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MACHINING STRATEGIES FOR AUTOMOTIVE STAMPING TOOL BASED ON MACHINING SIMULATIONS: A BENCHMARK OF HYPERMILL SOFTWARE.

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Machining of stamping tools for the automotive sector is a research topic of large interest. The industry is continually searching for strategies, machines, tools and parameters to improve machining performance, to increase the quality of the machined surfaces, and to reduce the total cost of construction and tryout phases of the stamping tools. The CNC machines allowed large developments in the machining sector. However, in order to explore the full potential of these machines in the cases of complex geometries such as automotive tools, the Computer Aided Manufacturing (CAM) software must be used. The CAM softwares are a powerful solution that enable a large number of analyses simulating different strategies allowing one to choose the best combination of operations, tools and parameters of a given toolmaker facility, as well as it can be a compelling argument to drive new investments to increase the competitiveness of the toolmaking industry. The Brazilian government program Rota 2030 possesses a line of research and development called Ferramentarias Brasileiras Mais Competitivas (FeB+C) (in English, More Competitive Brazilian Tool Shops), and within the context of this line, the MISCAE Project aims to investigate the applications of simulation tools to increase the competitiveness of the Brazilian toolmaking industry. This paper consists in one of the contributions of the MISCAE Project in the field of CAM simulations to develop the Brazilian industry. The objective of this paper is to perform a series of studies comparing different machining strategies applied to automotive stamping tools using the software HyperMILL, evaluating the processes commonly used in contrast to the most advanced resources proposed by the software. The combinations of different machines (3-axes, 3+2-axes and 5-axes), operations, cutting tools and parameters will be assessed, and the following parameters will serve as metrics: machining time per operation and the number of operations. As a result, a benchmark is provided for the Brazilian tooling sector.

Abstract.

Keywords: *CAM, machining time, strategies, CNC, benchmark*

1. INTRODUCTION

Currently, the automotive tooling sector is strongly influenced by the trend of innovation in the manufacturing of its molds and dies for stamping, seeking to reduce costs and increase the diversity of processes.

To adapt to this trend, and to maintain the level of global competitiveness, the companies involved in this industrial chain seek technological solutions and innovations to optimize the manufacturing process in the machining of these components, which are of high importance in the automotive sector. The Rota 2030 project aims to list these and other alternatives that are effective in raising the technological and competitive level of Brazilian Tool Shops (FeB+C).

Two of the important factors that constitute the manufacturing cost of the stamping tools are machining and finishing, as there are difficulties in the machining process due to the complexity of the shapes of the components. The surface finish of these machined components has great influence in the quality and dimensions of the stamped parts, requiring that the stamping tools possess surfaces with a high level of finishing. (CAVALLARI JUNIOR, 2013).

In fact, when dealing with unique parts or specific geometric figures characteristic of the automotive industry, some high-cost processing technologies are needed, especially automation services as in the case of CNC. Thus, modifications are sought so that the processes can achieve the best results in terms of cost and production time.

With the need for time optimization in the manufacturing industry, CAD/CAM systems have been helping to improve the quality of the manufacture of surfaces with complex geometries, in less time, increasing productivity and minimizing manufacturing costs (WRUBLAK; PILATTI; PEDROSO, 2008).

When these modifications are applied in milling machining processes, especially regarding to processes that need finishing with tight tolerances, there is a technological deficit in Brazilian tooling sector where companies seek simple processes and simple tools, thus bringing little innovation in terms of finishing complex parts for tooling.

Investigating the technologies for finishing of complex surfaces, it is observed that the conical barrel cutter can replace the common spherical mills used daily in the tooling industry. According to some project partners, China, where the promising market for these cutters was identified, the cutter pipe cones were evaluated and, as a result, it was found to be extremely efficient when invested in the finishing of automotive parts. Among some of its advantageous characteristics are greater durability, better finishing quality (i.e., less roughness), less machining time and lower production cost. With correct management, it is intended that this tool combined with the HyperMILL software is a profitable and technological alternative to raise the competitive level of Brazilian toolmakers.

In summary, this paper aims to make a comparison of strategies of machining for a B column component of the automotive sector, correlating machine tools with different capabilities (i.e., number of movable axes), machining time and programing machine using different cutting parameters and tools, inside HyperMILL environment.

2. MATERIALS AND METHODS

In this section, materials and methods will be briefly exposed. First, a definition of the CAD/CAM system will be presented. Then, the Hypermill software and the conical barrel cutter will be introduced. Then, the different strategies analyzed in the present work will be presented.

2.1 MATERIALS

- **CAD/CAM system**

The CAD/CAM (Computer-Aided Design/Computer-Aided Manufacturing) is a simulation system used to design and manufacture prototypes, finished products and production processes. CAM software uses the models and assemblies created in the CAD software to generate toolpaths for machines and tools to convert designs into physical parts. An integrated CAD/CAM system provides a complete solution, from design to manufacturing. Figure 1 presents a flowchart of the phases of the CAD/CAM/CNC chain applied in the manufacture of complex surfaces.

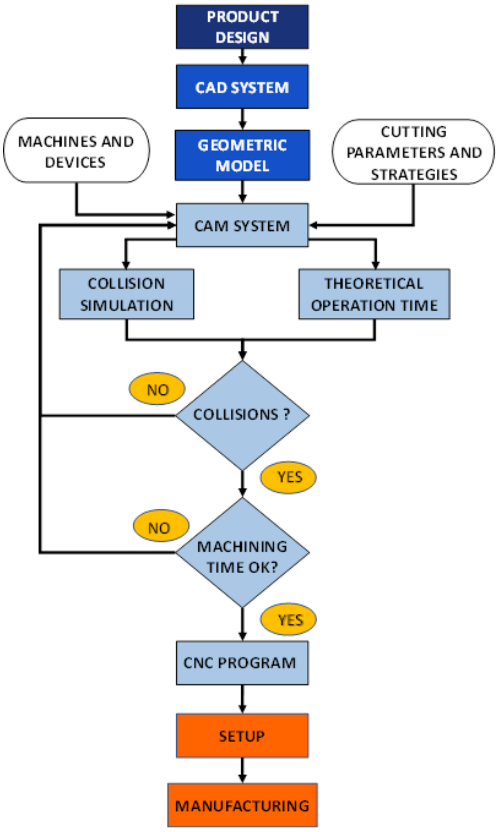

Figure 1. Flowchart chain of CAD/CAM phases manufacturing of complex surfaces.

- **HYPERMILL**

The HyperMILL CAM software is one of the solutions that has been used in the tooling industry, where the objective is to make the machining simulation and execution more accurate through its interpolation strategy. The CNC programming task is made easier since the software possesses features to generate the numerical code through basic interface commands, e.g., selecting the surfaces to be machined and defining the cutting parameters. Figure 2 presents an illustration where the surfaces of the B column punch that were analyzed in the present work were selected, and the interpolation that was performed. This software also possesses an interface for different cutting tools that enables quick integration of cutting tool parameters in the numerical code. As an example, the conical barrel milling tool that is used in the global market for its versatility in finishing complex surfaces is parametrized in a way that the user can quickly change the cutting tool features (radii, length, angles, etc.) and the software calculates the trajectory as well as identifies machining limitations (i.e., collisions and machinable areas). Combining the CAM's own interface and the characteristics of the cutting tool, one can obtain satisfactory results in terms of surface finishing, time reduction in the machining process and programming, increased use of the tool potential (e.g., automatic adaptation of the contact point of incidence), thus ensuring surfaces with high quality and tight dimensional tolerance.

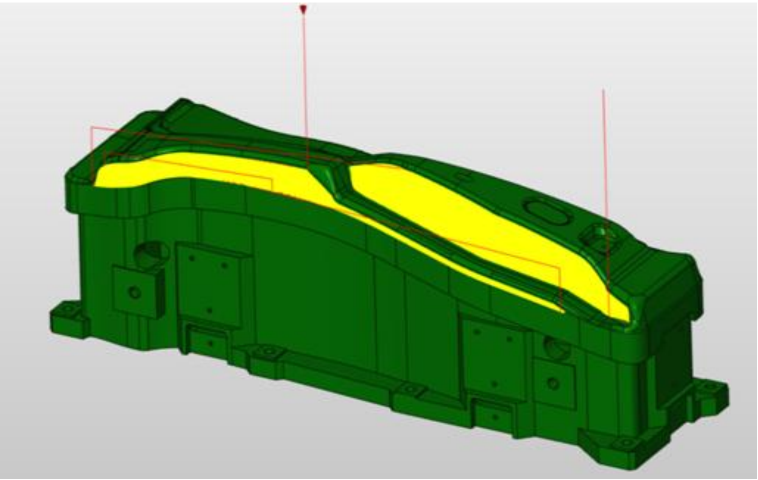

Figure 2. Selection of surfaces in software HyperMILL.
Source: Open Mind Technologies Brazil, 2021

- **CONICAL BARREL CUTTER**

The conical barrel cutter is a tool used in finishing and machining of complex surfaces due to its versatility. Thanks to its large radius, it allows a greater incidence of cutting contact, making it possible to take advantage of the full potential of the machining tool. Figure 3 illustrates the application of the conical barrel cutter for surface machining. Three key dimensions of this tool are the cone angle (α), the cone radius (r_c) and the tip radius (r_t). The large cone radius combined with optimal cutting parameters enable high surface quality and tight dimensional tolerances, achieving lower surface roughness. In addition, the spherical geometry at the tip confers adaptability in applications in CNC machines with 3-axes, 3+2-axes, and 5-axes. The larger diameter of the tool above the cone region implies in greater stiffness when compared to traditional spherical cutting tools with the same tip radius. The increase in stiffness reduces problems with vibrations and also contributes to better surface finishing.

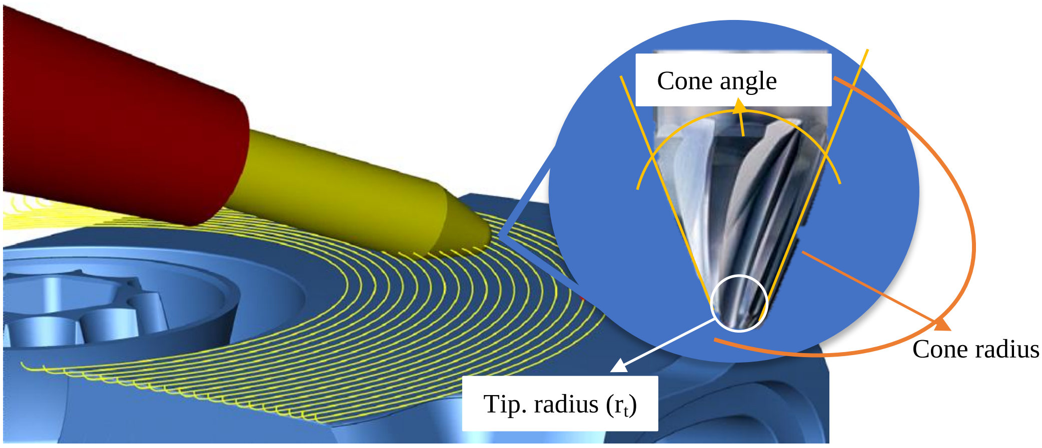

Figure 3. Barrel conical cutter.
Source: OpenMind Technology Brazil, 2021

2.2 METHODS

To carry out the simulations, it was necessary to assemble a matrix of combinations (Table 1), comparing the conical barrel cutter with the Spherical Cutter in different machines, having as output: time, programming cost and tool cost.

Table 1: Simulation combination: Operation × Type of Tool × CNC type Machine.

	OPERATION: FINISH	CNC MACHINE TYPE	TYPE OF TOOL
A		3-axes	Spherical
B		3+2-axes	Spherical
C		5-axes	Barrel
D		3-axes	Barrel
E		3+2-axes	Barrel

The second step was to set the machining parameters such as tool diameter, cutting speed (VC), cutting depth (AP), spindle speed (RPM - revolutions per minute) and feed rate (VF) for the tools. The parameters considered “optimal” for the operations are given in Table 2.

Table 2: Tool parameters.

OPERATION	CNC MACHINE TYPE	DIAMETER	VC	AP	RPM	VF (MM/MIN)
A	**3-axes**	$r_t = 12$ mm	2	0,3 mm	6419	6419
B	**3+2-axes**	$r_t = 12$ mm	2	0,3 mm	12750	2336
C	**5-axes**	$r_t = 16$ mm ($r_c = 1000$ mm)	3	3 mm	2100	822
D	**3-axes**	$r_t = 16$ mm ($r_c = 1000$ mm)	3	1 mm	2100	822
E	**3+2-axes**	$r_t = 16$ mm ($r_c = 1000$ mm)	3	1 mm	2100	822

After making the decision of the parameters, the HyperMILL software was fed with the information and set according to the milling cycle process to be carried out. Figure 4 shows a parameterization of the conical barrel cutter in the software, demonstrating the ease of programming. The same procedure was replicated for the other combinations.

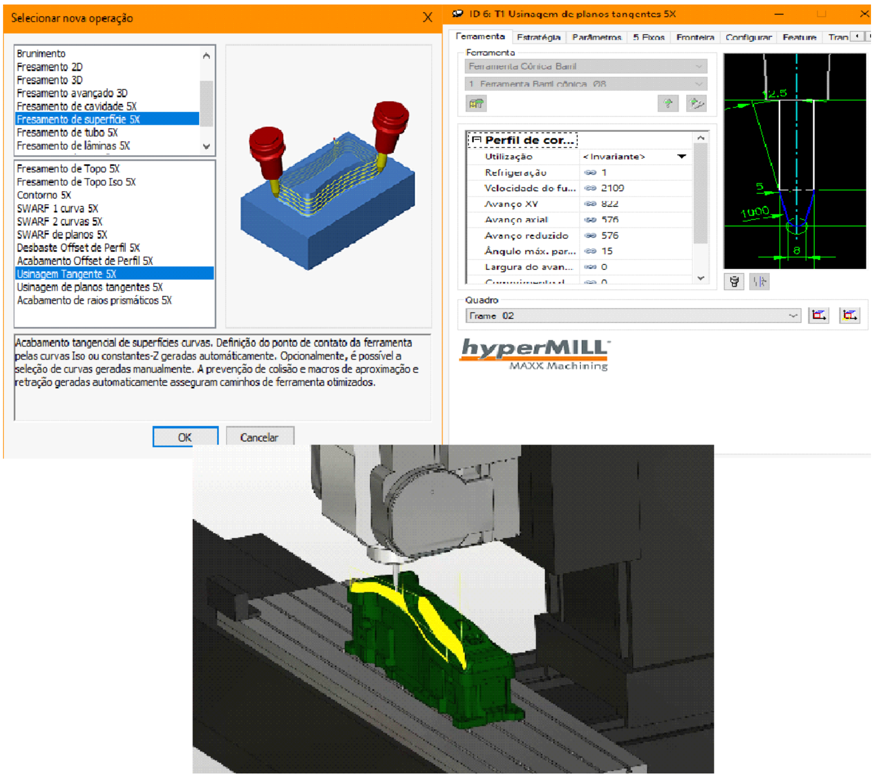

Figure 4: Feed of milling cutter Barrel Taper and parameters in HyperMILL and simulation.
Source: OpenMind Technology Brazil, 2021.

3. RESULTS AND DISCUSSIONS

After performing the simulations, Table 3 was obtained, which shows the results obtained for programming time and machining time for the respective combinations stated in the methodology.

Table 3: HyperMILL simulation results for machining time and programming time.

OPERATION	CNC MACHINE TYPE	MACHINING TIME (min)	PROGRAMING TIME (min)
A	**3-axes**	173	1
B	**3+2-axes**	67	7
C	**5-axes**	34	12
D	**3-axes**	105	1
E	**3+2-axes**	62	20

A. Finishing 3-axes spherical cutter

For the simulation of a spherical milling cutter in a 3-axes CNC machine using HyperMILL, the face selection strategy was used, which facilitated the choice of the programmer of the walls to be machined, obtaining a programming time of 1 minute, being an advantageous time. However, there are disadvantages when machining with a spherical cutter on 3-axes CNC machines. Generally, parts with complex surfaces in the automotive sector have large walls, which greatly limit machining movements, have less tangency, longer machining time, and consequently poor surface quality. Figure 5 shows the surface finish result of the simulation of machining with a 3-axes spherical milling cutter. The pink color reveals the area where material was not removed. The blue lines reveal the boundary between the machined and non machined areas. The pink and blue treads inside the machined surface (gray area) highlighted in Figure 5, as well as the kinky boundary (in blue) of the gray area indicates poor surface quality and the kinematic limitation of the 3-axes CNC.

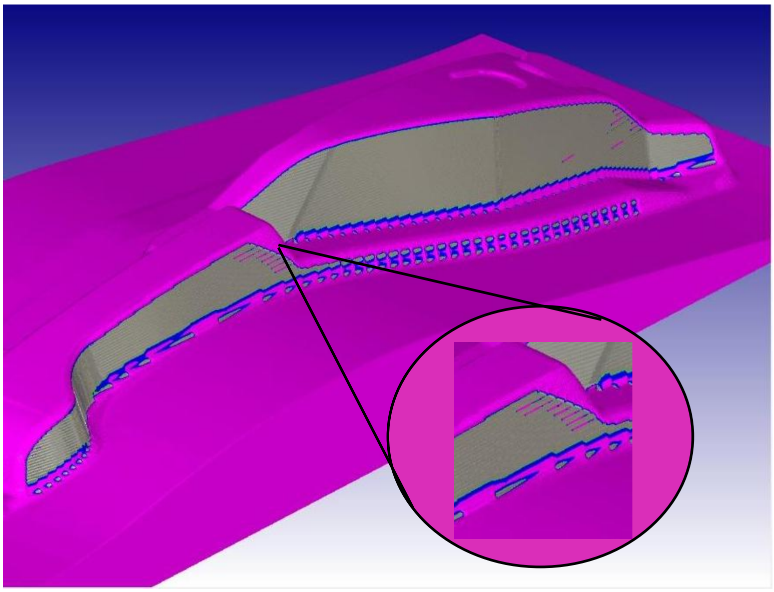

Figure 5: Finishing simulation with a spherical cutter on a 3-axes CNC machine.
Source: HyperMILL Software, Authors.

B. Finishing 3+2-axes spherical cutter

The simulation with 3+2-axes had a longer programming time of 7 minutes, but on the other hand it was more advantageous in machining. These machines enable a more stable process, because they allow a versatility of angles for the contact point in the machining, resulting in better superficial finish. Figure 6 shows the simulation results.

There was a reduction of the non machined area, and it can be seen that the blue boundary of the machined area presents smaller kinks, revealing a better quality of the machined surface. In addition, the small increase of 6 minutes in programming time was largely compensated by the reduction of machining time of 106 minutes (61%), resulting in a net saving of 100 minutes.

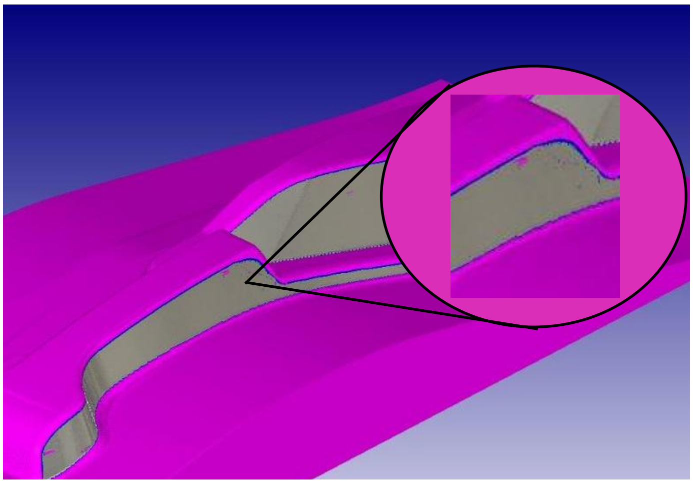

Figure 6: Finishing simulation with a spherical cutter on a 3+2-axes CNC machine.
Source: HyperMILL Software, Authors.

C. 5-axes simultaneous finishing for conical barrel cutter

The simulation for 5-axes using spherical milling was not performed, as it is not recommended since the feed is calculated from the slowest axis of the CNC machine (usually the slowest axis is the rotation axis), with this the machine acceleration becomes low, making it unfeasible to use in this situation.

However the conical barrel cutter combined with a 5-axes machine presented the best results in terms of time saving. Although the programming time has increased by 12 minutes, the machining time reduced from 173 to 34 minutes (80% reduction), which represents an 74% improvement in the total time combining programming and machining. This result reveals that this is the best combination for this kind of cutter. Nevertheless, expressive time reductions were found also using the conical barrel cutter in 3-axes and 3+2-axes machines, as will be seen in the sequence.

Figure 7 shows the results obtained in the simulation. And one can see that the surface finish provided by the conical barrel cutter is much better than all other solutions.

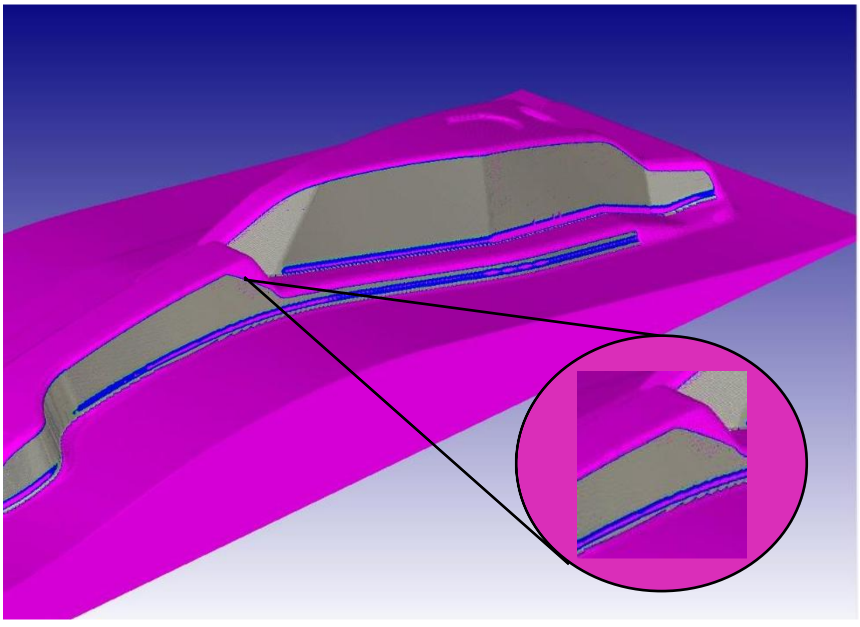

Figure 7: Finishing simulation with a 5-axes conical barrel cutter CNC machine.
Source: HyperMILL Software, Authors.

D. Finishing 3-axes conical barrel cutter

The 3-axes finishing using a conical barrel cutter is not one of the best scenarios, the best results for this configuration would be achieved for a plane face in a specific angle in relation to the tool. Therefore, it was required a study to find the best angle between the tool and the part, which was 14°. As a result, after the definition of the angle, the programming time is small, but it does not contain the full information of angle studies time. This strategy did not obtain a satisfactory surface finish, as can be seen in the pink areas in the gray faces shown in Figure 8, and also presents long machining time (105 minutes) as presented in Table 3. However, it is still better than using the spherical cutting tool in the same machine, presenting a reduction of 40% of the machining time, while presenting a better surface finish.

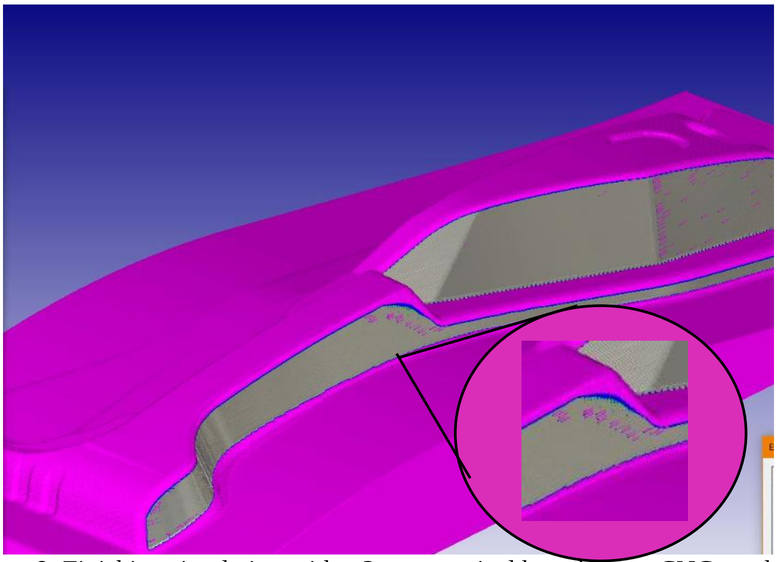

Figure 8: Finishing simulation with a 3-axes conical barrel cutter CNC machine.
Source: HyperMILL Software, Authors.

E. 3+2-axes finish with conical barrel cutter

Using a conical barrel cutter with a 3+2-axes machine is not as efficient as using a 5-axes machine, given the kinematic limitations of the first in comparison to the latter. As a result, this strategy presented a longer programming time, 20 minutes, compared to the 12 minutes of the 5-axes strategy. With respect to machining time, the 62 minutes of the 3+2-axes strategy are almost twice of the 5-axes strategy.

Comparing this strategy to the 3-axes using the spherical cutter, it provides a 64% reduction of the machining, and allows a better angle for indexing, making it more useful for the tool, obtaining greater depths of passes and better surface finish. Figure 9 shows the results obtained in the simulation.

However, in terms of 3+2-axes machines, there is not a significant reduction in machining time when compared to a spherical cutter using the same strategy. In addition, the CNC programming of the conical barrel cutter consumes more time compared to the spherical cutter. Therefore, the advantage of the conical barrel cutter, in 3+2-axes machines, resumes to surface finish, which is still key to the tool making industry.

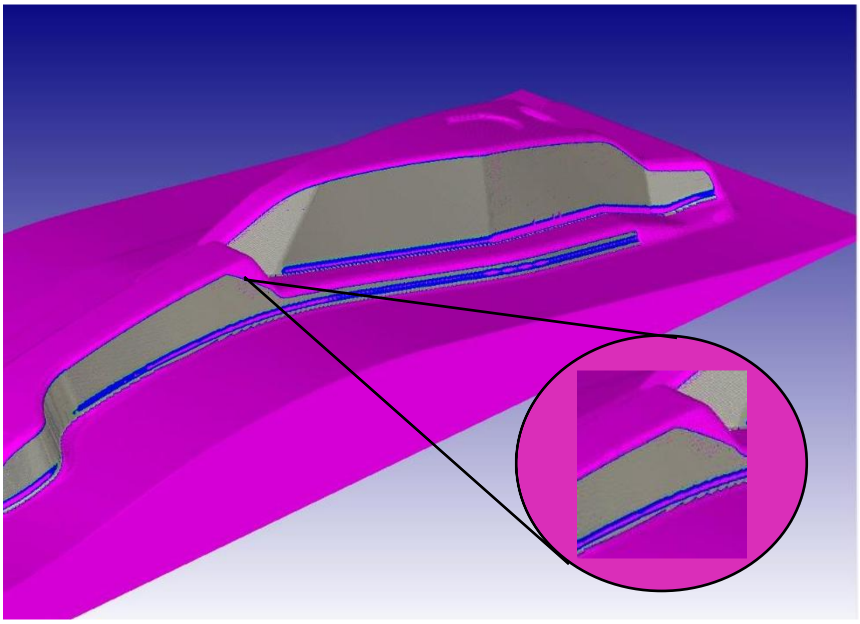

Figure 9: Finishing simulation with a 3+2-axes conical barrel cutter CNC machine.
Source: HyperMILL Software, Authors.

4. CONCLUSION

The present work assessed different machining strategies for finishing surfaces of a stamping tool of the automotive sector using the HyperMILL software. Comparisons were made using different machine tools, cutting tools and machining parameters. The CAM technology was of extreme importance to enable simulations and CNC programing in a noticeably short time. Such technology facilitates decision making in the face of different machining strategies, in addition to abruptly reducing programing time.

The 3-axes machining strategies using spherical cutter demonstrated what was already expected and commonly used in the industry, the surprising result was that even a 3-axes conical barrel cutter that does not use the maximum of the machining tool potential performed better than the normal spherical cutter, thus showing the agility and flexibility of the advantages of using this tool in the automotive sector in the tooling industry. The best scenario was characterized by the use of the conical barrel cutter with the 5-axes strategy, bringing 80% reduction of the machining time compared to the spherical cutting in 3-axes machines, together with better finishing. In terms of 3+2-axes machines, there is not a significant difference between the two cutters in terms of time saving, however the conical barrel cutter still provides better finishing which is of great importance in stamping tools.

The present work provides a benchmark that is of great relevance for the Brazilian Tool Shops in order to renew, innovate and modernize their machinery and operations. This consists of an important result to the Rota 2030 Project, as it serves as a reference to guide future investments, and to help in the development of the tooling industry in Brazil, thus becoming a reliable source to make companies more competitive.

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7. RESPONSIBILITY NOTICE