ASPECTS CONCERNING ELECTROLYTE FLOW MODELLING FOR AN EQUIPMENT OF ECM DEBURRING

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ABSTRACT: Over time, the performances of the technological equipments have evolved, allowing to obtain parts as precise as possible and with a lower manufacturing cost. At the same time, the complexity of the parts made increased, which led to the improvement of the used processes, the obtaining of hybrid procedures, the development of new tools and new equipment. With these, it is desired to deepen the deburring process. This is a non-productive process, which should be minimized as much as possible. Deburring includes all operations used to eliminate burrs, from deburring with the help of the human operator to finishing surfaces using CNC robots. The main categories of deburring are manual deburring, mechanical deburring, deburring using industrial robots, chemical/thermal deburring and electrochemical deburring. Manual deburring is not expected to be considered as the deburring surfaces are in hard to reach places, and this method involves low productivity and high processing time.
KEYWORDS: ECM deburring, electrolyte flow, pressure lost cases, COMSOL modelling

1. INTRODUCTION

Electrochemical deburring is a static machining. Electrochemical processing (ECM) uses the Faraday principle to remove metal from the workpiece. Michael Faraday found that if two electrodes are placed in a bath that contains liquid and when a potential is applied directly to the electrodes, the metal can be expelled from the anode and plated on the cathode.

The electrochemical deburring differs from the dimensional electrochemical machining by copying the tool-electrode form by the fact that there is no movement of the tool. The principle diagram is illustrated in Figure 1.

Electrochemical deburring is based on the phenomenon of electrolysis. The machining consists in removing the burrs that appear as a result of conventional processing, the material being taken through anodic dissolution.

The piece electrode (EP) is connected to the positive pole (anode +) of a DC generator, and the tool electrode (ES) to the negative pole (cathode -) of the same sources.

In the space between the two electrodes, called the working gap, an electrolyte is recirculated, at a pre-set pressure and speed. The electrolyte flow allows the creation of electrical contact and elimination of the burrs in the working area. Without the presence of the electrolyte, the particles can cause short circuits in the system. The burrs are removed from the piece by the electrochemical action generating a rounding of the sharp edges.

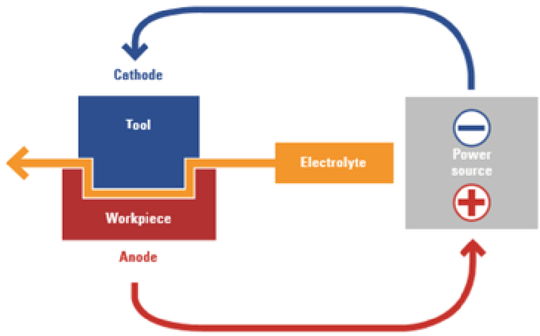


Figure 1. ECM Deburring process [2]

Figure 2 presents some of the parts that were machined using electrochemical deburring: a gearbox, a turbo charger and valve train.

Figure 2. Product examples for using ECM deburring [2]

The current density is much higher between the closest areas of the two electrodes, and as a result, the anodic dissolution will begin at the peaks of the burrs, which will disappear until the sharp angle of the surface of the piece is obtained.

The electrochemical processing regimes directly influence [1], the parameters such as productivity, shape and dimensional accuracy, as well as the roughness of the realized surfaces. For electrochemical deburring operation it is recommended to use current densities between 0.3 and 0.5 A / cm^2. The voltages used can have values between 8 and 24 V [1], depending on the size of the surface to be processed, but also on the materials from which the tool electrode and or the piece electrode are made.

The electrochemical deburring process is carried out in stationary equipment (made of electro-insulating materials) that ensure the tool-electrode attachment in the proper position with respect to the part surface, the orientation and fixing of the electrode-part, the electrolyte circulation, the current flow in the working area. The existence of suitable elements of isolation and sealing. Electrolyte flow is a very important and critical parameter in the analysis of electrochemical machining. Insufficient and improper electrolyte flow in the IEG may cause poor machining. The effect of cavitation, stagnation, and vortex flow can avoid up to a certain extent by avoiding sharp corner.
The electrochemical deburring equipment consists of the modules:

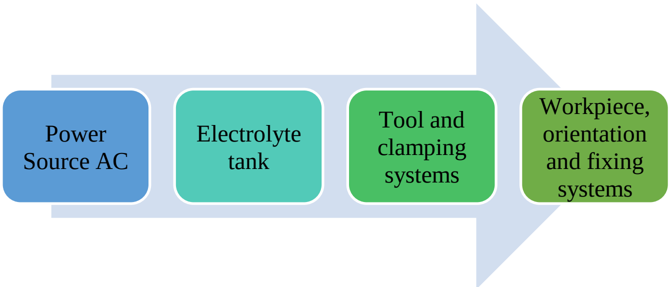


Figure 3. Setup for ECM deburring process

2. STATE OF THE ART ASPECTS

2.1 Internal Research

- **Device for deburring gears with inner teeth**

An example of a construction for the electrochemical deburring of the inner teeth of the gear wheels is the case presented in figure 4.

1 represents the motherboard; 2 - the electrode-part (pinion - anode); 3 - the electrode-tool (the cathode); 4 - electrically insulating support; 5 and 6 - electrically insulating sealing elements; 6 - the electrode-tool (the cathode); 7 - supporting elements; 8 - insulating part of the sprocket body; 9 and 10 - connecting elements at the terminals of the DC generator; 11 - electrolyte supply connection.

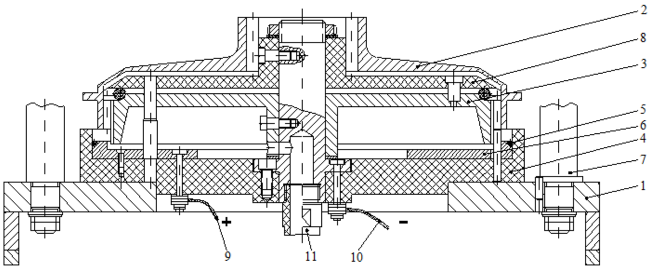


Figure 4. Inner gear teeth deburring device [1]

- **Device for deburring wheels with outer gear**

This device (figure 5) it is used to remove small (<1 mm) exterior bumps on cylindrical gears.
And in this case, the device consists of two specific subassemblies, namely:
- the upper one mounted on the electrode head of the installation formed - mainly - from the upper mounting plate 1 having also the role of bringing the working current to the electrode-part, and the working chamber 2 (glass) which also serves the mounting the electrode-tool.
- the lower one mounted on the table of the installation, having as main component elements: the electrode-tool 3, in relation to which it is centred and the electrode-part through the central area. To protect the tool electrode (made of copper), the contact surface between the two electrodes is materialized by the metal bushing 4 inserted in the insulation of the tool electrode. The sealing of the device is provided by gaskets 5 and 6. The electrolyte is brought to the working area by the central axis of the electrode head and, discharged through channels practiced in the tool electrode.

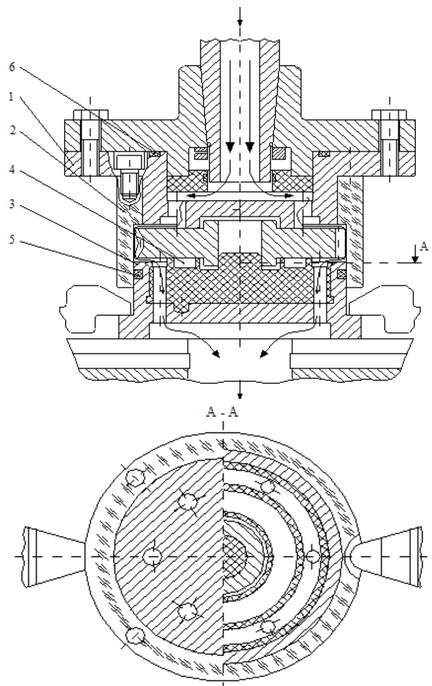


Figure 5. Device for deburring wheels with outer gear [1]

2.2 External Research

Analysing recent patents, it was decided to present three of them, relevant to the developed equipment.

Figure 6 shows the patent for an automatic and portable device for electrochemical deburring. It has advantages such as simplicity of operation, low costs, flexibility, occupying a relatively small space. The patent brings as a novelty the portability of the equipment, being a desired specification within the current product developed.

The deburring apparatus has motor (11) mounted on the rotating door housing (3), is connected by its output rod (5) of the agitator (6); tool electrode (20).

It includes three, machining power supply 1, a controller 2, the fixture 9, the motor 11, the stirrer 6, connecting rod 5, the tool electrode 20 and the wire housing means 24. The housing 3 is provided with a handle means at both ends 4, top handle 12 is provided, is provided above the rotating door, open the door when rotating the workpiece is mounted, the revolving door is closed when not in use, its interior divided into front and rear hatchback, the rear compartment placed fixture for clamping and positioning of the workpiece 9 with, in a front compartment of the machining power supply 1 and the controller 2 is mounted; the machining power supply 1 is a 20V DC power supply.

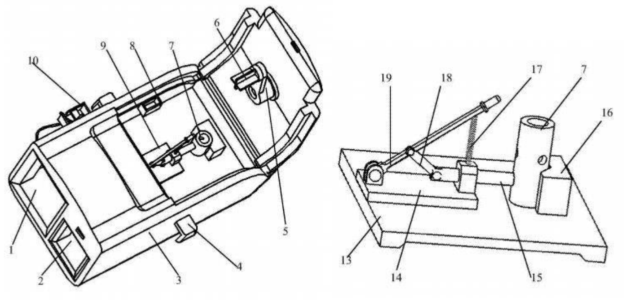


Figure 6. Patent CN 105269093 A [3]

Figure 7 shows a patent for an equipment for deburring parts of TZM (molybdenum alloy with titanium, zirconium and carbon particles). The novelty element is the regime of processing in impulses that leads to improvements in surface quality.

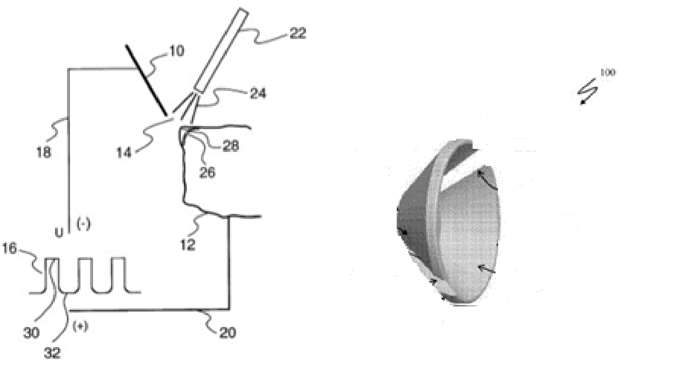


Figure 7.

Patent US OO6139715 A [4]   Patent AU 2016101408 A4 [5]

As shown in figure 7 a), the equipment employs a tool electrode 10 adjacent to a TZM workpiece 12. Tool electrode 10 and TZM workpiece 12 are situated so that there is a gap 14 between them. A pulse current DC source 16 is connected by a suitable lead 18 to tool electrode 10 and by a suitable lead 20 to TZM workpiece 12. Pulse current DC source 16 and leads 18, 20 are poled so that tool electrode 10 acts as a cathode and TZM workpiece 12 acts as an anode. The connection of pulse current DC source 16 to tool electrode 10 and TZM workpiece 12 impresses a current across gap 14 between tool electrode 10 and TZM workpiece 12.

The Australian patent shown in Figure 7 b) is for an electrode tool that can be used both for manual deburring and as an automated equipment. It is designed to deburr interior and exterior diameters, ensuring low cost / operation.

3. MODELLING OF PRESSURE LOST CASES

On the electrolyte path, from the entry into the electrode and up to the exit from the working area, pressure variations due to laminar load losses occur. This value is determined by the size of the mechanical work of the viscosity forces.

In fluid dynamics, Bernoulli's principle states that an increase in the speed of a fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy. [9]

The laminar load losses are highlighted by the Bernoulli's relation (1), written between 2 sections along a power line [1] (figure 8- [1]).

$$\frac{v_1^{\,2}}{2*g}+\frac{p_1}{\gamma}+z_1=\frac{v_2^{\,2}}{2*g}+\frac{p_2}{\gamma}+z_2+h_{r,1-2} \qquad (1)$$

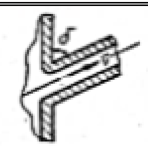
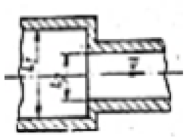
where: hr - laminar load losses

v - electrolyte flow rate [m /s]

p - pressure [daN /cm^2]

γ - specific electrolyte weight [daN / m^3]

z1,2 - distances from the plane considered fixed to the level of the two specific sections [mm]

	$\boldsymbol{h'_r = \xi \frac{v^2}{2g}}$ $\boldsymbol{\xi = 0,5 + 0,3cos\delta + 0,2cos^2\xi}$
	$h'_r = \xi \frac{v^2}{2g}$ $\xi = \left(\frac{n^{1,8}-1}{1{,}43n^{1,8}+1}\right)^2$ $n = \frac{L_1}{L_2} \le 100$

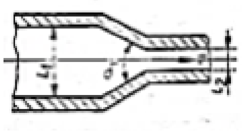
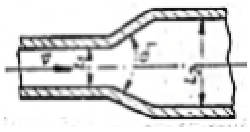
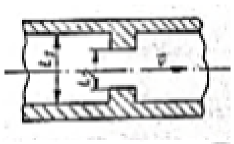
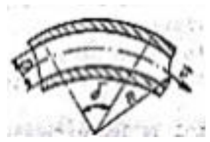
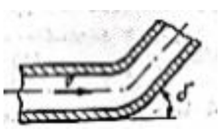
	$h'_r = \xi \frac{v^2}{2g}$ $\xi = \left(\frac{n^{1,8} - 1}{1,43n^{1,8} + 1}\right)^2 \cdot f(\delta)$ $n = \frac{L_1}{L_2} \leq 100$ $f(\delta) = \begin{cases} sin\delta; 0 < \delta < 90° \\ 1; 90° < \delta < 180° \end{cases}$
	$h'_r = \xi \frac{v^2}{2g}$ $\xi' = 3,2\left(\frac{n-1}{n}\right)^2 \cdot \left(tg\frac{\delta}{2}\right)^{1,25}$ $n = \frac{L_1}{L_2} \leq 100$ $0° < \delta \leq 45°$
	$h'_r = \xi \frac{v^2}{2g}$ $\xi = \left(\frac{L_1}{\varepsilon L_2} - 1\right)^2$ $\varepsilon = 0,63 + 0,37\left(\frac{L_2}{L_1}\right)^3$
	$h'_r = \xi \frac{v^2}{2g}$ $\xi = \frac{\delta°}{90°}\left[0,13 + 0,16\left(\frac{D}{R}\right)^{3,5}\right]$ $1 \leq \frac{R}{D} \leq 5$
	$h'_r = \xi \frac{v^2}{2g}$ $\xi = 0,95sin^2\frac{\delta}{2} + 2\ 05sin^4\frac{\delta}{2}$ $0° < \delta \leq 90°$

Figure 8. Pressure lost cases

The geometry and flow domain of the electrolyte flow path is modelled by using COMSOL Multiphysics simulation software. COMSOL is a cross-platform finite element analysis, solver and Multiphysics simulation software [8]. It allows conventional physics-based user interfaces and coupled systems of partial differential equations (PDEs). COMSOL provides an integrated development environment (IDE) and unified workflow for electrical, mechanical, *fluid*, acoustics and chemical applications.

From an engineering standpoint, it is important to predict and understand how the fluid (electrolyte in case of ECM deburring) flows inside a part with complex geometry, such as a mold. The mold has two parts: the core and the cavity and both have plenty of holes in different positions (some of them are intersected). The perpendicular holes were machined in a traditional way and the burr is difficult to be taken out.

The electrode (tool-cathode) is long-shaped, with a non-isolated part that corresponds to the cooling holes. The electrolyte flow inside the mold's core/cavity with laminar flow, which is stationary.

Laminar flow is a flow regime characterized by high momentum diffusion and low momentum convection. When a fluid is flowing through a closed channel such as a pipe or between two flat plates, either of two types of flow may occur depending on the velocity and viscosity of the fluid: laminar flow or turbulent flow. Laminar flow occurs at lower velocities, below a threshold at which the flow becomes turbulent. [6]

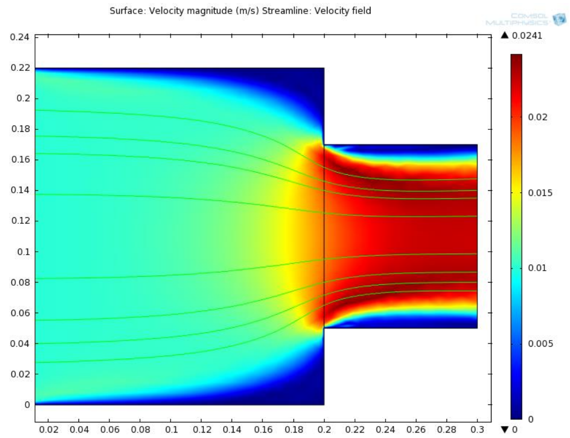


Figure 9. Streamlines and velocities for a part made with COMSOL Simulation (Laminar Flow)

The primary characteristic of laminar flow is a streamlined flow, lacking any swirls or cross currents. The fluid would flow without interference or disturbance, and the path of the flow wouldn't have any swirls or cross currents. 2D approach is used. Figures 9 and 10 illustrate a part of pressure lost cases from Figure 8.

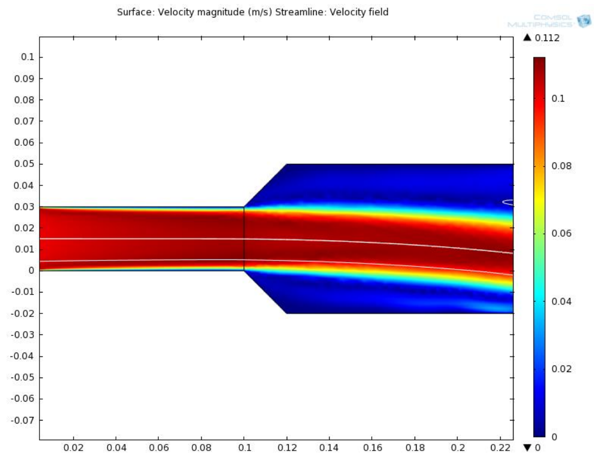


Figure 10. Streamlines and velocities for a part made with COMSOL Simulation (Laminar Flow)

4. MODELLING OF ELECTROLYTE FLOW OF INNER ECM DEBURRING

To illustrate the electrolyte flow during electrochemical deburring of inner surfaces, the following model examines laminar flow past a cavity mold**.**

Before starting a session in the COMSOL, it should be chosen the physics module to work with and the space dimension, Single-Phase Flow-Laminar Flow (Pre-set Study: Stationary) and 3D.
First, the mold is imported into COMSOL and the software checks the geometry in order to find any errors such as incomplete surfaces, holes, gaps and so on.

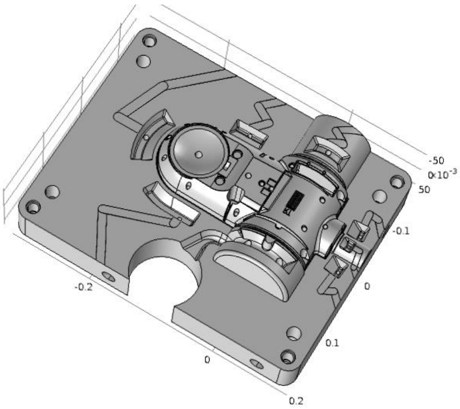


Figure 11. Cavity Mold imported in COMSOL

The next step is to assign a material from COMSOL's library. The electrolyte is an aqueous solution of NaCl with the following properties (figure 12):

Material Contents

	Property	Name	Value	Unit	Property
✓	Dynamic viscosity	mu	eta(T[1/K])[Pa*s]	Pa*s	Basic
✓	Density	rho	rho(T[1/K])[kg/m^3]	kg/...	Basic
	Ratio of specific heats	gam...	1.0	1	Basic
	Electrical conductivity	sigma	5.5e-6[S/m]	S/m	Basic
	Heat capacity at constant pressure	Cp	Cp(T[1/K])[J/(kg*K)]	J/(kg...	Basic
	Thermal conductivity	k	k(T[1/K])[W/(m*K)]	W/(...	Basic
	Speed of sound	c	cs(T[1/K])[m/s]	m/s	Basic

Figure 12. Electrolyte's properties (NaCl solution)

For solving any problem using numerical technique, it is first step to apply appropriate and exact boundary conditions, which defines the problem, in order to get the solution of that specific problem. A solution is always sensitive to the inlet boundary conditions; a great care is needed to be taken while imposing the boundary condition. To add an Inlet and Outlet for the electrolyte use the Physics toolbar and complete the sections with velocity/pression. The inlet corresponds to cavity mold's entrance for the cooling holes and the outlet for the; the value for pression is 1-2 MPa. The meshing process is a complex one, defined with physics-controlled mesh and a normal element size.

Meshing is used to discretizing a spatial domain in to simple geometric elements such as triangles (in 2D) or tetrahedral (in 3D) for getting the numerical solution. In figure 13 it's presented a statistic of the meshing network; the average element quality is 97,35%.

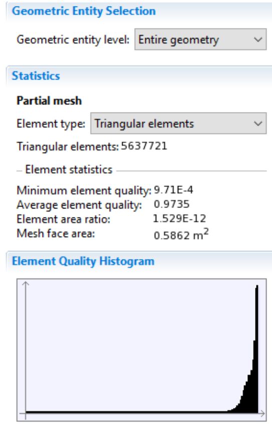


Figure 13. Meshing statistics

After computing, the solution regarding velocity and pressure of the electrolyte for the current simulation is presented in figures 15-20. In order to find an optimum solution, there are presented different cases of variation for inlet and outlet pression.
The geometry corresponds to the electrolyte flowing path for the current cavity mold. The boundary condition for the fluid flow (laminar) are presented in figure 14, as an outlet and inlet pressure corelated with the specific areas of the workpiece.

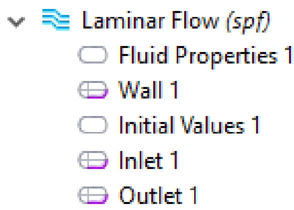


Figure 14. Boundary Conditions for one of the modelled cases

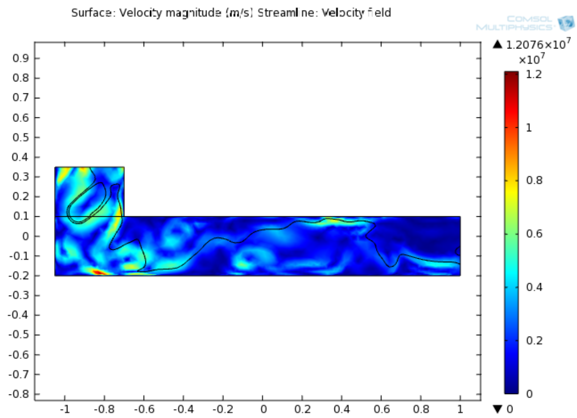


Figure 15. Velocity diagram for electrolyte with inlet pression 2 MPa and outlet pression 0,5 MPa (with streamlines)

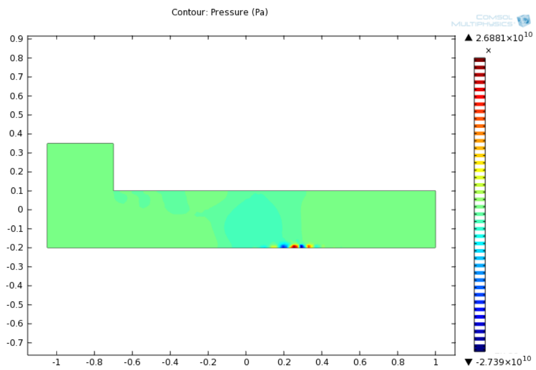


Figure 16. Pressure diagram for electrolyte with inlet

pression 2 MPa and outlet pression 0,5 MPa

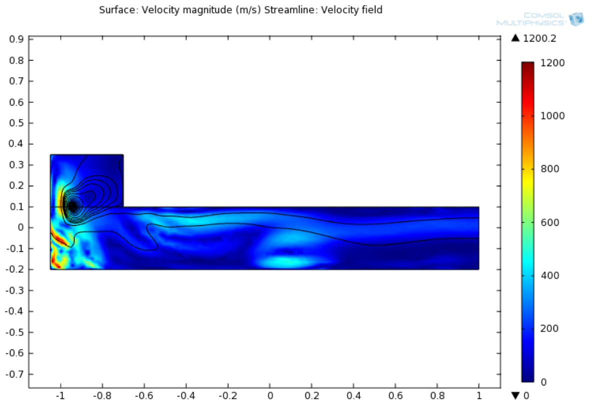


Figure 17. Velocity diagram for electrolyte with inlet pression 0,5 MPa and outlet pression 0,2 MPa (with streamlines)

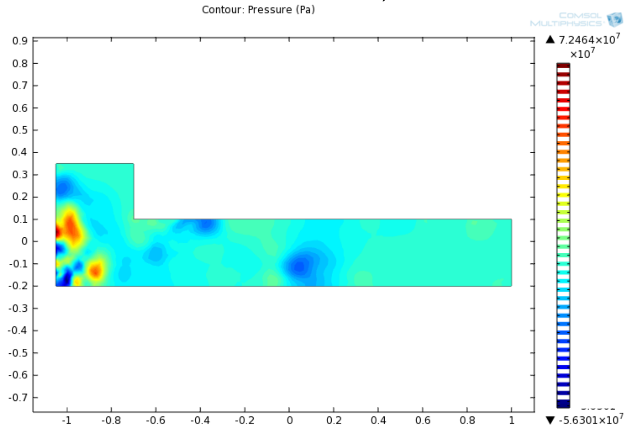


Figure 18. Pressure diagram for electrolyte with inlet pression 0,5 MPa and outlet pression 0,2 MPa

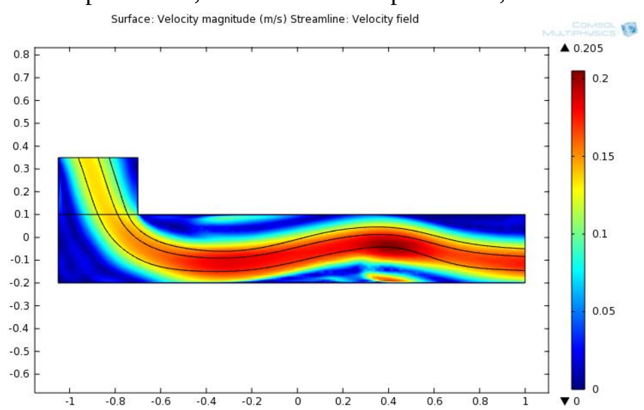


Figure 19. Velocity diagram for electrolyte with inlet pression 2 MPa and outlet pression 0,1 MPa (with streamlines)

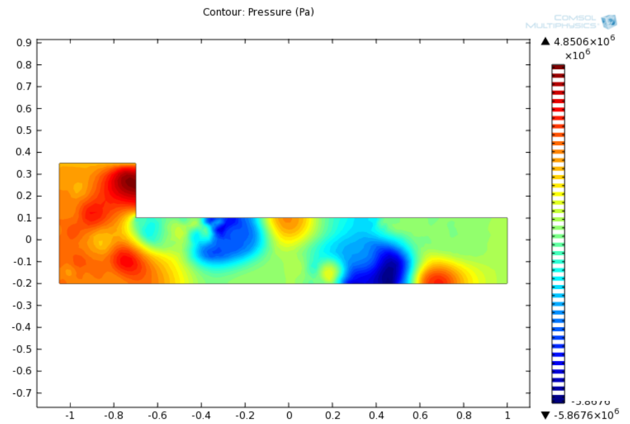


Figure 20. Pressure diagram for electrolyte with inlet pression 2 MPa and outlet pression 0,1 MPa

The optimum pressure for electrolyte's inlet is 2 MPa and for the outlet is 0,1 MPa, in order to obtain a deburring for the crossed holes machined on the cavity mold. The other cases, presented above, suggest that the velocity and pressure doesn't correspond to an electrochemical deburring.

5. CONCLUSIONS

In the further researches it will be studying the pressure and velocity variations on the workpiece geometry's domain, between 1-25 MPa (1 atm=0,1 MPa=10^5 Pa) and also on different geometries. In order to remove the burrs, it is needed to have a high inlet pressure corelated with a low outlet pressure.

The workpiece geometry influences the electrolyte flow and the removing process of the burrs. For the current modelling and simulation, the last case from figure 8 is available for analytic calculus. The pressure lost cases take place into the corners of the geometry.

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