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COMPARATIVE ANALYSIS OF SOME TRADITIONAL AND NON-TRADITIONAL CUTTING SCHEMES IN THE TURNING PROCESS

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Abstract: In response to the increased demand for optimized mechanical processing in order to process difficult-to-cut materials, increasing of productivity, improving the quality of machined workpieces and reducing the temperature in the cutting zone, the topics related to non-traditional (unconventional) cutting schemes in lathe machine processing are getting more interesting and actual for studying. Unconventional turning is widely used in the automotive industry, aerospace industry, medical equipment, electronics and other industries where the processing of hard, difficult-to-machine materials is required, as well as obtaining low roughness and high processing productivity. Unconventional turning process refers to the processes of machining materials that do not follow traditional turning methods. This may involve the use of specialized tools, different techniques or not widely used materials. Although non-traditional cutting schemes in the turning process are not as widespread or standardized as traditional lathe cutting schemes, they are increasingly being used in a variety of fields and applications. Unconventional (non-traditional) cutting schemes can be used for processing of workpieces that are difficult or impossible to manufacture using standard turning schemes. The problems related to the high requirements for the needed quality of the processed workpieces and the needed of the low-cost parts impose the need for changes in the processing methods and application of unconventional cutting schemes in production processes. These changes lead to solve the problems in unconventional turning, which is a broad term covering a variety of part processing techniques and methods. Unconventional turning uses new technologies, innovations and advances in manufacturing processes. Its focus is on the processing of difficult-to-cut materials and the processing of parts with high quality requirements at the same time low cost. When using non-traditional cutting schemes, in addition to the advantages, the disadvantages must also be considered in order to evaluate the real positives of introducing non-traditional (unconventional) cutting schemes. In this article, unconventional and conventional cutting schemes in the turning process are presented. After analyzing and comparison of the unconventional and conventional cutting schemes, their advantages and disadvantages are given. In the comparative analysis, an unconventional cutting scheme for turning parts with a simultaneously rotating tool and part was considered, in which it is possible to improve the quality parameters of the workpiece and heat distribution during processing of the parts.

Key words: cutting schemes in the turning process, unconventional (non-traditional) turning process, conventional (traditional) turning process.

1. INTRODUCTION

In today's fast evolving industrial world, achieving high quality products, increasing productivity and efficiency of work processes is essential for the competitiveness and successful functioning of companies in various industries. Achieving high quality requirements in the production of a product is a topical task in any modern production, [1]. This is also the reason to look for new and efficient processing methods, new kinematic cutting schemes and new technological equipment in the field of mechanical engineering.

Unconventional kinematic cutting schemes have been known since the 80s of the last century. They were used, although not widely, for processing various parts with different designs and overall dimensions, [2]. After the entry of the fourth industrial revolution, known as Industry 4.0, and the related development of machinery and technological equipment, the development of non-traditional kinematic cutting schemes has been observed and their application has become possible. Nowadays, this makes it possible for non-traditional kinematic turning schemes with simultaneous rotary tools and parts to be used in the processing of hard and difficult to cut materials.

In traditional kinematic turning schemes, requirements for high accuracy and low roughness are most often set. To achieve them, it is necessary to control the wear and temperature load of the tool in the cutting part, which turns out to be a difficult task when processing hard and hard-to-process materials. This is the reason for the search for alternative kinematic turning schemes. Non-traditional turning schemes, such as an unconventional kinematic rotary tool turning scheme, offer an opportunity to solve the above problem. In this kinematic scheme, the rotational movement of the tool is done with the help of an additional, external drive of the tool, through a spindle motor, [3, 4]. By using and applying the non-traditional turning tool scheme, an increase in the life of the cutting edge of the tool can be achieved by reducing wear, as well as reducing the temperature in the cutting area. The application of this kinematic scheme is typical for serial production, where it is cost-effective to finance the purchase of a modern lathe machine with milling options, provided with the kinematics to perform the necessary movements for the implementation of the kinematic scheme. This kinematic scheme can also be used in industries that do not have machines for turning milling. In this case, the application of the specified kinematic scheme is also suitable for serial production, in which it is cost-effective to design and manufacture the lathe tools and provide the necessary equipment for the application of rotary turning on a two-axis lathe with a rotating workpiece and a rotating tool, [5].

The review on the topic under consideration shows that the use of non-traditional turning schemes can offer a solution to the problems related to the accuracy of machining, the increased temperature in the cutting area and the wear of the cutting tool when processing parts from hard and hard-to-work materials, [6-9]. This would facilitate the processing of this type of material without the need to use complex and expensive processing methods and expensive large-sized machines. The choice of kinematic turning scheme depends mainly on the complexity of the manufactured product, the intended material for production, the lead time and accuracy required by the contracting authority, as well as the type of production.

The purpose of this article is to make a comparison between traditional and non-traditional kinematic turning schemes, to present their advantages and disadvantages, thus drawing attention to non-traditional turning schemes, which in dynamically developing production are of increasing interest for research and application in practice.

2. APPLICATION OF TRADITIONAL AND NON-TRADITIONAL KINEMATIC TURNING SCHEMES

Conventional kinematic turning schemes find a wide range of applications in various manufacturing sectors. They are most commonly applied in mechanical engineering, automotive, shipbuilding, aerospace, electronics, and other industries. By applying traditional kinematic turning schemes, high productivity, dimensional accuracy and low roughness of the processed surfaces can be ensured, [10, 11]. However, the problem with these kinematic schemes is the processing of hard and difficult-to-cut materials and the associated wear of the cutting edge of the tool and the increased temperature in the cutting area.

Non-traditional kinematic turning schemes are applicable in machinery, automotive, aerospace, medical technology, electronics and other industries where machining of hard and hard-to-machine materials is required. Improving the machinability of hard-to-machine materials, heat-treated materials with high hardness and stainless steels, increasing the durability of the cutting tool and reducing the temperature in the cutting area are of interest for research to this day. This is the reason why non-traditional kinematic turning schemes attract the attention of specialists and their expertise. Non-traditional kinematic cutting schemes in turning, the main purpose of which is to achieve high quality indicators of the workpieces, by reducing the wear of cutting tools and reducing thermal deformations, [12], are being intensively investigated.

The application of a turning scheme with a simultaneous rotary tool and workpiece helps to dissipate the temperature along the entire periphery of the cutting insert and reduce wear on the cutting tool, since in this case there is not a single point on the cutting insert of the tool that is in contact with the material to be processed during the entire turning period. This, in turn, leads to a significant increase in the life of the tool. The main purpose of developing this rotary tool turning technology is related to distributing heat and wear on the cutting insert more efficiently than single-point cutting technology.

3. COMPARISON OF TRADITIONAL AND NON-TRADITIONAL KINEMATIC TURNING SCHEMES

The traditional kinematic turning scheme is one of the most widely used kinematic schemes for machining. It is characterized by kinematics, in which there is a main rotational movement of the workpiece and feed movements of the cutting tool (or workpiece) along one of the two axes or simultaneously along both X and Z axes carried out by the cutting tool.

The machining of parts by cutting is based on the movements performed by the cutting elements of the tool in relation to the workpiece. The movements that are transmitted by the mechanisms of the machine tool to the cutting tool and the workpiece are determined by the selected kinematic cutting scheme. For each of the methods of traditional and non-traditional cutting, individual kinematic schemes are considered.

3.1 Traditional kinematic turning schemes

Traditional kinematic turning schemes are used in various industries, such as mechanical engineering, automotive, aircraft construction and others. These kinematic turning schemes are characterized by efficiency and reliability, which makes them preferred for the production of large series of parts, [13]. The structure of these kinematic schemes contains combinations of two types of movements: linear and rotational.

In the structure of a kinematic scheme of Figure 1(a) two motions shall be contained: one supply-rectilinear V_f and one rotary V_c motion:

•V_c is the main rotational motion that is performed by the workpiece;

•V_f - a linear feed movement along the Z-axis, which can be performed both by the tool and by the workpiece.

The kinematic scheme of Figure 1 (b) is composed of one rotary and one feed movement:

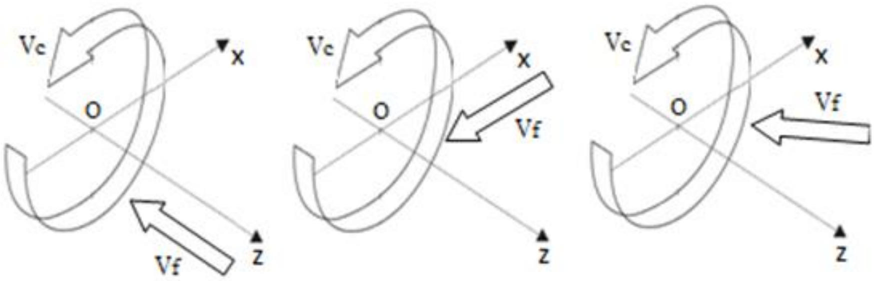
•V_c is the main rotational motion that is performed by the workpiece;

•V_f - a linear feed movement along the X-axis, which is performed by instruments.

The kinematic turning scheme shown in Figure 1 (c) contains one rotary and two feed movements:

•V_c is the main rotational motion that is performed by the workpiece;

•V_f - a linear feeding movement that is carried out simultaneously along the X and Z axes and can be performed only by the tool or in a combination of the tool and the workpiece.



a) *b)* *c)*

Fig. 1. Traditional kinematic turning schemes

The presented three traditional kinematic schemes are established in modern production and find wide practical application. They are applicable to both universal lathes and two-coordinate and multi-axis CNC lathes.

The need to process parts from hard and hard-to-machine materials through the use of these traditional kinematic schemes is a challenge. For this reason, it is necessary to apply a new approach to work, which uses non-traditional kinematic schemes in turning.

3.2 Non-traditional kinematic turning schemes

The improvement of the kinematics of modern machine tools makes it possible to apply non-traditional kinematic schemes in the processing of parts by cutting. This makes it possible to apply an unconventional kinematic scheme in turning, shown in Figure 2. It is a set of rotational and feeding movements.

•V_c is the main rotational motion that is performed by the workpiece;

•V_{cr} - rotational movement of the tool;

•V_f - a linear feed movement along one of the X and Z axes or simultaneously along the X and Z axes. V_f can be performed only by the tool or in a combination of the tool and the workpiece, depending on the kinematics of the machine.

•δ – the angle of establishment of the rotary tool (the angle δ is locked between the axis of rotation of the workpiece and the axis of rotation of the tool).

A key point in the application of the non-traditional kinematic scheme of turning is the rotational movement of the tool [14]. For the implementation of this kinematic scheme, a tool is proposed with a round plate mounted at the bottom of a cylindrical holder, in a rotating spindle (Figure 3).

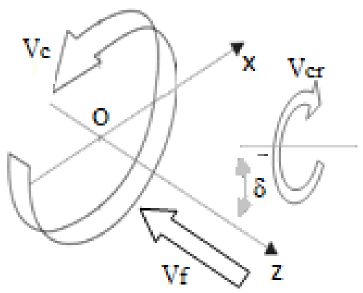


Fig:2. Unconventional kinematic scheme when turning with a rotary tool

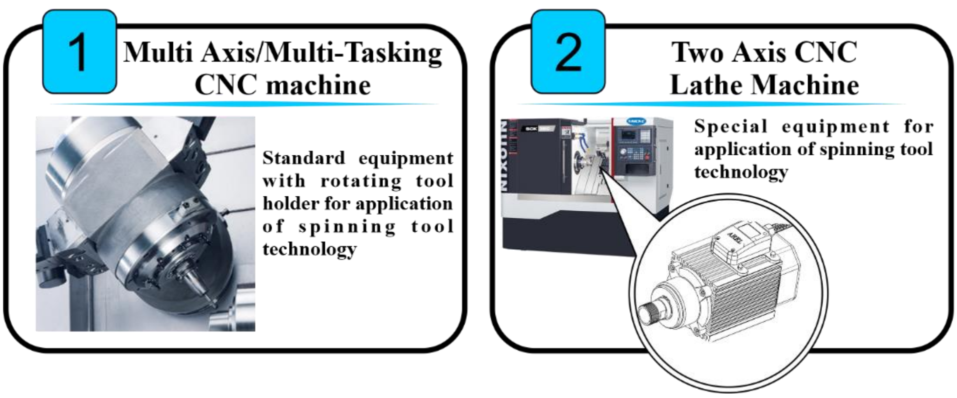
Fig. 3. Spinning tool for turning process

Unlike traditional kinematic schemes for turning, the application of the above-mentioned non-traditional kinematic scheme of turning with a spinning tool requires the presence of another additional axis necessary for turning the tool.
The practical application of this non-traditional kinematic scheme is made possible by the use of multi-axis CNC lathes (Figure 4(b)) or by means of a two-axis lathe with program control (Figure 4(a)), equipped with a specially developed device for fastening and driving the cutting tool.
In the traditional kinematic turning scheme, the use of two-axis and multi-axis machines does not require additional equipment, while in the non-traditional kinematic turning scheme, the use of two-axis machines requires the provision of a device for attaching the tool, for setting it at the required angle and for additional movement of the tool with the ability to adjust the rotational speed.

(a) (b)

Fig:4. Two-axis CNC lathe (a) and CNC multi-axis lathe (b), [15,16]

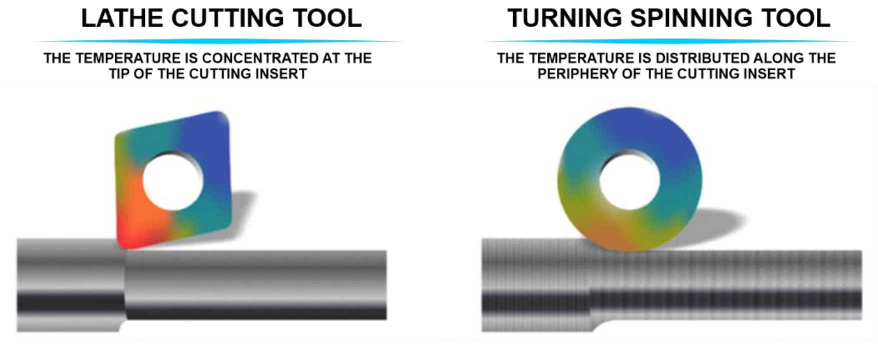
In Figure 5 presents the necessary equipment for fastening the rotary tools for the implementation of the non-traditional kinematic turning scheme through the use of a multi-axis CNC lathe-milling machine (Figure 5(a)) and through the use of a two-axis CNC lathe (Figure 5(b)).



(a) (b)

Fig.5. Equipment for the implementation of the non-traditional lathe kinematic scheme, [17, 18]

When using the non-traditional kinematic scheme of turning with a rotary tool, the aim is to reduce the temperature in the cutting area and, accordingly, to extend the life of the tool, [19,20]. Thanks to the rotational movement of the tool, the cutting edge goes through a thermodynamic cycle, during which uniform heating and cooling of the working part is observed, as shown in Figure 6(b). Thus, when turning with a rotary tool, it can increase the tool life by up to 2000%, [2]. With this kinematic scheme, the cutting conditions are no longer limited by the thermal phenomena of the process, but by the power of the machine, [21].



(a) (b)

Fig. 6. Influence of kinematic turning scheme on tool wear
a) Conventional cutting tool insert; b) Unconventional spinning tool insert

By rotating the tool, the wear of the cutting insert is evenly distributed along its entire periphery, in contrast to the conventional cutting scheme by using a carbide insert with a single cutting edge (Figure 6a), where heat is concentrated at the tip of the insert. In order to further reduce the rapid wear of the tool, it is necessary to use a lubricating coolant. When using coolant through the so-called oil mist effect, it is possible not only faster and more uniform cooling, but also protection against chip sticking, [22]. To date, no exact dependencies of cutting modes have been established when applying existing non-traditional cutting schemes, which obtain optimal results in terms of surface quality, process productivity and cutting tool life, [4]. That is why the study of non-traditional kinematic schemes is of interest for in-depth research.

The non-traditional kinematic turning scheme discussed in this article has its advantages and disadvantages summarized in Table 1. The advantages and disadvantages depend on the specific application conditions and the machining process and may vary depending on the specific requirements.

Table 1. Advantages and disadvantages of the unconventional kinematic turning scheme

Kinematic scheme	Advantages	Disadvantages
Unconventional kinematic turning scheme with a rotary tool	Reducing the temperature in the cutting area Reduction of cutting forces Friction reduction Vibration reduction Increase tool life	No exact dependencies of the cutting modes, and in particular the frequency of rotation of the workpiece and the tool, have been established, at which optimal results are obtained in terms of: -the quality of the treated surface; -the productivity of the process; -the life of the cutting tool.
	Improving the quality of the treated surface	Complex individual tool design
	Increase productivity	Limitation of the ratio of the radius of the cutting part to the expected geometry of the workpiece

The advantages and disadvantages discussed in Table 1 show that the non-traditional kinematic scheme makes it possible to solve problems related to tool durability, temperature in the cutting zone and friction.

Table 2 presents an assessment between traditional and non-traditional kinematic schemes in turning process according to different criteria.

Table 2. Comparison between traditional and non-traditional kinematic schemes by different criteria

Criteria	Traditional kinematic turning scheme			Non-traditional kinematic turning schemes		
	Bad rating	**Satisfactory rating**	**Excellent rating**	**Bad rating**	**Satisfactory rating**	**Excellent rating**
Heat Distribution		✓				✓
Process Performance		✓				✓
Vibration Occurrence		✓			✓	
Processing of hard-to-work materials	✓				✓	
Roughness reducing		✓			✓	
Versatility of the cutting process			✓	✓		
Cost			✓		✓	

4. CONCLUSIONS

After the comparative analyses, it can be noted that the round plate instruments have significant technological capabilities and a wide range of applications. In this case, the only limitation is the ratio of the radius of the plate to the expected geometry of the part. Stationary lathe tools with a round plate in their classic field of application are sensitive to vibrations, which is confirmed by many years of research on this subject. However, by applying the kinematic turning scheme by using a rotary tool, vibration is reduced, resulting in an increase in tool life and an increase in the quality of the machined surface, reducing roughness. Although rotary turning tools are also characterised by high productivity and wear resistance, precise dependencies of cutting modes, in particular the rotation frequent of the workpiece and cutting tool spindle, have not yet been established, in which optimal results are obtained in terms of surface quality, process productivity and cutting tool life, which is the subject of future in-depth research.

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