Selection strategy for milling parts on CNC MACHINES

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How to cite: A. Zalewski, S. Sobieski. Selection strategy for milling parts on CNC MACHINES.
Advanced Technologies in Mechanics, Vol 2, No 2(3) 2015, p. 9–23.
DOI: 10.17814/atim.2015.2(3).18

Abstract

Practical knowledge and experience of engineers, CNC programmers, operators related to the implementation of production tasks in the workshop are essential. Every day, developed, perfected for companies specialty, "technological knowledge base ", is a specific, dedicated to the particular conditions of the key to success – the "know -how "in the concrete conditions of production. This knowledge can be relatively easily processed and developed, in particular with regard to the development of technology in the CAM. Additionally subjected to simulation analysis allows comparison of different strategies and variations of part in the design of technology. Several years of authors experience in the analysis of the work 's CAM systems in many companies has enabled the formulation of universal principles of numerical simulations that take into account the individual characteristics of the workpiece and the specificity of the selected CNC machine with accessories. Conducted research on the production based on Catia V5 program and Mastercam X6 confirmed the validity of this approach and helped to correcting some of the assumptions developed algorithm.

KEYWORDS: **CAM**, **CNC**, **simulation**, **strategy**

Introduction

For over 30 years are developed CAM systems. Since then, various methods of tool path design are regularly verified in hundreds of manufacturing plants. In the quest for efficient production of offered tool path strategies relative to the workpiece, which provide a stable load on the tool, efficient machining, satisfactory period of tools work before the tool change and the quality of the surface finish. Draws attention to the large number of available solutions on the same technological task. When designing a technological process, technologist has many possible uses of tools of different diameter, length (reach), indexable or monolithic, different numbers of cutting edges, with different price, method of operation, cooling, and finally, with different cutting parameters. Which tool to choose? What strategy of the tool will be the best?

What are the cutting parameters for the selected strategy will be optimal? The article describes the drop-down simulation method for comparing multiple machining of the same parts. This approach can be classified as numerical methods. By limiting the analysis to the specific case, the discussion comes down to a finite number of solutions to the discrete nature. The results of calculations of partial depend on:

- types of tools (milling cutters in this case);
- cutting parameters;
- assumed operating conditions (cooling type, method of removal of chips, fixing
- of the workpiece, tool holder, machine kinematics and dynamics, the type and parameters of movement such as auxiliary input tool material);
- algorithms CAM software used to develop the tool pass on the basis of the cutting parameters definition.

Type tool is related to the shape and dimensions of the part, the requirements as to the accuracy and surface quality. Tool selection restricts the ability of the machine, fixing and price. The scope of the analysis described below can be limited only to existing tools, or check whether the purchase of the new will be a good project.

Cutting parameters are a very important element of the analysis. They depend on many factors. Designated in theory is verified experimentally. In particular, the radial depth of cut a_e, axial depth of cut a_p and feed speed V_f, will affect the result of the analysis.

Conditions of the tool work significantly narrow the field of application of cutting parameters. In this case they are described parametrically, i.e. based on previously machining operations performed on different machines, introducing a limitation in the possibility of their effective use. They are expressed either numerically or factors such as n_{max}, P_{max}, M_{max}, F_{max}, the area of machining, type of cooling, vibration damping ability and stiffness. This allows for conducting simulations in relation to specific conditions and chooses the best solution for a given machine.

Most modern, professional CAM software offers machining strategies appropriate to perform practically every part. Depending upon the path calculation algorithms in different CAM programs, form the tool movement path can be different. The differences may relate to its efficiency, the machining time or the tool life. In this case it isn’t comes to choosing a better CAM program, but a comparison of the strategies under a particular set of solutions. In carrying out the analysis on the basis of one, the same CAM program, the simulation allows the use of the best available approach in this case.

The study used a parametric record machining technology to create a “predefined” CAM technology (called templates). Once developed and proven technology can thus be “imposed” on another model of the workpiece. This provision also allows for the automatic design of many cases of tool paths (processing strategy) and various cutting parameters (variants within the same strategy) machining the same parts.

The same shape of the workpiece can be achieved employing different strategies movement of the tool. This usually results in a different shape of the trajectory of the tool and a different path travelled by the tool during machining.

In turn, for the same machining strategy, tool path has a similar shape. In the simulations, the following variants of machining (in a single strategy) examines the use of tools of the same type but with different diameters D_f, matched in each case the parameters such as radial depth of cut a_e and axial depth of cut a_p [9]. As a result of the removal of the same volume of material in each case requires a different tool paths and the use of other feed speed Vf.

It is difficult to realize in practice constant crosscutting layer at any time, especially when machining complex shape parts. To achieve a constant volumetric efficiency machining can be used to adjust the feed rate V_f [lit.]. Changing the feed rate can also apply to those phases of the tool work, which significantly changed the direction of motion (for example corners, small arcs). This is in turn related to the requirements of the machines servo geometrical precision and its dynamic capabilities.

The total tool path includes a number of phases of the tool work, which has not reached it assumed the cutting parameters (eg commuting, departures, short crossing the border material). The road and the speed of movement of the tool are adapted to local machining needs.

Given so many opportunities to change the path (trajectory) of the tool and feed rate, it is difficult to analytically determine the actual processing time. Comprehensive analysis enables the simulation of machining CAM system even at the design stage of the process.

Note the very broad range of factors, which may be taken into account (for example in the form of modified coefficients of simple experimental). Often assessment of the proposed machining operation is based on idealized cutting conditions, reduced to simplified models. In this case, it is possible to simulate different cases complicated processing (geometrically and technologically) part, in relation to the specific conditions in the workshop. Use predefined CAM technology dramatically accelerates the design processing, uses collected to date experience and knowledge of the company's employees on the use of specific equipment and instrumentation. During the analysis of the various processes it is easy to select another CNC machine and for her to receive the full results will be even more different from the previous ones, the greater are the differences in capabilities of machines. Each time, however, it should be the best solution for each case.

Similarly, designing similar geometrically and technology machining parts process, you can get a completely different solution, as for example, change the number of tool pathes for removing a given volume of material associated with the current parameters a_e and a_p. An optimal solution may therefore be to apply a completely different tools and machining strategies. Complete this analysis without the effective use of modern CAM programs, assisted techniques, knowledge bases, it does not seem easy to obtain (if at all possible).

The general weakness of the simulation process is its potential incompatibility with the actual implementation. The proposed solution is based on the use of verified decades CAM programs, working on the parameters tested in the workshop, supplemented by knowledge of CNC machines and experience specific team of technologists. Automatic comparison of dozens of alternative processes quickly determines the area potentially the best solution, because of the different evaluation criteria (time, cost, number of tools used, the type of machine).

1. Analysis of different strategies and implementation variants of machining operation

The aim of the study was to reduce the portion of the process of machining parts produced in series by at least 20%. Search for alternative solutions to a particular case. The use of the concept of automatic comparison of pre-defined technology has led to the creation of a prototype analytical tool in Catia v5 environment and parallel Mastercam X6, whose principle of operation is shown in figure 1

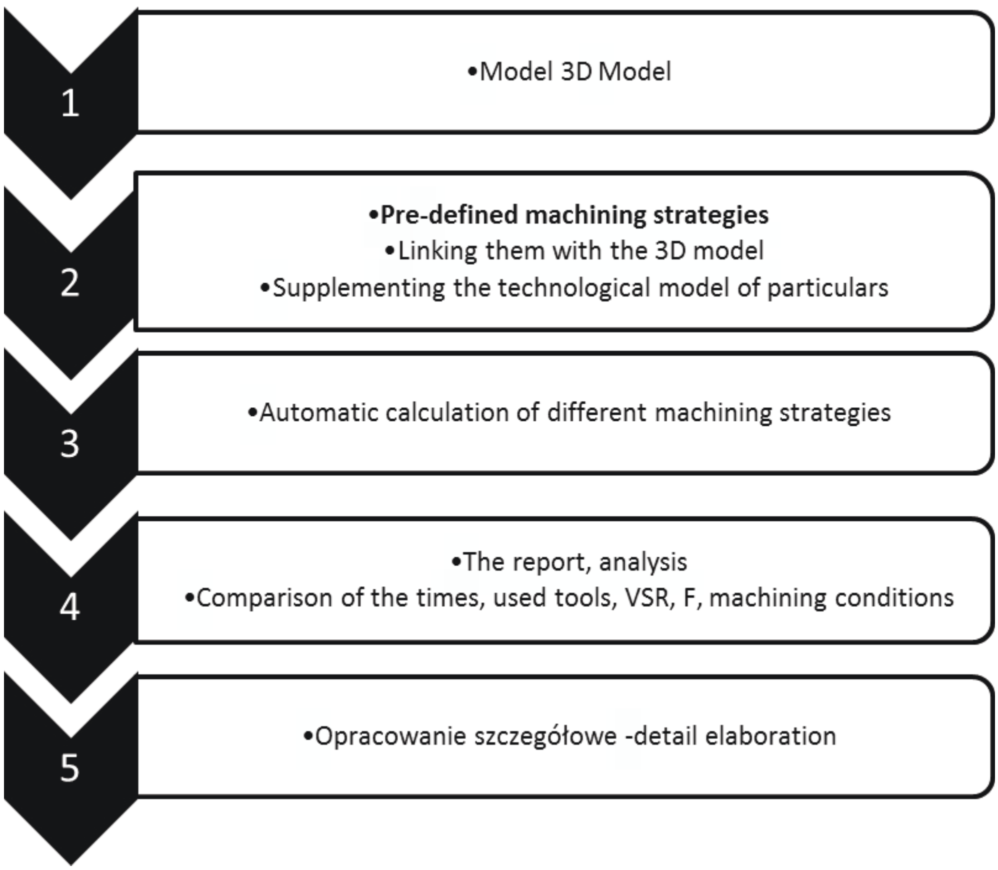


Fig.1. The work algorithm based on predefined machining strategies, which are directed to machining performance

Upon receipt of a new order, and the analysis of the 3D model (step 1), followed by search technologically similar case in earlier studies of CAM. Step 2 consists in linking the existing predefined strategy (and variants) with the new model, and adapts them to your own specific requirements of the order and the technical capabilities of the workshop. In step 3, the automatic conversion of different machining strategies first, and then the various options within the selected strategy. Reports in the form of graphs in step 4 allow the selection of solutions to develop a detailed (create a list of requirements, workshop documentation, programs, NC) in step 5.

In the article [1] devoted to the analysis focuses on the analysis of different machining options into a single strategy (comparison of different a_p, a_e, V_f, V_c, to work with the same tool). Efforts to get a similar power P [kW] and the average volumetric efficiency cutting Q_v [cm^3/min]. Other cutting parameters were selected in accordance with the tools manufacturer.

Table 1. Example of selection cutting data for milling of flat cylindrical cutter D16 (16 mm diameter [11,12]) for the individual variants

variant	a_e [mm]	a_p [mm]	n [rpm]	v_f [mm/min]	f_z [mm/z]	P [kW]	Q_v [cm^3/min]	v_c [m/min]	L [m]
1	3	5	4516	3775	0,209	3.1	57	227	131
2	5	5	2964	2431	0,205	3.2	61	149	164
3	8	5	2653	1349	0.127	3	54	133	119
4	8	5,3	2646	1323	0,125	3,2	56	132	85
5	12	5	2924	936	0.08	3.4	56	147	106
6	16	5	2646	624	0,059	3.3	50	133	82
7	16	3	2666	1248	0,117	3,4	60	134	141
8	12	3	3104	1601	0,129	3,2	58	156	147
9	8	3	3601	2535	0,176	3,2	61	181	155
10	5	3	4675	3404	0,182	2,8	51	235	116
11	3	7	4138	2516	0,152	3,1	53	208	111
12	5	7	3283	1536	0,117	3,2	54	165	116
13	8	7	2924	948	0,081	3,3	53	147	102
14	12	7	2606	615	0,059	3,3	52	131	93
15	16	7	1771	425	0,06	3,1	48	89	67
16	16	10	1671	287	0,043	3,2	46	84	54
17	12	10	2069	414	0,05	3,3	50	104	55
18	8	10	2129	605	0,071	3,1	48	107	68
19	5	10	2447	1038	0,106	3,2	52	123	77
20	3	10	3143	1785	0,142	3,2	54	158	86
21	8	13	2109	456	0,054	3,2	47	106	52
22	5	13	2208	777	0,088	3,2	51	111	76
23	3	13	2745	1373	0,125	3,3	54	138	78

Each of the analyzed cases was technically correct, and the differences at the time the procedure mainly due to the varying length of the path of movement of the tool. The shape of the tool path was close every time (this was due to the same strategy), but the length of the tool path (road) differ because of the different parameters a_p, a_e, and this resulted in a variable number of passes of the tool relative to the shape and dimensions of the workpiece. Founded feed rate V_f, was subjected to a small, local changes due to the movement phase tool (arrive, depart), but without the requirement to maintain a constant volume of cut.

There were considerable variation analysis results (fig. 2).

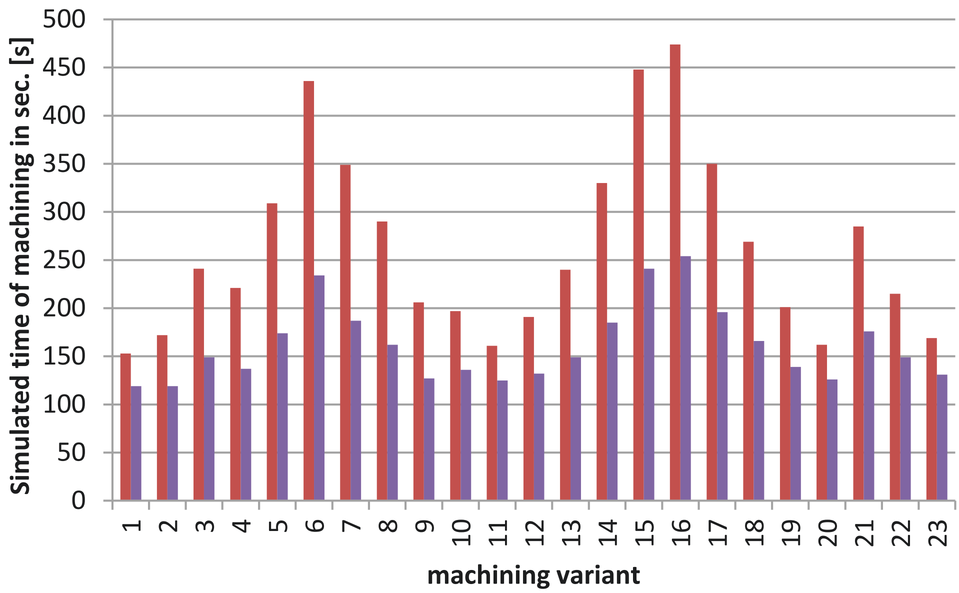


Fig. 2. Comparison of the total time and the time of cutting machining of different variants of the same strategy ("Outward helical") in the order of the options presented in Table 1 [1] (red – total time, blue – machining time).

Sequence variants from No. 1 to No. 23 are in line with developed cutting data table (Table 1, [1]). This order is somewhat random, as is apparent from the accepted order of conducted experiments. On the basis of figure 2 it can be concluded that minimal processing time, and thus cutting data, which would use, will characterize the variations. This analysis allows the comparison of different variants of the same milling parts. It should increase the radial or axial depth of cut? Machined with a large cross-section cut layer and apply a small a_p, ae, but a greater feed rate V_f? It also allows you to bypass these ranges cutting data, which clearly extend the machining time due to the mismatch between the shapes of the part, which results in significant prolongation of the tool path.

Different tool path strategies usually have other shapes trajectory of the tool. This is due to the shape of the workpiece, the type of tool, machining type (e.g., roughing or finishing) and manufacturing concept.

Examples of different traffic strategies tools for rough milling open pocket shown in the following examples (fig. 3):

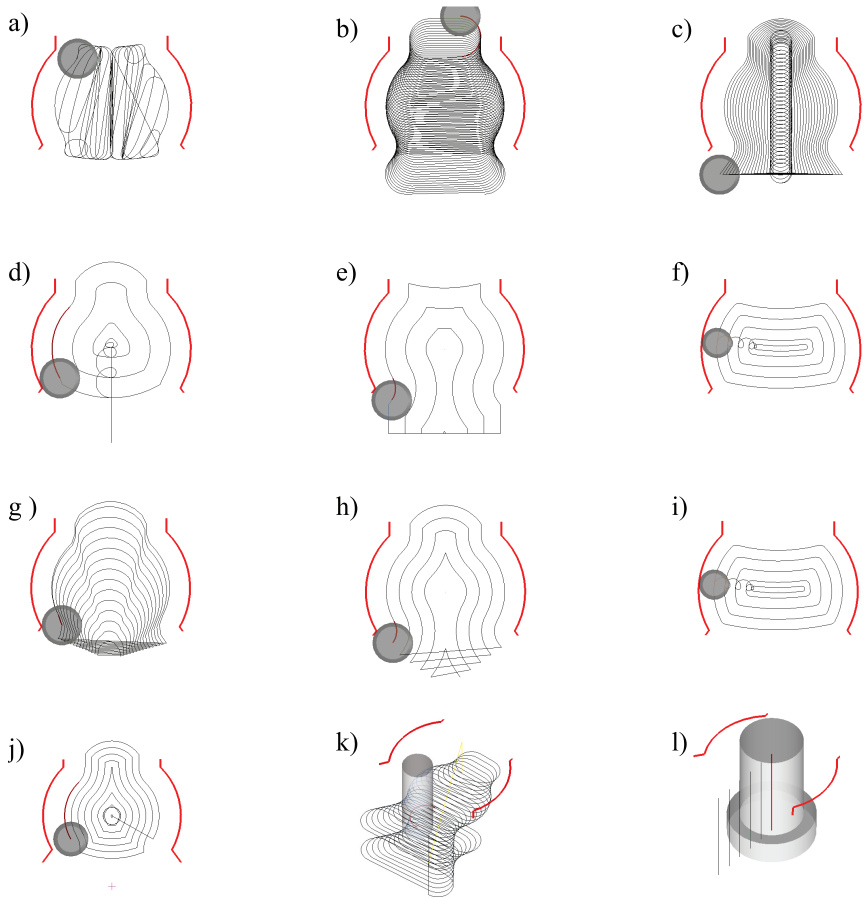


Fig. 3. Examples of various strategies open pocket milling (a-Trochoidal deep, c-Trochoidal + blend, d-pocket HSM, e- open pocket, pocket f-2, G-blend1, h-contour, and dynamic-2, j - pocket 2, k-Trochoidal shallow, l-Plunge)

Comparison of machining strategies and options for the same part should be based on specific criteria such as:

- processing time;
- cost of machining (cost of tools, power consumption, cost engineering, cost of inputs, etc.);
- quality of the machined surface (e.g., changes in the workpiece as a result of the cutting process, the size and shape machining allowance left);
- characteristics of the cutting process(chip form, the method of the chip evacuation, a cooling method, the impact of tool wear or damage tool, process stability, resistance to interference, the impact OUPN rigidity and vibration , etc.);
- cost of investment in means of production (purchase of new tools, tooling, equipment, CNC machine tools, etc.).

Match the optimal strategy - and within it - the best implementation variant machining procedure-selected parts based on all of these criteria is not easy [1]. The more that in some cases may lack sufficient data to effectively analyse these criteria. Therefore proposed that the following steps to follow:

1) Estimation of the necessary values at a level sufficient to conduct the theoretical analysis,
2) Examine using simulation methods (CAM) of all selected cases.
3) Preparation of reports comparing different solutions and potentially the best choice due to the adopted criteria.

2. Research conducted

In order to reduce the input data selection area for machining simulation, the following assumptions proposed:

- Initial value of the theoretical power P [kW] and the volumetric capacity of cut Q [cm^3/min] were determined on the basis of previously implemented technology. Subsequent trials cutting machining operations were corrected, depending on the running machining.
- Suitable for cutting parameters resulted from technical limitations of the industrial partner of the project and had to be possible to use in specific production conditions (the project was implemented in cooperation with a large manufacturing factory).
- Minimum cost of investment in the means of production (e.g. the cost of new tools, the cost of installing additional cooling air).
- Design strategies and machining options in such a way that the cutting process is at least satisfactory because of the estimated tool life.
- Analyses were performed only for roughing and surface roughness after machining was not particularly important.
- Basic criterion for the comparison was the duration of the machining, and criteria supporting the cost of tools and tool life (calculated theoretically as parameters correlated with the working conditions and the way the tool during cutting. Auxiliary criteria are described in [1]).

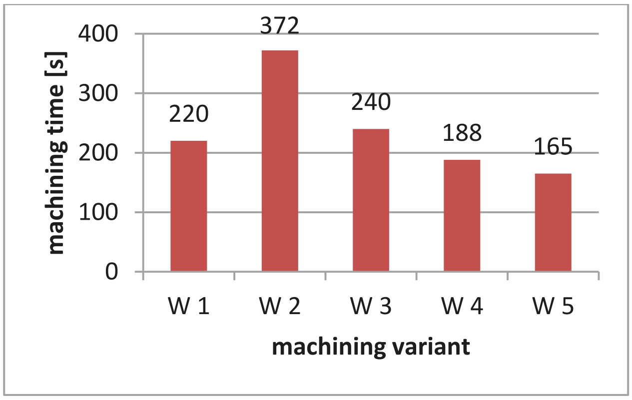
We analysed the treatment of open pocket measuring about 40x60x45 mm (simplified outline of the pocket is shown in figure 3) performed serially in steel with properties similar to stainless steel SAE-9310-HB330 (approximately 35 HRC). The task was the removal of about 111 cm3 of material in the shortest time (and the conditions described above). These experiments were carried out on the machine 3 axis DMC-104V (P_{max}=20 kW, M_{max}=100 Nm, n_{max}=12 000 obr/min) with Siemens 840 control system.

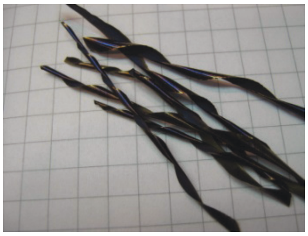
Taken trochoidal machining test strategy, one tool with the different variants of the cutting parameters.

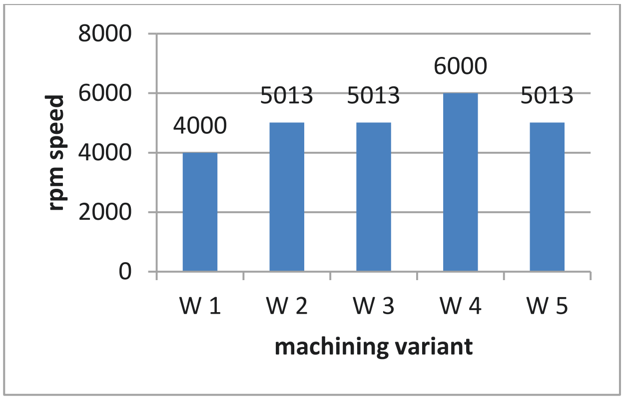
Table 2. Example of cutting parameters for milling of flat cylindrical cutter D16 (16mm diameter [11,12]) for the individual variants of trochoidal strategy

Wariant	a_e [mm]	a_p [mm]	n [obr/min]	v_f [mm/min]	f_z [mm/ostrze]	P [kW]	Q_v [cm³/min]	v_c [m/min]	M_c [Nm]	T [s]
W1	1,6	47,98	4158	1518	0,073	8,5	117	209	19	220
W2	0,8	47,98	5013	2507	0,100	7,0	96	252	13	372
W3	1,0	47,98	5013	2507	0,1	8,6	120	252	16	240
W4	1,0	47,98	5352	3024	0,113	10	145	269	18	188
W5	1,25	47,98	5013	2406	0,096	10	144	252	19	165

The following results for the machining strategy trochoidal machining open pockets (fig. 4):







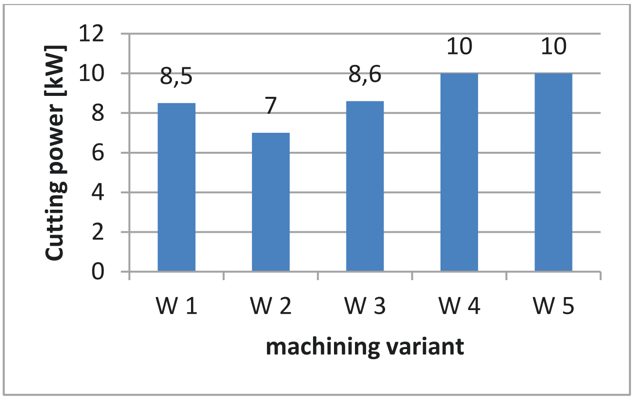


Fig. 4. Comparison of spindle speed and cutting power during trochoidal machining for 5 variants, and the machining time. Example of chips after machining

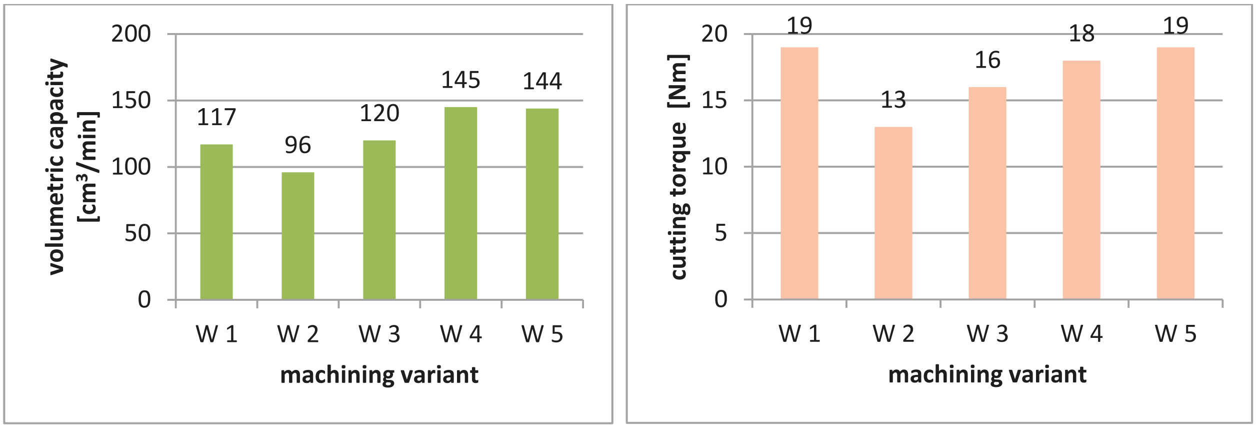


Fig. 5. Comparison of the maximum volumetric capacity during cutting and cutting torque during trochoidal machining for the five variants

Trochoidal machining (fig. 3b) is characterized by cutting movements and back movements; in this case, the maximum volumetric efficiency (fig. 5a) refers only to cutting movement. The average volumetric productivity of cut applies to the entire volume of material removed in relation to the machining time.

Practical checking on workshop selected machining variants showed the possibility of significantly exceeding the assumed parameters: cutting power and volume efficiency (which initially amounted to 3.4 kW and 54 cm^3/min). The best case (variant 5) was achieved shorter machining time compared to the standard output by 56%. This has encouraged further experiments related to the change of milling strategies. Here discrepancy obtained the machining time was even greater, and changing parameters such as power of cut, the moment of cut went far beyond the planned framework. The following comparative analysis cites a selection of experiments that illustrate the potential savings in processing time resulting from the theoretical analysis (confirmed in practice).

Table 3. Example of cutting parameters for each milling strategy (D16 – 16 mm diameter of flat cylindrical cutter, D42, D40 – 42 and 40 mm diameters of an indexable head cutter [11,12])

strategy	a_e [mm]	a_p [mm]	n [rpm]	v_f [mm/min]	f_z [mm/z]	P [kW]	Q_v [cm^3/min]	v_c [m/min]	M_c [Nm]	T [s]	tools
S1	1,6	23,09	3561	1271	0,089	3,3	47	179	8,8	600	**D16**
S2	1,25	47,98	5013	2406	0,096	10,0	144,0	252	19,0	165	**D16**
S3	7,68	46,18	1200	960 (plunge)	0,2	12	308 (max) 111 (averange)	158	95,5	60	**D42**
S4	40	2.8	1050	480	0,11	3,4	53	131	31	380	**D40**

Compared below (fig. 6, 7, 8) the use of four tools in four machining strategies which, after theoretical analysis have been reviewed in the workshop. Compared respectively two trochoidal machining strategies (differing substantially parameters) - S1 and S2, plunge machining (S3) and a step over machining (contour) - S4. The differences in time and during the simulated execution on the machine are usually of a few percent.

Taking into account the actual dynamic properties of the machine, the compatibility with the simulation was even higher.

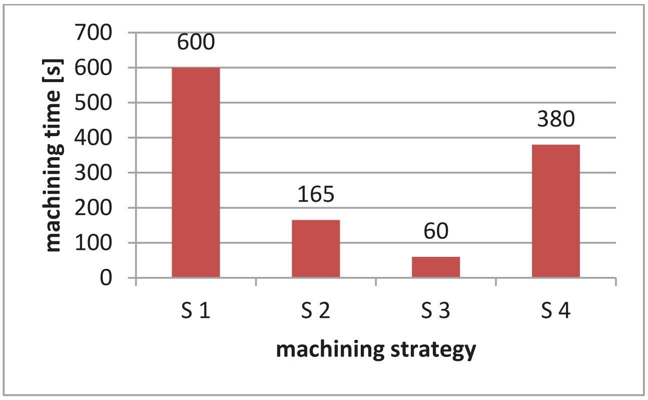


Fig. 6. Comparison of the machining time during machining for 4 strategies

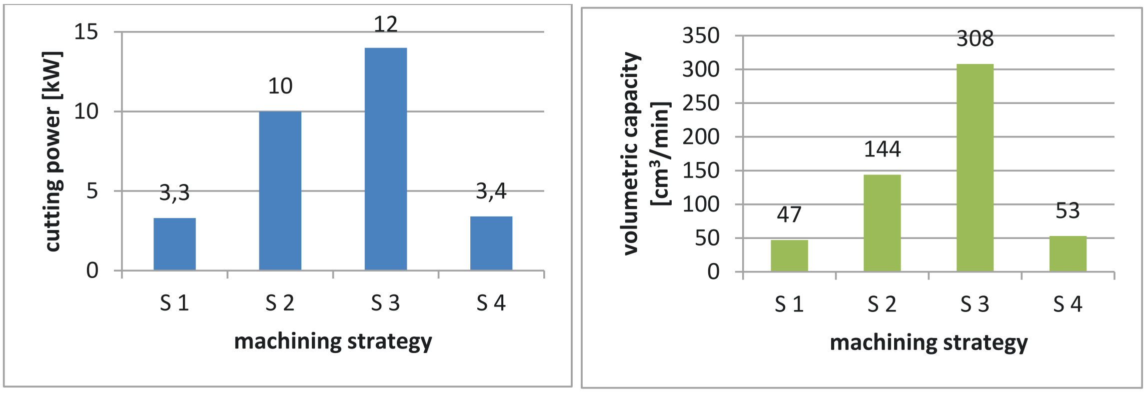


Fig. 7. Comparison of the power (a) and volumetric capacity (b) of machining for 4 strategies

Figure 7. (b) shows the instantaneous, maximum volumetric efficiency in the cutting procedure. The average volume efficiency (calculated as the volume of material removed in relation to the machining time) in this case was respectively 11.1 cm^3/min (S1), 40.3 cm^3/min (S2), 111 cm^3/min (S3), 17.5 cm^3/min (S4).

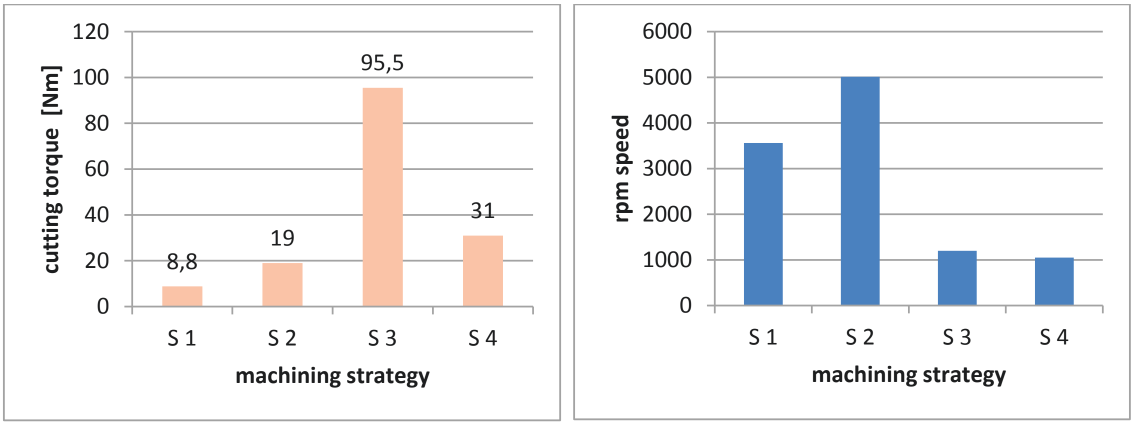


Fig. 8. Comparison of cutting torque moment and rotation of the spindle during machining for 4 strategies

 ISSN 2392-0327

To compare the effectiveness of different machining strategies were also applied economic analysis, which in addition to the price of tools (inserts) based on the number of expected machining operation up to tool change. This aspect, however, is not applicable to this article. In these cases, the machine worked properly throughout the range, and registered spindle load does not exceed the possibilities of machine tools and manufacturing process was stable. The tools during the assays described herein have not been visibly worn, and the cutting process proceeded without objection. According to the authors the most preferred solutions were strategies S3 (short time, but the worst surface quality) and S2 (a good time and quality of the surface) of figure 6, 7, 8.

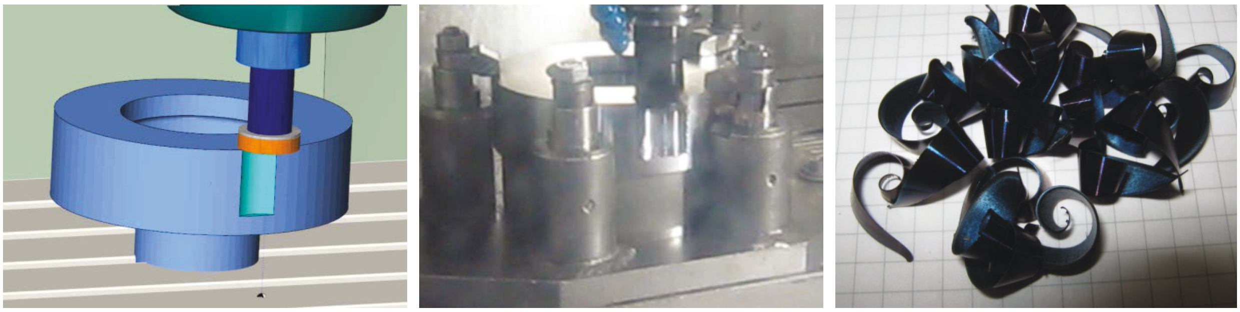


Fig. 9 Simulation on VR machine, machining, chips

In relation to the implementation of the output parameters of machining achieved:

- reduction of total machining time by the use of one pocket plunging to go coarse (including finishing) by almost 73%;
- the different variants of the same machining strategy used even three times the cutting power increased (from 3.4 kW to 10 kW) in relation to the originally used. Machining works properly;
- volumetric efficiency machining for several experiences was much higher than the input (reference Q = 53.0 [cm^3/min]), e.g. for the trochoidal machining was again an increase of nearly threefold (Q = 145.0 [cm^3/min]) and for plunging instantaneous volumetric efficiency was even Q = 308.00 [cm^3/min] (nearly six-fold increase), while maintaining the stability of the proces.
- cutting speed Vc = 252 m/min (an increase of nearly 100%) was considered the best for trochoidal machining with intensive air cooling.

Studies were conducted to the automatic machining simulation of the same part, concerning to many strategies, using a variety of tools and cutting variables. The analysis included 200 specific cases (strategies along with variants) machining of the same pocket with various tools. In studies in the workshop focused on those that would be potentially interesting for an industrial partner of the project, and gave a chance to verify the theoretical assumptions. Aim of the study was achieved.

Summary

The use of "predefined" CAM technology has many advantages of a universal character, such as [1]:

- Use database "technological knowledge", as predefined processes can be continuously improved and can provide practical solutions to technological achievements specific to the company.
- Reduce the requirements of competence designer CAM because predefined processes should facilitate the programming of less experienced employees.
- Better sharing of experience among staff designers of technological CAM (developed processes may be available for a number of employees).
- Unify of NC programs for CNC machine tools (especially important in large factories).
- Easier to estimate the machining time.
- Shortening the programming time of CNC machine tools.
- Easier to compare the level of technology used in different departments for some parts technologically similar.
- Creation scientific basis for raising the qualifications of technologists.
- Easy comparison of different strategies and variants, and choose the best solution due to the adopted criteria.

The proposed methodology allows for rapid comparison of a large number of possible solutions to a particular machining task in relation to the specific conditions in the workshop. Conducted analysis shows how much potential may lie in comparison to alternative technologies to perform the same operation on a CNC machine milling. Analysis of series-produced parts related to the number of about 1,000 units per year. Despite the large experience of technologists in the implementation of this procedure, it was shown the possibility of shortening the procedure by 50-70%.

It is worth noting that the practical nature of the proposed approach stems from the short time of receipt of the report (even counted in the hundreds charts) on the potential effects of the use of the individual solutions and easy comparison of different methods of milling technology.

If the technological process is more complex and diverse, the harder it is to answer the question of which strategies and machining options will best in the summary of a whole? Predefined patterns of technology use "locally" knowledge and technical capabilities to using simulation and comparison of multiple solutions within minutes or a few hours to answer the question, what to choose?

Carried out off-line analysis relate to individually defined, specific machines and tooling. So we can (already at the stage of the simulation) included in a range of dynamic capabilities of the processing (machine parameters and factors described in the form of additional technical conditions, such as the recommended speeds, the optimal diameter and maximum length tools, because of for example the possibility of vibration).

Description of dynamic area characteristics (machine - handle - workpiece - tool) can be systematically developed based on the observation of the subsequent machining tasks. You can in this respect also benefit from additional observation such as modal analysis, which will allow the determination of a set of characteristics of the FRF (frequency response function), for concrete tools and machining conditions. On the basis of the simulations of different strategies and machining options will be used most likely cutting parameters (e.g. limiting the possibility of self-excited vibrations flow).

This underlines the same opportunity to take into account in the analysis of real technical conditions for the construction of a workshop-based knowledge base of predefined technology. Therefore started works are related to the model of an expert system to support the work team of technological preparation of production, taking into account the specificities of a particular plant, department, and finally producing a single machine. One of the functions of such a system is to find the best solution (in a short time) machining for use in specific conditions. This will be important both during the design process and the preparation of tenders for subcontractors.

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