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CAD/CAM APPROACHES FOR MACHINING A MECHANICAL PART ON A VERTICAL CNC MACHINING CENTER

BY

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Abstract. The study presents the analysis and optimization of the CAM technology applied to the machining of a flange-type part on a vertical CNC machining center. The study aims to reduce machining time while maintaining the final geometry and the required machining accuracy of the part. The analyzed component has a medium level of geometric complexity and requires machining in two setups. The methodology included part modelling, definition of the machining operation sequence, cutting parameter setting, toolpath simulation, and machining time determination. Based on the assessment of the initial CAM variant, two machining operations with a dominant influence on the overall process duration were identified, for which alternative technological solutions and toolpath generation strategies were comparatively analyzed. The results showed a reduction in total machining time of approximately 9.37%, confirming the effectiveness of optimizing critical operations in improving CNC machining productivity.

Keywords: optimization, simulation, technology, time, tools.

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1. Introduction

In the context of the rapid development of numerically assisted manufacturing technologies, the competitiveness of machining processes is no longer determined exclusively by dimensional accuracy and the quality of the generated surfaces, but also by the possibility of reducing the total manufacturing time and increasing productivity, without compromising the functional requirements of the part (But, 2019). In the case of components machined on vertical CNC machining centers, the organization of the machining process becomes essential, particularly when the geometry of the work-piece includes contour surfaces, holes, cavities, or slots located on different faces and requiring several setups (Pjaziti *et al.*, 2025). Under these conditions, process performance depends not only on the cutting parameters, but also on the way in which toolpaths are defined, the approach direction, the type of machining strategy, and the sequence of operations (Groover, 2021). Therefore, the comparative analysis of programming variants and the virtual simulation of the machining process represent necessary stages for substantiating the selection of an appropriate technological solution, which results from the correlation between the workpiece geometry, the specific characteristics of the cutting tool, and the logic of the toolpaths generated in the CAM environment (Groover, 2020). Recent research results highlight that adapting the toolpath generation strategy to the geometric complexity of the workpiece represents an effective direction for reducing machining time, with a direct effect on improving the performance of CNC milling processes (Kukreja *et al.*, 2023). Based on these considerations, the objective of the paper is to analyze the CAM technology applied to the machining of a flange on a vertical CNC machining center, by identifying the critical operations in terms of execution time. The approach adopted in the study involved the development of the machining technology in the CAM environment, the virtual simulation and validation of the toolpaths, the comparative analysis of machining times and, in the final stage, the optimization of the operations with a major influence on the total process duration.

The original contribution of the paper consists in the comparative analysis of alternative technological variants applied to the critical machining operations, as well as in the evaluation of their effect on the total machining time of the flange.

2. Materials and Methods

The analyzed part is a flange-type mechanical component with medium geometric complexity, selected as a case study for evaluating the influence of CAM programming variants on the efficiency of the machining process. Fig. 1 presents the main dimensions and characteristic cross-sections of the analyzed part.

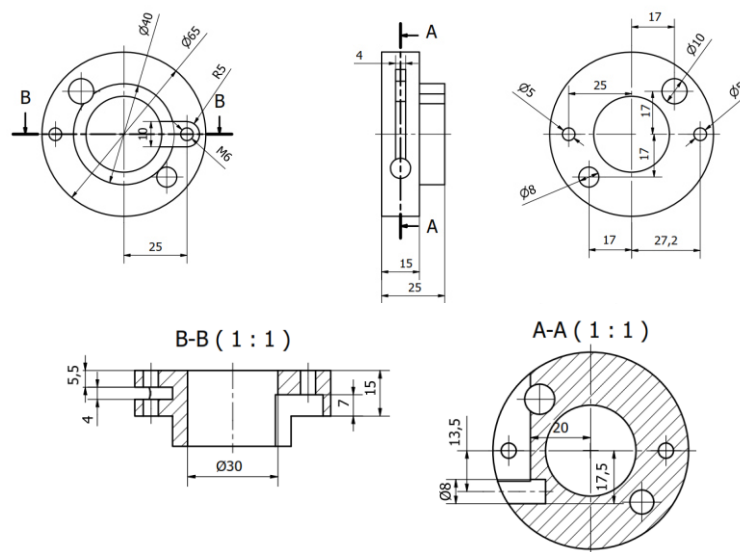


Fig. 1 – Main dimensions and characteristic sections of the flange.

The part consists of frontal flat surfaces, an external circular surface, a central bore, and several auxiliary geometric features: recess, holes of different diameters, and a lateral slot. The component is made of C45 steel, starting from a rolled blank with a diameter of 70 mm. The component was designed to be manufactured on a vertical CNC machining center, while program generation and process simulation were carried out in a CAM environment. The initial technological plan was organized into two setups. The first setup included the main operations required to generate the general shape of the part and most of its functional features. The second setup was used to complete the features located on the lateral side. The work-piece origin was defined at the center of symmetry of the component to ensure geometrical consistency between the two setups and to facilitate the establishment of a coherent coordinate system. This initial technological plan represented the reference variant subsequently used for identifying the critical operations and for the comparative evaluation of the analyzed programming variants. The stage of identifying the critical operations

in terms of machining time was preceded by the development of the CAD model of the part, as shown in Fig. 2.



Fig. 2 – CAD model of the flange.

Within the CAM technology analysis, it was necessary to identify the operations with the highest share in the structure of the total machining time. The selection of this criterion was based on the fact that execution time represents a direct indicator of process productivity, and its reduction can lead to an increase in the overall efficiency of machining (Reznicek and Horava, 2024). The method for identifying the critical operations involved, in the first stage, the determination of the estimated total machining time for the initial machining variant. In the next stage, the operations with the longest execution times were selected, provided that they also allowed the application of alternative machining strategies (Vavruska *et al.*, 2025).

3. Results and Discussion

The definition of the initial technological plan involved correlating each machining operation with the appropriate cutting tool and the corresponding cutting parameters. Tool selection was carried out according to the nature of the operations and the dimensions of the geometric features to be machined, while the working parameters were established in relation to the work-piece material, the type of tool used, and the specific requirements of each machining stage. Table 1 summarizes, for the two setups, the sequence of machining operations, the cutting parameters and machining time. The data presented in Table 1 formed the basis for the comparative analysis of machining times and for the selection of the critical operations for which alternative CAM programming variants were subsequently evaluated. Considering the relatively large number of operations involved, only the stages regarded as technologically representative were selected for detailed presentation. The corresponding screenshots of these stages are presented in Figs. 3-6. After identifying the critical operations in terms of machining time, the next stage of the study was dedicated to the development of alternative CAM programming variants for the selected operations.

Table 1
*Sequence of machining operations, cutting parameters and machining times
 for the two setups*

No.	Operation	Spindle speed [rot/min]	Feed rate [mm/min]	Machining time [min]
Setup 1				
1.	Center drilling of the central bore	800	18	0.48
2.	Drilling of the central bore	900	20	1.37
3.	Milling of the inner bore	1200	500	3.5
4.	Outer surface milling with the end face of the cutter	1200	500	8.44
5.	Center drilling of $\phi 5$, $\phi 8$, $\phi 10$ mm	800	18	2.3
6.	Drilling of the bores $\phi 8$ and $\phi 10$ mm	900	20	6.21
7.	Drilling of the bore $\phi 5$ mm	1000	23	1.15
8.	Milling of the recess	5000	1000	2.17
9.	Bore milling $\phi 8$ mm	5000	800	2.19
10.	Bore milling $\phi 10$ mm	5000	800	4.13
11.	Bore milling $\phi 5$ mm	8000	1000	0.46
12.	Center drilling of the recess bore	800	18	0.45
13.	Drilling of the recess bore	900	20	1.27
14.	Tapping M6 hole in the recess	100	100	0.29
Total machining time setup 1				34.41
Setup 2				
1.	Bore milling	5000	1000	2
2.	Lateral slot milling	10 000	1000	7.35
Total machining time setup 2				9.35

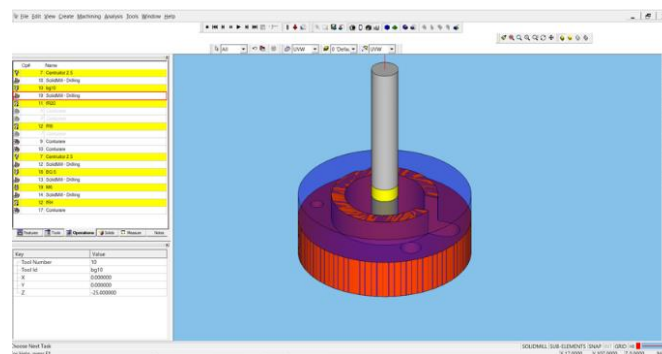


Fig. 3 – Operation 2, Setup 1, drilling of the central bore.

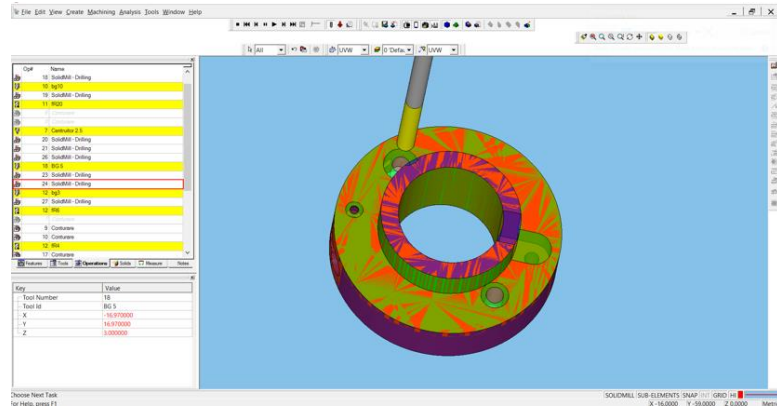
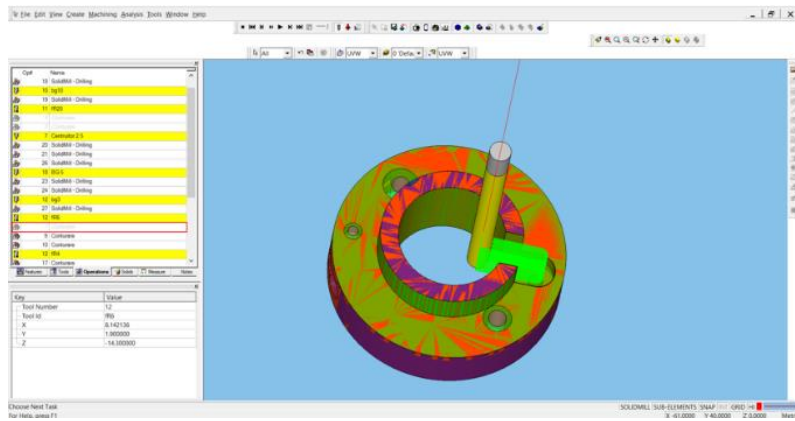
Fig. 4 - Operation 6, Setup 1, drilling of the bores with ϕ 8mm and ϕ 10 mm.

Fig. 5 – Operation 8, Setup 1, milling of the recess.

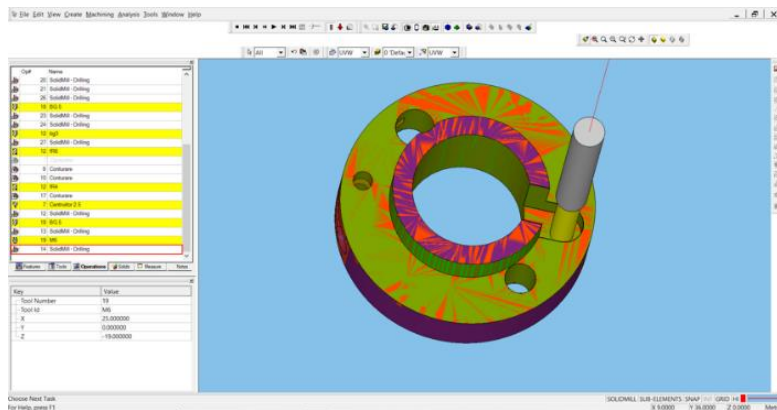


Fig. 6 – Operation 14, Setup 1, tapping of the M6 hole in the recess.

Table 1 shows that the estimated total machining time of the part is 43.76 min, including 34.41 min for Setup 1 and 9.35 min for Setup 2. The analysis of machining times highlights a high share of Operation 4 in Setup 1, corresponding to the outer surface milling and of Operation 2 in Setup 2, corresponding to the milling of the lateral slot.

The analysis of the technological process developed for the flange highlighted that the adopted machining solution is coherent from both geometric and technological perspectives; however, the distribution of machining times indicates the existence of significant optimization potential.

In the initial technological plan, the outer surface of the flange (Operation 4, Setup 1) was machined using the frontal part of the milling cutter. Since this operation had the highest share in the total machining time of Setup 1, it was selected for analysis, while the alternative variant involved machining with the lateral part of the milling cutter, without changing the cutting parameters. This modification aimed to reduce the machining time of the external surface through a more efficient use of the cutting tool, while maintaining the required contour geometry. The two analyzed variants are comparatively presented in Fig. 7.

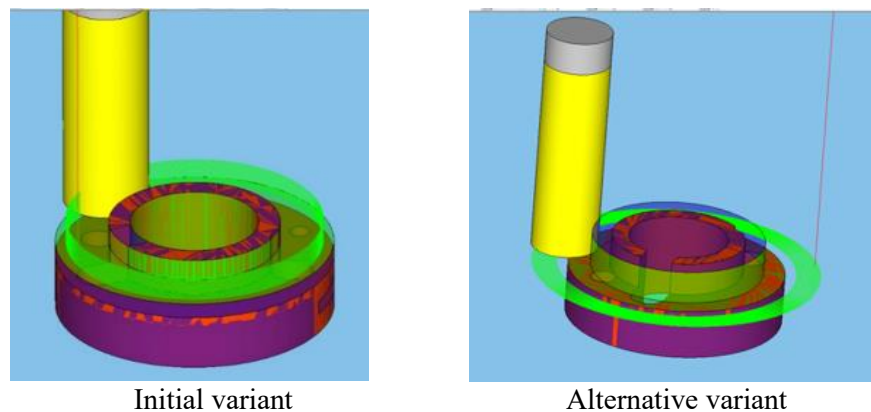


Fig. 7 – CAM strategy for the outer contour (Operation 4, setup 1).

In the case of Operation 2 in Setup 2, the study focused on the machining of the lateral slot. In the initial variant, the operation was performed using a 3 mm end mill, while in the proposed variant a 6 mm end mill was selected. In addition, the machining toolpath was reorganized so that the lateral slot could be produced in a single technological pass, while maintaining the cutting parameters used in the initial variant. This approach aimed to reduce execution time and simplify the process without affecting the final geometry of the machined feature. The comparison between the two variants is presented in Fig. 8.

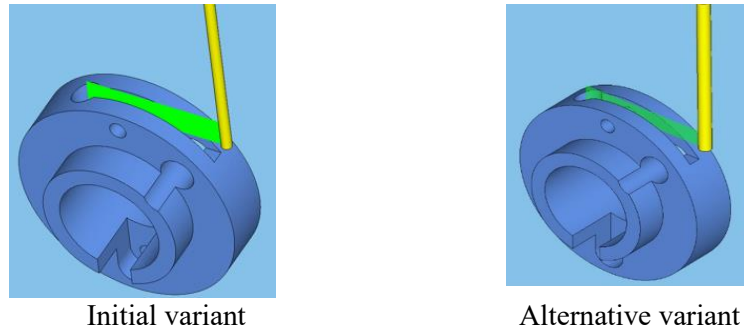


Fig. 8 – CAM strategy for the lateral slot (Operation 2, setup 2).

Fig. 9 and 10 present the comparative graphs of machining times for Operation 4 in Setup 1 respectively Operation 2 in Setup 2.

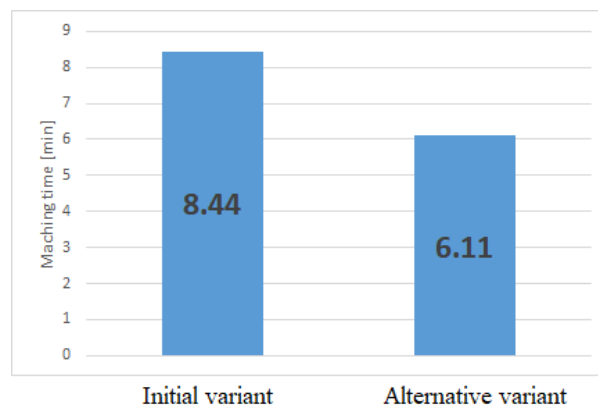


Fig. 9 – Comparative chart of machining times for Operation 4 in Setup 1.

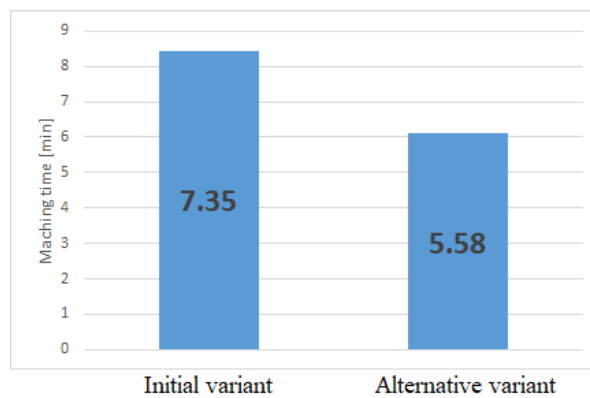


Fig. 10 – Comparative chart of machining times for Operation 2 in Setup 2.

Fig. 11 presents the total machining time graph for the two technological variants analyzed.

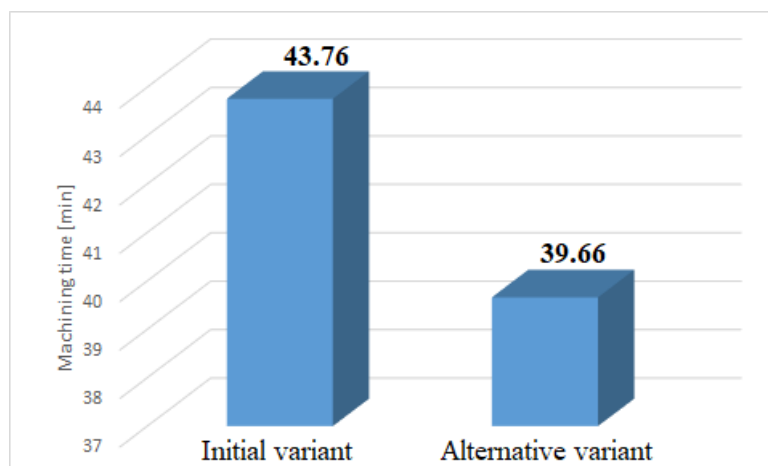


Fig. 11 – Comparative chart of the total machining time for the two technological variants.

The cumulative effect of these interventions led to a reduction in total machining time from 43.76 min to 39.66 min, corresponding to an approximate decrease of 9.37%.

The study shows that the comparative analysis of CAM variants and the identification of operations with a high share in the total process duration provide an effective basis for increasing productivity.

4. Conclusions

The identified critical operations were the milling of the outer surface in setup 1 and the milling of the lateral slot in setup 2, as these had the greatest influence on the total machining time. The initial variant required an estimated total machining time of 43.76 min, including 34.41 min for Setup 1 and 9.35 min for Setup 2. As a cumulative effect of the optimization, the estimated total machining time of the part was reduced from 43.76 min to 39.66 min, corresponding to an overall decrease of approximately 9.37%. The results confirm that CAD/CAM technology optimization can improve the efficiency of the machining process, and that the applied methodology can be extended to other parts with comparable geometry, machined in multiple setups.

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REFERENCES

- But A., *Comparative results of milling strategies implementation*, Materials Today: Proceedings, **12**, 219-224 (2019).
- Groover M.P., *Automation, Production Systems, and Computer-Integrated Manufacturing*, 5th Ed. Pearson, Hoboken, NJ, USA (2021).
- Groover M.P., *Fundamentals of Modern Manufacturing: Materials, Processes, and Systems*, 7th Ed., John Wiley & Sons, Hoboken, NJ, USA (2020).
- Kukreja A., Pande S.S., *Optimal toolpath planning strategy prediction using machine learning technique*, Eng. Appl. Artif. Intell., **123**, part C (2023).
- Pjaziti A. Tafilaj O., Gjellaj A., Berisha B., *Optimization of Toolpath Planning and CNC Machine Performance in Time-Efficient Machining*, Machines **13** (1), 65 (2025).
- Reznicek M., Horava C., *The Influence of the Choice of Machining Strategy on Production Technology*, Manufacturing Technology, **24** (1), 117–130 (2024).
- Vavruska P., Kasik F., Lomicka J., Cermak A., *Adaptive toolpath setup to reduce machining time when milling complex shape parts*, Int. J. Adv. Manuf. Technol., **139**, 2977–2995 (2025).

ABORDĂRI CAD/CAM ÎN PRELUCRAREA UNUI REPER MECANIC PE UN
CENTRU DE PRELUCRARE CNC VERTICAL

(Rezumat)

Lucrarea prezintă analiza și optimizarea tehnologiei CAM aplicate prelucrării unei piese de tip flanșă pe un centru de prelucrare vertical CNC. Studiul urmărește reducerea timpilor de prelucrare, cu menținerea geometriei finale și a preciziei impuse reperului. Piesa analizată are o complexitate geometrică medie și necesită prelucrarea în două prinderi. Metodologia a inclus modelarea piesei, stabilirea succesiunii operațiilor, alegerea sculelor, definirea parametrilor de așchiere, simularea traseelor sculelor și determinarea timpilor de prelucrare. Pe baza variantei inițiale au fost identificate două operații cu influență semnificativă asupra duratei totale a procesului, pentru care au fost analizate soluții CAM alternative. Rezultatele au evidențiat o reducere a timpului total de prelucrare cu aproximativ 9.37%, confirmând eficiența optimizării operațiilor critice în creșterea productivității procesului CNC.