TPM Vol. 32, No. S3, 2025
ISSN: 1972-6325
https://www.tpmap.org/

INFLUENCE OF CAD/CAM PROGRAMMING ON MANUFACTURING INDUSTRY

DARWIN ESTEYDIN ASTOLINGON MENDOZA[1], EDDIE JONATHAN PARIONA GUTIERREZ[2], NEICER CAMPOS VASQUEZ[3]

[1,2,3,4] UNIVERSIDAD PRIVADA DEL NORTE, FACULTAD DE INGENIERÍA, LIMA, PERÚ
[3] GRUPO DE INVESTIGACIÓN DESARROLLO E INNOVACIÓN UPN -IDIUPN
CORRESPONDENCE: EMAIL: neicer.campos@upn.edu.pe

ABSTRACT : The present article thoroughly explores the influence of CAD/CAM software on the manufacturing industry, highlighting key elements such as model transferability, the crucial importance of mechanical product design, and the continuous increase in the complexity of CNC machines. The primary objective is to impact the integration of software into the machine with the purpose of optimizing resource management, accelerating production processes, achieving optimal precision levels, and facilitating the manufacturing of parts with more complex geometric configurations. The relevance of modern computer tools in the manufacturing process of components is evident, emphasizing the importance of reconfigurable machine tools. The article extensively covers the design and programming procedure through software implementation, followed by a meticulous analysis of production times, highlighting the outstanding efficiency of modern machines in contrast to conventional ones. Furthermore, the mastery of software is emphasized to optimize the value chain, improving both efficiency and precision in the production process. Its crucial contribution to the manufacturing of more complex mechanical components is emphasized, leading to a significant reduction in the required production times.

Keyword: *Machining keyword. CNC. CAD/CAM. Post-processor.Edgecam.*

INTRODUCTION

Since the introduction of CAD and CAM software, ensuring seamless model portability between systems has been a crucial aspect in promoting their adoption. Various standardized solutions for data exchange have been proposed, including SET, VDA, and IGES. While these formats achieved some level of success, they did not fully meet the needs of CAD, CAPP, and CAM industries. To address these limitations, the international community introduced the ISO 10303 standards (Organización Internacional de Estandarización - ISO10303, 1994), known as STEP, building upon many of the standards (Kemmerer, July 1999)

The design of mechanical products plays a fundamental role in manufacturing, as it is estimated that approximately 70% to 80% of the total development and production costs are determined during the initial design stages. This process begins with conceptualizing an original product (S. Kalpakjian, S. R. Schmid, 2008) and concludes with obtaining the dimensions and shape of the parts (machine elements). Another important aspect is the selection of suitable materials and manufacturing processes, ensuring that the resulting machine performs its expected function without failure (Norton, 2011).

Today, machining processes demand increasingly complex CNC machine tools. 3-axis milling centers are gradually being replaced by 5-axis ones (Bologa O, Breaz R E, Racz S G and Crenganiş M, 2016). As components become more complex, the need for systems with higher precision arises; hence, CNC machines maintain error margins of ± 0.001 microns. To further enhance their capabilities, supplementary modules such as rotary tilt tables or additional linear axes can be integrated, although these modifications may introduce machining errors that must be accounted for (Suh S-H and Lee J-J, 1998) (Chen Z C, Dong Z and Vickers G W, 2023). Or even additional linear axes (Suh S-H, Lee J-J and Kim S-K, 1998). The inclusion of extra modules may lead to higher machining errors due to added deviations, an issue that has already been considered (Tsutsumi M and Saito A, 2024). To mitigate errors, modern CNC machines are already implemented with axes set according to the requirements for a specific job, maintaining precision in the finishing of mechanical components designed using CAD/CAM software. Adaptable machining systems have been explored as an approach to boost processing performance and enhance the versatility of technological devices (Abele E, Wörn A, Fleischer J et al, 2007) (Lorenzer T, Weikert S, Bossoni S and Wegener K, 2007). But there are few industrial implementations of them.

Contemporary CAM software are capable of detecting collisions in multi-axis machining systems; however, they depend on the kinematic representations of CNC equipment to execute this function. Standard software libraries offer limited models for the most widely used CNC machines, leaving users responsible for developing most of

them (R E Breaz, S G Racz, C E Girjob and M Tera, 2021). From another perspective, contemporary Computer-Aided Manufacturing (CAM) software packages can detect collision situations in machine tools with multiple axes of movement. However, to execute processes, it is essential to have kinematic models of the involved CNC machines. While some of these kinematic models for the most widely used CNC machines are provided as standard in program libraries, it is important to note that most of them must be built directly by users. Regarding post-processors, they are redesigned according to the characteristics and functionality of the CNC machine.
The primary focus of this investigative study lies in refining machining procedures for the manufacturing industry, achieved through the application of CNC machines. In this regard, the implementation of CAD/CAM programming is proposed to optimize resource utilization, streamline the production of mechanical components by reducing involved times, enhance milling and turning procedures, achieve optimal precision in project execution timeline planning, and enable the manufacturing of parts with more complex geometric configurations. Therefore, this research article was conducted in the city of Lima, Peru, within a manufacturing industry, considering the use of CAD/CAM technologies to produce complex mechanical components for injection molds. As a result, this research work was carried out in the city of Lima, located in the country of Peru, within a manufacturing industrial environment. In this context, the application of CAD/CAM software was considered with the aim of conducting the production of highly complex mechanical parts, intended for the manufacturing of injection molds with the assistance of CNC machines.
Ultimately, the use of technology focused on the manufacturing industry enables the development of large-scale strategies for producing components designed using CAD software. These components are then sent to CAM software and linked to CNC machines to produce the final product. In the final analysis, the adoption of technologies oriented towards the manufacturing domain provides the opportunity to devise large-scale strategies for producing components modeled through CAD software.
These components are then transferred to CAM software, which generates machining strategies to subsequently obtain G-codes for CNC machines. This process involves cutting the material to achieve the requested final producto. With the use of CAD and CAM technologies, the advantages, and possibilities of working in 2D and 3D environments are maintained, allowing the creation of solid parts with the required dimensional and design characteristics. This is reflected in the analytical capabilities of the tools used in the production process (Florin Ș., Rad M., Dobra P., and Adrian F., 2016).
Within systems related to digital manufacturing, there are some useful tools in the machining operations process (in core and cavity blocks). CAD/CAM systems can generate the necessary numerical control programs for programming and working on surfaces of complex systems, achieving the required results in machining and manufacturing operations (Pardo R., 2019). The creation of the three-dimensional template representation was carried out using Autodesk Inventor CAD design software. Subsequently, this representation was transferred to CAM software, as illustrated in Figure 1. This allowed the configuration of machining paths according to the complexity of the solid shape.
The generation of the three-dimensional representation of the component was carried out using the CAD design program Autodesk Inventor. Subsequently, this representation was imported into the CAM software, as shown in Figure 1, enabling the configuration of machining paths in accordance with the complexity of the solid geometry.

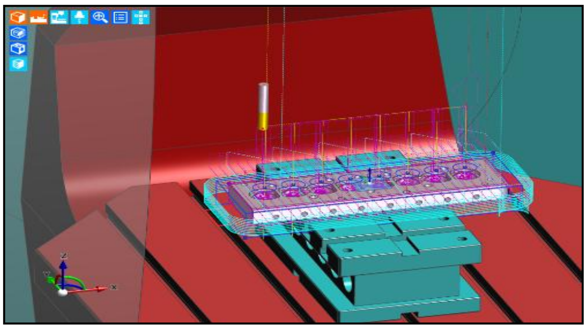


Figure 1. CAM Programming using Edgecam 2023.

In Figure 2, the model of tool geometries with carbide inserts for high feed chip removal is depicted.
Figure 2. High-Speed Tools for CNC Machining Centers.

In Figure 3, the qualities of inserts for varying material hardness types are delineated, categorized by the letters P, K, H. These inserts are versatile and exhibit prolonged durability during CNC machining.

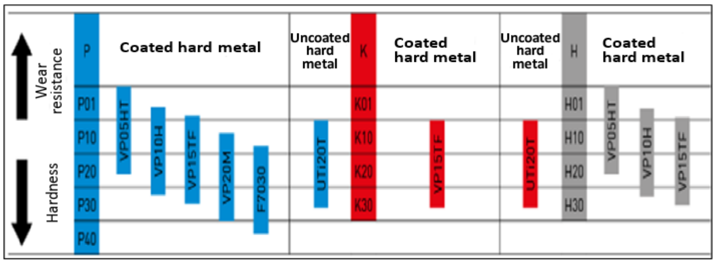


Figure 3. Overview of insert grades for CNC.
In Figure 4, machining strategies for the manufacturing of the component modeled in CAM software are illustrated. These strategies generate tool paths to execute the task on the CNC machine.

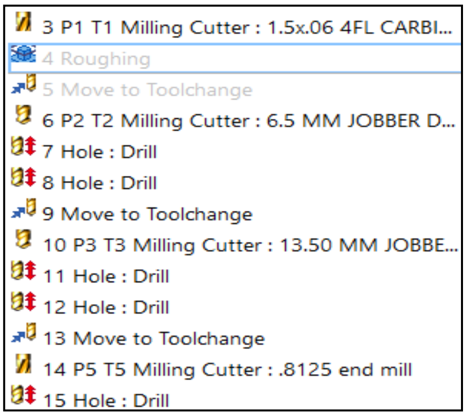


Figure 4. Machining Strategies in CAM Software.

In Figure 5, the quality and versatility of the chip breaker insert are demonstrated, maintaining the CNC machine in optimal conditions for extended operation.

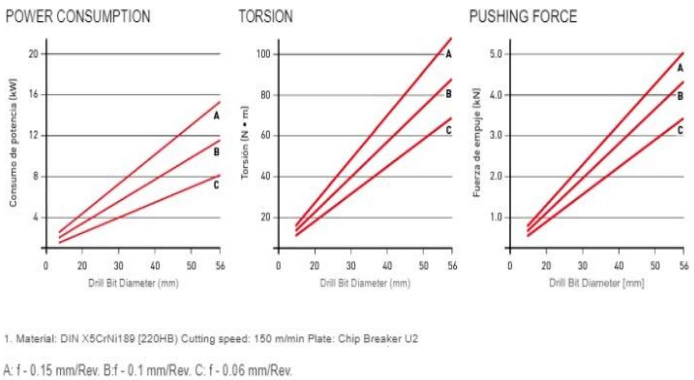


Figure 5. Cutting Resistance in TAF Drills.

In Figure 6, the assembly of a high-precision TAF drill for machining centers is depicted. This tool is designed for creating holes in solid surfaces.

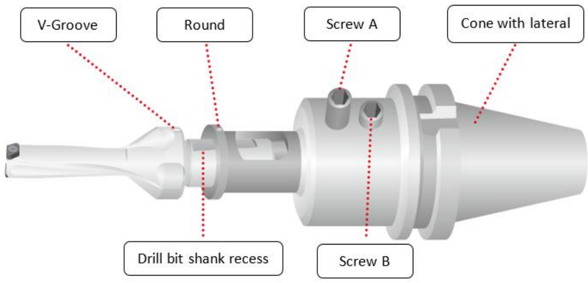


Figure 6. Assembly of TAF Drill on the BT40 Tool Holder of the HEIDENHAIN Controller in the CNC Machining Center.

METHODOLOGY

In the research, a mixed method approach, the PRISMA method, and the applied development of the CAD/CAM program were employed. This was achieved through the investigation of academic documents related to the research topic keywords, using principles of inclusion and exclusion (J. Pardal y B. Pardal, 2020). On the other hand, the application of the design and manufacturing process was developed through the use of CAD/CAM and CNC.
The search for terms or keywords in scientific documents was considered. These terms included "Efficiency," "CAD/CAM," "computer-aided design," "mold design," "computer-aided manufacturing," and "CNC." To broaden the information inquiry in the database, boolean operators such as "AND," "OR," and "NOT" were applied. Additionally, repositories such as Scopus, Scielo, ScienceDirect, ResearchGate, Alicia, and Redalyc were considered during the research pase. Next, a detailed flowchart is presented illustrating the process employed for gathering information from the mentioned databases. This process adheres to well-defined standards with the aim of accurately discerning which scientific articles should be included in the analysis and which should be excluded. In terms of inclusion criteria, all articles directly related to the field of engineering are included, and a time frame not exceeding 10 years is considered as part of the parameters for selection.

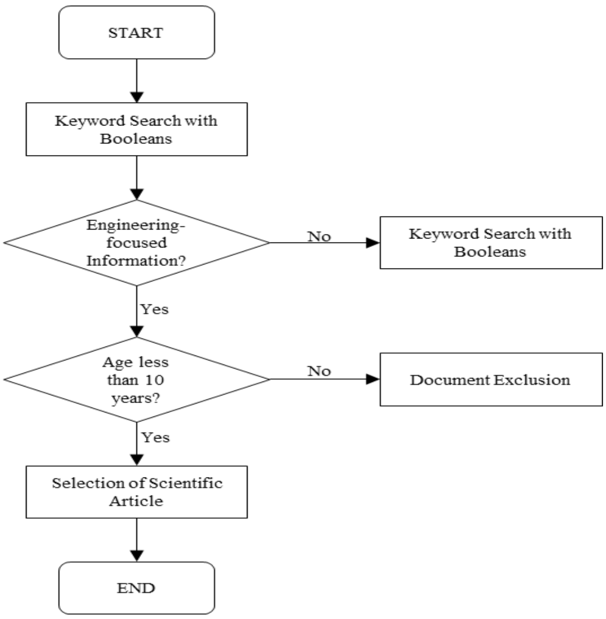


Figure 7. Flowchart of Research Article Information Retrieval.

After applying the search criteria based on the engineering field, keywords, and the time range, the search yielded a total of 10,225 articles globally. Subsequently, the irrelevant information was filtered, resulting in a total of 90 articles, as detailed in Table 1.

Table 1. Global data collection from search analysis.

Database	Number of articles	Number of searches
Scopus	10	1,875.00
Scielo	4	55.00
Redalyc	9	321.00
ScienceDirect	32	4,300.00
Alicia	10	87.00
ResearchGate	25	3,587.00
TOTAL	90	10,225.00

Similarly, Figure 8 reflects the quantities of research articles obtained through the inclusion and exclusion method from the initially filtered 90 articles for the research development within the last 10 years. Finally, a total of 30 articles remained for the investigation.

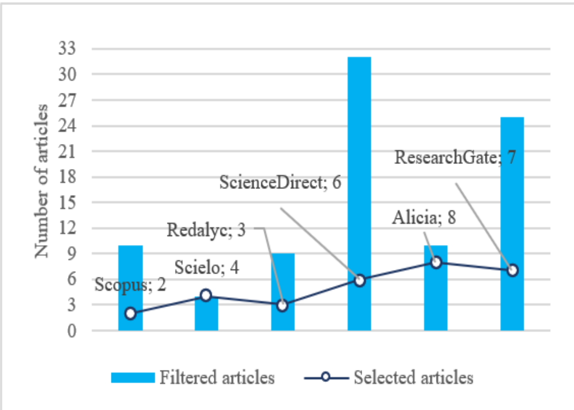


Figure 8. Selected Database Graph.

Below, the procedures to be followed for the effective application of CAD/CAM software are presented. These procedures intricately explain the operations and steps involved to achieve the final result. This is carried out through a process flowchart that details each stage of the procedure. It is crucial to highlight that, in this process, after completing the modeling in the CAD environment, the progression moves towards the programming phase in the CAM software before the work is executed on the CNC machine. This constitutes an essential step for the success of the project.

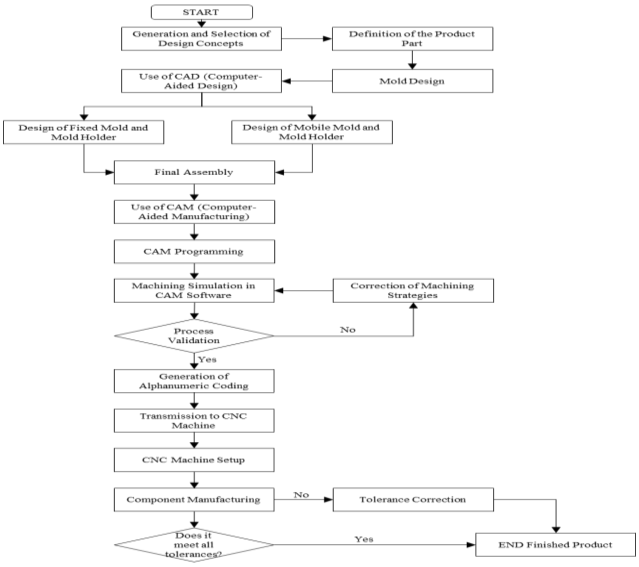


Figure 9. CAD/CAM Process Flowchart.

As detailed in the flowchart in Figure 9, the process begins with the creation and selection of the design, followed by the mold development using CAD software. This process is divided into two categories of mold design: fixed and movable. Once the mold design and its mold base have been determined, the final assembly is carried out in the CAD software environment. Once the mold is complete, it is transferred to CAM software, where machining is simulated. If the programming is correct, an alphanumeric code is generated, which is subsequently sent to the CNC machine, where the cuts are executed using CNC milling machines to manufacture the components.
If the model does not pass validation during the simulation stage using CAM software, corrections are made by applying different machining strategies that best suit the type of work to be executed. Subsequently, alphanumeric codes generated by the CAM software are obtained to be executed on the machining center. Following the sequence, the CNC machine is prepared with all the tools to be used and the steel to be transformed into a product. Finally, the program is executed on the CNC machine, and once completed, it undergoes quality control to validate the dimensional control of the manufactured component within the tolerances specified in the design.

RESULTS AND DISCUSSION

Research has demonstrated the application of design methods based on features and the use of feature identification for creating elements within a CAD/CAM model (Kramer, 1989) (Z. Gu, Y.F. Zhang, A. Y. C. Nee, 1995) (V. Allada and S. Amand, 1995) (K. Case and M. S. Hounsell, 2000). An alternative method is the combined solution, merging geometry analysis for interpreting imported models with design functions that allow their creation or adjustment (J. HAN, and A. A. G. Requicha, 1997) (T. Laako and M. Mäntylä, 1993).
Milling in machining is primarily divided into two types: face milling and contour milling. Precise toolpath generation is crucial in CNC machining, as the correct choice of the toolpath directly affects the quality and efficiency of machining the workpiece. Therefore, in the modern CAM process, toolpath post-processing is included. In the section toolpath method, it is determined through intersection lines obtained by intercepting the surface to be machined or its offset surface with some sections.
On the other hand, the residual height approach relies on the variation in height between two neighboring toolpaths on the processed surface of the part. The core concept of this technique is to model the surface using a curve or surface formed by the initial tool positions, compute the subsequent path from the previous one, and maintain a consistent height difference between the leading and trailing paths. Furthermore, it guarantees that the remaining height stays within the defined tolerance limits for the component.
Now, we will outline the equations applied in each machining type based on the equal residual height method. To do this, we propose considering the effective cutting radius of the tool as Re, the spacing between rows as L, the residual height as h, and the surface curvature radius as Rb. The formula for determining the pitch between rows is as follows:
Flat machining,

$$h = R_e - \sqrt{R_e^2 - \left(\frac{L}{2}\right)^2} \qquad (1)$$
$$L = 2\sqrt{R_e^2 - (R_e - h)^2}$$

In the actual process, since Re is much greater than h, the pitch between lines L can be calculated using the following formula:

$$L = \sqrt{8R_e h} \qquad (2)$$

Convex machining

$$h = (R_b - R_e)\sqrt{1 - \left(\frac{L}{2R_b}\right)^2} - \sqrt{R_e^2 - \left[\frac{(R_b+R_e)}{2R_b}L\right]^2} - R_b \qquad (3)$$

Simplifying and factoring the previous formula, we obtain:

$$L = \sqrt{\frac{8hR_eR_b}{R_b+R_e}} \qquad (4)$$

It is evident that the convex surface effectively decreases the residual height in comparison to the flat surface.

$$h = (R_b - R_e)\sqrt{1 - \left(\frac{L}{2R_b}\right)^2} - \sqrt{R_e^2 - \left[\frac{(R_b+R_e)}{2R_b}L\right]^2} - R_b \qquad (5)$$

Concave machining

$$h = R_b - (R_b + R_e)\sqrt{1 - \left(\frac{L}{2R_b}\right)^2} - \sqrt{R_e^2 - \left[\frac{(R_b+R_e)}{2R_b}L\right]^2} \quad (6)$$

Simplifying and factoring the previous formula, we obtain:

$$L = \sqrt{\frac{8hR_eR_b}{R_b - R_e}} \quad (7)$$

The equal residual height method refers to a concept used in surface machining processes to quantify the discrepancy between the actual height of a surface after machining and the desired height target at the end of the machining process. Figure 10 illustrates the types of machining: flat machining (A) refers to the practice of machining a flat surface, which involves creating a smooth and level surface by controlled material removal. Convex surface machining (B) aims to precisely alter the shape of the surface to achieve the desired geometry, typically by controlled material removal to obtain a flat and smooth surface. CNC machining on concave surfaces (C) involves using a CNC machine to shape and improve surface quality of objects with internal curvatures, such as concave surfaces, through precise material removal.

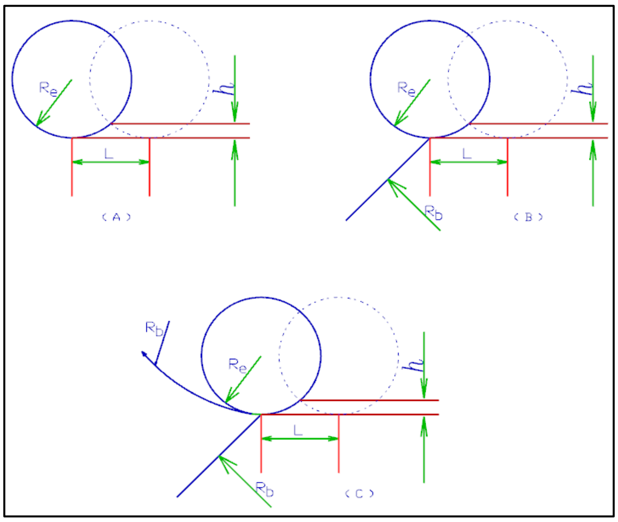


Figure 10. Equal Residual Height Method. (A) Flat Machining. (B) Convex Surface Machining. (C) Concave Surface Machining.

The concave surface, in fact, raises the residual height when compared to a flat surface. In the average residual height method for CNC machining, each toolpath is generated dynamically. To improve process efficiency, a maximum value can be set. To better control the workpiece surface and achieve higher processing quality, surface roughness, and shape, it is essential to select appropriate parameter values based on the specific processing system. The equal residual height method requires the residual height to be determined by surface quality. Moreover, it is possible to process up to a maximum value while preserving surface quality. In CAM software, there are various machining strategies such as Holes, Thread Mill, Face Mill, Roughing, Profile Milling, Flat Land Finishing, Parallel Lace, Flow Surface, and 3 to 5 Axis. These strategies implemented in CAM software allow the programmer to optimize the machining process for chip removal, generating rough cuts, finishes, and measurement on the controller. Figure 11 shows the Parallel Lace machining strategy, which allows for finishing three-dimensional surfaces modeled in CAD.

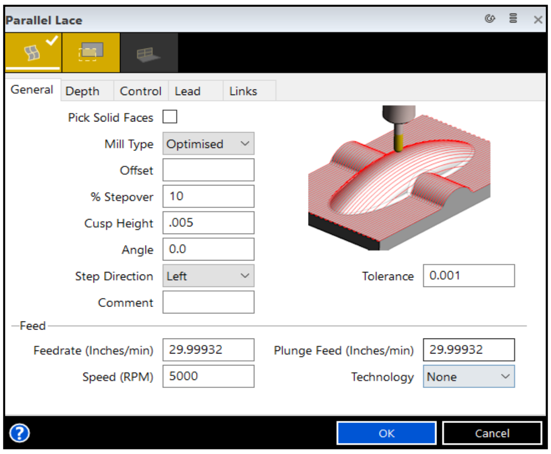


Figure 11. Parallel Lace Machining Strategy in CAM Software.

Figure 12 provides a visual representation of the diverse machining techniques employed to transform raw materials into the final product.

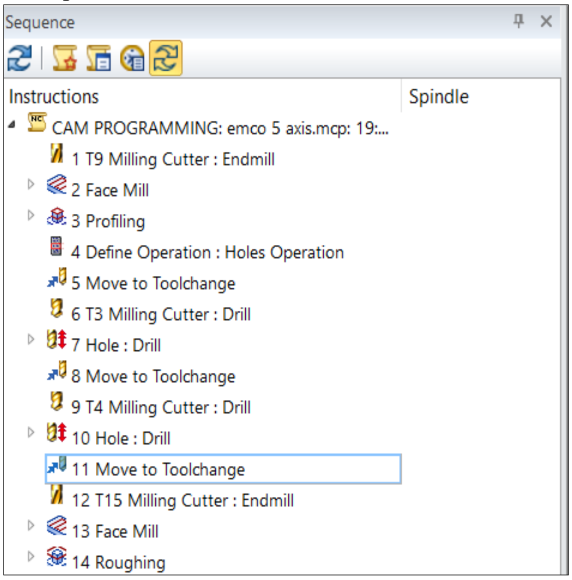


Figure 12. Component Programming through CAM Software.

In Figure 13, the verified component is achieved through the CAM software simulator.

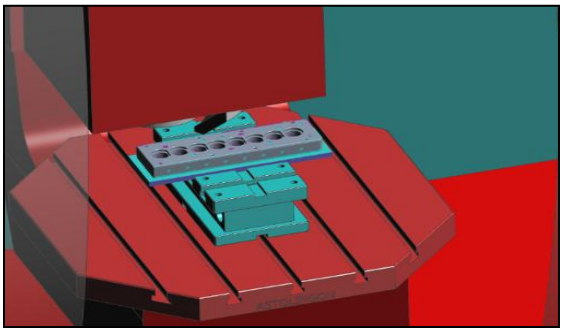


Figure 13. Verified Component in Edgecam 2023 Software.

Once confirmed through simulation that the component is correct, the next step involves generating the necessary alphanumeric codes for programming it into the CNC machine. This process is illustrated in Figure 14 (a) with a drilling program and in Figure 14(b) with a contouring program for the component.

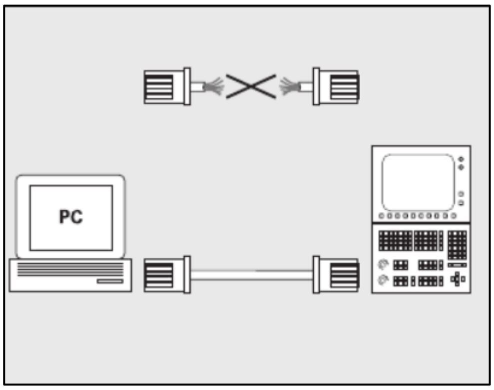
```
 TOOL CALL 3 Z S1250
L Z+633.7 FMAX M91
L X+280 Y+220 FMAX M91
 L X-110 Y+0.0 F MAX M3
 L B+0.0 C+0.0 F MAX
 L Z+100 F MAX M8
 CYCL DEF  200   DRILLING ~
 Q200=2          ;  SET-UP CLEARANCE ~
 Q201=-66.009    ;  DEPTH ~
 Q206=85         ;  FEED RATE FOR PLNGNG ~
 Q202=2          ;  PLUNGING DEPTH ~
 Q210=0          ;  DWELL TIME AT TOP ~
 Q203=+0.0       ;  SURFACE COORDINATE ~
 Q204=100        ;  2ND SET-UP CLEARANCE ~
 Q211=0.0        ;  DWELL TIME AT DEPTH
 L F MAX M89
 L X+100 F MAX
 L X+70 F MAX
 L X+40 F MAX
 L X+10 F MAX
 L X-20 F MAX
 L X-50 F MAX
 L X-80 F MAX M99
 L Z+633.7 F MAX M91
 L X+280 Y+220 FMAX M91
 B0 FMAX M91
 M5
```

(a)

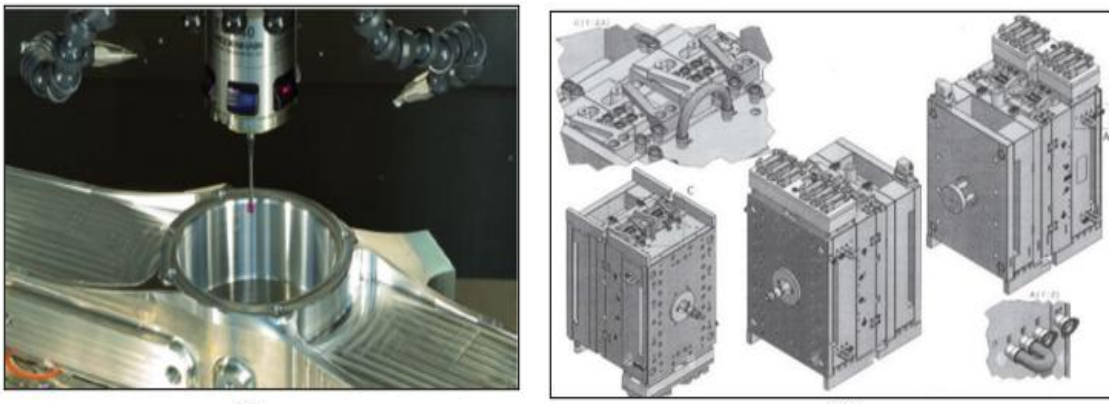
```
 BEGIN PGM 1 MM
 ;  HEIDENHAIN 5 Axis Mill1
L Z+633.7 FMAX M91
L X+280 Y+220 FMAX M91
B0 FMAX M91
 * - USER DEFINED ( CPL POST )
 TOOL CALL 9 Z S2400
L Z+633.7 FMAX M91
L X+280 Y+220 FMAX M91
 L  M3 M8
 L X-121.667 Y-89 F MAX
 L B+0.0 C+0.0 F MAX
 L Z+20 F MAX
 L Z+1 F MAX
 L Z+0.0 F500
 L Y+89 F288
 L Z+20 F MAX
 L X-73.333 Y-89 F MAX
 L Z+1 F MAX
 L Z+0.0 F500
 L Y+89 F288
 L Z+20 F MAX
 L X-25 Y-89 F MAX
 L Z+1 F MAX
 L Z+0.0 F500
 L Y+89 F288
 L Z+20 F MAX
 L X+23.333 Y-89 F MAX
```

(b)

Figure 14. (a) Heidenhain Codes for the Holes Drilling Strategy, (b) Heidenhain Codes for Profile Milling.
Figure 15 marks the initiation of loading the programs onto the CNC machine for execution, bringing the process to fruition and producing the physical component.
Figure 15. Data Transmission from Computer to CNC Machine.



Once the machining of the physical component is completed, verification is carried out using the ultra-precision electronic probe linked to the CNC machine to measure dimensions and tolerances as per the blueprint. This is depicted in Figure 16(a), (b)depicts the assembly of the finalized product of an injection mold.



(a) (b)

Figure 16. (a) Inspection of components linked to the machining center through CAM. (b) Injection Mold Assembly.

Table 2. Analysis of Manufacturing Times: Conventional vs CNC.

The data presented in Table 2 and Figure 19 conclusively highlight the superiority in temporal efficiency when using CNC. This system, previously programmed in CAM software to generate machining paths, significantly outperforms the "Conventional universal milling machine" in terms of temporal performance, where the effectiveness relies on the operator's expertise and experience to attain the specified dimensions according to the blueprint.

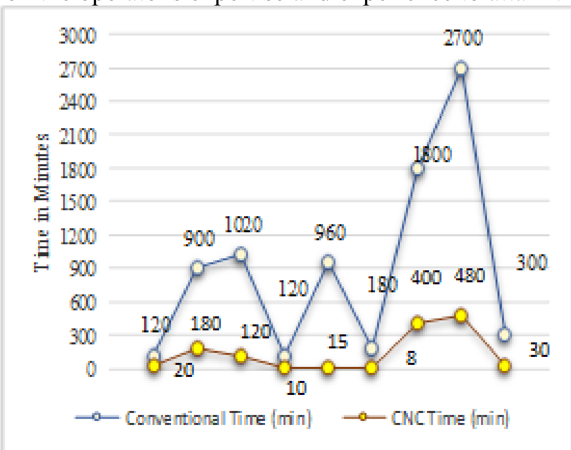


Figure 17. Time Behavior Based on Component Manufacturing.

Operations performed on the CNC machine are executed in significantly reduced time intervals, resulting in an optimization of the manufacturing process. This temporal advantage not only reduces operational costs but also

Component		**Support holder for complement**		
	Conventional Tools	**Universal conventional milling machine**	**CNC Tools**	**CNC Machining center**
Strategy	**Name**	**Time (min)**	**Name**	**Time (min)**
Planing	Tooling Ø 80 mm with planed insert	120	Tooling Ø 80.00 mm with planed insert	20
External Rough Contouring	Tooling Ø50 mm with insert	900	Fast Feed Ø 25 mm Tool with insert	180
External Finish Contouring	Tooling Ø50 mm with insert	1020	Finishing Tool APX 4000 Ø 20 mm	120
Drilling for M10	HSS Drill Ø8.50 mm	120	Supradrill Ø8.50 mm Drill	10
Coolant Drilling	HSS Drill Ø6.00 mm	960	Supradrill Ø6.00 mm Drill	15
Complement Cavity Drilling	HSS Drill Ø20.0mm	180	Taf Ø 30 mm Drill	8
Rough Contouring of Complement Cavity	Tooling Ø50 mm with insert	1800	Fast Feed Ø 25 mm Tool with insert	400
Finish Contouring of Complement Cavity	Finishing Tool APX 4000 Ø 20 mm	2700	Finishing Tool APX 4000 Ø 20 mm	480
M10 Threading	HSS Tap M10 x 1.5 mm	300	Thread Tapping Tool for Machine M10 x 1.5 mm	30
	Total Time	**8100**		**1263**

enhances product quality, ensuring a consistent level of precision. Furthermore, the capability for mass production is strengthened by maintaining the required accuracy in each machined component. It is concluded that using CAD/CAM technology alongside choosing a CNC machine for machining is a technical strategy that has a significant impact on production efficiency and economy.

CONCLUSION

The influence of CAD/CAM software in the manufacturing industry is significant. It focuses on aspects such as model portability, the critical importance of mechanical product design, and the increasing complexity of CNC machine tools. The application of CAD/CAM software and CNC machines has enabled companies to optimize design and production processes, facilitating the ability to design and simulate models in a digital environment before physical fabrication. This, along with the automatic generation of CNC machine codes, has led to increased efficiency and precision in manufacturing. Furthermore, these technologies have enabled the production of more complex mechanical components, driving innovation and competitiveness in the market.
According to results from operations conducted with CNC machines, there is a notably superior reduction in production lead times compared to conventional machine performance. Specifically, conventional machinery operates at slower speeds, while CNC machine efficiency is significantly enhanced, being 6.4 times greater than that of its conventional counterpart. Additionally, the capability of CAM software excels in creating highly complex programs, ranging from two-dimensional configurations to those involving five axes. This tool utilizes computational algorithmic processes to formulate and generate tool paths effectively and precisely. The influence of CAD/CAM software is notably demonstrated through comprehensive optimization of the value chain, encompassing every phase from initial design to the production stage. This software enables the achievement of higher levels of efficiency, fundamental expansion in adaptability, and continual implementation of progressive improvements in manufacturing procedures.

REFERENCES

- Abele E, Wörn A, Fleischer J et al. (2007). Mechanical module interfaces for reconfigurable machine tools, Production Engineering, vol. 1. pp. 421-428.
- Bologa O, Breaz R E, Racz S G and Crenganiş M. (2016). Bologa O, Breaz R E, Racz S G and Crenganiş M, Decision-making Tool for Moving from 3-axes to 5-axes CNC Machine-tool, Procedia computer science vol. 91, . pp. 184-192, 2016. .
- Bologa O, Breaz R E, Racz S G and Crenganiş M. (2016). Using the Analytic Hierarchy Process (AHP) in Evaluating the Decision of Moving to a Manufacturing Process Based Upon Continuous 5 Axes CNC Machine-tools, Procedia computer science, vol. 91. 683-689,.
- Chen Z C, Dong Z and Vickers G W. (2023). Automated surface subdivision and tool path generation for 31212-axis CNC machining of sculptured parts, Computers in Industry, volo 50.
- Florin Ş., Rad M., Dobra P., and Adrian F. (2016). Design of A Low Cost CAD – CAM Convertor For CNC Applications, IEEE 20th International Conference on System Theory, Control and Computing (ICSTCC).
- J. HAN, and A. A. G. Requicha. (1997). Integration of Feature based Design and Feature Recognition. Computer Aided Design. Vol. 29 No.5. 393-403.
- J. Pardal y B. Pardal. (2020). Anotaciones para estructurar una revisión sistemática, Rev. ORL(online) vol. II, nº 11. pp. 155- 160.
- K. Case and M. S. Hounsell. (2000). Feature modelling: a validation methodology and its evaluation. J. of Materials Processing Technology. vol. 107. pp. 15-23.
- Kemmerer, S. J. (July 1999). STEP The Grand Experience. Manufacturing Engineering Laboratory, National Inst. of Standards and Technology.
- Kramer, T. R. (1989). A parser that converts a boundary representation into features representation. Intl Journal of CIM. vol. 2. No. 3. pp. 154-163.
- Lorenzer T, Weikert S, Bossoni S and Wegener K. (2007). Modeling and evaluation tool for supporting decisions on the design of reconfigurable machine tools, Journal of Manufacturing Systems, vol. 26.
- Norton, R. (2011). *Diseño de máquinas. Un enfoque integrado, 4ª ed.* México: Prentice Hall.
- Organización Internacional de Estandarización - ISO10303. (1994). In *Integración y sistemas de automatización industrial - Representación e intercambio de datos de productos - Parte 1: Descripción general y principios fundamentales.*
- Pardo R., A. (2019). CAD / CAM system for rapid prototyping by adding or subtracting materials using Computer Numerical Control (CNC), IEEE XXVI International Conference on Electronics, Electrical Engineering and Computing (INTERCON).
- R E Breaz, S G Racz, C E Girjob and M Tera. (2021). Study on the application of CAM techniques on CNC lathes with Y axis and driven tools, Materials Science and Engineering, vol. 1009.
- S. Kalpakjian, S. R. Schmid. (2008). *Manufactura, Ingeniería y Técnología 5ª ed.* México.
- Suh S-H and Lee J-J. (1998). Five-Axis Part Machining with Three-Axis CNC Machine and Indexing Table, Manufacturing Science an Enginering.
- Suh S-H, Lee J-J and Kim S-K. (1998). Multiaxis machining with additional-axis NC system: Theory and

development, The International Journal of Advanced Manufacturing Technology, vol.14.

- T. Laako and M. Mäntylä. (1993). Feature Modelling by Incremental Feature Recognition. Computer Aided Design. vol. 25 No. 8. 479-492.
- Tsutsumi M and Saito A. (2024). Identification of angular and positional deviations inherent to 5-axis machining centers with a tilting-rotary table by simultaneous four-axis control movements, International Journal of Machine Tools and Manufacture, vol. 44.
- V. Allada and S. Amand. (1995). Feature-based Modelling Approaches for Integrated Manufacturing: State-of-the-art Survey and Future Directions, International Journal of Computer Integrated Manufacturing. vol. 8, No. 6. pp. 411-440.
- Z. Gu, Y.F. Zhang, A. Y. C. Nee. (1995). Generic form feature recognition and operation selection using connectionist modeling. Journal of Intelligent Manufacturing. vol. 6. pp. 263-273.