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INFLUENCE OF THE SEQUENCE OF PROCESSING OPERATIONS ON THE WORKPIECE DEFORMATIONS

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Abstract: *The accuracy of processing parts with low rigidity is influenced by their deformation during the cutting process. Deformations are influenced by several factors such as the cutting parameters, the fixing mode, the processing sequence etc. To obtain parts that need to correspond to the indications in the technical drawing, it is necessary to study these deformations and establish an appropriate processing technology. The work presents the establishment of a machining sequence of grooves by turning on a part with low rigidity based on the finite element analysis of the deformations of the part during processing.*

Key words: *workpiece, deformations, groove processing, finite element.*

1. INTRODUCTION

The continuous increase in the performance of computer numerical control processing systems and cutting tools determine the machining companies to resort more often to process parts at high speeds in order to reduce machining times. Increasing the values for cutting parameters also determines the increase of the cutting forces which together with other factors such as the fixing mode, or the processing sequence can lead to the deformations of the parts and tools during processing which influences dimensional and geometric accuracy. Deformation of tools and parts during machining processes are important factors in the design of working steps, which can affect the dimensional accuracy, the roughness, the precision of the shape and the position of the surfaces of the machined part. They can also influence the tool life of the cutting tools and may favor the appearance of vibrations. Selecting correct parameters for cutting machining operations to reduce processing errors has been studied by several researchers who approached different study methods.

Thus, in the paper [1] the theoretical analysis and mathematical modeling of the deformations and stresses of the grooving tool are made. The cutting forces which affect the cutting tool life have been measured by various machining experiments. The effects of variations in cutting parameters used in the grooving operation on the deformation and stresses of the cutting tool were studied by using FEM, and then an artificial neural network model was developed to predict them. Authors [2], starting from the observation that the deformation that appeared when processing the previous layer will influence the nominal cutting depth of the current layer and establish a dynamic model based on an iterative calculation to predict the deformation in the processing of a thin-walled part. The dynamic model is validated by comparing the simulation result with the experimental one. Article [3] presents a method for optimizing in two stages the processing sequence and the processing parameters in order to suppress the deformation of the parts with low rigidity. In work [4], taking into account the working sequence, the feed direction, the orientation of the tool, the cutting force, is simulated a method to minimize displacement of the workpiece, which is validated by experiments. Article [5] proposed a way of predicting errors in the processing of thin-walled parts using finite element analysis. The proposed methodology considers the effect of temperature and forces in the cutting process,

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and it develops a formula for cutting speed optimization. The authors [6] present a finite element analysis model, which is validated by processing tests to predict the deformation of the part during the milling process. Considering both the deformation of the workpiece and the tool, using the finite element method, in [7] a dynamic model was proposed to predict milling errors. To reduce the deformation of the machined part, based on the cutting force model, authors [8] identified a combination of cutting parameters which directly influence the processing deformation. It is presented a strategy for deformation control by tool path planning.

2. METHODOLOGY

By increasing the requirements for ensuring high dimensional accuracies for chip machining parts, there is also the problem of ensuring the accuracy of the shape and position of the part surfaces. These requirements are strongly influenced by the machining conditions, which are influenced by many factors, including the rigidity of the technological system consisting of the machine tool, the tool and the workpiece being machined.

The paper presents the machining of a cylindrical part with grooves by turning. The material of the workpiece is C45, and the technical drawing is presented in fig. 1. From a technological point of view, the piece is composed by cylindrical surfaces and the dimensions, the shape and position deviations, and the roughness make possible to process on the lathe. The piece processing involves several clamps, which are done on several CNC lathe machines.

For grooves processing are used Cutting insert GX24-3E400N04-UD4, cutting tool material WKP23S Tiger·tec Silver, which allow cutting speed Vc=250 m/min and working feed 0.2mm/rot, and width 3mm, and a very good tool life [9]. Due to the considerable length of the part relative to the final diameter of the grove, the rigidity of the workpiece changes according to the sequence of grove processing. As a result, the size of the deformations is influenced by order of processing of the grooves.

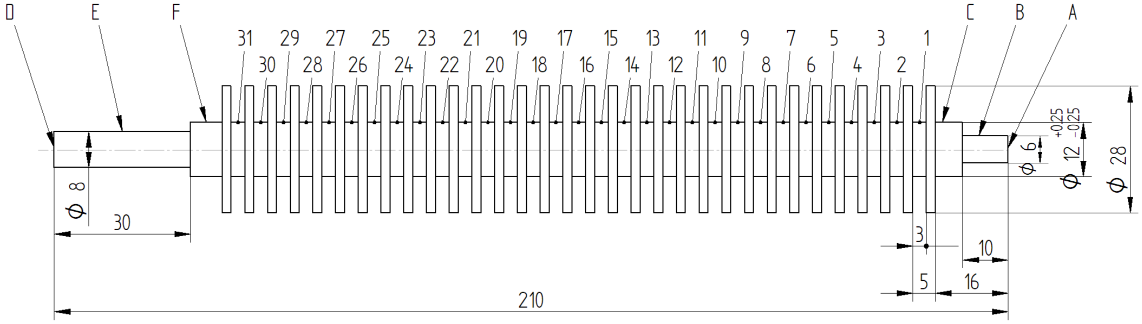

Fig.1. The workpiece and the groove numbering.

In order to reduce machining deformations, four machining variants were studied, aiming to establish the sequences of machining processing of the grooves, so that the machined part deformations fall within the specifications of the technological drawing.

Variants differ in each other by order of processing operations (Variant 1, Variant 2), the shape of the blank (blank A, blank B) from which the grooves processing is started, and by the grooves processing sequences (sequence 1, sequence 2).

Table 1.

Processing operation of the workpiece mode 1

No.	Variant 1	
	Cutting operation	**Surface**
1	facing, centering	A
2	roughing, finishing	B, C
3	facing, centering	D
4	roughing, finishing	E,F
5	roughing, finishing	G
6	grooving	1-31

In the first situation (Variant 1), the technological process is presented in table 1. Before the grooves processing, the blank 1 looks like in fig. 2.

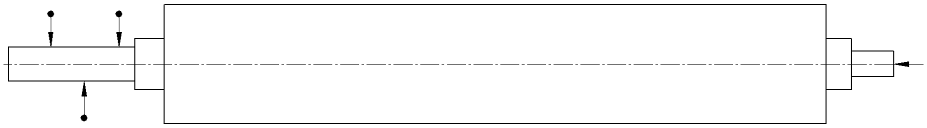

Fig. 2. Variant 1 - the blank 1, before the grooves processing.

In the second situation (Variant 2), the technological process is presented in Table 2. Before processing grooves, the blank 2 looks like in figure 3.

For each blank variant (blank 1, blank 2), there are considered two grooves processing sequences. In the first variant (sequence 1), grooves are processed consecutively, starting by groove 1 up to 31, and in the second variant (sequence 2), grooves are processed alternately, starting from the middle to the ends (sequence 2). Table 3 shows the sequence of processing the grooves.

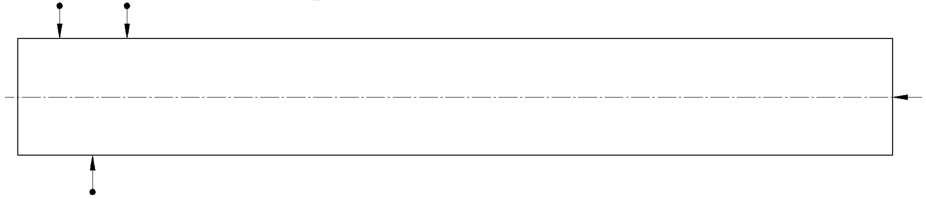

Fig. 3. Variant 2 -the blank 2, before the grooves processing.

Table 2.

Processing operation of the workpiece mode 2

No.	**Variant 2**	
	Cutting operation	**Surface**
2	facing, centering	A
3	facing, centering	D
4	roughing, finishing	G
5	grooving	1-31
6	roughing, finishing	B, C
7	roughing, finishing	E,F

In the cutting process, they occur forces which produce deformations of the technological system, which will be more evident if they have a variable character.

For cutting parameters mentioned above, the cutting force was determined considering that the chip formation is due to the successive shear of layers of material, brought in a plastic state by force exerted by the rake face of the knife.

In the literature [10], [12] and [13] there are presented different approaches regarding the theoretical determination of the cutting force as well as the indication of influencing parameters.

For the processing of grooves, the resulting cutting force is defined by the components (fig.4):

P_Y - the radial component;

P_Z - tangential component.

Table 3.

The sequence of processing the grooves

Sequence 1		**Sequence 2**	
Cutting order	**Groove number**	**Cutting order**	**Groove number**
1	1	1	16
2	2	2	15
3	3	3	17
4	4	4	14
5	5	5	18
6	6	6	13
7	7	7	19
8	8	8	12
9	9	9	20
10	10	10	11
11	11	11	21
12	12	12	10
13	13	13	22
14	14	14	9
15	15	15	23
16	16	16	8
17	17	17	24
18	18	18	7
19	19	19	25
20	20	20	6
21	21	21	26
22	22	22	5
23	23	23	27
24	24	24	4
25	25	25	28
26	26	26	3
27	27	27	29

28	28	28	2
29	29	29	30
30	30	30	1
31	31	31	31

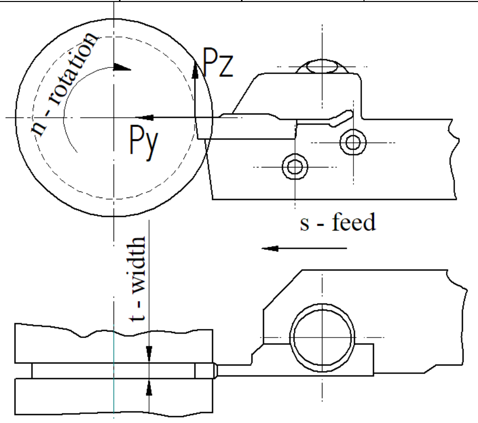

Fig. 4. Groove cutting.

The size and orientation of the cutting force depend on several parameters: the depth and width of cut, the working feed, the geometric characteristics of the cutting insert, the mechanical properties of the cutting insert and the workpiece material, the use of coolant-lubrication, the coefficient of friction between the tool and the workpiece, the wear of the cutting edge, etc. For the grooves processing, the relationships for determining the components P_Y and P_Z in daN, according to [10] are:

$$P_Y = C_Y \cdot (HB)^{e_2} \cdot \frac{1+\left(\frac{\cos\kappa}{\cos 45^{\circ}}\right)^{0.5}}{2} \cdot K_Y \cdot t^{0.9} \cdot s^{0.75} \quad (1)$$

$$P_Z = C_Z \cdot (HB)^{e_2} \cdot \left(\frac{\sin 45^{\circ}\kappa}{\sin\kappa}\right)^{0.25} \cdot K_Z \cdot t \cdot s^{0.75} \quad (2)$$

HB - Brinell hardness of workpiece material,

$HB = 207$ [11]

κ – side cutting edge angle;

$\kappa=90^{O}$

K_Y, K_Z, - coefficients representing the influence of some secondary factors ;

$K_Y=1.14$;

$K_Z=1$

C_Y, C_Z – coefficients according to insert cutting material and piece material

$C_Z = 3.57$;

$C_Y=2.32$

e_2– exponent depending on the processed material

$e_2=0.75$

After replacement is obtained:

$$P_Z = 2173.5 \quad [\text{N}]$$

$$P_Y = 508.9 \quad [\text{N}]$$

The resulting force is given by:

$$R = \sqrt{P_Y^2 + P_Z^2} \quad (3)$$

$$R = 2232.3 \ [\text{N}]$$

The area of the section of the detached chip is:

$$A_a = s \cdot t \quad (4)$$

The contact pressure on the chip is:

$$p = \frac{R}{A_a} \quad (5)$$

$$p = 3719.9 \ [\text{MPa}]$$

Due to the cutting force the workpiece is deformed, the deflection expression depending on the way that the workpiece is clamped on the lathe. For the case when the workpiece is clamped in the chuck and in the revolving centre (fig. 5) the deflection expression is given by (6)[10]:

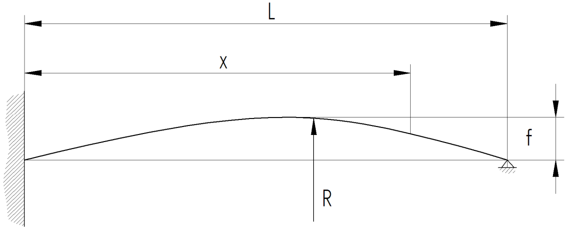

Fig. 5. Deflection of the workpiece.

$$f = \frac{R \cdot x^3 (L - x^2) \cdot (4 \cdot L - x)}{12 \cdot E \cdot I \cdot L^3} \quad (6)$$

For bars with variable moment of inertia, as is the case of the presented part, analytical methods for determining deflection become difficulty to be applied. A method that simplifies to some extent is the graphical method described in [14].

Considering the bar in fig.1 with variable inertia moments, on which the bending moment diagram is constructed, in any section where the inertia moment is I_i, the differential equation of the mean deformed fiber is:

$$E \cdot I_i \frac{d^2 f}{dx^2} = -M \quad (7)$$

In the previous relation, the moment of inertia I_i has changed in steps. The largest moment of inertia I_0 is considered. By multiplying the relation (7) by I_0 gives:

$$E \cdot I_i \cdot \frac{I_0}{I_0} \cdot \frac{d^2 f}{dx^2} = -M \qquad (8)$$

or

$$E \cdot I_0 \cdot \frac{d^2 f}{dx^2} = -M \frac{I_0}{I_0} = M_r \qquad (9)$$

The differential equation is reduced to that of the bar with constant momentum, considering that at intervals the reduced momentum Mr to be those indicated in the expression (9).

3. FEM ANALYSIS

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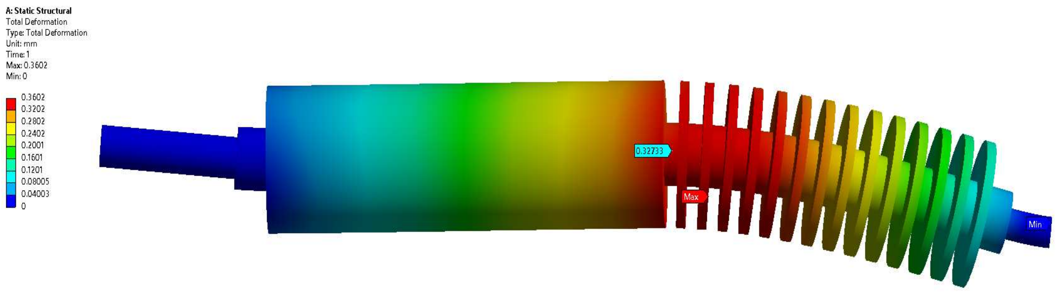
Taking into account both of the large amount of work to determine the deflection produced by cutting force in each section and the stage of previous machining (124 runs – 31 grooves and 4 cases), finite element analysis was used. To study the deformations which appear at the grooves turning, the ANSYS application was used.

To determine the deformations of the workpiece was applied for each groove, taking into account the updated shape of the part that is processed in four machining cases.

The main stages of the analysis consisted in: importing the solid model, discretizing the structure, applying loads and constraints, solving equations, and analyzing the results. There were analyzed the stresses and deformations which occur during the processing of each groove.

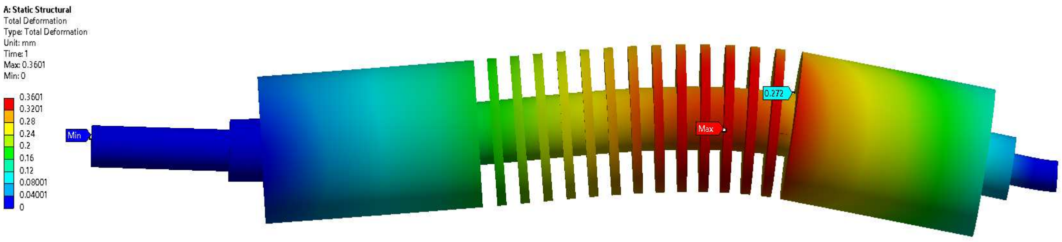
In all cases, the maximum stress does not exceed the allowed value of the workpiece material.

The elastic deformations of the workpiece are different for each groove in all processing cases. In figures 6-9 are shown the maximum deformations resulting from the simulation of the workpiece processing.



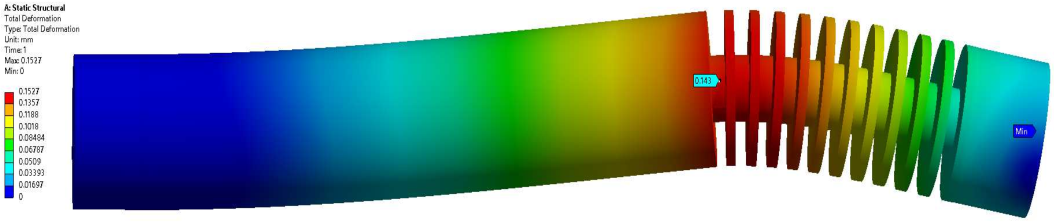
Nodes: 962877
Elements: 672515
Element size: 1mm
Maximum deformation 0.327 mm

Fig. 6. Case 1: Blank 1, Sequence 1; Groove 14.



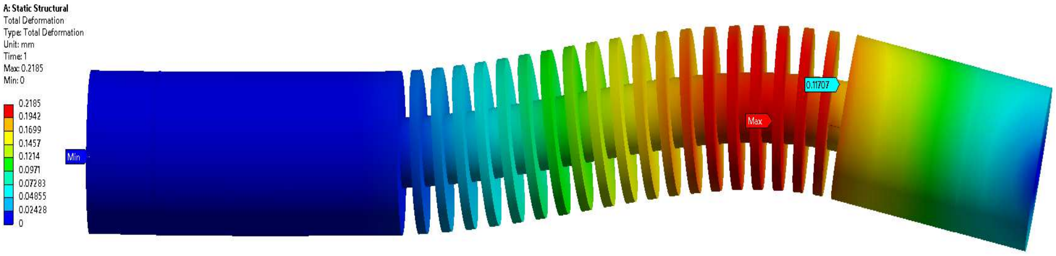
Nodes: 966055
Elements: 674873
Element size: 1mm
Maximum deformation 0.272 mm

Fig. 7. Case 2: Blank 1, Sequence 2; Groove.



Nodes: 1348779
Elements: 960253
Element size: 1mm
Maximum deformation 0.143 mm

Fig. 8. Case 3: Blank 2, Sequence 1; Groove 11.



Nodes: 1214590
Elements: 847114
Element size: 1mm
Maximum deformation 0.117 mm

Fig. 9. Case 4: Blank 2, Sequence 2; Groove 6.

After analysis, the deformations for each machining variant and for each groove are shown in fig.10, fig.11, fig.12, fig.13.

By analysis the graphs you may notice that the minimum deformation is recorded for case 4 of processing. The maximum deformation in this variant corresponds to groove 7, and the deformation value is 0.117 mm.

After completion of processing, the maximum deformation of the diameter is 0.23 mm, falling within limits indicated in the technical drawing.

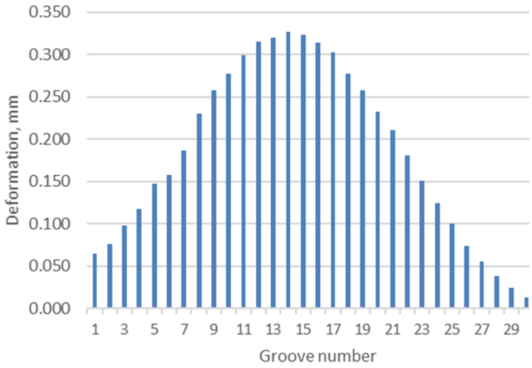


Fig. 10. The workpiece deformation.
Case 1 (blank 1, sequence 1)

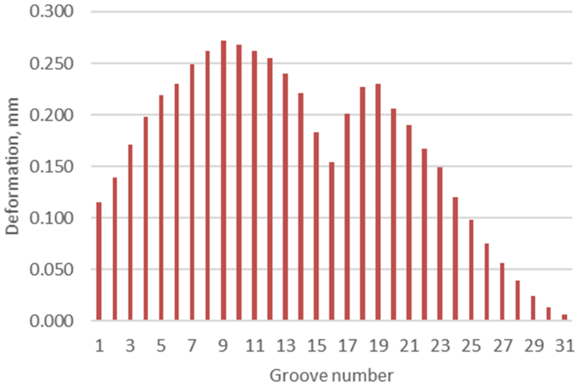


Fig.11. The workpiece deformation.
Case 2 (blank 1, sequence 2)

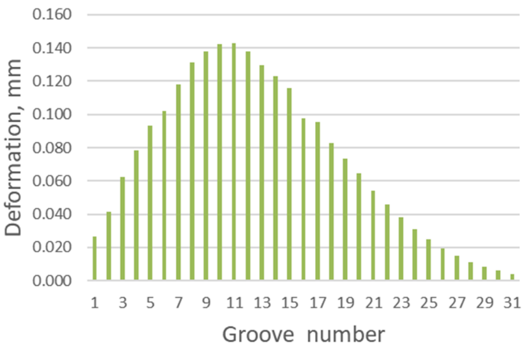


Fig.12. The workpiece deformation. Case 3 (blank 2, sequence 1)

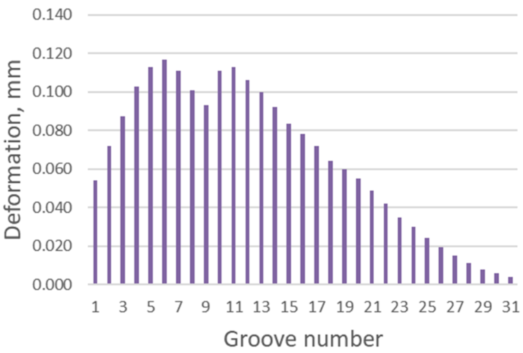


Fig.13. The workpiece deformation. Case 4 (blank 2, sequence 2)

4. CONCLUSION

The paper presents a study on choosing the processing sequence for a piece with low rigidity, for which four variants of processing technologies were realized.

For the used cutting parameters, the value of the cutting force was assessed and the finite element analysis allowed the determination of the deformations of the piece during the processing of each groove, and highlighted the variation of the processing in which the deformation was the smallest.

Using finite element method, you can adapt the processing technology simultaneously by decreasing costs by eliminating the expensive preliminary experiments necessary to validate the designed technological process.

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Influența succesiunii operațiilor de prelucrare asupra deformărilor piesei de prelucrat

Rezumat: *Precizia de prelucrare a pieselor cu rigiditate mică depinde de deformația acestora în timpul procesului de așchiere. Deformațiile sunt produse de forța de așchiere, care este influențata de parametrii regimului de așchiere, modul de fixare , secvența de prelucrare strategia de lucru. În cazul unui număr mare de piese Ce urmează a fi prelucrate Este necesară studierea acestor deformații si stabilirea unei succesiuni de prelucrare care sa permită obținerea piesei în tolerantele prescrise. Folosind analiza cu elemente finite pentru determinarea deformațiilor piesei prelucrate, în lucrare se prezintă un studiu privind stabilirea succesiuni de prelucrare a unor canale prin strunjire pe o piesă cu rigiditate scăzută, care se execută în serie mare.*

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