TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 68, Issue Special I, May, 2025

OPTIMIZATION OF MANUFACTURING PROCESSES, THE NEW CNC TECHNOLOGIES IMPLEMENTATION

Adrian BUT, Cristian-Eusebiu POPESCU

Abstract: *The paper presents the stages of manufacturing a part in a CNC milling center, stages chosen specifically to present new machining technologies on CNC machine tools. In some of them, comparisons were made between different machining processes with positive but negative recommendations regarding the machining options, which we consider useful for application engineers. In other cases, comparative graphs were drawn with the time achieved through different processes, graphs regarding the amount of material removed.*

Experience and permanent upgrading of knowledge are essential in computer-aided programming, to operate and program the machines with numerical control. The actual machining of this part was done to certify and validate the theoretical and simulated arguments on different CAM (Computer Aided Manufacturing) software.

Keywords: *Computer Aided Manufacturing applications, CNC milling strategies,*

1. INTRODUCTION

The topic of the paper consists of analyzing one test part of manufacturing, with the aim of presenting solutions for optimizing the manufacturing process using different CNC milling strategies. In an optimized system all components operate to the limit of their maximum capacity, although none are beyond their operating limits.

To prevent the tool damage, rotational speed and feed should stay in the boundary of maximal load for existing tool path. This way of setting the rotational speed and feed leads to the fact that in the sections with lower load the tool works slower compared to its maximum.

So, we will indicate trying to keep the tool working up to its limit through the whole trajectory, which means that we attempt to reach constant material withdrawal and steady cutting forces. Unstable cutting force may result to tool damage or slow manufacturing [2].

The paper presents new methodologies, validates them and makes them known.

2. STATE OF THE ART

To have a reference plane, we will need to face mill the material, a basic, simple operation, but here too, there are several processing options. CAM software is prepared to respond to several situations, but the one who decides is the programming engineer, depending on what is desired and what is available.

2.1 Face mill operation

A planning operation can be done from the outside to inside (Fig. 1), or from the inside to the outside (Fig. 2) or by milling in the forward direction (climb milling) or combined, both in the forward and counter-forward directions (conventional milling) (Fig. 3) [1].

The recommendation, the optimization would be to process from the outside to the inside and in the fed direction. Thus, the cutting tool is in permanent contact with the material and the cutting parameters can be defined according to the recommendations from the cutting tools catalogs.

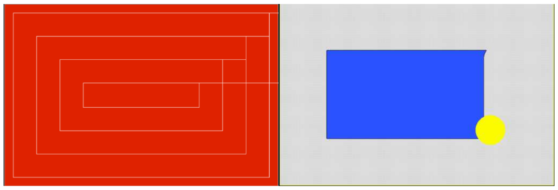

Fig. 1. Face milling operation from external to internal, climb milling.

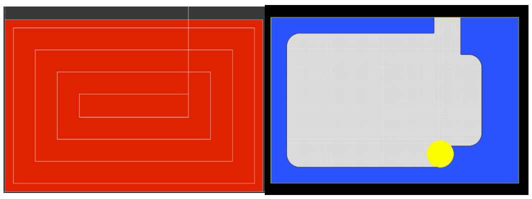

Fig. 2. Face milling operation from internal to external - climb milling.

That is, the cutting tool should be engaged in the processing with 70% of its diameter, the entry into the material is made after a radius and not directly into the material and the milling cutter should be in permanent contact with the material until the processing is completed [9].

This technical detail leads to an increase in the life of the cutting tool, to the elimination of repositioning times outside the material or to the avoidance of impact shock or milling both in the feed direction and against the feed (this solution is also possible) (Fig. 3).

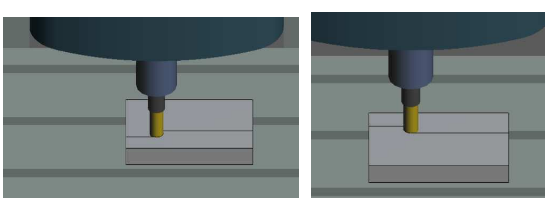

Fig. 3. Face milling operation from external climb + conventional milling.

Fig. 4. Analysis of chip thickness, radial and axial forces, power consumption and cutting tool deflection during face milling operation.

A constant chip thickness value is observed during the face mill operation (the value prescribed as machining depth). The cutting forces in the process have low values - axial ones with values of 20 N, and radial ones between 70 N and 80N. The power consumption of the spindle is 0.35 kW, and the deformation at the cutting tool tip is 2.5 microns, with fluctuations at the center of the part. The material removal method is from the outside to the inside (Fig. 4).

2.2 Roughing with large depths of cuts

After the face milling operation, the next roughing operation is carried out. A roughing with large depths was chosen. An operation known under different names, depending on the CAM software used. ("Volumill" in CIMATRON, "Dynamic milling" in MASTERCAM or "I-machining" in SOLIDCAM) [3]. A relatively new productive operation, through which the material removal is done at a very high cutting depth of 20 mm (in this case, but the entire active part of the milling cutter can be used), a radial penetration of a with a maximum of 20% of the diameter of the cutting tool. Thus, the entire active part of the milling cutter can be used. In classic milling processing, 1-5 mm of the milling cutter was used, the rest being unused. So, an optimization was chosen regarding the more efficient use of the cutting tool and of course the machining time.

The Roughing process: is a significant portion of every part… Hours, Days… Part Roughing represents ~50-75% of the overall machining process.

Mold Cores / Cavities Rouging~25-50% of overall machining process.

Goals for the roughing process are faster material removal and a safe process.

Typical Roughing Part is not optimized:
Unequal tool loads: Causing tool wear & short tool life, compromised by slower feeds (Fig. 5).

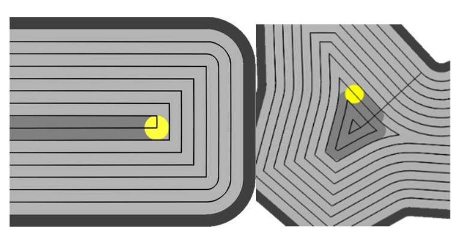

Fig. 5. Unequal tool loads at Slotting are represented.

Volumill solution: Reliable, High material removal rate, huge down step with high feed rate, All-rounded, constant sidestep, optimized feed-rates.[5]. The paper presents innovations in the latest milling strategies (Volumill) - totally different from classic milling methods**.**

A constancy of the chip size is observed (a fact resulting from a rigorous calculation regarding the process control). This time, for this operation, the radial forces reach up to 800 N, the power consumed reaches up to 3 kW (considering that we have a cutting depth of 15 mm, it is a more than adequate value – the maximum machine power is 5.9 kW) (Fig.6).

So even with machines that have low drive power, machines with very large cutting depths can be done. Such processing could not be conceived in classic milling. The modality that the part was manufacturing, the control of the movements of the cutting tool are rigorously generated by computer-aided manufacturing (CAM) software. Moreover, today computer-aided programs can evaluate if there are collisions (Fig.5), correctly estimating the manufacturing time.

This way, machining can be optimized, the trajectories of cutting tools can be visualized in advance, and the machining process can be controlled. We also observe deformation at the tool tip of up to 0.02mm. Since the deep milling operation is a roughing operation, a deflection of 0.02mm is acceptable (Fig. 6).

2.3 Finishing operation of the outer walls

The finishing operation of the outer walls follows, the chip thickness value decreases (corresponding to the cutting depth programmed as finishing depth), the values of the axial and radial forces in the process decrease, the power consumed up to 1 kW, and the deviations at the tool tip become micron values of 0.006 mm (Fig. 7).

2.4 Full milling operation

The full milling operation follows, another operation with higher power consumption (up to 1.5 kW), tool wear is accentuated, radial forces increase significantly. The deflection at the tool tip reaches 0.016 mm (Fig. 8).

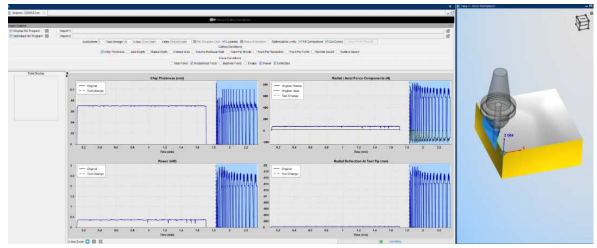

Fig. 6. Analysis of chip thickness, radial and axial forces, power consumption and cutting tool deflection during milling operation with large depths of cut.

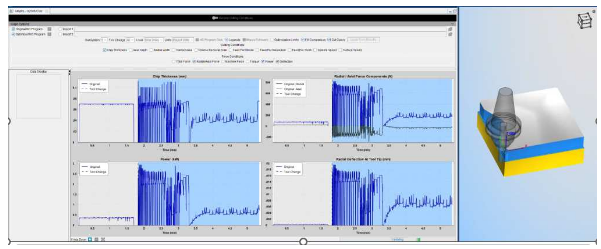

Fig. 7. Analysis of chip thickness, radial and axial forces, power consumption and cutting tool deflection during the finishing operation of the outer walls.

Fig. 8. Analysis of chip thickness, radial and axial forces, power consumption and cutting tool deflection during the full milling operation.

When using the full milling to make grooves in the workpiece, of course, high radial forces occur, high power consumption is consumed to drive the main spindle. The entry is made by the trochoidal method to avoid full entry.

The work highlighted an important detail regarding this type of machining. These channels are separated by a thin wall. Machining these thin walls is part of atypical machining. If until now the first option was to use climb milling in the feed direction, this time, the thin walls are machined in conventional (against the feed). Moreover, in order not to deform the wall, the two sides of the wall are machined alternatively (Fig. 9) so that the radial forces in the process do not press the wall too much and deform it [*2].

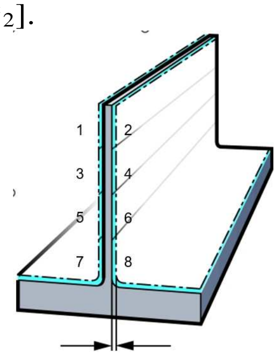

Fig. 9. Manufacturing thin walls.

2.5 Pocketing

Considering that pocketing is a widely used operation in CNC milling, two cases are presented:

1. Pocket milling using the helical method (the first recommended option) followed by contour milling [4].
2. With the helical method we can make a hole in solid material and it is possible to move simultaneously in a circular path (x and y) and axially (z) at a defined pitch (Fig.10).

This changes the process compared to straight ramping. Rotating anticlockwise ensures just climb milling (not full slotting) with better chip evacuation capability.

Should be considered first choice for pocket machining compared to straight ramping, because is flexible – one tool many shapes/diameters, no chip control problems, manage interrupted entrances and exits, at curved surfaces for example, low power and torque requirement, reduced axial cutting forces, reduced burr, can run as dry process – no coolant [9].

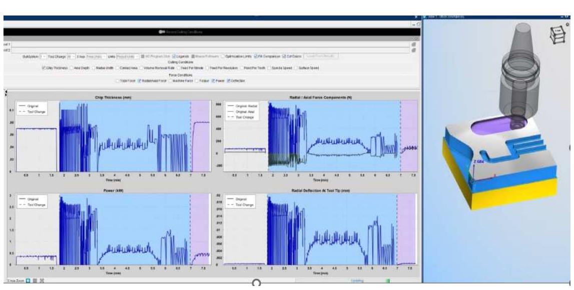

Fig. 10. Analysis of chip thickness, radial and axial forces, power consumption and cutting tool deflection during the pocketing milling using the helical method.

3. The second method uses a full plunge of the cutter (plunge milling), followed by ramp milling in both directions (Fig. 11).

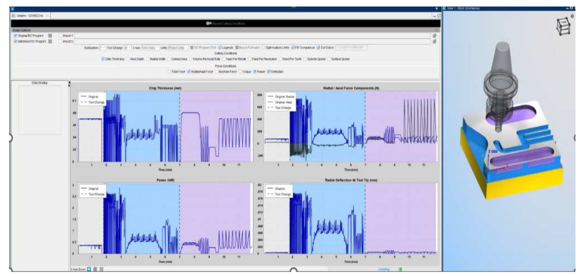

Fig. 11. Analysis of chip thickness, radial and axial forces, power consumption and cutting tool deflection during the pocketing milling using the ramp milling in both directions.

A greater chip thickness is observed when entering the material, milling being an intermittent operation, a change in the values of the radial and axial forces is observed when entering and exiting the material (values that can reach up to 600 N), the power used to drive the main spindle reaches up to 1 kW and the deflection at the tip of the tool has small values.

In Figure 12 we have:

D_c- diameter of cutting tool [mm]

a_p- axial depth [mm]

l_m- length of ramping distance [mm]

α - ramping angle [^{o} grade]

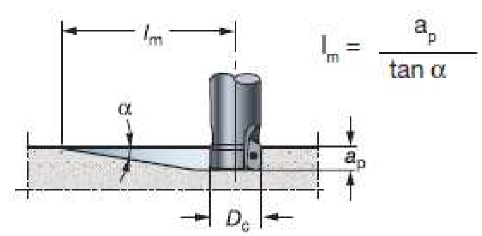

Fig. 12. Ramp milling strategy.

Higher values of axial cutting forces are observed (which is expected using the plunge milling method, (the cutter diameter is the same as the channel diameter) and having the channel geometry suitable for the ramp milling process, such a machining strategy was also chosen for analysis.

2.6 Climb versus conventional

Also in this work, on this test part, milling in the feed direction (climb) and milling against the feed direction (conventional) were performed. It was highlighted that on the same piece, the same material, with the same milling cutter, using two different milling methods, different quality of the machined surface are obtained (Fig. 13).

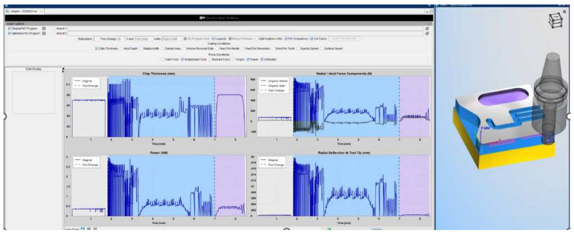

Fig. 13. Analysis of chip thickness, radial and axial forces, power consumption and cutting tool deflection during the climb and conventional milling strategies.

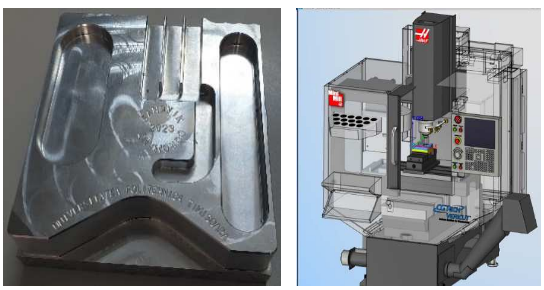

Fig. 14. The final part manufactured and the Minimill CNC milling center.

3. CONCLUSIONS

The test part was designed so that in the analysis of the technological itinerary it would present novelties and solutions, regarding the optimization of milling processing on CNC machine tools.

In the first operation, the face milling operation, three solutions were presented: face milling from the outside to the inside, face milling from the inside to the outside and zigzag milling using both forward and counter-forward milling.

The choice was made for outside-to-inside milling, with permanent contact of the cutting tool with the material, using 80% of the milling diameter.

When using milling for roughing with large depths of cuts a_p= 15 mm, a lot of advantages are observed: the machining time is substantially reduced from 9.13 min by milling on the Z axis with successive passes a_p=5 mm (so three passes) when milling the entire depth of 15 mm. to 4.31 min. Also, another important advantage is the use of the entire active part of the cutting tool (Fig. 15).

The part will be machined with a new strategy, the axial engagement is equal to the total machining depth a_p=15mm and the radial engagement is 10%/Dc.

The radial engagement is small, the tool paths are tangent to the surface to be machined, and the volume of material removed in one pass is small, as a result much higher cutting rates can be used. Due to the high rates, the machine time is significantly reduced.

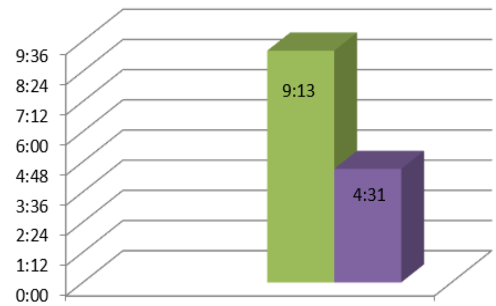

Fig. 15. Manufacturing time; Constant Z 9,13 min, Volumill 4,31 min.

The tool edge is in contact with the material for a very short time, heat transfer is reduced, there is no need for coolant, and the chip is not colored.

Following the study and tests carried out, it was concluded that the new machining method (Volumill) is much more productive than the previous ones, the quality of the parts produced is better (roughness for example), the tool life is significantly increased, and additional costs are reduced, such as the cost of the coolant and its neutralization after use.

The two oval pockets, we processed them in two different ways. As we mentioned, manufacturing a pocket in milling parts is frequently used. The first one, with the larger diameter (having space for the cutting tool to generate its helical movement), obtained penetration into the material - is the most used method [8].

Should be considered the first choice for pocket machining compared to straight ramping with having the following advantages:

- Flexible – one tool of many shapes/diameters,
- No chip control problems,
- Manage interrupted entrances and exits, for example at the curved surfaces,
- Low power and torque requirement,
- Reduced axial cutting forces,
- Reduced burr,
- Can run as a dry process – no coolant [4].

The second pocket has a diameter like the diameter of the cutting tool and has a length enough to apply the ramping milling method.

All these technical details will be useful for the application engineers to understand well the CNC technologies. To establish the power consumed by the spindle, to determine the forces, and cutting tool deflection during different milling operations and to establish the chip thickness, was used Vericut - a CAD/CAM software. Vericut is a power software used to improve performance of the CNC machine tool, to reduce machine cycle times, to improve tool life, to minimize wear and tear on the machine tool.

6. REFERENCES

[1] Hazarika, M., Dixit, M., *Setup planning for machining*, Springer International Publishing, 2015.

[2] But, A., *Advanced machine-tools and manufacturing systems,* Editura Politehnica-Timisoara, 2009.

[3] *Metal Cutting Technology* Technical guide

[4] ***SPINWORKS, Pokolm cutting tools catalog, 2016.

[5] Kumar, C., Deb, S., *Generation of optimal sequence of machining operations in setup planning by genetic algorithms*, Journal of Advance Manufacturing Systems vol. 11, nr. 01, pp. 67-80, Jun. 2012.

[6] Sormaz, D.N., Arumugam, J., Ganduri, C., *Integration of rule-based process selection with virtual machining for distributed manufacturing planning*, Process planning and scheduling for distributed manufacturing, Springer, 2007.

[7] Nikolaus, K., *Manufacturing: Self-Organizing Factories*, Siemens-Digital Factories, 2014.

[8] But, A., Mazuru, S.et al, *Fabricatia asistata de calculator,* Editura Tehnica, UTM, ISBN 978-9975-45-743-9, Chisinau, 2021.

[9] Sandvik Coromant Technical guide 2020

[*1] *** www.haascnc.com

[*2] *** www.sandvik.coromant.com

[*3] *** Metal Cutting Technology, Training Handbook Sandvik

Optimizarea proceselor de prelucrare, implementarea noilor tehnologii CNC

Lucrarea prezintă etapele de prelucrare a unei piese pe un centru de frezare CNC, etape alese dedicat, pentru a prezenta noile tehnologii de prelucrare pe mașini-unelte CNC. În unele etape, s-au făcut comparații între diferite procese de prelucrare cu recomandări pozitive, dar și negative cu privire la opțiunile de prelucrare, recomandări pe care le considerăm utile inginerilor de aplicații. De asemenea, s-a trasat grafice privind timpul realizat prin diferite procedee, evidențiindu-se noua strategie de prelucrare Volumill. Experiența și perfecționarea permanentă a cunoștințelor tehnologice sunt esențiale îin programarea asistată de calculator a mașinilor-unelte cu comandă numerică. Prelucrarea efectivă a acestei piese a fost realizată pentru a certifica și valida argumentele teoretice și simulate pe diferite software CAM (Computer Aided Manufacturing).

Cuvinte cheie: *Aplicații de fabricație asistată de computer, strategii de frezare CNC,*

Adrian BUT, PhD**,** Assoc. Professor, Politehnica University of Timisoara, Materials and Manufacturing Engineering Department, E-mail: adrian.but@upt.ro, Tel.: +4072671509.

Cristian-Eusebiu POPESCU, PhD student, Politehnica University of Timisoara, Materials and Manufacturing Department, E-mail: popescucristi79@gmail.com, Tel.: +40726215127.