F}_{D_{2-3}} = \frac{S_{D2}^2}{S_{D3}^2} = 0.994$$

(3.10)

$$\hat{F}_{L_{2-3}} = \frac{S_{L2}^2}{S_{L3}^2} = 1.067$$

After comparing the determined empirical values of the Fisher criterion with the Fisher quantile ($F_{\alpha, k1,k2} = F_{0.05, 33, 33} = 1.51$) it was found that $\dot{F} > F$ therefore the dispersions of the diameter and linear size when using the ECOCOOL MACH 40 coolant are smaller than when using the VASCO 6000 coolant. It was found that reducing the cutting speed when using the VASCO 6000 coolant does not lead to a decrease in the deviations from the set nominal values of the controlled dimensions.

4. The hypothesis of equality of mathematical expectations of the controlled dimensions was verified when using lubricating and cooling fluids, brands ECOCOOL MACH 40 and Vasco 6000 and at cutting speeds Vc = 150 m/min and Vc = 125 m/min and lubricating and cooling fluid Vasco 6000.

To verify the hypothesis, the Student criterion was used, the empirical values of which were determined in accordance with the dependencies:

- *when using two lubricating and cooling fluids – 3.11:*
- *when processing with different cutting speeds – 3.12:*

$$\hat{t}_{D_{1-2}} = \frac{\left|\overline{D}_1 - \overline{D}_2\right|}{s_{D_{1-2}}} \cdot \sqrt{\frac{n_1 n_2}{n_1 + n_2}} = 0{,}4688$$

(3.11)

$$\hat{t}_{L_{1-2}} = \frac{\left|\overline{L}_1 - \overline{L}_2\right|}{s_{L_{1-2}}} \cdot \sqrt{\frac{n_1 n_2}{n_1 + n_2}} = 2.975$$

$$\hat{t}_{D_{2-3}} = \frac{\left|\overline{D}_2 - \overline{D}_3\right|}{s_{D_{2-3}}} \cdot \sqrt{\frac{n_1 n_2}{n_1 + n_2}} = 0.069$$

(3.12)

$$\hat{t}_{L_{2-3}} = \frac{\left|\overline{L}_2 - \overline{L}_3\right|}{s_{L_{2-3}}} \cdot \sqrt{\frac{n_1 n_2}{n_1 + n_2}} = 0.1487$$

After comparing the empirical values of the Student's criterion with the Student's quantile $t_{\alpha,k} = 1.999$ (where $\alpha = 0.05$; $k = n_1 + n_2 - 2$) it was found that the average values of the controlled size D = 11.8 ± 0.2 mm do not differ when processing with the ECOCOOL MACH 40 and Vasco 6000 coolants ($t_{D1-2} < t_{\alpha,k}$). The values of the controlled sizes obtained when processing with speeds Vc = 150 m/min and Vc = 125 m/min and Vasco 6000 coolants also do not differ significantly (D = 11.8 ± 0.2 mm and L = 11.6 ± 0.2 mm, $t_{D2-3} < t_{\alpha,k}$; $t_{L2-3} < t_{\alpha,k}$). A significant difference in the average linear dimensions L=11.6±0.2 mm is observed when processing with lubricating coolant, brands ECOCOOL MACH 40 and Vasco 6000 ($t_{L1-2} > t_{\alpha,k}$).

The results of the statistical analysis of the influence of the type of coolant on the accuracy of dimensions and cutting speed show:

- *In the experiments conducted with the ECOCOOL MACH 40 and Vasco 6000 brands of lubricant coolant, comparable average values were obtained for the dimension D=11.8±0.2 mm. However, with respect to the linear dimension*

L=11.6±0.2 mm, there is a significant difference in the measured average values, that is, there is a significant influence of the type of coolant on the accuracy of linear dimensions.

- *At cutting speeds Vc = 150 m/min and Vc = 125 m/min and application of the Vasco 6000 coolant, no significant difference is observed between the average values of the controlled dimensions. It is found that the deviations of the controlled dimensions D and L when machining at a lower speed are larger, i.e. the stability of the technological process is not improved. In this regard and in accordance with the fact that reducing the cutting speed leads to an increase in the machining time from 43÷46 s to 62÷65 s and to an increase in the cost price of the machined part, it is recommended that the machining of the parts with the application of the Vasco 6000 coolant be carried out at a cutting speed Vc = 125 m/min.*

3.5. Efficiency of the innovative design of the quick-change holder in the production of bearing rings

In the production of parts for rolling bearings, turning is the main method for surface treatment. Depending on whether it is rough, clean or fine, it reaches 7÷14 degrees of accuracy, with roughness Rz 160÷1.6 µm and Ra 0.4÷1.25 µm.

The task of this study is, based on the information gathered in sections 3.3 and 3.4, to improve the efficiency of the production process in the production of rolling bearing rings by using a quick-change and adjustable cutting tool. The goal is to shorten the duration of the production process and increase production efficiency. The efficiency of the innovative quick-change holder design was investigated in the production of bearing rings with dimensions according to Fig. 3.11.

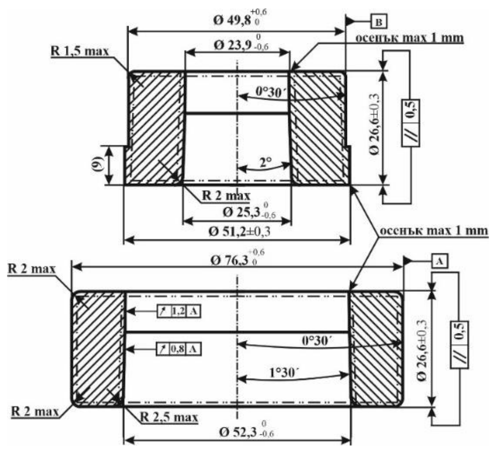


Fig.3.11. Drawing of the manufactured bearing ring

Parallel studies were conducted for the machining of bearing rings, in one case monolithic holders were used, and in the other - quick-change - Fig. 3.4.

The turning process was implemented with a cutting tool - Fig.2.11g. and cutting mode: Vc = 150 m/min, f = 0.05 mm/rev and ap = 0.02 mm.

From the results obtained in the research process, it was found that with the selected cutting mode and processed material, the average wear of the carbide inserts is after processing 650 blanks. This life of the cutting edge is achieved after observing the requirements for average roughness, as well as the deviation of linear dimensions. With a production cycle of 6÷7 s per operation and an eight-hour work shift – 28800 s, the theoretical productivity is within the limits of 4100÷4800 bearing rings for replacement. Therefore, for one work shift it is necessary to make 7 readjustments of the cutting tools.

On this basis, the time losses for changing and readjusting the metal-cutting tools and, consequently, the deviations from the theoretical (maximum) productivity of the assembly line are presented in table 3.7

Table 3.7. Experimental results

Characteristic	Standard holder	Quick-change holder
Time for one-time tool change and readjustment, s	1 380	53
Time for changing and readjusting the tool for a work shift – 8 h, s	9 660	371
Unrealized production at a cycle time of 6 seconds per work shift, pcs.	1 610	62
Unrealized production at a cycle time of 7 seconds per shift, pcs.	1 380	53
Productivity at a production cycle of 6 s per work shift, pcs.	3 190	4 738
Productivity at a production cycle of 7 s per work shift, pcs	2 734	4 061
Unrealized production compared to theoretical at a cycle time of 6 s, %	33,54	1,291
Unrealized production compared to theoretical at a cycle time of 7 s, %	33,54	1,288

3.6. Conclusions

Based on the statistical data obtained during the research, the following more important conclusions can be formulated:

1. The statistical verification of the parametric hypotheses for equality of mathematical expectations and dispersions proves that comparable values of the average roughness of the machined surfaces are obtained when using a standard and quick-change holder, but the dispersion of the roughness is less, respectively, the stability of the technological process is greater when using a quick-change holder.

2. The use of a quick-change holder leads to greater tool life, much less time for changing worn cermet inserts, as well as less time for setting up the equipment (40 times compared to using a standard holder).

3. The proposed approach to selecting tooling equipment through statistical analysis proves the effectiveness of the application of a quick-change holder in turning. Its use leads to increased productivity as a result of reducing auxiliary time, while ensuring high and stable quality of the machined surfaces.

4. The statistical verification of the parametric hypotheses for equality of mathematical expectations and dispersions proves that when processing with different cutting speeds, comparable values of the controlled diametric and linear dimensions are obtained, as the dispersions of these dimensions are smaller at higher cutting speeds, i.e. the stability of the technological process is greater.

5. The type of SOT has a significant impact on the dispersions of the controlled diametric and linear dimensions, as when turning with ECOCOOL MACH 40 they are smaller than when using Vasco 6000. This is evidence of greater stability of the technological process when using ECOCOOL MACH 40 and is a prerequisite for obtaining higher quality of the machined surfaces. The type of lubricating coolant used has a significant impact on the accuracy of the investigated linear dimension and a negligible impact on the accuracy of the diametric dimension.6. The proposed approach for selecting cooling medium and cutting speed creates conditions for optimizing working conditions when turning parts made of 42CrMoS4 steel using quick-change holders.

7. It has been proven that for an eight-hour working day in a three-shift continuous operation mode for seven days, the productivity of the line for bearing rings with a standard holder, depending on the production cycle, is 57414÷66990 parts, and when using a quick-change holder it is 85281÷99498 parts.

8. It has been proven that when using a quick-change holder for turning parts from bearing steels, due to the improvement of the cutting process during turning and quick-changeability when adjusting another machined part or wear, the productivity of the production line increases by 32.25%.

Chapter Four: Optimization of Cutting Modes in Machining with the Developed Quick-Change Holder

4.1. Selection of Input Variables and Objective Functions

In order to analyze the influence of technological factors on the geometry of the machined surface during turning and the durability of cutting tools, mathematical models must be compiled and a statistical analysis must be conducted – ANOVA (Analysis of Variance).

In it, the cutting speed (Vc, m/min) – X_1, and the feed (f, mm/rev) – X_2 are selected as input variables (controlled factors). The parameter Ra of the roughness of the machined surfaces – Y_1 (Ra, µm) and the durability of the metal cutting tool - Y_2 (T, pcs.).

When evaluating the roughness parameter Ra, a control size Ø15.7+0.2 was used – on the part from Fig.4.2.

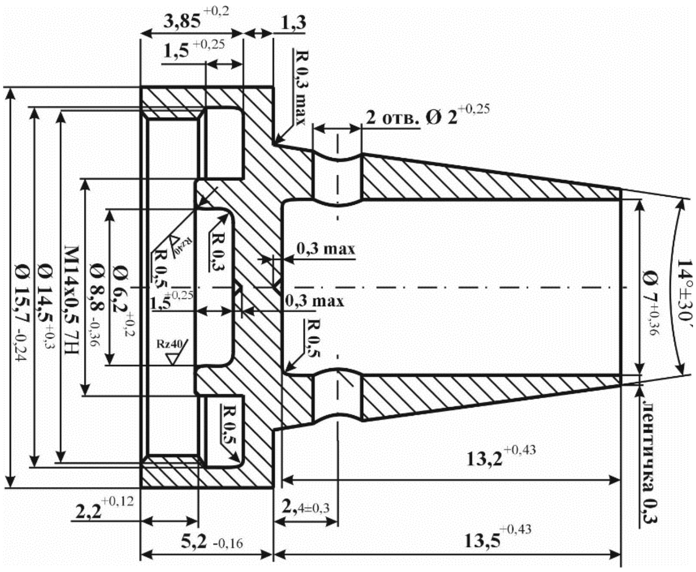


Fig.4.2. Detail drawing

1.2. Compilation of empirical models

To compile the empirical models, multifactorial planned experiments were conducted using an optimal central compositional design at factor levels according to Table 4.1**.**

Table 4.1. Areas of variation of factors

factor levels	X_1,(Vc) m/min	X_2, (f) mm/tur	coded value
$X_{i0} + \Delta X_i$	170	0,18	+1
X_{i0}	150	0,15	0
$X_{i0} - \Delta X_i$	130	0,12	-1

To complete the experimental design – Table 4.5, preliminary single-factor experiments were conducted on turning batches of 550 parts, with measurements made in groups of 50 parts.

The experimental results are presented in Fig. 4.3 ÷ 4.5, respectively at cutting speeds of 130, 150 and 170 m/min.

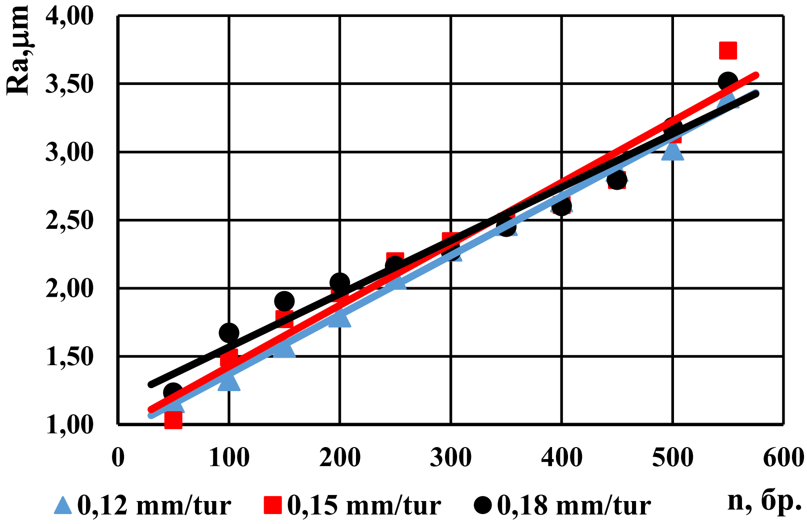


Fig.4.3. Roughness when machining batches of 550 parts at a cutting speed Vc, = 130 m/min and a feed of 0.12; 0.15 and 0.18 mm/rev

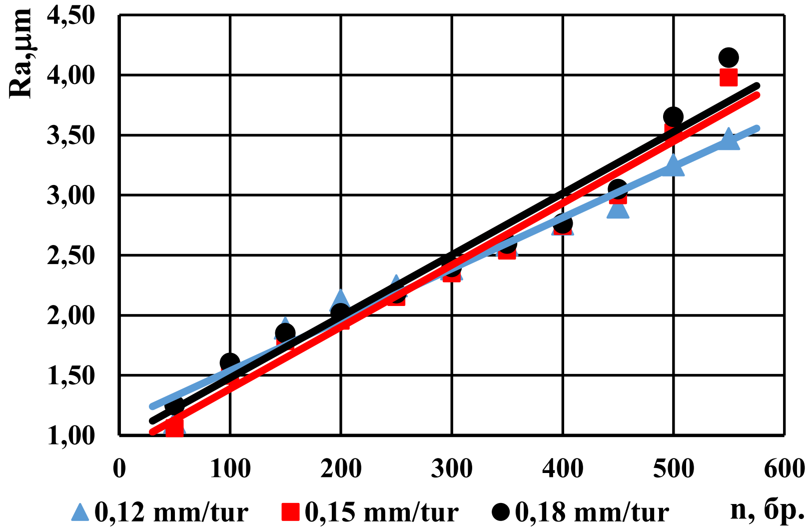


Fig.4.4. Roughness when machining batches of 550 parts at a cutting speed Vc, = 150 m/min and a feed of 0.12; 0.15 and 0.18 mm/rev

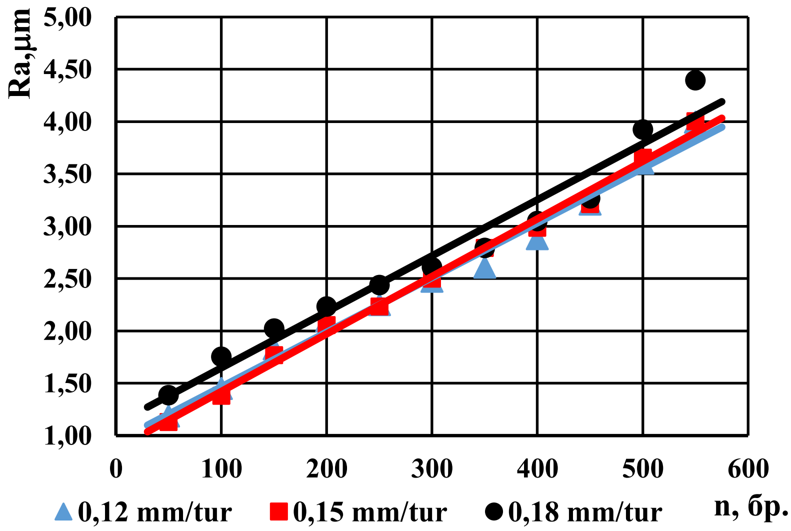


Fig.4.5. Roughness when machining batches of 550 parts at a cutting speed Vc, = 170 m/min and a feed of 0.12; 0.15 and 0.18 mm/rev

Table 4.5. Experimental design

№	X_0	X_1	X_2	$X_1 X_2$	X_1^2	X_2^2	Y_1	Y_2
1	+1	+1	+1	+1	+1	+1	3,927	390
2	+1	-1	+1	-1	+1	+1	3,182	475
3	+1	+1	-1	-1	+1	+1	3,605	420
4	+1	-1	-1	+1	+1	+1	3,022	490
5	+1	+1	0	0	+1	0	3,658	405
6	+1	-1	0	0	+1	0	3,131	480
7	+1	0	+1	0	0	+1	3,654	440
8	+1	0	-1	0	0	+1	3,254	465
9	+1	0	0	0	0	0	3,523	450

4.2. Compilation of empirical models

1.2.1. Empirical model for Y1 (Ra,μm)

The obtained regression model for determining the roughness (Ra, μm) when machining with the innovative toolholder design has the form 4.6.

$$Y_1 = 3{,}4395556+0{,}30916667X_1+0{,}147X_2 \quad (4.6)$$

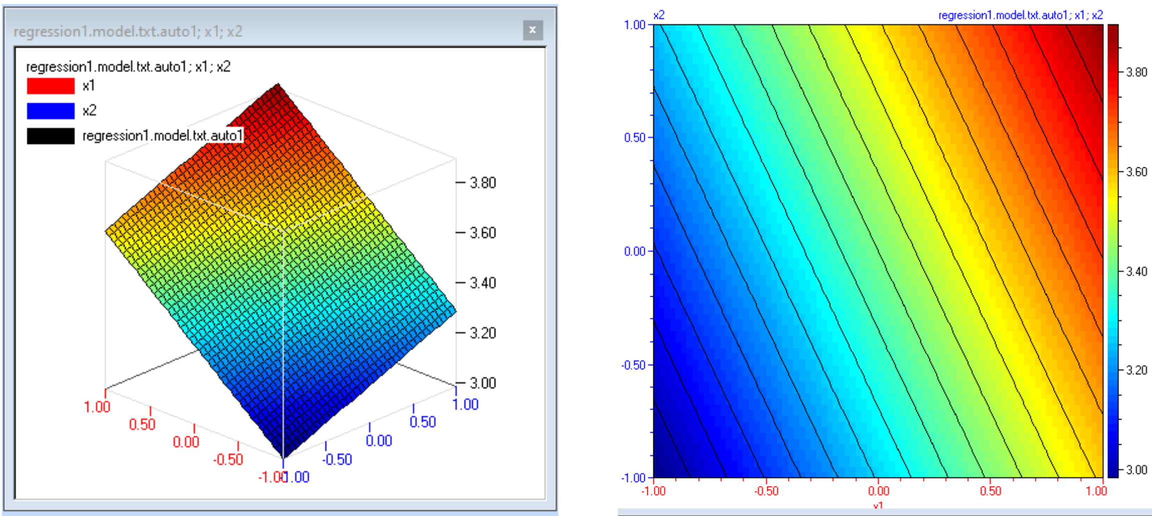
The adequacy check of the model by Fisher's criterion according to 3.6 shows that the calculated value is F=2.44691, is less than the tabulated F_T (0.05; 2; 6) = 5.14325, which means that the obtained model is adequate. The graphical dependencies according to 4.6 are presented in Fig.4.6.

1.2.1. Empirical model for Y2 (T, pcs.)

The obtained regression model for determining the tool durability (T, pcs.), when using the innovative knife holder design, has the form 4.8.

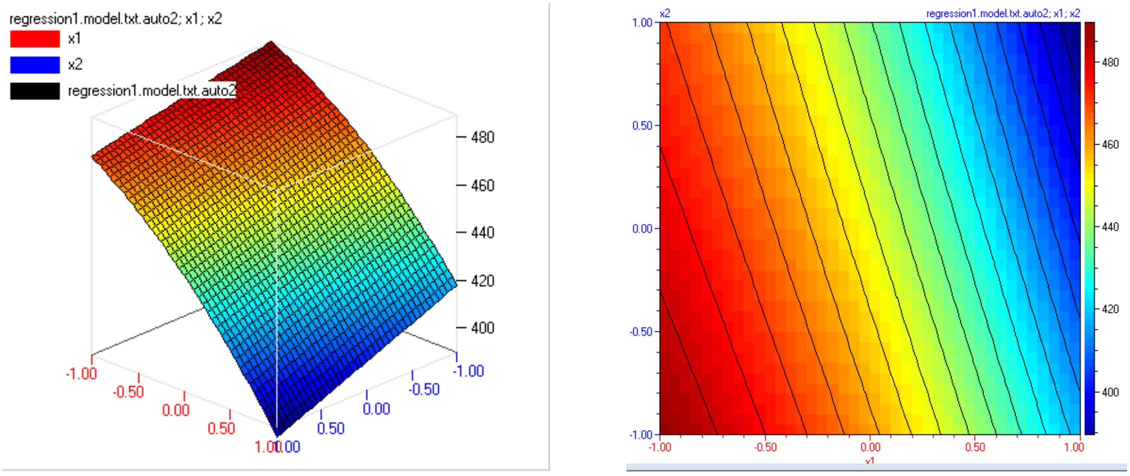
$$Y_2 = 451{,}66667-38{,}333333X_1-11{,}666667X_2-8{,}3333333X_1^2-3{,}75X_1X_2 \quad (4.8)$$

The adequacy check of the model by Fisher's criterion according to 3.6 shows that the calculated value is F=2.77645, is smaller than the tabulated F_T (0.05; 4; 4) = 6.38823, which means that the obtained model is adequate. The graphical dependencies according to 4.8 are presented in Fig.4.9.



a. b.

Fig. 4.6. Graphical interpretation of the mathematical model for Y_1
a – in a three-coordinate system; b – in a two-coordinate system.



a.. b.

Fig. 4.9. Graphical interpretation of the mathematical model for Y_2
a – in a three-coordinate system; b – in a two-coordinate system

4.3. Conclusions

From the conducted studies and the results obtained, the following important conclusions can be formulated:

1. The change in roughness during turning of short rotary parts was monitored depending on the cutting speed - Vc = 130÷170 m/min, and the feed - f = 0.12÷0.18 mm/tur, at a constant cutting depth - ap = 1.5 mm.

2. Graphical dependences for the change in the average roughness - Ra, µm, as a function of the cutting speed and feed, for batches of parts from 50 to 550 pieces, have been developed.

3. It has been proven that with an increase in the number of processed parts from 50 to 550, the average roughness of the processed surface increases by 3.5÷4.5 µm.

4. It has been proven that the cutting speed has a more significant influence on the average roughness. With its increase from 130 to 170 m/min, the roughness of the processed surfaces in batches of 550 parts increases by approximately 1 µm.

5. It has been proven that with a roughness limit of Ra=3.0 µm with a cutting speed of 130 m/min, up to 450 parts can be processed regardless of the feed. With an increase in the cutting speed to 170 m/min, while maintaining the roughness requirement, up to 400 parts can be processed.

6. Based on the experimental results obtained, empirical models have been compiled for the influence of the factors cutting speed and feed on the average roughness of the machined surfaces and the tool life.

7. A variance analysis was performed with Qv Stat Lab ANOVA and it has been proven that the minimum average roughness of the machined surfaces combined with maximum tool life is achieved at Vc = 130 m/min and f = 0.12 mm/tur.

CONTRIBUTIONS OF THE DISSERTATION

The results obtained in the research process allow for the formulation of contributions in two main areas – scientific and applied (original and confirmatory in nature) and applied.

A. Scientific and applied contributions

A.1. Creation of new classifications, methods, designs, models, methodologies

- Innovative design of a quick-change tool holder, increasing tool life, reducing the dispersion of the average roughness Ra and reducing auxiliary time.
- Statistical approach to tool selection.
- Mathematical models of the dependence of the average roughness Ra and tool life on cutting speed and feed.

A.2. Obtaining and proving new facts

- The use of ECOCOOL MACH 40 lubricating and cooling fluid leads to improved dispersion of controlled diametrical and axial dimensions.

B. Application Contributions

- Workable design of quick-change tool holder.

DOCTORAL PUBLICATIONS

1. **Karlovski G.,** K. Krumov, I. Aleksandrova, S. Tsenkulovski, I. Mitev. Selection of Instrumentation Based on Statistical Analysis. In: 32nd International Scientific Symposium Metrology and Metrology Assurance, MMA 2022, Conference Proceedings, Sozopol, 7-11 September 2022, Code 185634, DOI: 10.1109/MMA55579.2022.9992429, ISBN 978-166548569-2 (Scopus).

2. **Karlovski, G.,** K. Krumov, I. Aleksandrova, S**.** Tsenkulovski, Improving the Hard Turning Process when Machining Bearing Steels, XXXII International Scientific Symposium “Metrology and Metrology Assurance 2022”, Sozopol, 2022,$31.00 ©2022 .

3. **Karlovski, G.,** A System for Quick-change Tool Mounting, „Автоматизация на дискретното производство“ бр.5, София, 2023, с.82÷85. ISSN 2682-9584

4. Karlovski, G., Application of quick-change holders as a way to increase efficiency in the production of blanks with CNC machines, "Automation of Discrete Production" issue 5, Sofia, 2023, pp. 86÷90. ISSN 2682-9584.

5. **Karlovski, G**., K. Krumov, I. Aleksandrova, Selection of Coolant and Cutting Based on Statistical Measurements when Working with Quick-Change Holders, XXXIII International Scientific Symposium “Metrology and Metrology Assurance 2023”, Sozopol, 2022, pp38÷42, ISSN 2603-3194.

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TITLE: STUDY OF THE PARAMETERS OF THE TURNING PROCESS WHEN WORKING WITH QUICK-CHANGE TOOLHOLDERS

Author: mag. eng. Georgi Veselinov Karlovski

ABSTRACT: *In this dissertation work, an innovative design of a quick-change tool holder has been developed. Through statistical analysis, the technological advantages of the innovative design over monolithic tool holders have been proven regarding the average roughness of the machined surfaces and the durability of the tool.*

The influence of the type of lubricating and cooling fluid on the dispersions of controlled diametrical and linear dimensions has been monitored, as when turning with ECOCOL MACH 40 they are smaller, compared to Vasco 6000. The effectiveness of the developed innovative design of a quick-change tool holder has been implemented in production conditions when manufacturing bearing rings.

Empirical models have been developed to determine the average roughness of the machined surfaces and the tool life depending on the cutting speed and feed when using the innovative quick-change toolholder design.

Keywords: *quick-change toolholder, medium roughness, tool life, imperial models, coolants,*