OPTIMIZATION BY SIMULATION OF SURFACE MACHINING ON CNC MACHINE TOOLS USING CAD-CAM TECHNIQUES

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Abstract: *The paper is focused on the theoretical and practical application aspects concerning the approach methods to CNC simulation using the CATIA program, Machining module. The authors propose some variants of optimization, such as: the type of the cutting tool used, path and division pattern of the stock left for machining, parameters of cutting regimes, efficient use of machine-tools (rotative speed, feed and positioning speed) and tools (durability), reducing the processing time in order to obtain the imposed precision (roughness) etc. There are presented some images and numerical data obtained from simulations, which permit conclusions about the possibilities of optimizing the machining process.*
Key words: *CAD-CAM, manufacturing, optimization, numerical control, CATIA, simulation.*

1. INTRODUCTION

Preparing the piece for processing on a machine-tool with numerical control involves the generation of command information, all data is then stored in a preset order within a storage device. Programs can be generated directly on the machine, the operator writes the necessary instructions using the available interface or by using a CAD-CAM program and a virtual model of the piece [4]. Defining the piece in a CAD environment is used as the entry date to generate the program with one of the complex existing programming languages [2], [5]. Thus, the simulation is justified to optimize the process because CAM programs elaborate the NC machine code. In the case of manual developing and writing, the allocated time is disproportional to the time of processing. The command for machine is provided by the numerical control equipment (NEC), designed for the following types of machine tools: lathes, milling, grinding, hobbing machines. The machine-tools, by their kinematics structure, execute simple movements (rotation, translation) in relation to the numerically controlled axes. The axes of coordinates are assigned to couples of translation or rotation of the machine.

Each processing program for the piece, compatible with the machine, consists of a sequence of sentences written in a logical sequence based on a specific syntax [2], [4]. On the modern CNC equipments the user may program, in addition to coordinates, other geometrical information regarding the compensation of length and tool diameters. Thus, it is possible to make various corrections on the dimensions, clearances and vibrations appeared in the fixture devices of the piece on the machine-tool etc. In general, the corrections are introduced to the ECN machine console by a specific address, and a group of digits for the correction.

Companies in a wide range of industries, including aerospace, automotive, medical equipment, machine-tools and consumer goods, use CATIA design solution for a variety of computer-aided manufacturing tasks, from tool path generation and verification for simple lathe machining, 2.5 axis machining and very complex 5-axis machining, all the way to post-processing functions.

2. INITIAL CONDITIONS

In the current analysis it is used a machine-tool of vertical processing center (MCV) type with 5-axis (3 translations and 2 rotations) numerically controlled. The CAM processes on the machine-tool are simulated in the CATIA v5 [4] working environment, together with the cutting tools, toolholders, necessary fixture devices and process parameters (cutting regimes, tools paths, different ways of dividing the stock left for machining, the quality of processed surface). A simplified representation of the machine, axes and its mobile units are presented in figure 1. As shown in figure 1, the X, Y and Z axes assure movements for feed and/or positioning on the longitudinal, transversal and vertical directions. On the lower end of the vertical sled (*VS*) is a suitable milling head (*MH*) with a main shaft (*MS*). The milling head provides a variable position of the tool axis (*T*), by rotation movements around the Y and Z axes (B-axis), respectively, (C-axis).

The sizes of the used stock are 195×105×45 mm and the material is a high alloyed steel. The piece, represented in figure 2 as a 3D model, has a prismatic form and it is provided with two cavities C1 and C2 connected by a channel with radius of 10 mm. Inside the cavity C2 is a prominence P1. The cavities are defined by complex surfaces whose generating and directing curves may or not be defined analytically. The other processed surfaces of the piece are simple (plane, revolution). Choosing the machine-tool and of the milling head was determined mainly by the shape of the two cavities. Thus, during the processing, the rotation axis of the tool at any point of the machined surface must be perpendicular to the tangent to the surface at that point.

The chosen machine-tool has the following technical characteristics: movement on axes X = 800 mm, Y = 600 mm, Z = 500 mm, B = -110^0 ... 110^0 and C = 360^0, spindle speed max.: 12,000 rpm, the power of the principal electric engine: P = 12 kW, the power of the electric engines for the feed/positioning movements: X and Y: 3 kW, Z: 5.5 kW, machining feedrate max.: 6000 mm/min and rapid feedrate: 30000 mm/min, tool change: number of tools: 30, tool changing time: 2 s, the toolholder cone type: HSK; NC system: Sinumerik 840.

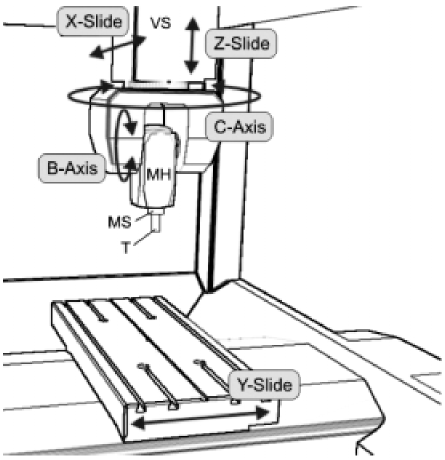


Fig. 1. *Simplified representation of the 5-axis machine tool*

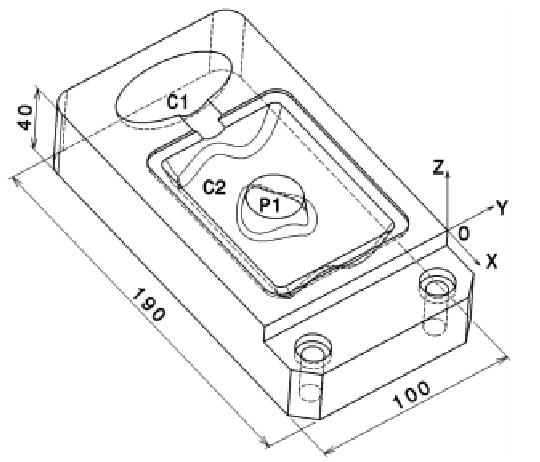


Fig. 2. *Three dimensional representation of the workpiece*

Some of the features listed are inserted into the Numerical Control tab (figure 3) available for selection/definition of the CNC equipment in the CATIA Machining module.

In order to establish the technological system, together with the machine-tool are defined the cutting-tools and necessary fixture devices for the application of the machining processes. As a result, these data are inserted in CATIA into the available options during the simulation phases of each operation for the technological process.

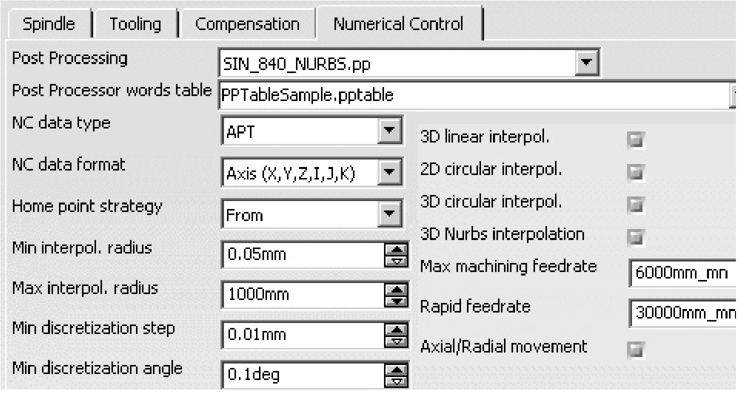


Fig. 3. *Some characteristics of the CNC equipment*

The fixture devices are not defined by default in the program, but only are taken into account by the user when choosing a surface of the piece that will not enter into the feed/positioning movement paths of the tool. The CATIA v5 program allows the user to define the cutting tools, offering many variations (corresponding to the technological process).

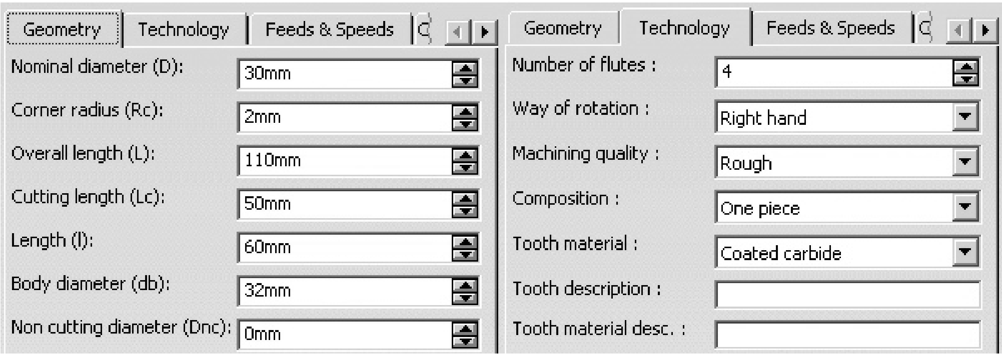


Fig. 4. *Some fields used to establish the cutting tools characteristics*

For the stock's material there are selected the ISO P20 tool steel milling grades. The user can determine the main features for the each tool: the diameter and length of the active part, total length, diameter and shape of the holder, the number of teeth, the tool type for the corresponding surface shape and for the applied technological process, the piece's material etc. Thus, for example, figure 4 shows some of the fields available in the program for introducing these features.

For the current analysis, in the paper are presented some data regarding the characteristics of the cutting tools: diameter of the cutting part, material and form of plates, constructive angles of the tool's edge etc.

3. STAGES OF SIMULATION

Due to the relatively large number of machined surfaces on the piece, there are imposed many technological operations for the stock: face milling, drilling, circular milling (widening), internal and external millings and, also, complex millings for the two cavities C1, C2 and for the connecting channel. Among these, in the paper are presented in a detailed manner only the milling of the cavities. For the other areas, the analysis spreadsheet data are shown with reference to: tools, cutting parameters and the required processing time.

Thus, figure 5 shows the following sequence of processing: face milling 29×100×10 mm in three passes (*a*), face milling 160×100×2 mm in one pass (*b*), drilling Ø10×30 mm (*c*), widening by circular milling Ø16×5 mm (*d*), internal contour milling Ø84×60×2 mm (*e*) and external contour milling 215×125×40 mm (*f*).

In the table 1 are presented some data resulted from the simulation process of the preliminary operations.

For the processing of each of the two cavities, considered as main surfaces, it is used a roughing and a finishing operation. The two operations are performed in the same fixture used in the milling process on the external contour.

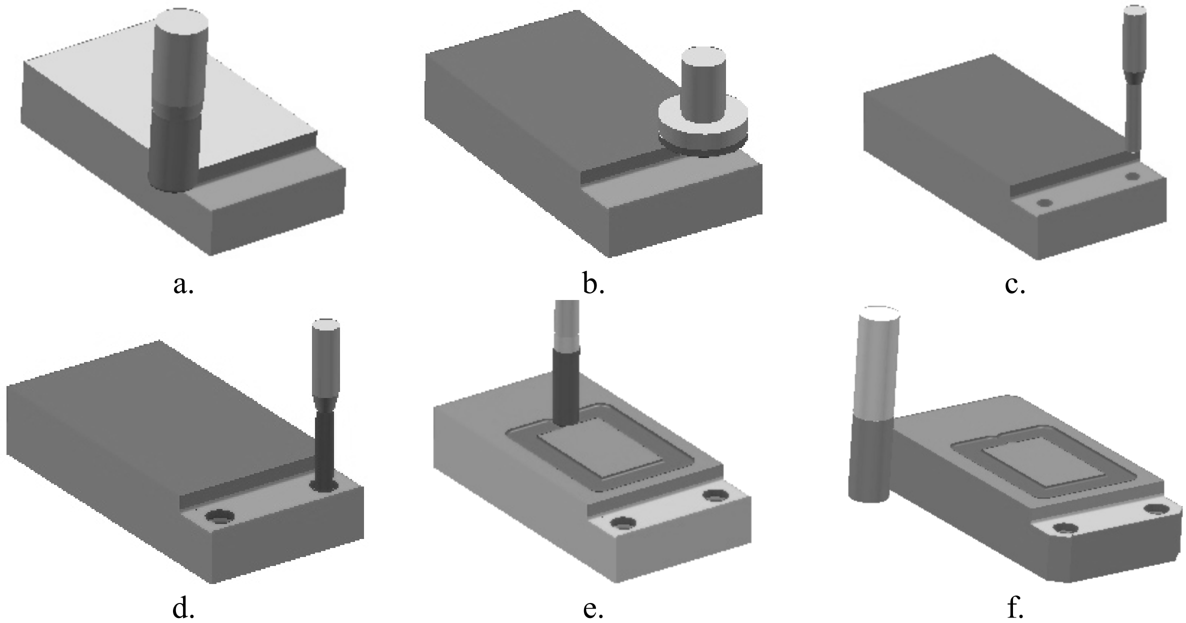


Fig. 5. *Pictures taken during the preliminary processing*

Table 1. *Data of the simulation process*

Op. no.	Operation name	Cutting tool	Process parameters*	Duration	
				t_m	t_t
1	Face milling (fig. 5, *a*)	End mill with 4 teeth, P20, K_r=90^0	h_{ex} = 0.2, v_c = 185, n_c = 1840, v_f = 1000, P_c = 10, M_c = 56, Q = 230, d=3.5	25	28
2	Face milling (fig. 5, *b*)	Milling head with 5 teeth, P20, K_r=90^0	h_{ex} = 0.15, v_c = 230, n_c = 1460, v_f =1050, P_c = 3, M_c = 19, Q = 260, d=2	51	56
3	Drilling (fig. 5, *c*)	Cylindrical shank twist drill, P20	f_n = 0.18, v_c = 60, n_c = 1900, v_f = 340, P_c = 1.3, M_c = 6.7, Q = 27, d=30	22	27
4	Widening by circular milling (fig. 5, *d*)	End mill with 3 teeth, P20, K_r=90^0	h_{ex} = 0.05, v_c = 230, n_c = 7300, v_f = 431, P_c = 0.9, M_c = 1.2, Q = 14, d=5	6	18
5	Internal contour milling (fig. 5, *e*)	End mill with 4 teeth, P20, K_r=90^0	h_{ex} = 0.1, v_c = 215, n_c = 4200, v_f = 1700, P_c = 3.3, M_c = 7.3, Q = 55, d=2	9	12
6	External contour milling (fig. 5, *f*)	End mill with 4 teeth, P20, K_r=90^0	h_{ex} = 0.05, v_c = 235, n_c = 3000, v_f = 1100, P_c = 6.6, M_c = 21, Q = 88	34	39

* h_{ex} (mm) - chip thickness, v_c (m/min) - cutting speed, n_c (rot/min) - spindle speed, v_f (mm/min) - feed speed, P_c (kW) - cutting power for removal of chips, M_c (Nm) - cutting torque, Q (cm^3/min) - metal removal rate, f_n (mm/rot) – feed, d (mm) - cutting depth, t_m (s) – machining time, t_t (s) – total time.

For the optimization by simulation in the CAM environment provided by CATIA there are proposed the following criteria: the tool path (division pattern of the stock left for machining), the surface accuracy (roughness), processing duration and the behavior of the machine-tool in working conditions (power and cutting torque).

The tool path is formed by generating and directing curves resulted from generator movements. Also, there are auxiliary movements: for positioning, for rapid approach and retract, for wear compensation of the tool cutting edge, for changing the tool. CATIA allows the user to set up certain options in relation to these criteria: the tool path is chosen between the variants presented in figure 6, the process parameters were calculated and entered in the fields of the dialog window (figure 7).

It was selected a ball-ended mill with two plates of circular form (Ball nose), the tool diameter is Ø10. The results for the calculated process parameters are: power 1.6 kW and cutting torque 1.7 Nm.

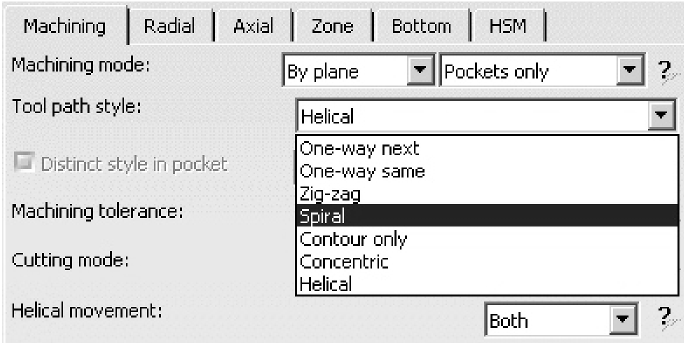


Fig. 6. *Variants for choosing the tool path*

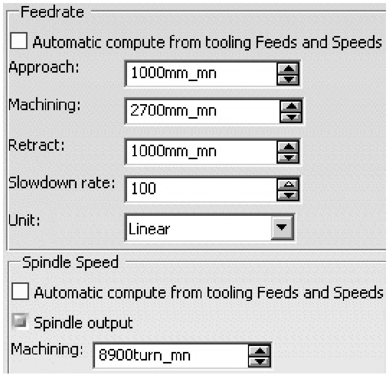
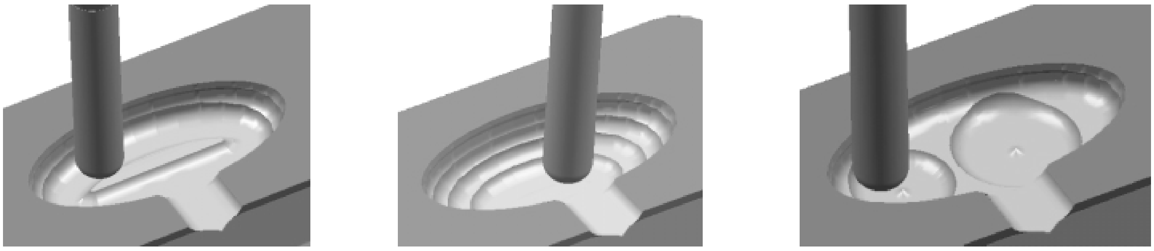


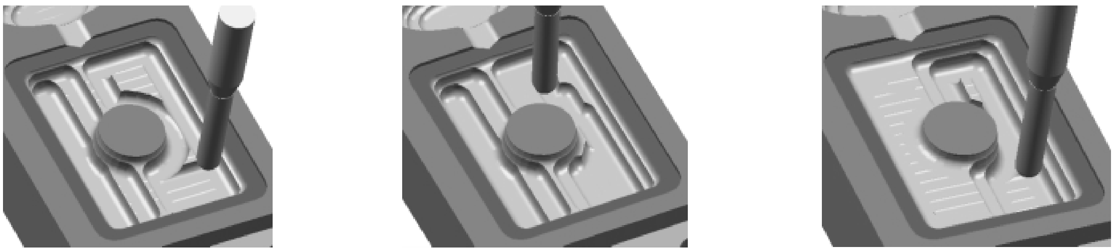
Fig. 7. *Parameters for the roughing operation of the cavity C1*

Figure 8 presents three examples of the tool paths for processing cavity C1: One way next, Spiral, and Concentric, selected from those provided by CATIA. Using the same type of tool and the same regime it is simulated the processing of cavity C2 in all of the tool path variants proposed by the program, the most used three of them being presented in figure 9.



a. One way next b. Spiral c. Concentric

Fig. 8. *Variants for the machining paths in the roughing mill of cavity C1*



a. One way same b. Spiral c. Zig-Zag

Fig. 9. *Variants for the machining paths in the roughing mill of cavity C2*

Applying the simulation for the processing of cavities, different durations of time resulted, depending on the path chosen for the tool. Further, table 2 presents some results for both the roughing milling operations. Based on these results and the analysis of processed surface (figure 8 and figure 9) the user has several options to choose from: the variant with the smallest processing time to get the greater number of pieces during the prescribed sustainability tool.

Table 2. *Results of simulation for the roughing processing with different tool paths*

Cavity C1, tool diameter Ø10			**Cavity C2, tool diameter Ø10**		
Chosen path	Machining time, s	Total time, s	Chosen path	Machining time, s	Total time, s
One way next	26	65	One way next	51	189
One way same	28	67	One way same	59	197
Zig-zag	28	47	Zig-zag	60	81
Spiral	27	38	Spiral	70	82
Concentric	39	93	Concentric	71	266
Helical	28	42	Helical	58	91

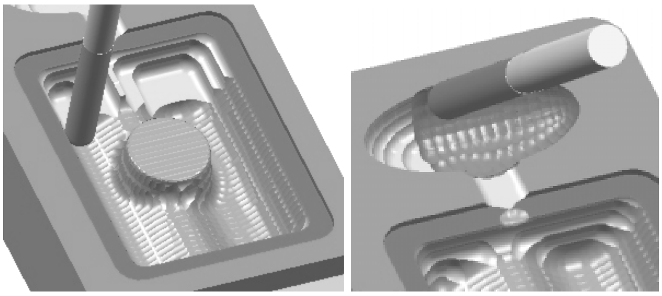


Fig. 10. *Finishing process for both cavities*

Another variant consider the lowest total time, if the processing is applied on a small lot of pieces, which confers an increase in productivity operation. In the third variant, with the greatest durations, the tool is in contact more time with the cutting layer, the result being a lower roughness, but the tool is subject of an intense wear process.

Of course, choosing another tool and/or another process will result in other machining and total times. For each of the two cavity surfaces C1 and C2 is performed a finishing process with an imposed roughness of 0.15 mm. In this purpose, for the simulation there are consecutively chosen two mill type tools with two plates of circular form [6], of Ø8 and Ø10 diameter. Figure 10 show two images taken during the processing of cavities. It can be observed the tools' path, how they made the finishing operation, but also the tool tilting required to finish the cavity C1. During processing the tool's axis position and orientation are variable, condition satisfied by choosing a 5-axis CNC machine. Therefore, the uniformity of roughness is assured. Process parameters: v_c = 157 m/min, v_f = 450 mm/min, P_c = 1.7 kW.

Comparative time results of the simulation for the finishing process of both cavities and the two tools are presented in table 3.

Table 3. *Results of the simulation for finishing with various tool paths and diameters*

Cavity C1, tool diameter Ø8			**Cavity C1, tool diameter Ø10**		
Chosen path	Machining time, s	Total time, s	Chosen path	Machining time, s	Total time, s
Zig-zag	79	140	Zig-zag	59	100
One way	81	144	One way	60	105
Cavity C2, tool diameter Ø8			**Cavity C2, tool diameter Ø10**		
Chosen path	Machining time, s	Total time, s	Chosen path	Machining time, s	Total time, s
Zig-zag	508	628	Zig-zag	512	634
One way next	508	550	One way next	512	555
One way same	508	562	One way same	512	567

5. CONCLUSION

After the simulation of the machining operations applied to the analyzed piece, the program can automate the generation of NC programs. The obtained numerical values are relevant, justifying the criteria choice. Five-axis milling assisted by the CATIA v5 program provides advanced methods for effective and optimized machining and surface finish.

6. REFERENCES

1. Brăgaru, A., Picoş, C., Ivan, N., (1996), Optimizarea proceselor şi echipamentelor tehnologice. Editura Didactică şi Pedagogică, Bucureşti, ISBN 973-30-4447-4.
2. Catrina, D., Drăghici, M., Zapciu, M., Enciu, G., (1999), Programarea maşinilor-unelte cu comandă numerică. Editura BREN, Bucureşti, ISBN 973-9493-08-4
3. Ghionea, A, Predincea, N., Zapciu, M., Constantin, G., Tănase, I. Sandu, C., Hreanu, O., (2006), Maşini-unelte. Lucrări practice. Editura AGIR, Bucureşti, ISBN 978-973-720-107-2.
4. Ghionea, I., (2009), CATIA v5. Aplicații în inginerie mecanică. Editura BREN, Bucureşti, ISBN 978-973-648-843-6.
5. Kief, B. H., (2001), NC/CNC Handbuch. Carl Hanser Verlag Wien, ISBN 3-446-21756-8.
6. ***, (2008), Cutting tools from Sandvik Coromant. Main catalogue. Turning. Milling. Drilling. Boring. Toolholding, C-2900: 6 ENG/01. Printed in Sweden, www.coromant.sandvik.com.
7. ***, CATIA V5R15., (2005) - *Documentație de firmă*. Dassault Systemes.