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CONTENT

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IMPACT OF CUTTING CONDITIONS ON THE LOAD ON SERVO MOTORS AT A CNC LATHE IN THE PROCESS OF TURNING A CLUTCH HUB

VIOLETA KRCHEVA, MARIJA CEKEROVSKA, MISHKO DJIDROV AND SASKO DIMITROV

Abstract. The purpose of the research in this paper is to investigate the impact of cutting conditions on the load on servo motors at a three-axis computer numerically controlled (CNC) Hitachi Seiki Seicos lathe. The analyzed parameters (cutting speed, feed, and depth of cut) play a crucial role in the turning process. It is significant that each cutting condition directly alters the value of the load on the power system and has a significant effect on cutting forces, which in turn affect the load on the servo motors at the CNC lathe during the process.

1. Introduction

The material removal process is a process where material from a starting workpiece is removed to machine a final product. This term refers to a family of shaping operations, of which the most important is machining. The most common application of machining is to shape metals into functional products. This involves the action of a sharp cutting tool that cuts away the excess material on the starting workpiece to produce the required shape and dimension. The process in which the main purpose is to remove the excess material by using a harder cutting tool is known as a metal cutting process, while all material removal processes are related to machining. [13]

In practice, metal cutting is not just one process but a variety of processes. The three most common types are: turning (including facing, taper turning, contour turning, form turning, chamfering, cutoff, threading, boring, drilling, and knurling), drilling, and milling. The common feature is the separation of the material using the cutting tool to form a chip and create a new surface on the workpiece (Fig. 1). To perform the metal cutting processes, a relative motion is required between the workpiece and the cutting tool. The relative motion is achieved by realizing a primary motion (the cutting speed) and a secondary motion (the feed). [4]

The basic operation of turning is one of the most commonly performed operations in metal cutting processes (Fig. 1). The chuck of a lathe holds the rotating workpiece while the cutting tool is moving along a particular axis, cutting away a layer of material to form a cylindrical surface or a surface with a more complex profile. The number of meters measured on the circumference of a rotating workpiece that passes thecutting edge of the cutting tool in one minute is known as *cutting speed* (v). The distancepassed by the cutting tool in an axial direction during each rotation of the workpiece in one minute is known as

Keywords. Cutting speed, feed, depth of cut, workpiece, motion, asynchronous.

feed (*f*). The millimetric thickness of the layer of material removed from the workpiece is known as the depth of cut (*d*). [7], [15].

The factors that affect metal cutting processes (cutting speed, feed, depth of cut, cutting fluid, cutting tool, chip, and machinability) determine major independent variables in metal cutting processes. Changes in the independent variables determine dependent variables, which include: type of chip produced; force and energy dissipation during cutting; temperature increase in the workpiece, tool, and chip; tool wear and failure; and surface finish and integrity of the workpiece. [6]

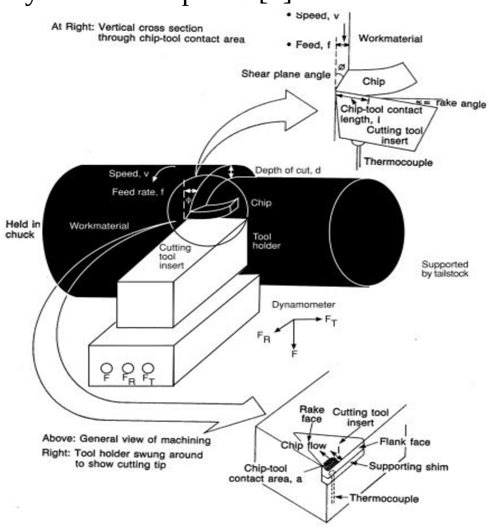

Figure 1. *Characteristics of the metal cutting processes* [15]

Performing the metal cutting processes requires compatible machines. The requirement of the machine is to provide power for the operation at the determined cutting conditions that affect the operation, workpiece, required power, and load on the machine. Depending on the cutting conditions, the realization of the turning operation contributes to the required power, i.e., the appropriate load on the power systemof the computer numerical control (CNC) machine. Today, CNC machines have become an integral part of the industry. The accuracy connected to dimensional correctness, surface finish, and precision in every aspect that is achieved through CNC machines cannot be achieved in conventional processes. [8], [10]

This paper relates to machining with a CNC machine, a process that is widely used in industry. Concerning the machining process, various studies related to cutting conditions, their characteristics, and their impact have been extensively studied in a variety of mechanical engineering literature (for example [1], [3]-[15]). The paper is structured in four sections. After the introduction, the second section refers to the explanation of the research. In the third section, the obtained results are discussed, and in the fourth section, a conclusion and a potential application of the research are presented.

2. Research

This research illustrates a part of the clutch hub manufacturing process. It refers to a material removal process that is implemented on the three-axis CNC Hitachi Seiki

Seicos LIII lathe (Fig. 2a). The motion in the process is realized in a three-dimensional coordinate system and is powered by a servo motor for primary motion (rotation of the spindle) and servo motors for secondary (linear) motion along the X, Y, and Z axes, respectively. These servo motors operate on the principle of asynchronous electricmotors.

Figure 2. *(a) CNC Hitachi Seiki Seicos LIII lathe, (b) Workpiece, (c) Cutting tools*

An asynchronous servo motor is an asynchronous electric motor that includes an encoder (rotation motion detector) and is used with controllers for providing closed loop control and feedback. This motor can be placed with high accuracy, and it can also be controlled precisely according to the requirements of the applications. [2]

The realization of primary motion (Fig. 2b) is directly related to the function of a servo motor with a maximum power of 15 kW. The realization of secondary motion (Fig. 2c) is directly related to the function of three servo motors, where the servo motor for secondary motion along the X axis has a maximum power of 8,9 kW and the servo motors for secondary motion along the Y and Z axes have a maximum power of 4,6 kW. The requirements for motion along the axes to perform the turning operation with certain cutting conditions contribute to the variable load on the servo motors that power these motions.

Apart from turning, the additional required machining operations that relate to turning and can also be implemented on this CNC lathe are drilling, facing, boring, and chamfering.

Turning, boring, and drilling operations are applied when generating cylindrical or more complex surfaces of rotation. The facing operation is applied when generating a flat surface normal to the axis of rotation by feeding the cutting tool from the surface towards the center or outward from the center. [15]

With the intention of precisely analyzing the operations included in the processes implemented on this CNC lathe, appropriate 2D drawings are created with the

AutoCAD software and explained in the following.

First, the shape and dimensions of the starting and final workpieces are illustrated. The starting workpiece that is used to produce the final clutch hub (Fig. 3a) is the forged clutch hub (Fig. 3b). According to the dimensions, shape, and geometry of the clutch hub and the forged clutch hub, two cutting phases consisting of several cutting operations that include cutting tools (and their geometry) and cutting conditions (cutting speed (v), feed (f), and depth of cut (d)) are clearly explained and visually presented.

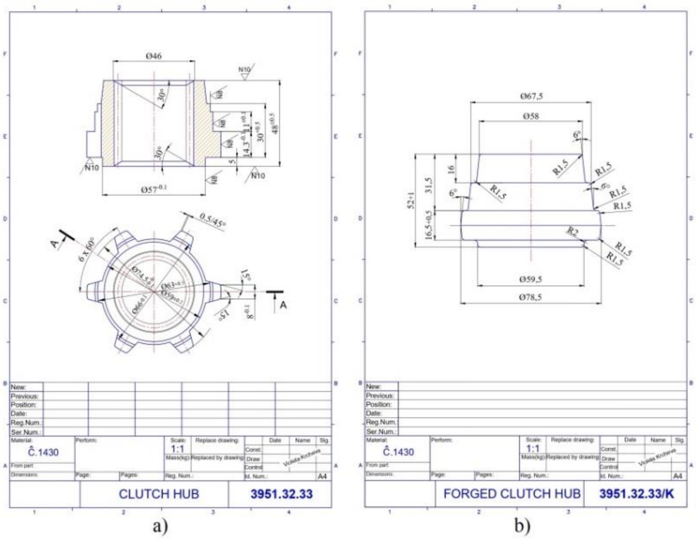

Figure 3. *(a) Clutch hub, (b) Forged clutch hub*

The ***first phase*** relates to the shorter side of the forged clutch hub and is structured into four passes.

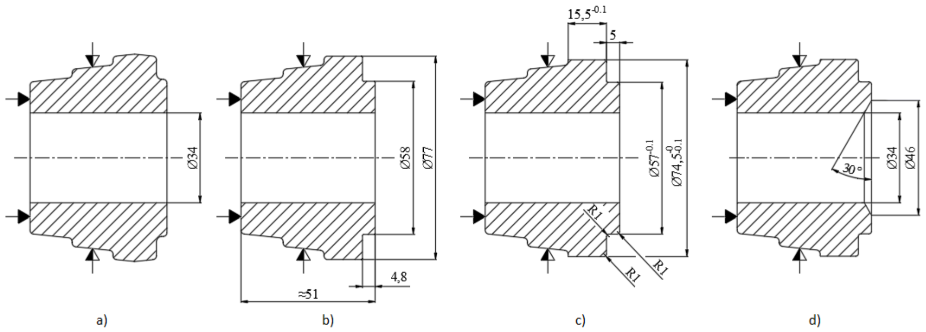

Figure 4. *Structure of the first pass*

The *first pass* is defined just by one cutting operation: drilling (Fig. 4a). In order to perform this operation, a cutting tool moves linearly interpolatively along the Z axes. The predicted cutting tool is a straight-flute drill DS20-D3400DM40–04 with indexable inserts DS20-0508-P and DS20-0508-C, manufactured by SANDVIK Coromant (Fig. 5a). The geometry of this cutting tool is determined by the values presented in Table 1, while the values of the predicted cutting conditions are given in Table 2.

The *second pass* is defined by two cutting operations: turning and facing (Fig. 4b). To realize this operation, a cutting tool moves in a linear interpolative motion along the X and Z axes. The predicted cutting tool is a combination of the PCLNR 2525M 12 shank tool (Fig. 5b) and the CNMG 12 04 08-PM 4325 indexable insert (Fig. 5c), each manufactured by SANDVIK Coromant. The geometry of this cutting tool is determined by the values presented in Table 1, while the values of the predicted cutting conditions are given in Table 2.

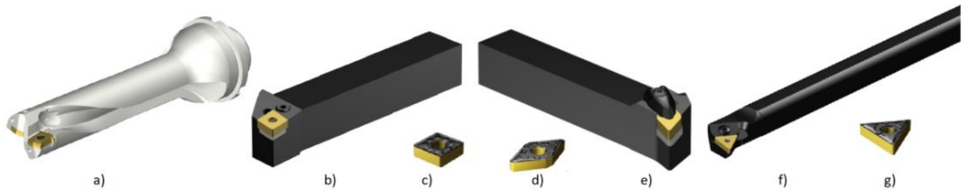

Figure 5. *Cutting tools*

The *third pass* is also defined by two cutting operations: turning and facing (Fig. 4c). Completing this operation depends on linear and circular interpolation motions on a cutting tool oriented on the X and Z axes. The predicted cutting tool is a combination of the DDHNL 2525M 15 shank tool (Fig. 5f) and the DNMG 15 06 08-KF 3225 indexable insert (Fig. 5g), each manufactured by SANDVIK Coromant. The geometryof this cutting tool is determined by the values presented in Table 1, while the values of the predicted cutting conditions are given in Table 2.

Table 1. *Geometry of cutting tools*

Geometry of cutting tools	*Fig.5a*	*Fig.5b,5c*	*Fig.5d,5e*	*Fig.5f,5g*
Tool cutting egde angle (k) [º]	81	95	107,5	91
Tool lead angle (k_1) [º]	/	-5	-17,5	-1
Inclination angle (λ) [º]	0; 0	-6	-7	/
Orthogonal rake angle (γ) [º]	/	-6	-6	/
Corner radius (r) [mm]	0,8; 0,35	0,8	0,8	0,8
Effective length of the cutting edge (l) [mm]	/	12	14,7	15,7
Insert shape	/	Rhombic 80º	Rhombic 55º	Triangular
Cutting diameter (a) [mm]	34	/	/	/
Usable length (t) [mm]	137	/	/	/

And the *fourth pass* is defined as a single cutting operation: chamfering (Fig. 4d). To realize this operation, a linear interpolation motion on this cutting tool oriented on the X and Z axes is required. The predicted cutting tool is a combination of the S25T-

PTFNR16 16-W shank tool (Fig. 5f) and the TNMX 16 04 08-WF 1515 indexable insert (Fig. 5e), each manufactured by SANDVIK Coromant. The geometry of this cutting tool is determined by the values presented in Table 1, while the values of the predicted cutting conditions are given in Table 2.

Completing these four passes results in the realization of the first phase.

The ***second phase*** relates to the longer side of the forged clutch hub and is structured into three passes.

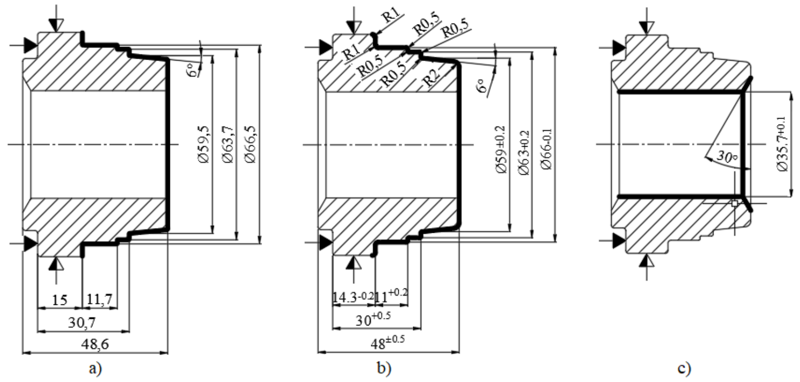

Figure 6. *Structure of the second phase*

The *first pass* is defined by two cutting operations: turning and facing (Fig. 6a). To realize this operation, a cutting tool performs linear and circular interpolation motions oriented on the X and Z axes. The predicted cutting tool is the same as in the second pass in the previous phase (Fig. 5b, Fig. 5c). The geometry of this cutting tool is determined by the values presented in Table 1, while the values of the predicted cutting conditions are given in Table 2.

Table 2. *Cutting conditions*

Cutting conditions	*First phase*				*Second phase*		
	First pass	*Second pass*	*Third pass*	*Fourth pass*	*First pass*	*Second pass*	*Third pass*
v [m/min]	450	750	800	750	700	900	750
f [mm/min]	0,07	0,12	0,2	0,12	0,1	0,14	0,12
d [mm]	÷56	1,2÷2,8	0,5÷1,2	÷2,7	0,5÷2,5	0,2÷1,2	÷2,7

The *second pass* is defined by two cutting operations: turning and facing (Fig. 6b). To perform this operation, a linear and circular interpolative motion of a cutting tool along the X and Z axes is required. The predicted cutting tool is the same as in the third pass in the previous phase (Fig. 5d, Fig. 5e). The geometry of this cutting tool is determined by the values presented in Table 1, while the values of the predicted cutting conditions are given in Table 2.

And the *third pass* is defined by two cutting operations: chamfering and boring (Fig.

6c). To perform this operation, a cutting tool moves in a linear interpolative motion along the X and Z axes. The predicted cutting tool is the same as in the fourth pass in the previous phase (Fig. 5f, Fig. 5g). This cutting tool is moved in a linear interpolative motion along the X and Z axes to realize this operation. The geometry of this cutting tool is determined by the values presented in Table 1, while the values of the predicted cutting conditions are given in Table 2.

Completing these three passes results in the realization of the second phase.

3. Results and discussion

In view of the fact that cutting conditions contribute to achieving the appropriate quality of the surface finish on the workpiece, accuracy of the dimensions, and correctness of the shape, the control unit of the CNC lathe tends to achieve and maintain the cutting conditions during all passes in the process of turning.

Regarding the value of the predicted cutting speed, feed, and depth of cut, i.e., the predicted cutting conditions for the first and second phases, in the section that follows, their effect on the primary and secondary motion in the turning process is discussed.

The *cutting speed* is the first parameter discussed. Considering that the value of the cutting speed is given for each pass, the variation of the primary motion in the following diagrams is presented in intervals, pointing to the beginning and the end of the pass, respectively.

The beginning of each pass is indicated by “b” and this abbreviation appears after every ordinal number of the pass, and the end of the pass is indicated by “e”. It is noticeable that at the end of one pass the next pass begins, and the value of the cutting speed for every pass is presented at the beginning and end of the same pass.

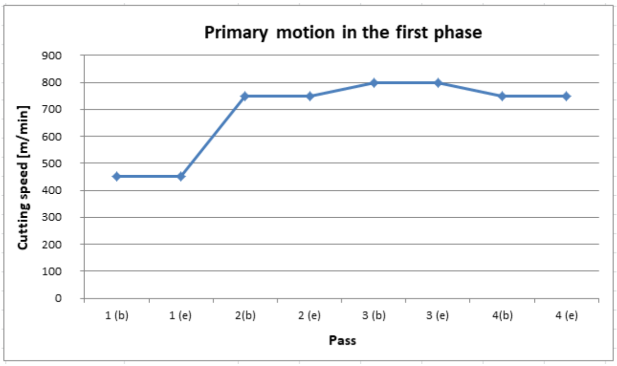

Figure 7. *Primary motion in the first phase*

The variation of the predicted cutting speed related to the primary motion during the realization of every pass in the first phase (structured in four passes) is illustrated in Figure 7, and for the second phase (structured in three passes), it is illustrated in Figure8.

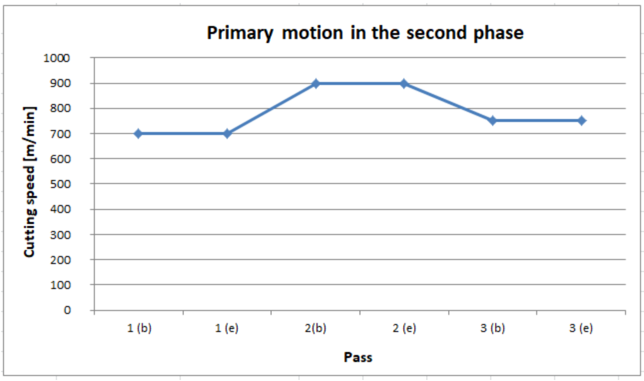

Figure 8. *Primary motion in the second phase*

It can be seen in Figures 7 and 8 that the presented value of the cutting speed in the diagram corresponds to its predicted value for every pass. It is noticeable that each pass begins and ends with the predicted cutting speed, forming the diagram of the primary motion in the first phase (in Figure 7) and in the second phase (in Figure 8).

The *feed* is the second parameter discussed. The value of the feed, as well as the cutting speed, is given for the beginning and end of every pass in the following diagrams.

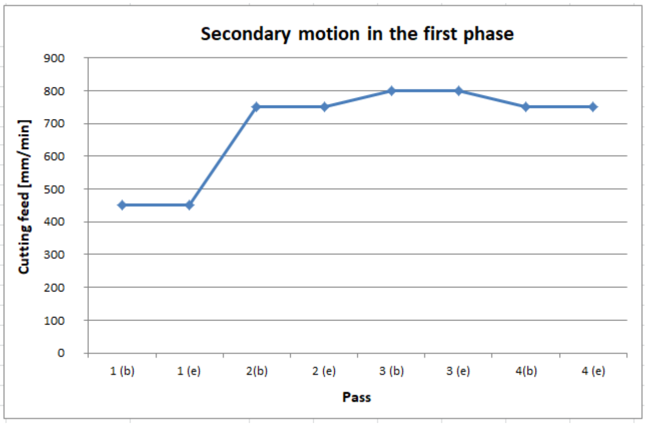

Figure 9. *Secondary motion in the first phase*

The variation of the predicted feed related to the secondary motion during the realization of every pass in the first phase (structured in four passes) is illustrated in Figure 9, and for the second phase (structured in three passes), it is illustrated in Figure 10.

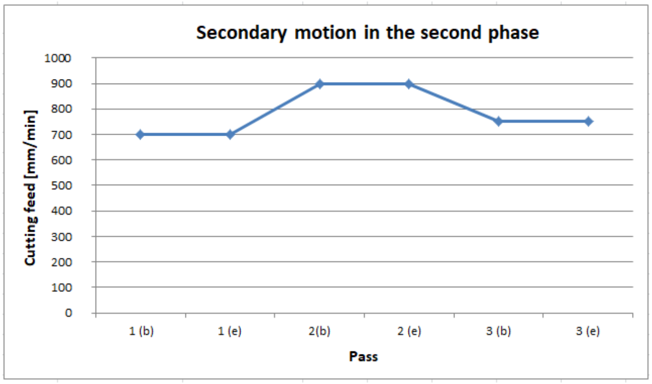

Figure 10. *Secondary motion in the second phase*

It can be seen in Figures 9 and 10 that the presented value of the feed in the diagram corresponds to its predicted value for every pass. It is noticeable that each pass begins and ends with the predicted feed, forming the diagram of the secondary motion in the first phase (in Figure 9) and in the second phase (in Figure 10).

The *depth of cut* is the third parameter discussed. The value of the predicted depth of cut is variable for every pass in the phases, i.e., for each pass of the cutting tool along the contour surface that is subject to machining.

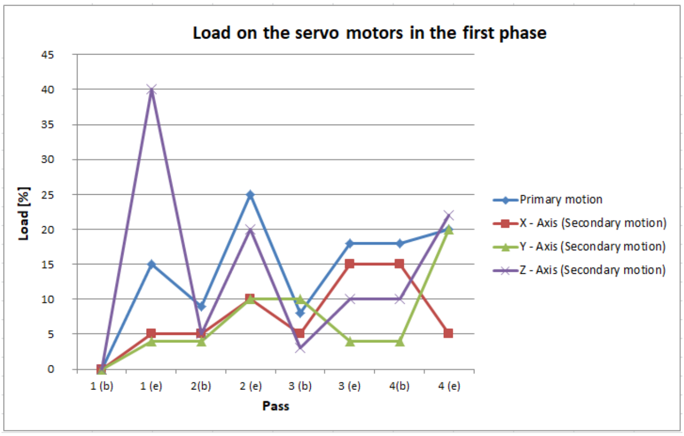

Figure 11. *Load on the servo motors in the first phase*

The variable depth of cut while simultaneously maintaining the predicted cutting speed and feed, results in a variable load on the servo motors that power the primary and secondary motion during the phases.

The variation of the load on the servo motors, according to the predicted depth of cut, throughout the realization of every pass in the first phase (structured in four passes) is illustrated in Figure 11, and for the second phase (structured in three passes), it is illustrated in Figure 12.

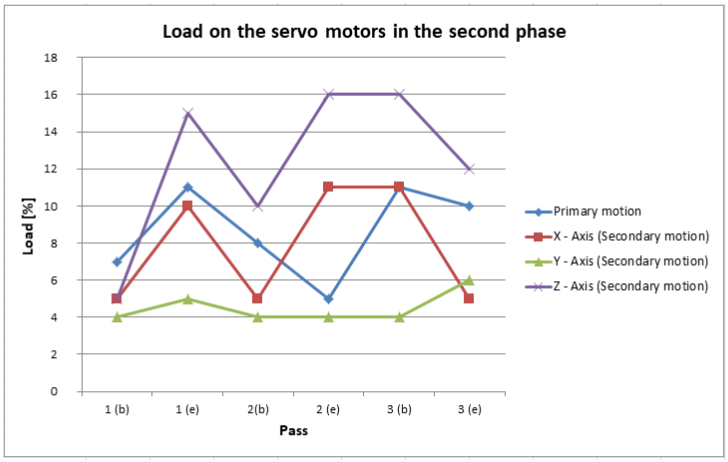

Figure 12. *Load on the servo motors in the second phase*

Relating to this parameter, it is also noticeable that each pass begins and ends with a different value for the load on the servo motors, forming the particular diagram for the load on the servo motors for the first phase (in Figure 11) and for the second phase (in Figure 12).

As the value of the predicted depth of cut alters during every pass, the load on the servo motors that power the primary and secondary motions varies. It is obvious that the increasing value of the depth of cut increases the value of the load on the servo motors, while the decreasing value of the depth of cut decreases the value of the load on the servo motors. The maximum value of the load is in the first pass in the first phase and in the third pass in the second phase (on the servo motor that powers the secondary motionalong the Z-axis), for the highest value of the predicted depth of cut.

4. Conclusion

In this paper, the impact of cutting conditions on the load on servo motors at a CNC lathe in the process of turning a clutch hub is presented. Regarding the value of predicted cutting speed, feed, and depth of cut as parameters that express the cutting conditions, they have a considerable impact on the process of turning.

The presented results indicate that the predicted cutting speed and feed are maintained in the process. The maintenance of these parameters contributes to achieving and maintaining the quality of the surface roughness and surface finish while turning the workpiece with certain geometry, shape, and size.

When adding the variable value of the depth of cut as the third parameter that impacts these components, the maintenance of the depth of cut (during maintenance of the cutting speed and feed) contributes to various loads on the servo motors that power the realization of the primary and secondary motion in the process.

Therefore, the main advantage of the study in this paper is the opportunity to examine the impact of cutting conditions in high-precision turning processes because, to obtain a quality-produced workpiece, precision in the technology and precision in the motion are crucial.

This study is further recommended for analysis and research where the load on the servo motors is at a very high rate with an intention to decrease the value of the depth of cut (or other two parameters) and increase the number of passes that can accomplish the requirements in the process.

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