

CASE STUDY OF THE IMPLEMENTATION OF A CAD/CAM SYSTEM FOR PLASTIC INJECTION MOLDS IN A COMPANY OF TWO WHEELS SECTOR IN MANAUS INDUSTRIAL POLE

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Abstract. *This work shows a research project that developed a case study and solution to a CAD/CAM system implementation process at a components manufacturer by parts for motorcycles Company located on Manaus Industrial Sector. The project adopted the software NX 7.0 as computational tool. Given the absence of CAD/CAM system and lack of intellectual resources to operate these higher-level systems, it was noted the lack of local capacity to the production of plastic injection molds, and this situation requires the process to be outsourced. Considering this scenario, the company found itself in many difficulties concerning to the manufacture of parts and components, since their designs are coming from the matrix of outside, and most of them were sent in A3 printed boards. These boards were first sent to engineering sector for conference and adaptation, in case drawing changess were needed according to available machinery and tools at Manaus branch. Then, the boards were sent to the tooling sector, in printed format, for digitalization (modeling) on 2D (CAD) and subsequently programmed for machining (CAM). The main reason of sending parts for tooling at printed format instead digital was given by the incompatibility between the software used in tooling, TopSolid, and the used in engineering, AutoCAD Vision, causing long delays in the productive process, since the tooling should to redraw parts previously designed instead programming manufacture and machine it. The deployment process of CAD/CAM system has come a long way since the structuring environment (drawing office) used for modeling/projecting of parts and components produced by the enterprise, until its total implementation and operation. For this, the production process was divided into four stages: Training and staff qualification; Environment preparation to receive the new system; Study and Research in the enterprise and Knowledge application into company's environment. At the end of new CAD/CAM system implementation process, positive results were obtained, since the new system abled great improvement in quality of parts and components produced by the company, since toolmakers and designers involved in the project received necessary training to operate the software and, the process became more streamlined. So new software enabled drawings received by engineering could be sent in digital format for tooling to be programmed for machining. The project's main objective was also achieved, since the company can now produce its own plastic injection molds, eliminating outsourcing and reducing process costs.*

Keywords: *Computer Aided Design, Computer Aided Manufacturing, Plastic Injection Mold*

1. INTRODUCTION (Times New Roman, bold, size 10)

This work presents the implantations of CAD – computer aided design/CAM – computer aided manufacturing, in a two wheels company of Manaus. This demand was due to the inefficiency of the used system in producing components and injection molds. Was realized the structuring of modeling environment and new system implantation in the company.

The company found difficulties on components and parts machining, since these drawings came from an external pattern and, mostly printed in A3 boards. This boards were first sent for engineering sector for conference and adequation, if necessary modifications according with the machinery and tools available in Manaus filial. Then the boards were sent to the tooling sector, in printed format, for digitalization (part modeling), 2D (CAD), and later this parts modeled were programmed for machining (CAM). The main reason for parts being sent in print format (boards) for tooling sector is that the software used on engineering sector wasn't compatible with the one used on tooling, leading in productive process delay, since the tooling redraw the parts, instead just programming for manufacturing and machining.

The injection molds used in determined parts and components processes, were outsourced, since the software used by the company, while allowing the modeling, don't have good performance and the designers and toolmakers responsible by it development don't had adequate training in the software.

Then, this study aimed to present the company process optimization by the implantation of new system CAD/CAM software, starting of the environment structuring (layout) until the new system implantation. The software used in the new CAD/CAM system was the NX 7.0 (Siemens PLM Software), since this allows that parts and components are

designed, modeled, tested (machining simulation) and later sent to the machining center. The software proposed has compatibility with extension AutoCAD (.dwg) files, permitting that the files modified by engineering was sent for tooling in digital format, not in printed format. This facilitates the process since only the generation of parts machining strategy will be necessary, process simulation and program routing for machines, if the program is correct. Other criteria used for software selection, is based on the Verifying List for new CAD/CAM system, proposed by Voisinnet (1998).

For both, a description of the ideal state for configuration of modeling environment was realized, based in norms, researches, observations, photographic registries, among others. Even, a historical survey and bibliographical references about CAD/CAM systems will be realized, describing their functions, advantages and disadvantages, relating the experiences obtained by other companies that already have this system implanted.

2. THEORETICAL REFERENCES

2.1. CAD/CAM systems

Hordeski (1986) says that in a typical CAD/CAM system user interacts with the computer via graphic terminal, drawing and producing with information storage in a server, permitting more efficiency on development of engineering routine activities, since the automation of repetitive functions were provided, developing this activities more efficiently and quickly comparing with manual methods. Since the information is storage on computer memory instead of printed copy. The data transfer tends to be faster, reliable and less redundant.

CAD supports project functions; storage of drawings independent of their complexity; recuperation and modification of archives; data entry via terminals or table tracer; new projects elaboration from existent projects. The CAD systems are most than simple drawings, permitting volume, weight, dimensions, resistance, among others kind of calculus, being quickly realized by computer, eliminating the construction of expensive test models. The CAM permits that machines executes operations through computer instructions. Enable that computer determines the *forward* and spindle; dimensional measures; tooling selection; feed rate control; cut depth, forces and moments to be applied (Hordeski, 1986; Martins e Laugen, 2001).

Romeiro-Filho *et al.* (2010) says that CAD/CAM softwares are classified like high-end or top of market the classical softwares based on mainframes (central computers), being result of first CAD systems and of recent products created for Workstations. These softwares do applications CAD that could be considered classical: the automobile, aerospace, metal-mechanics with a greater sophistication degree, etc. There's another group of CAD software's classification, low-end, or, base of market, developed for personal computers. This software's group, lower cost, usually has limitations on the projective resources, making it interesting only for applications that don't need a large number of calculus, like simple products, architectural drawings and common applications of small companies, etc.

2.3. Environment adaptation and computerized workstations

The ergonomic recommendation for workstations projection involves behavioral patterns of users and observations of system requirements, and the tasks demands. The basic principle to be observed during the workstations projecting is that the furniture should be as flexible as possible. (MORAES E PEQUINI, 2000).

The continue work on graphic terminals demands height adjusts and keyboard and screen distances. The controls for dimensions adjusts, according to Grandjean (1988 *apud* Moraes and Pequini, 2000), should be easily handled, particularly when work is distributed turns.

Iida (2005) says that one relevant factor on projecting environment is the layout that consists on space distribution or relative positioning of various components on environment. For layout elaboration some criteria should be observed, presented on the following:

- Importance – most important elements should be placed in a prominent position, allowing continuous observation or manipulation;
- Use frequency – Frequently used items should be placed in a prominent position or easier to reach and manipulation;
- Functional arrangement – elements with similar functions should be placed in blocks;
- Use sequence – elements used in some operational planning must be arranged in their sequence of use;
- Flow intensity – the flow of materials, information or intense body movements determine which proximity the elements must be arranged;
- Preferred links – Distinct elements with connections flow of activities should be closer allocated.

Regarding space for people movement, Iida (2005) points out the necessity of correct sizing of gaps in halls, passages and stairways. Drury (1985 *apud* Iida, 2005) reports that when a hall narrows to less than 60 cm, the probability of errors (bumping into people and walls) was above 80% at small speeds. Increasing the width from 64 cm, people can walk normally without forcing the body movements in ever increasing speeds.

According with NBR ISO 9050:2004, the minimum spacing for people movement should be between 120 and 150 cm, allowing the circulation up two people (a pedestrian and wheelchairs) and 150 a 180 cm for two wheelchairs, providing the passage and to maneuver the chairs.

The design of spaces for human activities and accommodations also requires attention. Moraes and Pequini (2000) argue that these spaces, ranging from 86 to 92 cm (or 100 cm), to chairs away from the work surface. Diffrient (1981*apud* Moraes and Pequini 2000) explains that the chairs next to the work surface should be 56 cm from its proximal edge and could be up to 50 cm under the table, according to NBR ISO 9050:2004.

2.4. Human adaptation and training

As the worker achieves experience on the execution of specific tasks, he becomes able to regulate his energetic expenditure, accelerating the execution of his activities, reducing the fatigue and increasing his productivity. Otherwise – the absence of experience – difficult the execution of tasks increasing the possibility of errors and the sensation of fatigue. (IIDA, 2005).

One way of potentiate the professional tasks results occurs through the training organization, especially when changes on activities are realized, resources and/or task environment; or when the professional is beginner in the company.

According to Iida (2005), training is the enrichment of memory through operational knowledge, providing increase of declarative knowledge (Standards, manuals and others) and operational (how to do) when applied to specific activities.

3. MATERIALS AND METHODS

In order to implement a new CAD/CAM system in a company of two wheels of PIM, was necessary to follow some steps, shown below:

3.1. Study of environment layout

Consisted not only in the evaluation of the conditions of environment where the system will be inserted, proposing improvements, ordering better system functions according with ergonomic parameters and standards founded on the literature about circulation and layout for new workstations. Measurements were realized utilizing: 01 (one) measuring tape; pencil; eraser; annotation paper; clipboard. Unsystematic observations were realized too with the intent of characterizing the problems founded and photographic registrations of the environment, supporting the comprehension of the current situation.

3.2. Staff Training

Consisted in three months training on NX 7.0 software offered by UFAM (Amazon Federal University) in agreement with Siemens PLM Software, aiming to enable the involved people in all modules offered by NX, named: Modeling (environment to create parts and components), Assembly (junction of parts and components), Mechanical Free Form (modeling from surface), Manufacturing (generation and simulation of machining programs from parts and components), Molding Wizards (generation of plastic injection mold cavities) and Electrode Design (generation of electrodes for determined surfaces). NX 7.0 software was chosen based on Voisin Checklist (1988). The materials used during the training were: 30 (thirty) desktop computers, software books, pen, annotation paper and 01 (one) data show.

3.3. Inquiries

Simultaneous and consecutive verbalization techniques were used to inquire the workers. According with Moraes and Mont'Alvão (2007) this techniques were used during the operator activity execution through posterior presentation of observations, respectively, in order to improve the knowledge about the activities realized on the environment.

For both, 6 (six) people were inquired, being 4 (four) toolmakers form 5 (five) and 2 (two) engineers.

3.4. CAD modeling and CAM programming

At this stage was the application of molding knowledge obtained during the training, redrawing parts modeled in the old system and digitalizing the boards sent by the parent company, located on the Exterior, and realizing CAM programming, simulating the machining in virtual environment, to send data for machining center CNC, decreasing errors and material waste, accelerating the final product manufacturing.

Tests for machining the first injection plastic molds cavity were realized, using CHSHAPE800 (Azul Resinas) resin, tools and machinery provided by the company. This allowed the operators and designers to visualize the obtained results on parts and components, for modeling process improvement through the generation of new machining strategies, and selection of appropriated tools.

For achievement of best results, was primordial training of machining techniques in advanced level through a complementary course, called “Machining Strategies”. For both, were used 10 (ten) notebooks and 01 (one) data show.

4. RESULTS

4.1. Previous environment state

4.1.1. Activities of tooling sector

The tooling sector was responsible for the modeling (CAD) and manufacturing (CAM) of parts and components produced by the company, being these components for motorcycles, like: boards, transformation circuit case, generators, among others.

However, the tooling sector should be responsible only for manufacturing, since the engineering sector is the primary developer of parts and components to be produced. This demand stemmed according to the following issues: 1. The engineering sector received the drawings of parts to be projected, from the parent company on the exterior, in A4 printed boards, since the software used on the parent wasn't compatible with the engineering sector software, AutoCAD Vision (.dwg). The engineers were responsible for draw the parts, and, if necessary to adapt these according with the machinery and tooling available on the company; 2. The tooling received the drawing from the engineering in printed format, because the software used (TopSolid) don't support the software platform used by the engineering, being necessary to remodel in its software, programming the manufacture, generating some production delays.

4.1.2. Computational resources and technical procedures

The CAD/CAM system implanted on tooling sector had three computers, one machining center with CNC command and one wire electro-erosion machine. The software CAD/CAM used by this sector allowed that the parts were modeled (CAD) and manufactured later (CAM). The computers were connected directly for a FTP (File Transfer Protocol) of one machining center (CNC) by cables, permitting that the parts projected and modeled (CAD), be manufactured through a program generation (CAM), that enables the visualization if the machine strategies were in accordance with what will be produced, through simulation. If the strategies are attending to the objectives, the program is post processed and sent for the machining center.

In the case of the wire electro-erosion machine, by the fact that the machine isn't connected to a network, the parts were projected on TopSolid and exported for other software, called Pythagoras – only one with extension accepted by the machine – then the program was generated and saved in a pen drive that will be connected on the machine for part manufacturing.

The knowledge acquired for toolmakers on the software was insufficient, because they didn't had a satisfactory training, since the training received was only of four days. Furthermore the program interface wasn't interactive, difficulty the software handling since the toolmakers waste much time trying to project parts. Only with some use, they realized that the purchased software didn't attend completely all the company needs, which meant that new software alternatives were sought.

4.1.3. Environment state

The room used for parts and components modeling was the Tooling Sector Administration. This room was composed by a physical space of 24 m², comprising 3 workstations incorrectly sized, like: cabinets and equipments, was notorious that people and wheelchairs circulation was compromised by the excess of furniture in the environment, as shown below, Fig. 1.

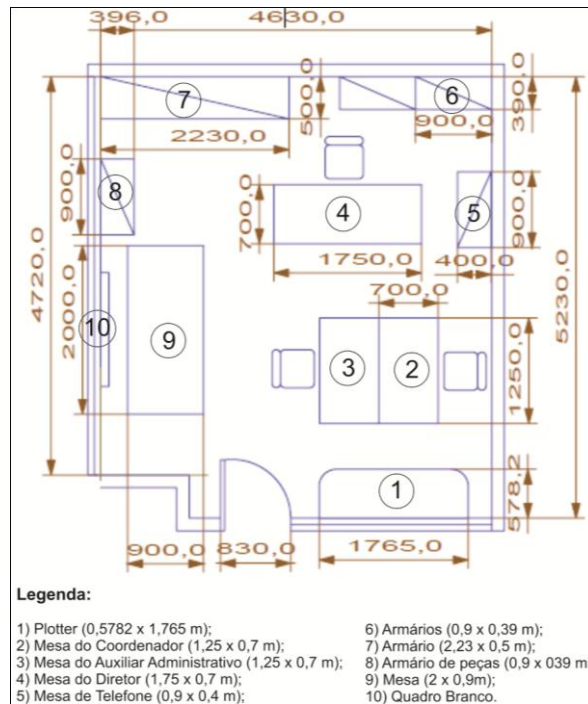


Figura 1 – Tooling Administration's Sector layout (with measures and furniture).

With the implantation of new system, the company will be able to hire three new designers permitting more speed for parts modeling process, making clear the need of environment restructuration.

4.2. New productive experiences - Current environment state

4.2.1. Training

The chosen software was the NX7.0, since it integrates knowledge in industrial design, geometric modeling, advance analysis, graphic simulation and engineering, providing resources in hybrid modeling by the integration of constraints and geometric modeling. Beyond geometric modeling parts, allows the user drawing complex free forms, mixing solid and surface modeling techniques in a set of tools.

NX 7.0 software, beyond being more interactive than the previous software, has a package more adequate for the company needs, since had environments like *assembly* (assemblies parts for products confection), *mold wizards* (plastic injection molds confection), *shape studio* (complex surfaces drawing and plates by *NURBS* – Non Uniform Rational Basis Spline), *electrode design* (creation of erosion electrodes), having *sketch* (project) environments and *manufacturing* (products manufacture) much simplified.

The software seller, in partnership with UFAM – Amazon Federal University – offered a training of three months in all software environments, attending a class with just over 30 students, being 05 toolmakers and 01 engineer of the focal study company.

4.2.2. Environment layout

With the resources offered by the software, the company had the need to hire new designers (as showed on Fig. 2), resulting in the acquisition of new chairs and equipments (three computers and one printer) to be used at a table with 2,00 x 0,9 m, in the Administration of Tooling Sector, where the modeling activities were developed. With new furniture arrival, was noted that the people circulation space (between the two tables showed on Fig. 3) was reduced, corresponding to a space less the 90 cm recommended for one person circulation. So, was verified a difficult on free people circulation and speed reduction on activities execution in the environment.



Figura 2 – Designers executing parts modeling. Three computers on one table are noted.

Based on realized observations, was proposed a new organizational layout for the environment. This news layout permitted better flow of people inside the environment, circulation of wheelchairs, easy access to parts and documents storage in the cabinets, and to equipments (computers, plotter and printer).

Unfortunately, the new layout was denied by tooling sector coordination, because would be necessary the discard of the current furniture for confection of new (adequate for environment measures) would generate costs for company.

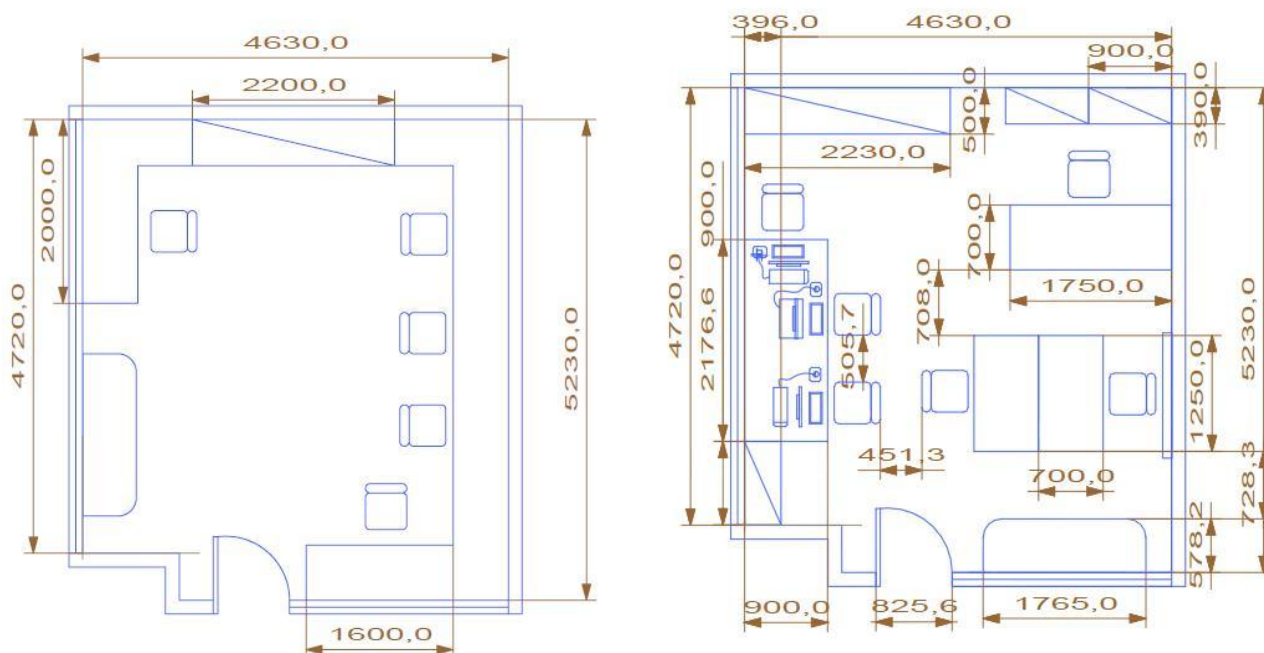


Figura 3 – At left, layout proposed for Tooling Administration Sector Room. At right, layout accepted by coordination.

Although the environment had obtained better space utilization, was impossible to solve the problem of people circulation between the designers and administrator table, since the space between the two chairs, even close to the work surface, don't reach the minimum space of 90 cm.

4.2.3. CAD/CAM system implantation results

The implantation of new CAD/CAM system in the company has improved the production of parts, because of the union of new software (NX 7.0), with the training realized, providing to the toolmakers and designers the knowledge for best generation of machining strategies, permitting better finishing on products quality.

First, was put in practice the modeling (CAD) knowledge acquired during the training in business environment, providing the remodeling of parts and components produced by the company and the digitalization of boards produced in the Exterior. After, were generated and simulated the programs (CAM) needed for parts producing.

To prove the knowledge obtained, a case study with two parts produced for the company was realized, being used 01 "Puncture Stamping" and 01 "Case of Transformer Circuit". Initially, modeling (CAD) was made and then the manufacturing program (CAM) of parts.

During first part machining, the "Puncture Stamping", some difficulties was found with regarding the machining strategy used, resulting on break tooling. This problem could be solved with "Machining Strategies" course that

consisted on two extended modules offered by UFAM in partnership with ITA – Aeronautical Technology Institute, to complement the courses previously offered by company developer of NX 7.0, Siemens PLM Software.

After the course offered, was continued the first part machining, since the toolmakers and designers would be able to set properly the equipment and tools to be used, making the process more efficient.

Figure 4 shows the finishing difference obtained from the puncture machined by the previous system (right) and by the new system (left). The strategy generated by NX 7.0 has smooth surface finishing, with defects and beaten absence.



Figura 4 – Puncture machining used on printing engine. At left, the puncture machined with NX 7.0; at right, with TopSolid.

Although TopSolid (software used on old CAD/CAM system) is a “low-range” software (low cost, large resources, but with low quality), the part finishing result occurred by software misapplication, being generated inadequate machining strategies, because of toolmakers lack of training, providing parts with lower superficial finishing.

The second part machining, the “Case of Transformer Circuit”, was made from a plastic injection mold on resin, avoiding waste of raw material, on this case, steel. The chosen resin was CHSHAPE800 (Azul Resinas), using as criteria for selection its low cost and machinability characteristics, like:

- Lightweight;
- Easy glue;
- Speed Machining;
- Low density;
- Less wear cutting tools;
- Excellent machinability;
- Dimensional stability;
- Ease of working with hand tools
- Resistance in the contours;
- Low water absorption;
- Excellent surface finish;
- Reduced dispersion of dust.

The mold cavity machining was divided on the steps below:

- a) **Component Modeling:** A part model was done using *Modeling* environment, with real dimensions of part that will be injected in the mold;
- b) **Mold Cavity Modeling:** Using *Mold Wizards* environment, first work piece is defined (raw) and then the closing geometry (what will be considered positive and negative). Everything negative is “core” and positive, “cavity”. On “Case of Transformer Circuit” case there’s two cavities and one core.
- c) **CAM Programming:** Using *Manufacturing* environment, operations and tools are defined and their sequence of use during the process. The steps related to operations are divided as following: thinning, pre-finishing and finishing. The machining strategies were configured according with tools available in the company, being used the operations below, as showed on Tab. 2:

Table 1 – Tools used on mold machining.

		Ferramentas	Operações
Cavity	Superior	Milling cutter right top 24 mm	Planar Mill
		Milling cutter right 24 mm	Cavity Mill
		Milling cutter right 18 mm	ZLevel Profile
		Millig cutter ball end 4 mm	ZLevel Profile

Core		Milling cutter right top 8 mm	Face Milling
		Millig cutter ball end 8 mm	ZLevel Profile
		Millig cutter ball end 2 mm	ZLevel Profile
		Milling cutter right top 4 mm	ZLevel Profile
	Inferior	Milling cutter right top 24 mm	Planar Mill
		Milling cutter right top 24 mm	Cavity Mill
		Milling cutter right top 18 mm	ZLevel Profile
		Milling cutter right top 18 mm	Face Milling Area
		Millig cutter ball end 3 mm	ZLevel Profile
		Millig cutter ball end 2 mm	ZLevel Profile
	Superior Face	Milling cutter right top 24 mm	Cavity Mill
		Milling cutter right top 12 mm	Face Milling
		Milling cutter right top 12 mm	ZLevel Profile
		Milling cutter right top 8 mm	ZLevel Profile
		Milling cutter right top 4 mm	ZLevel Profile
		Millig cutter ball end 4 mm	Contour Area
		Millig cutter ball end 2 mm	Contour Area
	Inferior Face	Milling cutter right top 24 mm	Cavity Mill
		Milling cutter right top 12 mm	ZLevel Profile
		Milling cutter right top 4 mm	ZLevel Profile
		Millig cutter ball end 2 mm	Contour Area

The functionality of operations is listed bellow according with Siemens PLM Software (2010), training book of *NX Manufacturing Fundamentals*.

- Cavity Mill: General thinning (3 axes);
- Contour Area: Selected regions finishing (3 axes);
- Face Milling: Face milling planar (face mills 2,5 axes);
- Planar Mill: Planar machining 2D (2,5 axes);
- ZLevel Profile: Side walls machining - pre-finishing (3 axes).

d) Simulation: On *Manufacturing* environment too, a simulation of productive process is made before the machining, ordering to avoid programming errors and assess the finishing improved by tools and operations to be used.

e) Machining: This step is divided in 6 sub-steps, like: block measurement and resin cut, blocks dimensions conference, using a caliper rule, blocks numeration, blocks fixation for machining, sending program (simulated) for CNC and then, machining.

After completion of all steps and its sub-steps, the final result is obtained, testing mold cavity, ordering to evaluate the obtained results (superficial finishing and parts quality) with the new system. Figure 5 illustrates the mold cavity of “Case of Transformer Circuit”.

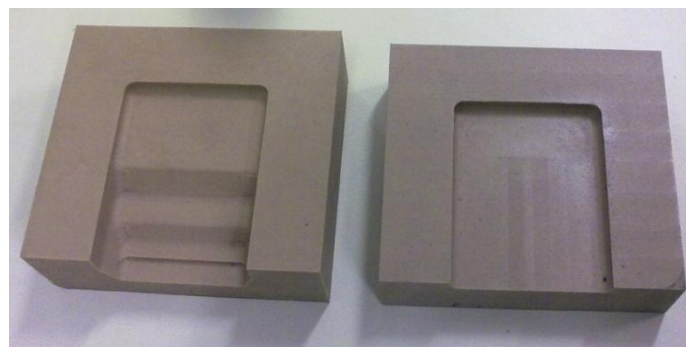


Figure 5 – Mold cavity opened for better visualization.

Based on Fig. 5, is notorious that, for initial tests, satisfactory results were obtained with regard of molds production. However, some adjusts will be necessary regarding the machine strategy used, aiming better finish and quality for the molds. Before, the company didn't machined its own injection molds, being necessary their outsourcing, what in the future will be possible, since the new software permitted their machining, being necessary only the improvement of the used strategies.

6. CONCLUSION

The company analyzed, through the use of NX 7.0 software, trainings offered to toolmakers and restructuration of tooling administration environment, obtained significant gains over its productive process in a whole.

In the principle, was necessary the restructuring of tooling administration environment, since the same don't presented conditions that, not only propitiate people circulation, and sequencing and organization of work accelerating the activities to be realized. Although, the structural recommendations for the environment were based on standards and ergonomic concepts, not all could be admitted due to impediments established by the company according with the politics and operating standards.

However, even not configured in the proper way, the environment provided the necessary conditions for the great performance of the new system, allowing its implantation.

The implantation of the system, through the use of NX 7.0 software - greater interactivity in the previous system -, combined with the offered training, provided some gains to the company: higher process efficiency, lower time for parts production, lower costs, increase on the quality of parts and the machining of molds cavity in resin.

Therefore, it appears that improvements were obtained in the company productive process, both as regards the use of new CAD/CAM system, like the utilization of some ergonomic recommendations proposed for the environment.

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