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Manufacturing of injection moulding tool with five axis milling machine

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ABSTRACT

Purpose: The main intention of this paper is to show the advanced technology for production of the electrode for EDM that has a relatively complex geometry. Five axes CNC machining centre is used for production of an example ice scrapers since application of other type of machine requires a lot of auxiliary time and resources.
Design/methodology/approach: Advanced manufacturing technology involves the application of various software tools and technologies, among them the tools and technology to automate the design, analysis, testing and manufacturing occupy a key position.
Findings: The main outcomes are decrease of production time, better quality of surface and product geometry. Decrease of cutting time refers to decrease of number of used tools, preparation time is lower in comparison with conventional machines.
Research limitations/implications: The practical part included the design of electrode in the CAD system, SolidWorks 2010, production of NC program for the operating unit Haidenhain iTNC 530 in CAM system ESPRIT 2010, and finally making the electrode on five axis machine center DMG DMU 40 Monoblock.
Originality/value: Presented technology for a five-axis machining centre, ensures a great advantages in the process preparation while reduced set-up time, reduced number of required accessories and devices, reduced number of special tools is needed. This knowledge can support the development and design of technological processes
Keywords: Machining; Five axis milling machine; CAD/CAM; Injection moulding

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1. Introduction

Workshops, specialized in metal removal, placed very high demands for machining, low production costs, reliable delivery, rational management of material and information flows in production systems, and the possibility of competition in highly demanding markets. All this is impossible without new approaches to machining processes such as CNC technology and application of CAD / CAM systems.

The well-known task in making the tool for injection moulding is a production of adequate electrode geometry for electro discharge machining (EDM). Therefore a lot of small details should be under attention while determining machining technology, because the panel for making moulds, guidelines, ejectors and other accessories is easy to obtain since they are produced in standard dimensions.

The 5-axis milling is widely used in machining of parts with complex geometries. Although, in general, this process increases the process capability, it also brings additional challenges due to complex process geometry and mechanics. In milling, cutting forces, tool deflections, and chatter vibrations may reduce part quality and productivity [1].

When machining complex geometries, the orientation and positioning of the work-piece on the table are chosen by the operator from the Computer-Aided Manufacturing (CAM) software. These two factors have considerable influence on the machining time [2]. The quality of the product is also one of the most important point of view in the market competition, international trade, and in a strategic purpose [3].

When deciding on the processing phases for a part, a significant impact of its geometry should take into analysis. In this manner, the difficult to cut surfaces represents the problem for machining from certain angles, but however, due to rapidly evolving technologies, today there are machines with several axes and it is possible to use CAD / CAM systems. The processing part geometry has a very important impact on cutting process and it is therefore necessary to optimize cutting regimens for each material.

Tool and die firms are usually small in number and total employment. They play a central role in manufacturing innovation: any durable-goods manufacturer seeking to introduce a new product is likely to require customized tools, dies, and moulds to make metal, plastic, and ceramic components. While most tool and die production is used to make consumer durable goods, the industry also plays an important role in manufacturing of such equipment [4].

Disciplines in CAD/CAM technology are shown in Fig. 1.

Benefits of the optimization of machining process of complex form products, can be achieved when high performance machine tools and cutting tools are used. The optimisation refers on the use of the cutting tools, improving the surface quality, stock removal while four or five axes machine tools are used.[5]

Disadvantages of three axes machining results from the existence of very low cutting speeds, even null when the tool axis is normal to the machined surface. This mode of machining generates a bad surface quality. Surfaces have a poor topography and important anisotropy. A suitable slope of the cutting tool by the means of the fifth machine tool axis, improves considerably work piece machined surface quality [6].

From practical point of view, searching for high-speed, collision-free trajectory planning methods for NC machines, and taking into consideration the qualitative assessment of obtained solutions in terms of optimality, have the great importance [7].

Prediction of machining forces is also an important parameter in high performance cutting of free form surfaces that are commonly used in aerospace, automotive, biomedical and die/mould industries [8].

1.1. Advantages and disadvantages of CNC technology

Although 5-axis milling machines and CAM systems with 5-axis capabilities have existed for many years, it is fairly recent that have been useful for the manufacture of Moulds and Dies. Challenges facing 5-axis CAM programmers involve more than just making collision free 5-axis CAM cutter-paths. Programmers must consider not only cutter-path calculation times, but also collision checking calculation times, in relation to all programming times [9].

Advantages of CNC technology can be summarized:

- Programs are in various ways to enter the engine control unit,
- Programs are easier to modify and supplement it,
- Correctness of the program can be simulated on the machine itself,
- Less time programming and preparation processing,
- Complexity of parts produced is larger,
- A control unit supports 3D geometric models as a basis for automatic generation of programs,

Disadvantages of CNC technology are:

- CNC machines can require significant initial investment,
- Training for operators may be more complex and expensive,
- Maintenance costs are higher.

These disadvantages are less important than the profit provided by CNC technology. This is supported by the fact that the conventional NC machines are now completely suppressed from use. 85% of the machines made today belong to the CNC class.

CNC technology is now applied in many fields of industry and processes:

- Machining processes: turning, milling, drilling, grinding, electro, plasma cutting, laser cutting, punching, bending, etc.
- Welding and assembly processes,
- Managing the production and transportation equipment: robots, cranes, vehicles.

1.2. Description of the EDM process

The principle of EDM, also called electro discharge or sparkerosion machining, is based on the erosion of metals by spark discharges. When two current-conducting wires are allowed to touch each other, an arc is produced. If we look closely at the point of contact between the two wires, we note that a small portion of the metal has been eroded away, leaving a small crater.

Although this phenomenon has been known since the discovery of electricity, it has been highly developed. The EDM process becomes as one of the most important and widely accepted production technologies in manufacturing industries [11].

Principle of operation: The EDM system consists of a shaped tool and the work piece, which are connected to a power supply and placed in a dielectric fluid. When the potential difference between the tool and the work piece is sufficiently high, a transient spark discharges through the fluid, removing a very small amount of metal from the work piece surface.

The capacity discharge is repeated at rates between 50 kHz and 500 kHz, with voltages usually ranging between 50 V and 380 V and currents from 0.1 A to 500 A.

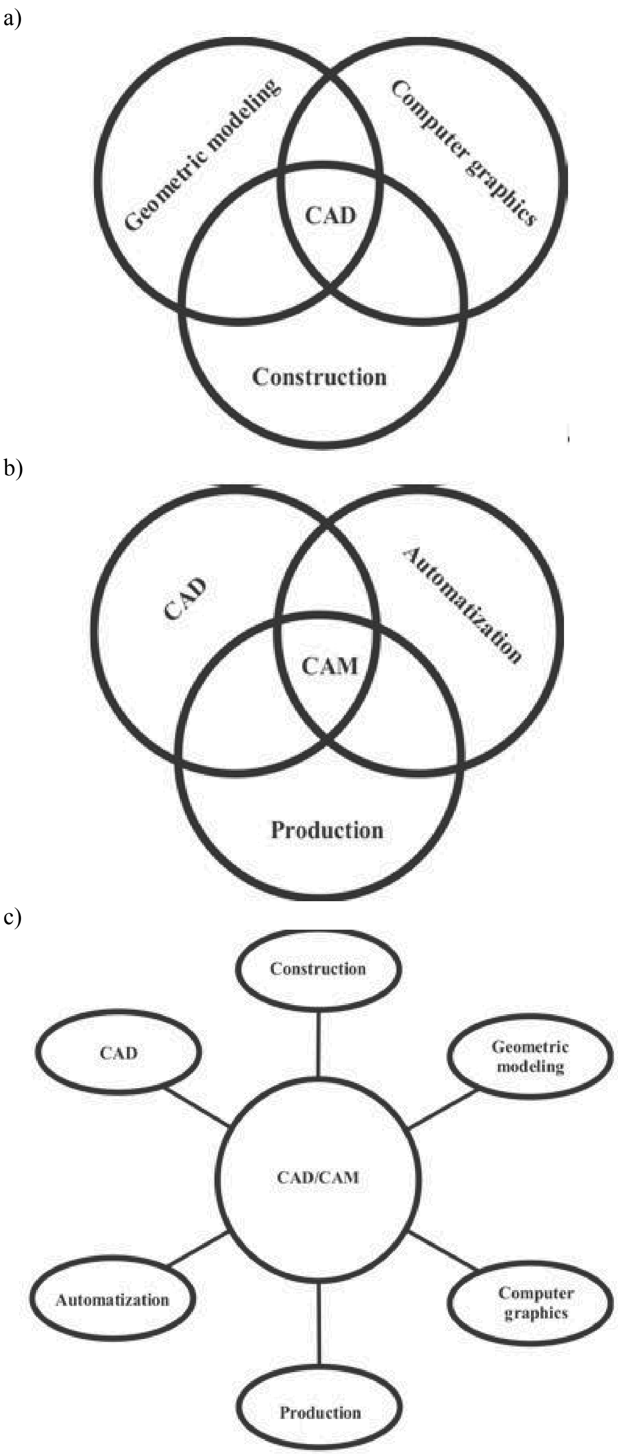


Fig. 1. Discipline in CAD/CAM tehnologies [10] a) CAD discipline, b) CAM discipline, c) CAD/CAM system as integrator

The dielectric fluid acts as an insulator until the potential is sufficiently high, and it then acts as a flushing medium and carries away the debris in the gap, which is a critical part in the process. Thus, the downward feed of the tool is controlled by a servomechanism, which automatically maintains a constant gap.

The most common dielectric fluids are mineral oils, although kerosene and distilled and deioniser water may be used in specialised applications. The work piece is a fixture within the tank containing the dielectric fluid, and its movements are controlled by numerically controlled systems. The machines are equipped with a pump and filtering system for the dielectric fluid.

The EDM process can be used on any material that is an electrical conductor. The melting point and latent heat of melting are important physical properties that determine the volume of metal removed per discharge. As these values increase, the rate of material removal slows. The volume of material removed per discharge is typically in the range of 10^{-6} to 10^{-4} mm^3. Because the process does not involve mechanical energy, the hardness, strength and toughness of the work piece material do not necessarily influence the removal rate. The frequency of discharge or the energy per discharge is usually varied to control the removal rate, as are the voltage and current. The removal rate and surface roughness increase with increasing current density and decreasing frequency of sparks.

2. Basic structure of CAM system

On Fig. 2 we can see the sequence of making process in CNC systems. First in CAD system we must make geometry of product, after that in CAM system realize tool path. That code is not readable for control unit on machine. Therefore, using a process called post-processing, translating program code from the PLM system to standard (ISO) code, or code that supports the control unit is available. Post-processing is the final process of integrating all the operations and procedures planned for the development of products, as well as shaping the program for specific NC machine control unit. The PLM systems, as one of the outputs, providing opportunities for generating tool path files (CL-file). However, generated by the CL file contains user instructions for making parts based on the product model of syntax and semantics are not in accordance with specific instructions for the CNC machine control unit. Such a file must be translated into a form acceptable to the control unit. Fig. 3 shows scheme of post-processing process.

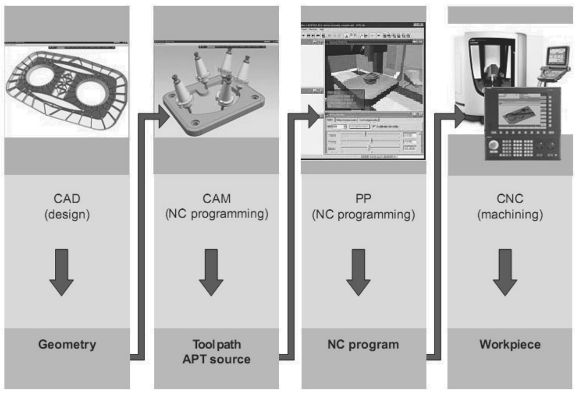


Fig. 2. The sequence of making process of machine parts in modern CNC systems [12]

After translating the file path instruction tools in instruction for control unit and the alignment of instruction with its characteristics, the files are generated for the control of CNC machine tools, as well as listing the files. Transferring the program obtained by the control unit can be done in several ways, depending on its type. Older versions are used for this purpose punched tape, but modern versions contain a unit with a control computer.

The body of the program have a command, G-and M-functions for managing the movement of tools, coordinate movements, information about treatment regimes etc., and is fully compliant with the characteristics of the selected control unit.

3. Material for making the electrode

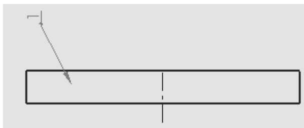
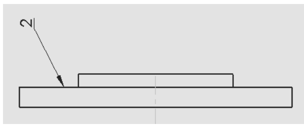
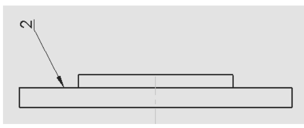
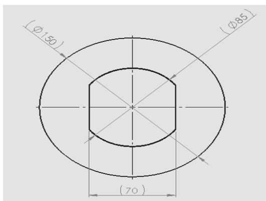
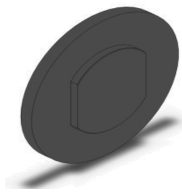
The material for making electrode is the copper, but in tested case only for the display we used aluminium alloys, marked with the European norm: EN AW 2030 (Al Cu4PbMg).

Mechanical properties of the testing material Al Cu4PbMg:

- tensile properties Re = 205 MPa,
- upper limit of strength Rm = 350 MPa.

The content of alloying elements are: C - max 0.19 %, Mg - 0.31-0.64%, P - max 0.025 %, S -max 0.025 %, Si - 0.18-0.37 %, Ni - 3.18 -3.87%, Cu - 3.9%, Pb - 1.2%, Mn - 0.6%

Table 1.
Steps for preparing blank part

Operation	Tools	Positions revolver	Cutting parameters	Fig. of operation	Showing of operation in isometric
Clamping material					
Rough turning forhead	CNMG160408WF	1	v_c=200 m/min f_n=0.2 mm a_p=3 mm		
Rough turning contour	CNMG160408WF	1	v_c=200 m/min f_n=0.2 mm a_p=3 mm		
Finish turning contour	TCMT 16T304E	2	v_c=250 m/min f_n=0.12 mm a_p=0.3 mm		
Milling paralel surface rough and finish	TM mill Ø12 mm	5	v_c=140 m/min f_n=0.08 mm a_p=2.5 mm		

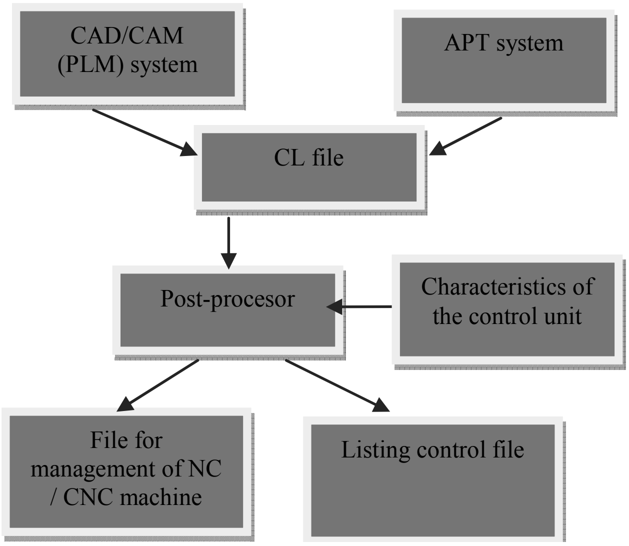


Fig. 3. Shema of post-procesing process [10]

For making the electrode on five axis machine, first we must prepare raw material for clamping in DMG DMU 40. Table 1 shows steps in preparing material.

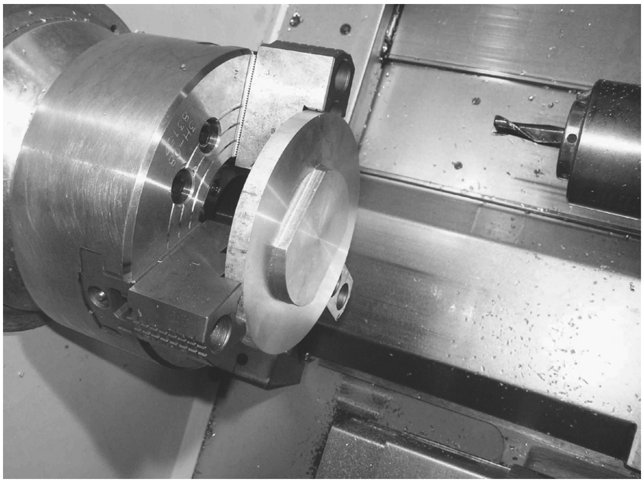


Fig. 4. The prepared material for the electrode after machining [14]

4. Technological procedure for making electrodes

4.1. Machine selection

For the production of electrodes for ice scrapers, we have selected the five axis machining center DMG DMU 40 Monoblock, shown on Fig. 5, with technical data shown in Table 2. Direct measurement system is ensured for all axes and CNC control unit Haidehain iTNC 530 for maximum accuracy when processing.

With the help of the coordinate system can be simply, quickly and unambiguously describe any point on the workpiece, and to determine its position in space. The coordinate system has meant the 2-3 axis, which intersect at one point. This intersection is called the null point of the coordinate system. Axes are perpendicular to each other and are denoted with X, Y and Z axis, while in five additional axial machines A, B and C depending on the design of the machine (Fig. 6).

Fig. 5. DMG DMU 40 monoblock [13]

Table 2.
Technical data of DMG DMU 40 Monoblock

Motion axis X	400 mm	Clamping toolholder in spindle: SK40
Motion axis Y	440 mm	
Motion axis Z	480 mm	The control unit: Haidenhain iTNC 530
Motion axis A	90°/-30°	Working area of C axis: Ø max 450 mm
Tools magazine:	20	Weight: 5500 kg
Max. Power on 12 000 rev/min:	15 kW	Max. force: 4000 N

4.2. Tools selection

The plan of tools is a document that allows the machine operator to make the adjustment tools, and treatment with specific tools, the order and manner as provided in the program. Shows Table 3.

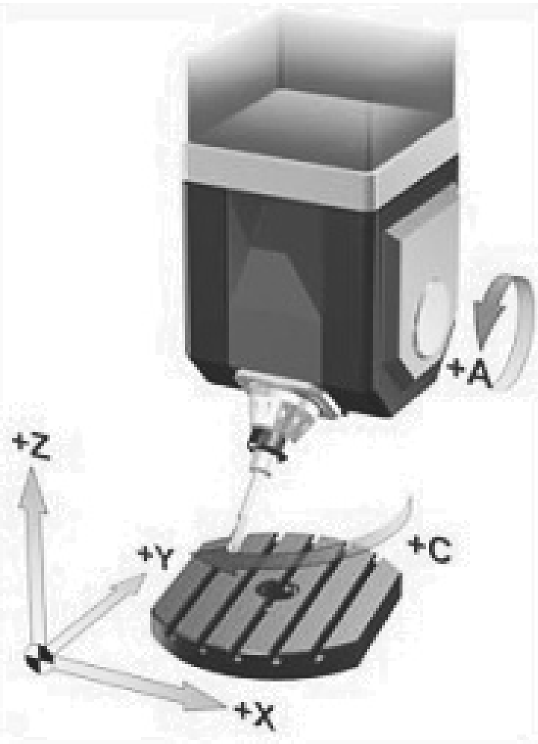


Fig. 6. Controlled axis for five axis machining

Table 3.
Plan of tools for making electrodes

Position in tool magazine	Name of tool	Method of clamping tools	Number of cutting edges	Remark
1	Mill Ø40 mm	SK40	5	
2	Mill Ø12 mm	SK40	2	Holder type ER32 with shell 12 mm
3	Mill Ø4 mm	SK40	2	Holder type ER32 with shell 4 mm

4.3. Simulation of production electrodes in the CAM program ESPRIT 2010

Esprit 2010 CAM software package is designed for companies whose activities in the area of products, typically the more complex geometry, machining procedures. The package includes modules for conventional milling, simultaneous three axis machining, five axis machining and simultaneous index, turning and EDM.

At the beginning of the programming of the machine, several important assumptions are determined:

- It is necessary to define the blanks, to CAM based on comparing blank and the finished pieces could calculate the tool path, and their collision,
- Postprocessor must be made entirely of professional teams, because any error in the postprocessing of data in the CAM can be fatal for the system in terms of collision with a machine tool or the workpiece
- Requires a virtual machine in the CAM and the whole definition of a real environment to the axis of motion simulation to be as faithful when creating pieces
- List of the tools that are present on the machine, together with their associated corrections that have in the list of tools and a place in the magazine.

Fig. 7 shows an screen which appears during the programming process.

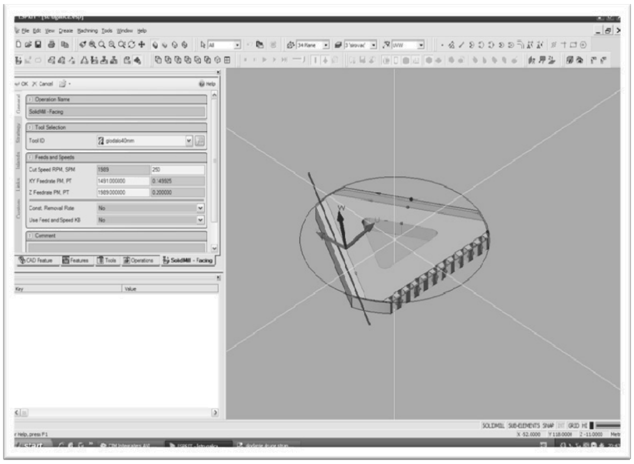


Fig. 7. Milling operations left slope of electrode [13]

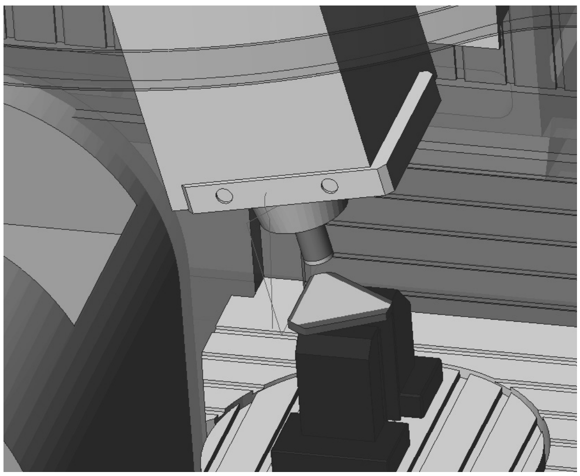


Fig. 8. Milling operation on virtual machine [15]

Parametres for cutting:

1. Tools => Mill SANDVIK Ø40mm with 5 edges
2. Velocity of cutting => from catalog v_c=250 m/min

3. Feed f_{xy} => from catalog f_{xy} = 1491 μm/min
4. Feed f_z => from catalog f_z = 1989 μm/min
5. Depth of cutting => a_p =3 mm
6. => Full clearance = 100 mm
7. => Clearance = 10 mm
8. => Entry mode = 30 mm
9. => Exit mode = 30 mm

It is important to note that when choosing any surface that is not perpendicular to the main coordinate system ESPRIT 2010 assigns the coordinate systems that can be selected at any time. Fig. 8 shows the virtual machine in the grip.

4.4. Sett-up the machine

Coordinate system on the machine, ie the piece, it must coincide with the coordinate system used in the ESPRIT 2010 software package, it is calibrated using a piece of 3D taster (Fig. 9).

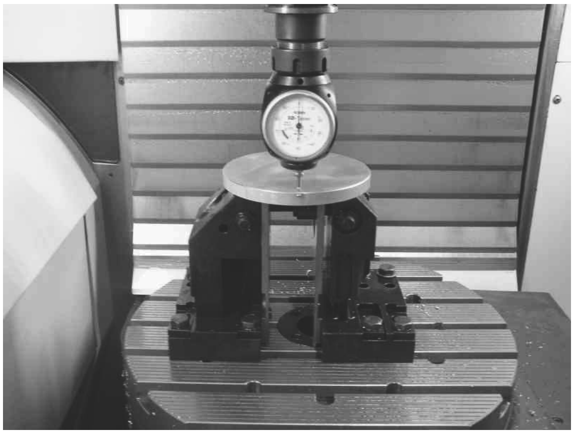


Fig. 9. Calibration blanks with 3D taster [14]

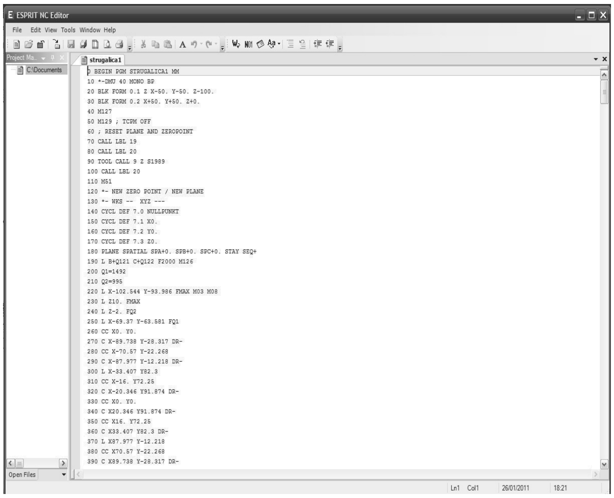


Fig. 10. Program part created in postprocessor for the machine DMU 40 [13]

4.5. Machining on the machine DMU 40 monoblock

After the set-up phase, the machining of the workpiece in ESPRIT 2010 software package can be defined after the post-processing in a Haidenhain iTNC 530. Postprocessor contains all the information and data that the machine has a control unit Haidenhain iTNC 530. After postprocessing program part is presented on Fig. 10. The program contains all the relevant information necessary to machine it did from beginning to end.

After the post processing is over, a program is loaded into the control unit using a USB memory key and run it in auto mode. Then the machine starts and takes the first tool-defined program and making the work piece, after machining, work piece looks like on Fig. 11.

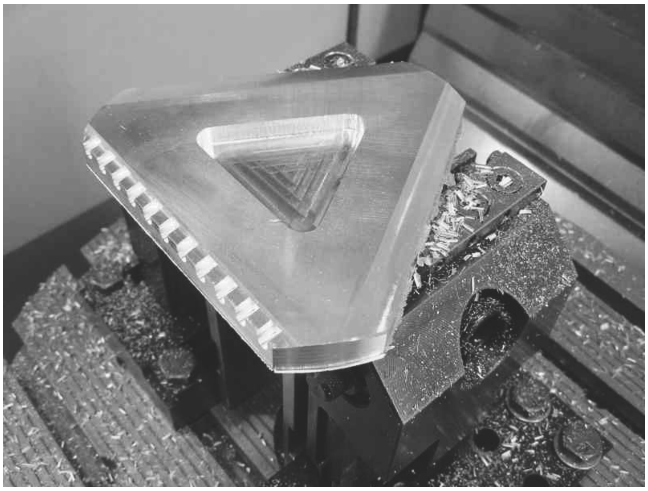


Fig. 11. Electrode for EDM of ice scraper after machining [14]

4.6. Tool for injection moulding ice scraper

After the electrode is made, the process of electro erosion process in the main panel of tools starts to get the negative form of the ice scrapers, and then follows the conclusion of the whole tool.

The tools used are the elements of KERN which are standardized and can be ordered in various sizes. The appearance of the finished tools to view Figs. 12 and 13, where the visible upper and lower part of tool, guiding elements of the main tool, the main upper and lower parts of the tool engraved with scraper, ejector plate filler channels, and guides.

The material is a standard tool panel or DIN 1.2162 standard 21MnCr5. Construct steel is suitable for heat treatment, which is achieved by cementing the tensile strength of about 700 N/mm^2. The alloy is used for the main panel where there is a plastic injection molding, the material after heat treatment is resistant to wear

Ice scrapers are made from polystyrene. Polystyrene is a plastomer which is classified into standard plastics. Polystyrene is amorphous polymer and its possible to modify all types of styrene copolymers. Polystyrene is characterized by excellent dielectric and mechanical properties, and are very good processability. Polystyrene is generally processed and procedures injection molding or extrusion of hard foam boards. Because of the generally excellent processability can be applied to other processing methods such as blow molding and thermal forming.

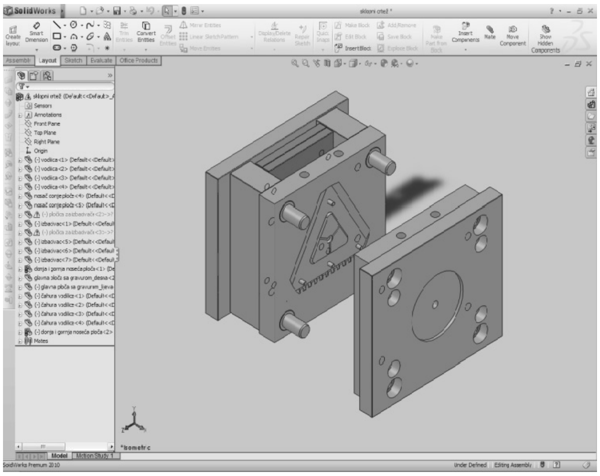


Fig. 12. Tools for injection molding of ice scrapers designed software package SolidWorks 2010 [13]

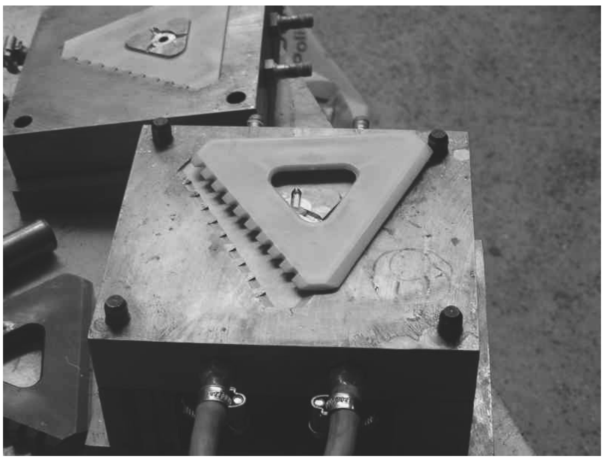


Fig. 13. Finished tools for injection molding and the molded [14]

5. Conclusions

With respect to the work piece geometry, the classic three axial machining centre cannot perform the machining of the ice scraper in one clamping, but in several of them. Five axis machine provides excellent opportunities and cost savings in the preparation and finishing times.

CAM systems have a wide meaning, since, in the general case, covering a large number of functions and activities that belong to different areas of manufacturing, engineering and technology. Generally, CAM systems are software tools that support the extensive use of computers for planning and designing of technological processes of production, operation and management of production, ie production processes. Modern methods of product development and related processes, we can say that CAM systems are a logical continuation of the CAD system. So today, these systems do not meet as independent, but as an integrated subsystem of CAD / CAM and PLM systems. As such, they have great robustness and reliability, provide significant advantages.

Acknowledgements

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