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IMPACT OF SELECTING THE CUTTING TECHNOLOGY ON PRODUCTION TIME AND COST

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Abstract

This paper analyzes the technology of cutting processing for supports the mold clamping jaws made of 1C60 material. The number of clamping moves, required to produce the workpiece, is defined, as well as the adoption of necessary cutting tools with appropriate cutting modes on the basis of used material and CNC machine. A detailed analysis is provided for the circumferential milling of pockets with diameters of Ø250 mm and height of 30 mm, Ø200 mm and height of 30 mm, and Ø100 mm and height of 40 mm. This is due to the material volume processed per unit of time, which significantly affects the production time of a workpiece. The impact of selecting the offered circumferential milling operations in the HSMWorks software package on production time and tool life is analyzed, using the 2D Pocket and 2D Adaptive Clearing software options. A comparative analysis of the workpiece production time and cost is provided.

Keywords: *circumferential milling, cutting modes, processing technology, production time, CAM programming*

1 INTRODUCTION

Milling is a cutting process involving a chip removal. The tools used in milling operations are called the milling cutters, and machines for processing are called the milling machines. The main rotational motion is performed by the tool, while the auxiliary linear motion is performed by the workpiece [1]. In a circumferential milling, the used milling cutter has the cutting edges arranged around its circumference, with at least two cutting edges. Face milling is used for processing larger surfaces, and in this process, the cutting edges are located on the tool face. The cutting modes in the milling process are determined by the cutting speed. The main processing time is calculated using equation (1) [1]:

$$t_g = i \cdot \frac{L}{n \cdot S} [min]. \qquad (1)$$

The cutting speed in the milling process represents the circumferential speed of the milling cutter (2):

$$V = \frac{D \cdot \pi \cdot n}{1000} \approx \frac{D \cdot n}{320} [m/min] \qquad (2)$$

The removal rate is calculated by equation (3):

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$$q = a \cdot b \cdot V_s [mm^3/min] \quad (3)$$

The support of the mold clamping washers is made of the material 1.0601.

The mechanical properties of material and its chemical composition are presented in Tables 1 and 2 [2].

Table 1 *Mechanical properties of material 1.0601[2]*

Designation	Tearing strength (Rm) $[N/mm^2]$	Yield strength (Re) $[N/mm^2]$	Elasticity modulus (E) $[N/mm^2]$	Toughness $[MN/m^{3/2}]$	Hardness (HRc)
1C60/1.0601	$1250 \div 1450$	460	$(2{,}1 \ldots 2{,}2) \cdot 10^5$	5.5 ± 0.4	20.3

Table 2 *Chemical composition [2]*

Chemical composition (expressed as %)								
Designation	C	Mn	P	S	Si	Cr	Mo	Ni
1C60/1.0601	0.57÷0.65	0.60÷0.90	≤0.045	≤0.045	≤0.4	≤0.4	≤0.1	≤0.4

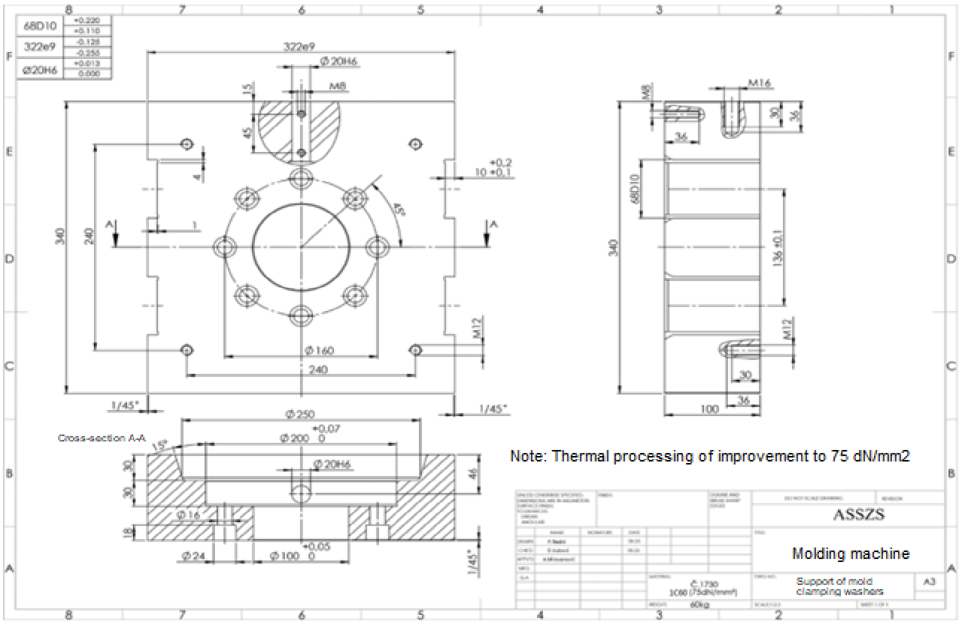
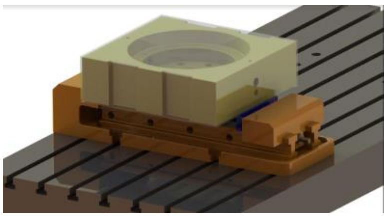
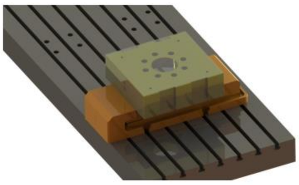
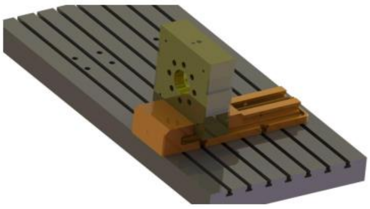
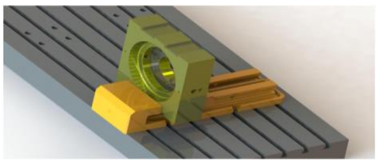
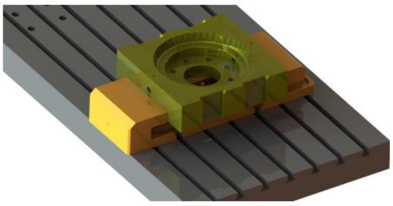


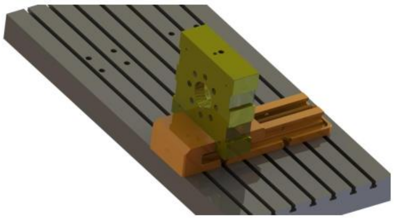
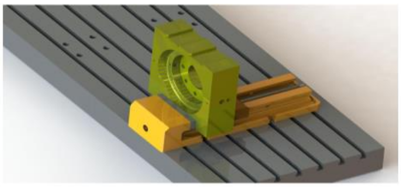
Figure 1 *Support of mold clamping washers [3]*

2 CLAMPING AND TOOL SELECTION

By analyzing the supports of clamping washers, a minimum of 11 clamping moves necessary for the proper production of a clamping washer has been defined. Table 3 provides an overview of clamping, along with description of operations involved in each clamping move [3].

Table 3 *Presentation of clamping and description of operations involved [3]*

	Clamping move no. 1 Face milling, circumferential milling, the operation of interior contour milling of Ø250 mm diameter, the production of a conical part at an angle of 15^{o} by the internal circumferential milling operation, contour milling of the radius R5 mm, interior contour milling of Ø200 mm diameter with an additional 0.3 mm for further processing, interior contour milling of Ø100 mm diameter with an additional 0.3 mm for further processing, drilling 12 holes, drilling 4 threaded holes using a Ø6.4 mm drill, M8 thread cutting, and drilling 8 holes using a Ø16 mm drill.
	Clamping move no. 2 Face milling, interior contour milling of a pocket with diameter of Ø24 mm and height of 18 mm, drilling 4 holes, drilling 4 threaded holes using a Ø9.6 mm drill, and M12 thread cutting.
	Clamping move nos. 3 and 4 As the workpiece is symmetrical, only one clamping move is shown. The operation includes tapping the Ø20H6 pocket and M16 threaded hole, drilling the Ø20H6 pocket using a Ø16 mm drill, widening the Ø20H6 pocket with an additional 0.3 mm left for fine processing, drilling the Ø12.8 mm threaded hole using a Ø12.8 mm drill, and M16 thread cutting.
	Clamping move nos. 5 and 6 As the workpiece is symmetrical, only one clamping move is shown. Circumferential milling of the 68D10 slot with an additional 0.3 mm for further processing, and production a relief channel using a Ø3 mm milling cutter.
	Clamping move no. 7 Additional processing after thermal treatment. Additional processing of the Ø200 mm diameter to the required dimension using interior contour milling, additional processing of Ø100 mm diameter to the required dimension using interior contour milling.

	Clamping move nos. 8 and 9 Additional processing after thermal treatment. As the workpiece is symmetrical, only one clamping move is shown. Additional processing of the Ø20H6 pocket to the required dimension.
	Clamping move nos. 10 and 11 Additional processing after thermal treatment. As the workpiece is symmetrical, only one clamping move is shown. Contour milling of the 68D10 slot to the required dimension.

By analyzing the supports of clamping washers, the minimum number of necessary cutting tools was defined. A detailed description of the cutting tools, along with the cutting modes determined on the basis of recommendations of the tool manufacturer, material from which the support of clamping washers is made (1C60/1.0601), and the CNC machining center used, is shown in Table 4. To produce this workpiece, the "HAAS VF5/50" CNC milling machine (three operational axes: x, y, and z) was used [4].

Table 4 *Description of cutting tools and cutting modes [5]*

No.	Tool name	Manufacturer	Tool and plate ID	Diameter [mm]	Number of cutting plates/teeth [z]	Length of cutting edge [mm]	Cutting speed Vc [o/min]	Feed per tooth a_z [mm]
1	Milling head	Garant	213300 125/8 213340	Ø125	8	-	200	0.45
2	Spindle-shaped milling cutter	Garant	203024 20	Ø20	4	102	70	0.17
3	15° conical milling cutter	HAAS	01-0132 02-0487	Ø30.6	3	9.5	150	0.3
4	Radius milling cutter	Garant	207154 5	Ø5	2	9	33	0.02
5	Spindle-shaped milling cutter	Garant	202392 20	Ø20	3	40	190	0.19
6	Tap	Holex	111005 3.15	Ø3.15	2	16	25	-
7	Drill	Holex	122777 6.5	Ø6.5	2	53	95	-
8	Hole punch	Garant	132640 M8	M8	3	35	15	-
9	Drill	Holex	114360 16	Ø16	2	120	31	-
10	Drill	Holex	114360 9.6	Ø9.6	2	87	31	-
11	Hole punch	Holex	132645 M12	M12	3	24	7	-
12	Drill	Garant	114400 12,8	Ø12.8	2	80	25	-
13	Hole punch	Garant	132150 M16	M16	3	32	15	-
14	Spindle-shaped milling cutter	Holex	202760 3	Ø3	4	12	70	0.01
15	Spindle-shaped milling cutter	Garant	203372 20	Ø20	10	75	115	0.04
16	Spindle-shaped milling cutter	Garant	203024 12	Ø12	4	76	70	0.06

The tools used to produce the support of clamping washers are shown in Table 5, which lists the tools necessary for production the supports of clamping washers [5].

Table 5 *Tools for production the supports of clamping washers [5]*

 Milling head	 Spindle-shaped milling cutter	 Conical milling cutter
 Radius milling cutter	 Tap	 Milling cutter made of hard metal with TiAlN coating
 Hole punch	 Spindle-shaped milling cutter with TiAlN coating	 Drill with TiN coating

3 DESCRIPTION AND PRODUCTION TIME COMPARISON

The analysis of the processing operations available in the HSMWorks software package shows that there are two possible options for processing pockets: 2D Pocket and 2D Adaptive Clearing. The machining-times of these two software package options will be compared.

- Producing a pocket with diameter of Ø250 mm and height of 30 mm using the 2D Adaptive Clearing option.

The tool path for this option is shown in Figure 2.

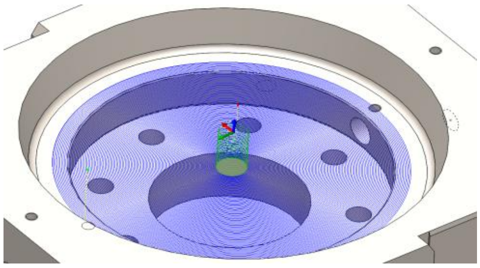


Figure 2 *Tool path for the 2D Adaptive Clearing option*

In this operation, the tool steps down to the predefined height and radially removes material with the entire length of cutting edge, with a material load of 1 mm. The volume of material removed in this operation is V = 1471.8 cm³. The time needed to process this pocket is 25 minutes and 5 seconds.

- Producing a pocket with diameter of Ø250 mm and height of 30 mm using the 2D Pocket option.

The tool path for this option is shown in Figure 3.

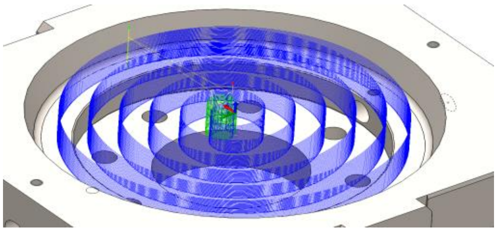


Figure 3 *Tool path in 2D Pocket option*

When using this option, 80% of the tool diameter is engaged. Milling is performed frontally and radially up to the predefined diameter, with a cut depth of 1 mm. The passes are repeated until the tool reaches the predefined height. The volume of material removed in this operation is V = 1471.8 cm^3. The time needed to process this pocket is 48 minutes and 26 seconds.

- Producing a pocket with diameter of Ø200 mm and height of 30 mm using the 2D Adaptive Clearing option.

The tool path for this option is shown in Figure 4.

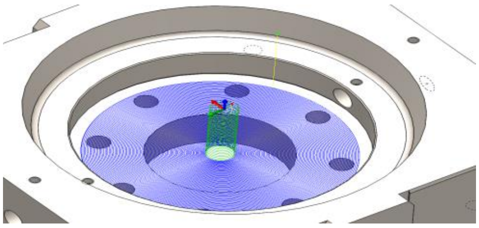


Figure 4 *Tool path in the 2D Adaptive Clearing option*

When using this option, the tool steps down to the predefined height, radially removing material with the entire length of cutting edge, with a material load of 1 mm. The volume of material removed in this operation is V = 942 cm^3. The time needed to process this pocket is 18 minutes and 16 seconds.

- Producing a pocket with diameter of Ø200 mm and height of 30 mm using the 2D Pocket option.

The tool path for this option is shown in Figure 5.

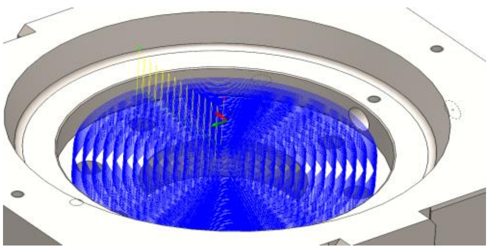


Figure 5 *Tool path in the 2D Pocket option*

When using this option, 80% of the tool diameter is engaged. Milling is performed frontally and radially up to the predefined diameter, with a cut depth of 1 mm. The passes are repeated until the tool reaches the predefined height. The volume of material removed in this operation is V = 942 cm^3. The time needed to process this pocket is 70 minutes and 55 seconds.

- Producing a pocket with diameter of Ø100 mm and height of 40 mm using the 2D Adaptive Clearing option.

The tool path for this option is shown in Figure 6.

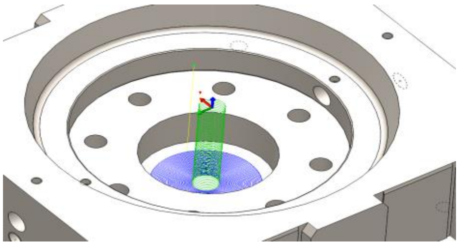


Figure 6 *Tool path with the 2D Adaptive Clearing option*

When using this option, the tool steps down to the predefined height, radially removing material with the entire length of cutting edge, with a material load of 1 mm. The volume of material removed in this operation is V = 314 cm^3. The time needed to process this pocket is 5 minutes and 25 seconds.

- Producing a pocket with diameter of Ø100 mm and height of 40 mm using the 2D Pocket option.

The tool path for this option is shown in Figure 7.

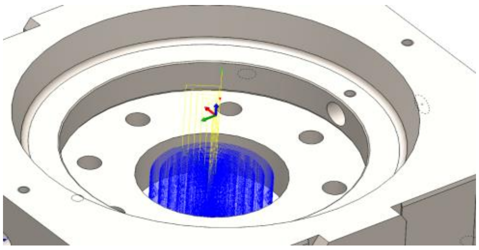


Figure 7 *Tool path in the 2D Pocket option*

When using this option, 80% of the tool diameter is engaged. Milling is performed frontally and radially up to the predefined diameter, with a cut depth of 1 mm. The passes are repeated until the tool reaches the predefined height. The volume of material removed in this operation is V = 314 cm^3. The time needed to process this pocket is 21 minutes and 55 seconds.

If the time needed to produce the analyzed pockets (Ø250x30 mm, Ø200x30 mm, and Ø100x40 mm) using the aforementioned software package options is compared, it can be seen that the total time needed to produce the analyzed pockets using the 2D Adaptive Clearing option is 48 minutes and 46 seconds, i.e., 0.813 hours. When using the 2D Pocket option, the time needed for production is 141 minutes and 16 seconds, i.e., 2.35 hours.

The production cost using the 2D Adaptive Clearing option is EUR 48.78, while using the 2D Pocket option, the production cost is EUR 73.2. The considered hourly rate for the CNC machine is EUR 30.

Table 6 provides an overview of comparison between the production times of each aforementioned option in the HSMWorks software package.

Table 6 *Production time for Ø250x30 mm, Ø200x30 mm, and Ø100x40 mm pockets using the 2D Adaptive Clearing and 2D Pocket options*

Analyzed pocket	2D Adaptive Clearing option	2D Pocket option
Ø250x30 mm	25 min 5 s	48 min 26 s
Ø200x30 mm	18 min 16 s	70 min 55 s
Ø100x40 mm	5 min 25 s	21 min 55 s
Total time [min and s]	48 min 46 s	141 min 16 s
Total time [h]	0.813 h	2.35 h

4 CONCLUSION

While analyzing the technical drawing of the workpiece to be processed, defining the number of clamping moves, and selecting the processing operations, the comparison between the production time during the first clamping move and time needed for processing the Ø250x30 mm, Ø200x30 mm, and Ø100x40 mm pockets using the 2D Adaptive Clearing and 2D Pocket operations of the HSMWorks software package was performed due to the significant volume of material to be removed. The time needed to produce the analyzed pockets (Ø250x30 mm, Ø200x30 mm, and Ø100x40 mm) differs significantly. The time needed to produce the three analyzed pockets using the 2D Adaptive Clearing option is 48 minutes and 46 seconds, i.e., 0.813 hours, whereas their production time using the 2D Pocket option is 141 minutes and 16 seconds, i.e., 2.35 hours. The difference in production time when using the 2D Adaptive Clearing and 2D Pocket options is 1.537 hours, i.e., EUR 46.11.

Using an inadequate programming method for production the machine parts has increased the production cost. The analyzed machine part is produced in batches of 10 or 20 pieces due to the needs of production process and the production plant. Considering the defined batches, the differences in production time and cost for a batch of 10 pieces are 15.37 hours, i.e., EUR 461.1, whereas for a batch of 20 pieces, they are 30.74 hours, i.e., EUR 922.2.

Simultaneous time analysis in the process shows that the CAM programming of machine parts can proactively has the impact on production time and cost of machine parts, as well as the tool life.

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