IOP Conf. Series: Materials Science and Engineering **400** (2018) 022044 doi:10.1088/1757-899X/400/2/022044

Methodology for optimizing cutting parameters on milling process

A E Pena, F D Anania and C Mohora
University Politehnica of Bucharest, Department of Machine Tools and Manufacturing Systems, Spl. Independentei, No. 313, sector 6, 060042, Bucharest, Romania

E-mail: andra.pena@yahoo.com

Abstract. Obtaining a better surface roughness with less time and energy consumption is an essential consideration in machining today. Choosing the right strategy for finishing milling is a difficult task to achieve when milling complex surfaces. It is essential to improve production rate and cutting quality. This paper presents a way to optimize the milling process based on the tool path trajectory type for inclined or complex surfaces machined with a ball end mill. In this case the speeds and feeds differ because the depth of cut changes according with the effective diameter for a ball nose mill. The research is based on several steps: the cutting regime is calculated with the classic formulas, then the part is machined and the quality of the resulting part is analysed by roughness measurement; a correction coefficient is calculated and the feederate is adjusted. The procedure is resumed and the tool setup is done, the part is machined and time, roughness and length of the trajectory are measured in order to validate the correction coefficient

1. Introduction

Establish of efficient machining parameters has been a problem that has confronted manufacturing industries for nearly a century, and is still the subject of many studies. Optimum machining parameters are of great concern in manufacturing environments, where economy of machining operation plays a key role in competitiveness in the market [1].

The complex approach of milling process that considers all factors that influence the processing accuracy: machine tool (stiffness), cutting tools (clamping type, tool length – in order to avoid buckling and occurrence of vibration, the tool type, the hardness of the workpiece, the type of toolpath used is difficult to achieve and implement in a software.

Under the machining field, it is widely known that over-loading of a spindle, excessive cutting force, chatter, tool wear and other constraints may lead to major problems such as tool breakage, product quality deterioration and even worse machine breakdown. The goal of the optimization software is to assign appropriate machining parameters for producing an NC part program based on two criteria, minimum machining time and optimal surface quality [5].

Actually, the improvement of one factor in machining process is not always possible without the worsening of another one. Using multi-objective optimization technique would be very helpful for this difficult decision making. In order to reduce energy consumption of cutting process, both surface roughness and material removal rate should be considered together [6].

2. Methodology for optimization

Sometimes the aim is to have high material removal rate as is the case for roughing procedure (high productivity) and sometimes we want the finest finishing pass without making the tool rub, which shortens the tool life.

Almost all CNC toolpaths are based on the concept of one toolpath being offset from another by some distance; this offset distance is generally called the step over. When using the side of an end mill to mill a profile, a series of 'cusps' are generated. The height of the cusp, - h, is determined by the cutter diameter, Dc, and feed per tooth, fz

When selecting a finishing toolpath, the first consideration should be the required surface finish. If you are creating a mold and the surface finish must be extremely smooth, you will have to make different choices from the case in which you are cutting sculpted surfaces with a large surface finish tolerance. The surface texture and climbing tendencies may limit the feed rate, especially when the radial depth of cut is small.

Our research describes a method designed to help the engineers to determine the optimum feeds and speeds for particular tool trajectories for finishing milling phase. Getting the best feed and speed for a particular tooling and cutting situation is one of the most important steps to ensure maximum material removal rates, best surface finishes, and better tool life.

The optimization is done based on experimental data and theoretical calculus. A general schema of the finishing feed optimization algorithm that emerges after this research is presented in figure 1.

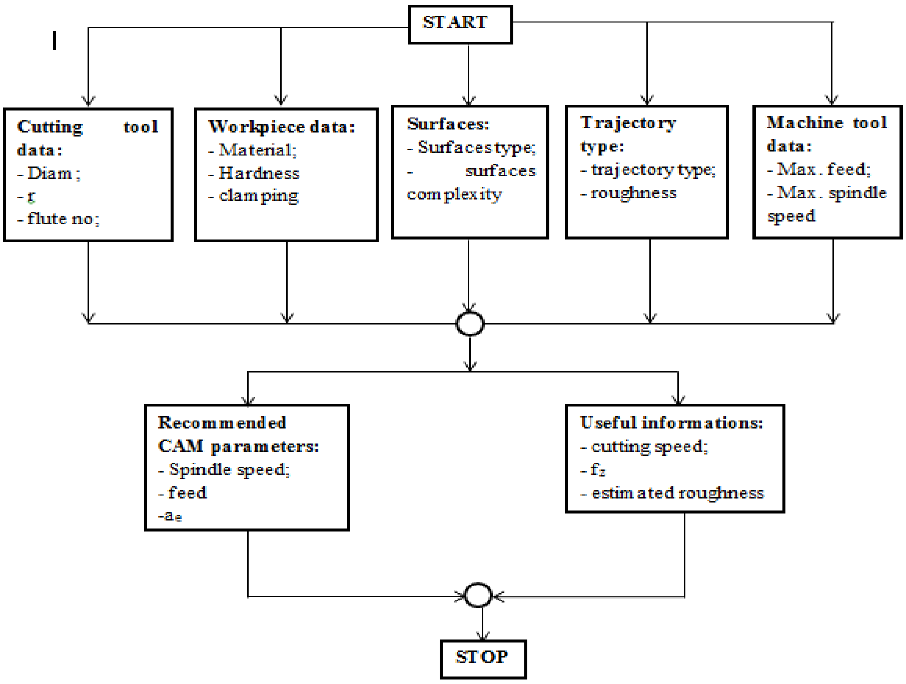

Figure 1. Optimization algorithm general schema.

The first stage is the machine selection, the material to be machined, and the cutting tool used. The setup of the machine tool can be done by entering information such as the type of machine, machines, spindle speed limit and maximum feed. This will ensure that the suggestions made after calculations will not a spindle speed or feed that are faster than the machine can handle, or a cut that takes more horsepower than the machine limit.

The next choice is the type of the material that will be machined. The selection is done based on the materials hardness values from a data base.

Then cutting tool will be chosen. Based on this selection the values for the cutting speed and feed is calculated. The lead angle of face mills is the angle of the shoulder that would be involved in cutting. A straight square shoulder has a 90 degree lead angle. Lead angle also affects the speeds and fees. You can use a feed rate grater for a 45 degree lead angle cutter than for a 90 degree, and it will generally produce a good finished surface.

Depending on which tool type you select the calculus changes. If the selection is for an endmill, the cutting speed and feed are calculated based on the formula 1; if the option is for a ballnose cutters, its diameter is obtained according with the equation (2).

$$V_c = \frac{\pi \cdot D \cdot n}{1000} \text{ [m/min]},$$

$$F = nzf_z \text{ [mm/min]} \tag{1}$$

where: D – the tool diameter in mm; n – spindle speed in rpm; F – feed rate in mm/min; z – no. of flutes; f_z – feed/tooth

$$d_{eff} = 2\sqrt{a_p(d_1 - a_p)} \tag{2}$$

In the case of a ball end tool when milling inclined surfaces, the diameter of the tool is calculated with the formula [7]:

$$d_{eff} = d_1 \cdot \sin\left(\alpha + arccos\left(1 - \frac{2 * a_p}{d_1}\right)\right) \tag{3}$$

where d_1 – tool diameter in mm; α- approach angle of tool axis in [^{0}]; a_p – axial depth in mm; d_{eff} – true tool diameter in action in mm

The result is that the speeds and feeds differ because the depth of cut changes according with the effective diameter for a ball nose mill.

Related to the above equations are the parameters of cut: the cut depth (axial depth – a_p) and the cut width (radial depth – a_e). The cut width and cut depth are expressed as a percentage of tool diameter.

These are basic information that every engineer is using when is programming the milling process. The problems appear when the geometry of the workpiece is complex and the surface quality requirements are high. Many engineers specialized in CNC say that it should always be used climb mill because it leaves a better surface finish, requires less energy, and is less likely to deflect the cutter. Conversely, manual machinists are often taught never to climb mill because it's dangerous to do on a machine that has backlash [8].

The most usual tool trajectories encountered in the majority of the CAM programs uses both climb and conventional milling. Based on the need to obtain a small value for the surface roughness several types of tool trajectories needs to be tested and the resulted roughness analyzed. In previous papers [9] this problem is approached and the entire procedure and the description of the toolpaths used for our research are presented.

The validation of the correction coefficient applied to the federate offers satisfying results and lead to the conclusion that our approach is good and the surface roughness improves for every tool trajectory tested.

Another point of view is the productivity obtained because when reducing the feed, the time for machining increases and when reducing the radial step over, the tool trajectory is longer and this means the tool life shortens.

For every element that influences the cutting processes a logical schema is done. In figure 2 is presented the logical schema for the calculus made in the case of the cutting tool. This schema is embedded in the general schema from the figure 1.

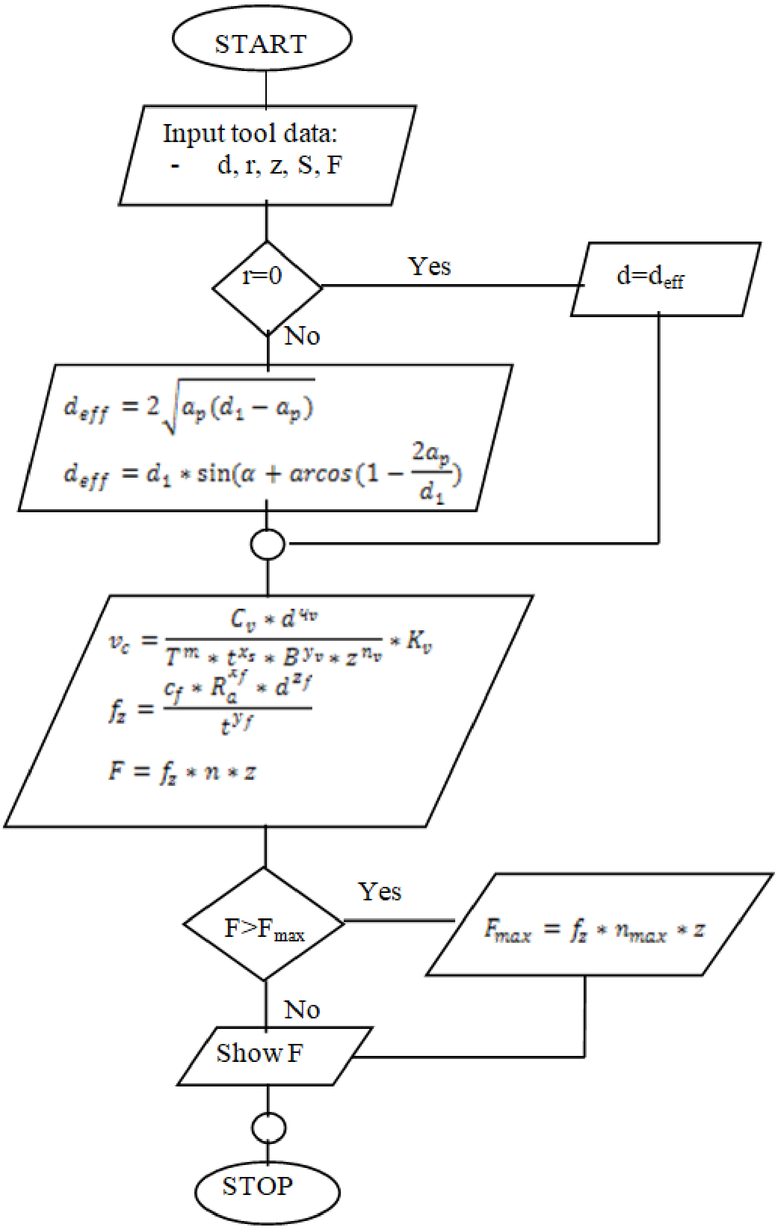

Figure 2. Feed calculus algorithm.

In the calculus algorithm of the optimum feed and side step for finishing phase in milling process based on tool trajectory type some correction coefficients had been implemented for 6 tool trajectories types [10].

These coefficients are calculated based on equation 4.

$$c_{R_a}^t = \frac{R_a^{ref}}{R_a^t} \quad (4)$$

where t = 1...6 -tool trajectories; sd^t –reference surface deviation for each trajectories type; sd^{ref} – constant reference value

These coefficients are used to calculate the feed and radial step according with equation bellow.

$$F = \frac{f_z n z}{c_{R_a}^t}$$
$$a_e^t = \frac{a_e^{ref}}{c_{Ra}^t} \qquad (5)$$

In the figure 3 is presented the optimization software developed based on previous algorithm.

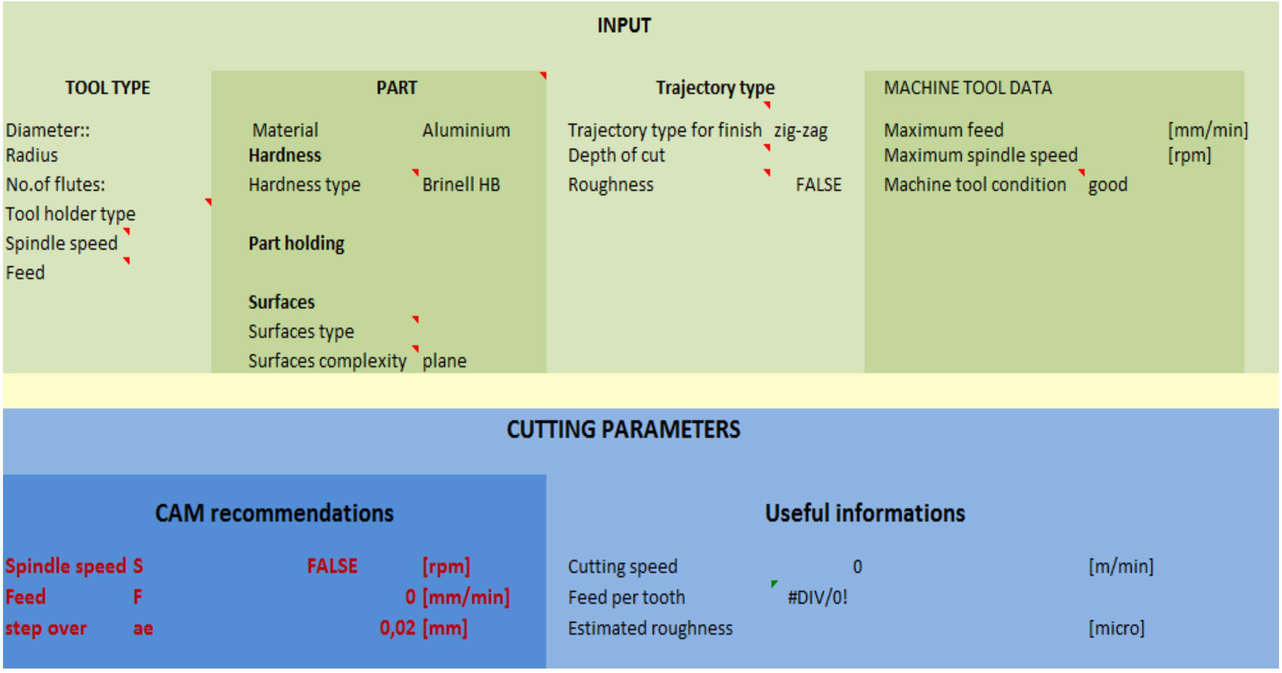

Figure 3. Software interface.

3. Optimization study case

A test piece with drafted surfaces with different tool trajectories types was machined in order to validate the calculus algorithm, correction coefficients and optimization software. The fallowing parameters were measured: the surface roughness, machining time and tool trajectory length. The 6 areas were finished by 3 axis milling with the following cutting parameters: F = 1500 mm/min, n = 7000 rpm, a_p = 0.3 mm, v_c = 202 m/min (calculated with the effective diameter; d_{eff} = 9.2 mm). The step over used is 0.2 mm. The trajectories analyzed are standard strategy from Cimatron E12. The tool used is a 10 mm ball end mill with 2 flutes and the material is a common 6061Al.

Each of the 6 areas was finished by a different tool path strategy (figure 4):
1 – the tool moves perpendicular on X axis from bottom to top with parallel cutting;
2 – the tool moves similar to strategy 1, but the cutting starts from top to bottom;
3 – parallel between top and bottom curves;
4 – spiral from outside to inside;
5 –between top and bottom curves similar with toolpath 2, but the tool moves on circular curves;
6 – between curves – lateral.

In all cases is used both climb and conventional milling because the tool moves in zig-zag. The trajectories 1 and 2 are located symmetrically to the X axis in order to analyze the influence of tool movement on surface quality. The trajectories that are alike are placed in mirror so that the displacement from X axis is the same.

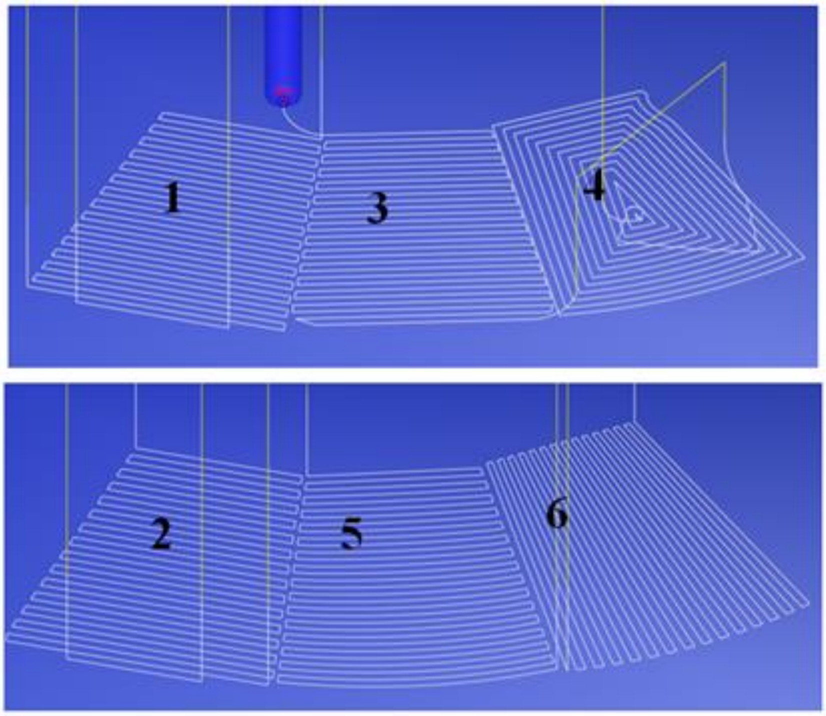

Figure 4. Tool paths types.

The results obtained after machining are presented in table 1.

The values presented in table 1 are achieved after simulating the milling process in Cimco software.

Table 1. Measurements results.

	Tool trajectory	1	2	3	4	5	6
Total tool path length [mm]	Not optimized	5721.032	5705.659	3565.929	3687.37	3902.756	4629.037
	Feed optimization	5721.032	5705.659	3565.929	3687.37	3902.756	4610.723
	Radial step optimization	10259.48	6889.804	5447.293	3687.37	7526.755	6502.819
Tool path length with feed rate [mm]	initial	3651.935	3655.635	3504.849	3622.644	3691.903	4418.124
	Feed optimized	3651.935	3655.635	3504.849	3622.644	3691.854	4418.119
	a_e optimized	6605.702	4308.586	5386.129	3622.644	7334.126	6284.282
Number of cutting moves	initial	306	306	662	1758	2544	477
	Feed optimized	306	306	662	1758	2544	477
	a_e optimized	556	362	1062	1758	5085	681
Surface	Initial	0.53	0.59	0.65	0.5	0.9	0.6

roughness [μm]	Feed optimized	0.5	0.52	0.54	0.5	0.6	0.5
	a_e optimized	0.5	0.4	0.4	0.5	0.5	0.4

As we can see this from table 1, the one-way toolpath will produce a better surface finish, but because the tool needs to reposition after each pass will take longer to run. When using the spiral or helix toolpath, the tool starts on outer edge or in the middle of stock. Machining in this manner it's shortens the cycle time because the cutter stays in contact with the workpiece during the entire cycle.

As we can see the increase of time varies from 4% up to 88%. In the case of trajectory 2 the increase of time is 12% if we optimize the process by reducing the feed or the step over. The trajectory 1 is similar with 2, but the starting point and the tool movement is from down to up. In this case, the increase of time is 88% when the step over is reduced by applying the correction coefficient. Also the toolpath length and the cutting length increase which leads to cutting tool wear.

In the same manner when analyzing all the toolpaths length and cutting moves for every trajectory used and based on the values obtained for the surface roughness the decision of using one toolpath or another can be taken. If the goal is to increase the productivity, these coefficients could be used for multiplying the cutting parameters.

It is beneficial to have a machine with the closest accuracy and the most rigidity possible. To maximize feed, the controller must be able to compensate for acceleration, deceleration and spindle growth. The controller also plays an important role in the ability to process the vast amount of information required for die/mold machining at high speeds.

4. Conclusions

Taking into account the workpiece geometry, not always we have the possibility to use a tool path that we know is suitable for machining that material. Then we use as alternative another toolpath and is necessary to find the best cutting regime parameters.

If the requirements are for the surface quality, then these coefficients are used for the reduction of feed or step over. But if the goal is to have good productivity we use the coefficients for multiplying the parameters with the value corresponding to every toolpath. The software helps engineers to calculate the right values for the cutting regime parameters before the process takes place.

The results obtained in this paper confirm that the proposed method is a very useful tool for optimization of cutting parameters. The validation of the coefficients gave good results regarding both the surface quality and the time spends for milling – the productivity is not affected by the reduction of some cutting regime parameters.

This paper was limited only in finding the optimization from the point of view of trajectory type used. The implementations of corrections regarding the other elements that are involved in the machining process will be discussed in other papers.

Next step in our research will be a software development for more materials. The initial research presented in this paper was made to validate our idea for using tool trajectory types like a coefficient in machining parameters calculus.

Acknowledgment: This work has been funded by University Politehnica of Bucharest, through the "Excellence Research Grants" Program, UPB – GEX 2017. Identifier: UPB- GEX2017, Ctr. No. /2017".

5. REFERENCES

[1] Hari Vignesh S 2013 Optimization Of Temperature, Tool Wear And Surface Finish In Turning Of 6063 Aluminium Alloy Using Rsm *International Journal of Engineering Research & Technology (IJERT)* **2**(4) 2535-2541

[2] Chen J S, Huang Y K and Chen M S 2005 A study of the surface scallop generating mechanism in the ball-end milling process *International Journal of Machine Tools and Manufacture* **45**(9) 1077- 1084
[3] Stahovec J and Kandráč L 2013 Optimization of cutting conditions for the reduction cusp height in the milling process *Transfer inovácií* **25** 244-248
[4] Balázs M, Jozef B and Ildikó M 2012 Experimental Verification of Cusp Heights when 3D Milling Rounded Surfaces *Acta Polytechnica Hungarica* **9**(6) 101-116
[5] Firman R and Xun X 2013 Advanced CNC system with in-process feed-rate optimization *Robotics and Computer-Integrated Manufacturing* **29** 12–20
[6] Jihong Y and Lin Li 2013 Multi-objective optimization of milling parameters e the trade-offs between energy, production rate and cutting quality *Journal of Cleaner Production* **52** 462-471
[7] Pokolm – tehnical manual, available at www.broos-tools.ro
[8] http://www.cnccookbook.com/CCCNCMillFeedsSpeedsStepover.htm, accessed 02.10.2017
[9] Pena A E, Anania F D and Zapciu M 2015 Research concerning optimum cutting parameters according with tool path strategy for finishing procedures *IOP Conf. Series: Materials Science and Engineering* **95** 012020 doi:10.1088/1757-899X/95/1/012020
[10] Pena A E, Anania F D and Mohora C 2017 The milling process simulation- a way to optimize the influence of toolpath strategies on surface quality *Tehnički vjesnik / Technical Gazette*, **24**(2) Tehnički vjesnik / Technical Gazette, DOI: 10.17559/TV-20150828143457 pp 385-389
[11] Anania F D, Pena A E and Zapciu M 2017 Surface quality and machining time optimization based on feedrate correction function of tool trajectories types, *Tehnički vjesnik / Technical Gazette* **24**(4) Tehnički vjesnik / Technical Gazette, https://doi.org/10.17559/TV-20150921113741 pp 987-992