

THE INFLUENCE OF DIFFERENT ISOLATING MATERIALS APPLIED TO ULTRASONIC HORNS SPECIFIC TO HYBRID ELECTROCHEMICAL MACHINING

Cornel-Cristian Enciu¹, Liviu-Daniel Ghiculescu²
POLITEHNICA University of Bucharest, [1cornel.enciu@upb.ro](mailto:cornel.enciu@upb.ro), [2daniel.ghiculescu@upb.ro](mailto:daniel.ghiculescu@upb.ro)

ABSTRACT: The paper deals with the study of influence for different materials applied to some ultrasonic chains, specific for electrochemical machining and micro electrochemical machining. Materials like polyvinyl chloride, polyamide, polyethylene, epoxy resin, were applied to the lateral part of ultrasonic horn-tool assembly, that has to be immersed in the electrolytic liquid. The influence of each material on resonance frequency was analyzed and a comparison between the parameters was made for the developed models considering the geometry of them. The study was realised using the program COMSOL Multiphysics. Also, some charts regarding the variation of own frequency for ultrasonic horns considering the depth of the applied material, were presented and analyzed. Finally, were exposed some solutions of output technological parameters for further improvement.

KEYWORDS: modeling, simulation, electrochemical machining, isolating materials.

1. INTRODUCTION

Electrochemical machining is a manufacturing process based on the phenomenon of anodic dissolution through the controlled sampling of the part material in an electrolytic cell, in this case, the part being the anode and the tool being the cathode. In most cases the electrolytic liquid is composed of salt and water, combination known as sodium chloride (NaCl), or it can be used sodium nitrate (NaNO₃) [1, 2]. In the modelling of ECM processes, it is required to take in consideration some steps like: electric field distribution, and consequently charged particles movement, the flow of electrolyte liquid, and subsequently, thermal distribution, and finally the anodic dissolution [3, 4]. The chemical reactions that appear during the manufacturing process can damage the ultrasonic chain components, in particular the horn and at the same time the tool that is assembled on the concentrator (assembled by gluing or with a screw) [5, 6]. So, these elements have to be protected by adding other materials (polyvinyl chloride, polyamide, polyethylene, epoxy resin) and after this implementation the next challenge is to see the influence of the protection materials in relation with the eigenfrequency of the ultrasonic chain. To protect the tool and simultaneously to manufacture a surface is a very big challenge using electrochemical machining assisted by ultrasonic component (ECM+US). The ultrasonic component increases the quality of surface roughness eliminating the passivated layer that can appear during the process [7, 8, 9]. In industries like automotive, aerospace, medical, chemical, and the list can be longer, these

nonconventional manufacturing processes will be a trend in the next years, representing a good solution for improving the technological parameters.

2. MODELING AND DIMENSIONING OF AN ULTRASONIC CHAIN

COMSOL Multiphysics, Structural Mechanics with Eigenfrequency variant was used for modelling and dimensioning some ultrasonic chains. To build the geometry of each part of the assembly it was necessary to apply geometry operations like Rectangle, Square, Circle. To create a relation between the obtained structures were applied some Booleans functions like Difference, Union, and after that could be added a Chamfer operation to build a technological assembly in the area where the assembly will be mounted on the manufacturing machine. The tools were developed for the next processing: a circular geometry with the diameter of 4 mm, other similar geometry having a hole of 1 mm in the center, on a depth of 0.5 mm, a tool for electrochemical polishing with a diameter of 32 mm, other similar tool having a hole of 4 mm in the center, on a depth of 4 mm. All models were analyzed using a transducer with an own frequency of 40 kHz, but for the last two, specific for electrochemical polishing, was used a transducer with an own frequency of 20 kHz too.

For the first two models the working parameters are the same, excluding the area of the tool and the thickness of the protective layer that can vary. These things are also valid for the last two models, but it is important to mention that the length of the

concentrator steps will be different in relation with the transducer used.

Name	Expression	Value	Description
l1	37.3[mm]	0.0373 m	entrance step length
r1	19[mm]	0.019 m	input step radius
l2	35[mm]	0.035 m	output step length
r2	10[mm]	0.01 m	output step radius
modulE	2.1e11	2.1E11	modulus of elasticity C45
rr	r1-r2	0.009 m	connection radius steps
alfa	10	10	inclination degrees
argum	3.14*alfa/180	0.1744	inclination radians
a	(l2-r1)*tan(argum)	0.004582 m	horizontal leg tapered triangle
b	10[mm]	0.01 m	the lower rectangular side
delta	r2-a	0.005418 m	material radius left at the bottom
rgs	1[mm]	0.001 m	tool hole radius
hgs	5[mm]	0.005 m	depth of the hole where the tool is located
ls	15[mm]	0.015 m	tool length
las	ls-hgs	0.01 m	tool active length
rprezon	3[mm]	0.003 m	bolt radius
hg	10[mm]	0.01 m	hole depth
lprezon	8[mm]	0.008 m	bolt length
zcanal	0.045	0.045	nodal canal parameter
rcanal	2[mm]	0.002 m	nodal canal radius
pfateta	1[mm]	0.001 m	side facet parameter
gPVC	1[mm]	0.001 m	PVC layer thickness
lscula	1[mm]	0.001 m	side of the tool
scerc	1[mm]	0.001 m	circle sector removed
ccorectie	0.918[mm]	9.18E-4 m	correction coefficient

Figure 1. Working parameters for Model 1 and 2 (40 kHz)

Name	Expression	Value	Description
l1	34.8[mm]	0.0348 m	entrance step length
r1	19[mm]	0.019 m	input step radius
l2	25[mm]	0.025 m	output step length
r2	15[mm]	0.015 m	output step radius
modulE	2.1e11	2.1E11	modulus of elasticity C45
rr	r1-r2	0.004 m	connection radius steps
rgs	15[mm]	0.015 m	tool hole radius
rprezon	3[mm]	0.003 m	bolt radius
lprezon	8[mm]	0.008 m	bolt length
hg	10[mm]	0.01 m	hole depth
hscula	15[mm]	0.015 m	tool height
zcanal	0.031	0.031	nodal canal parameter
rcanal	2[mm]	0.002 m	nodal canal radius
pfateta	1[mm]	0.001 m	side facet parameter
gPVC	1[mm]	0.001 m	PVC layer thickness

Figure 2. Working parameters for Model 3 and 4 (40 kHz)

Name	Expression	Value	Description
l1	63.5[mm]	0.0635 m	entrance step length
r1	26[mm]	0.026 m	input step radius
l2	60[mm]	0.06 m	output step length
r2	15[mm]	0.015 m	output step radius
modulE	2.1e11	2.1E11	modulus of elasticity C45
rr	r1-r2	0.011 m	connection radius steps
rgs	15[mm]	0.015 m	tool hole radius
rprezon	3[mm]	0.003 m	bolt radius
lprezon	8[mm]	0.008 m	bolt length
hg	10[mm]	0.01 m	hole depth
hscula	15[mm]	0.015 m	tool height
zcanal	0.069	0.069	nodal canal parameter
rcanal	2[mm]	0.002 m	nodal canal radius
pfateta	1[mm]	0.001 m	side facet parameter
gPVC	1[mm]	0.001 m	PVC layer thickness

Figure 3. Working parameters for Model 3 and 4 (20 kHz)

The polyvinyl chloride (PVC) was added and studied for each model mentioned above, including the last two models that were also realised for a transducer of 20 kHz, but the other materials like polyamide, polyethylene, epoxy resin were analyzed only for the horn-tool assembly that has a transducer with a frequency of 40 kHz. The thickness of these materials was varied replacing the parameter “gPVC”, that can be seen on the last line of the pictures with the working parameters from

COMSOL Multiphysics. In the next image, it can be seen the structure of the horn-tool assembly and the area where was applied the isolating material.

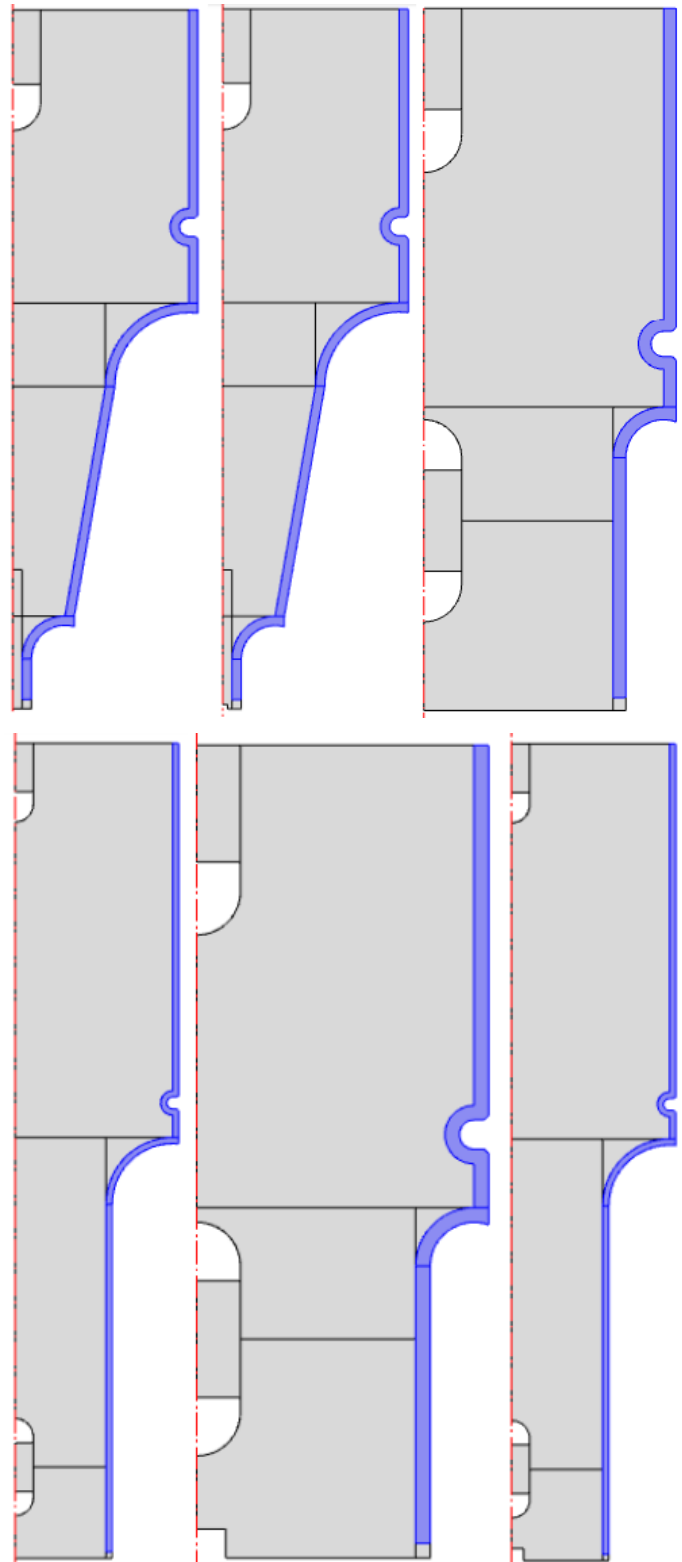


Figure 4. Application of isolating material for each model

A condition for the tool concentrator assembly to work at optimal parameters is that the frequency of the concentrator is equal to the frequency of the transducer. In order to fulfill this condition, it is necessary that the horn be brought to the resonance frequency, changing the lengths of its input and output stages, l_1 and l_2 .

In the next table are related the results for each model developed. It can be observed the difference between the initial and the final values specific for each model designed.

Table 1. Dimensioning of concentrator steps

	Initial value of l ₁ [mm]	Initial value of l ₂ [mm]	Final value of l ₁ [mm]	Final value of l ₂ [mm]
Model 1_40 kHz	31.67	33.78	37.3	35
Model 2_40 kHz	31.67	33.78	37.3	35
Model 3_40 kHz	31.67	24	34.8	25
Model 3_20 kHz	64.98	69.32	63.5	60
Model 4_40 kHz	31.67	24	34.8	25
Model 4_20 kHz	64.98	69.32	63.5	60

Some of the 3D models are presented in the next pictures. It can be observed the value of the eigenfrequency for each model related, the deformation bar, obtained from COMSOL Multiphysics.

In the area where the concentrator is blue it means that the amplification is very close to zero and the nodal point can be determined, and then all assembly can be fixed on the machine tool. The red colour indicates the area where the amplification is maximum and it has to be in the same place with the tool.

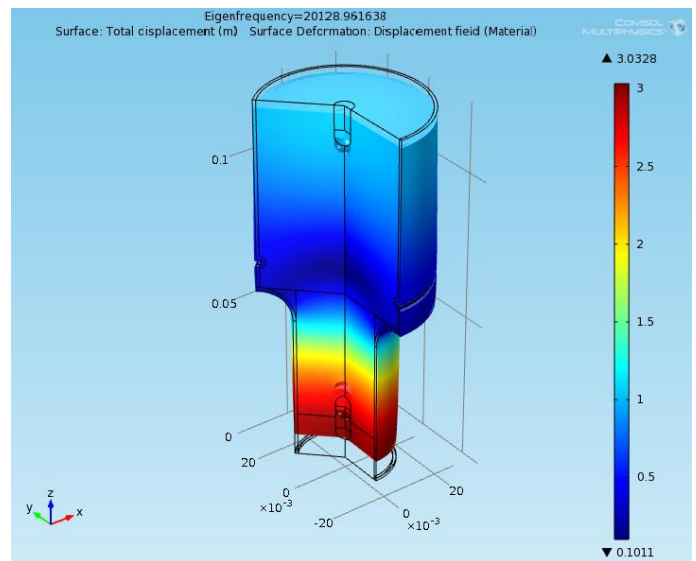
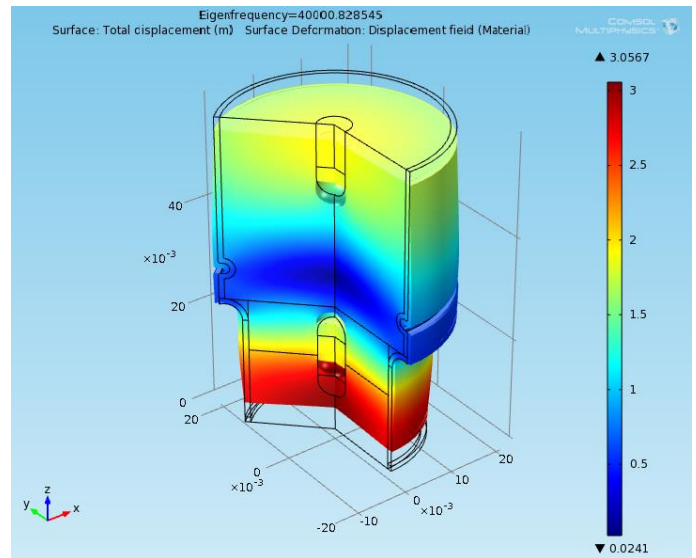


Figure 5. 3D models of horns developed

To have a better vision of the process in the next picture are presented two 3D models, with all the components required for this type of manufacturing.

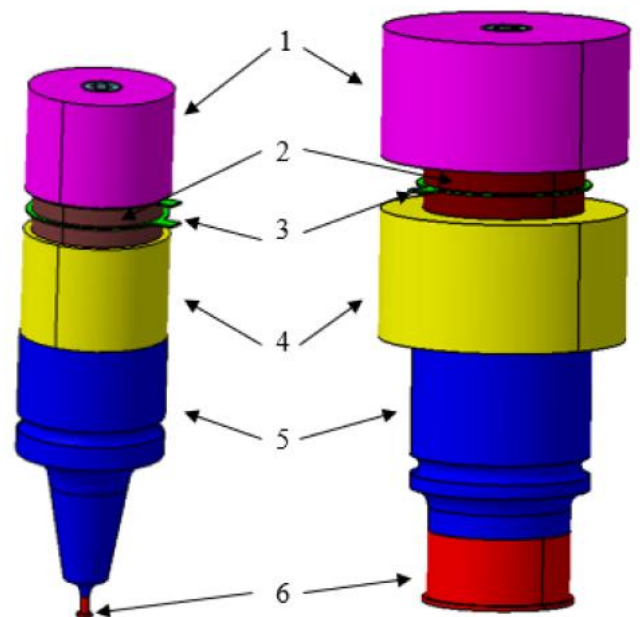
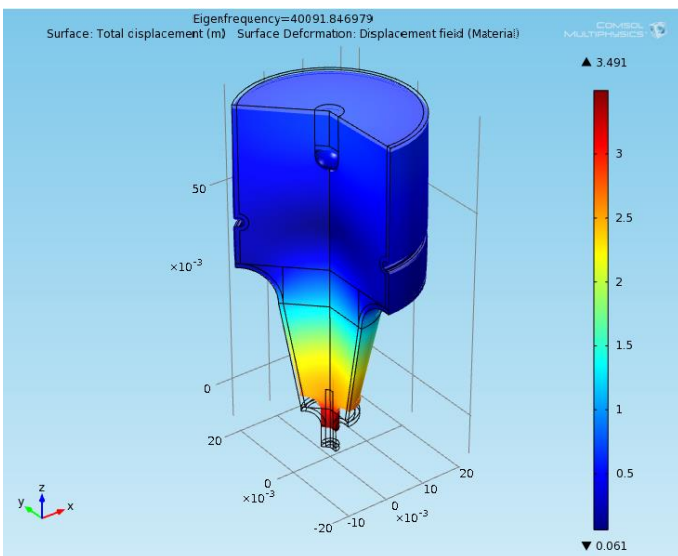


Figure 6. Two types of complete ultrasonic chains

- 1 - reflective bushing (reflect the oscillation. It is part of the transducer)
- 2 - piezoceramic plates (converts electrical oscillation into mechanical oscillation. It is part of the transducer)
- 3 - copper blades (it transmits the electrical oscillation to the piezoceramic plates. It is part of the transducer)
- 4 - radiant bushing (transmits the ultrasonic oscillation to the ultrasonic concentrator. It is part of the transducer)
- 5 - ultrasonic horn (ensures amplification of the elongation transmitted by the ultrasound generator)
- 6 - tool (remove the material)

3. APPLICATION OF ISOLATING MATERIALS

The characteristics of the materials used as a protective element between the electrolytic liquid and the concentrator-tool assembly are presented in the figures below.

Property	Name	Value	Unit	Property group
✓ Density	rho	1760[kg/m...]	kg/m^3	Basic
✓ Young's modulus	E	2.9e9[Pa]	Pa	Young's modulus and Poisson's ratio
✓ Poisson's ratio	nu	0.4	1	Young's modulus and Poisson's ratio
Coefficient of thermal expansion	alpha	100e-6[1/K]	1/K	Basic
Relative permittivity	epsilon	2.9	1	Basic
Thermal conductivity	k	0.1[W/(m*K)]	W/(m*K)	Basic

Figure 7. PVC characteristics

Property	Name	Value	Unit	Property group
✓ Density	rho	1140	kg/m^3	Basic
✓ Young's modulus	E	2.9e9	Pa	Young's modulus and Poisson's ratio
✓ Poisson's ratio	nu	0.39	1	Young's modulus and Poisson's ratio

Figure 8. Polyamide characteristics

Property	Name	Value	Unit	Property group
✓ Density	rho	930[kg/m^3]	kg/m^3	Basic
✓ Young's modulus	E	1.09e9[Pa]	Pa	Young's modulus and Poisson's ratio
✓ Poisson's ratio	nu	0.43	1	Young's modulus and Poisson's ratio
Coefficient of thermal expansion	alpha	150e-6[1/K]	1/K	Basic
Heat capacity at constant pressure	Cp	1900[J/(kg*K)]	J/(kg*K)	Basic
Relative permittivity	epsilon	2.3	1	Basic
Thermal conductivity	k	0.38[W/(m*K)]	W/(m*K)	Basic

Figure 9. Polyethylene characteristics

Property	Name	Value	Unit	Property group
✓ Density	rho	1100	kg/...	Basic
✓ Poisson's ratio	nu	0.35	1	Basic
✓ Young's modulus	E	1e9	Pa	Basic
Thermal conductivity	k	k(T[1/...]	W/(...)	Basic

Figure 10. Epoxy resin X238 characteristics

These material characteristics were defined in COMSOL Multiphysics, to see the influence of each of them.

The following tables show the results regarding the influence of these isolating materials in relation to the resonance frequency.

Table 2. The influence of PVC

	Frequency without PVC [Hz]	Frequency with PVC [Hz]	Eigenfrequency with PVC [Hz]
Model 1_40 kHz	43642	42407	40091
Model 2_40 kHz	43645	42411	40094
Model 3_40 kHz	42842	42370	40000
Model 3_20 kHz	18313	18098	20128
Model 4_40 kHz	42884	42409	40035
Model 4_20 kHz	18321	18106	20142

For the first two models analyzed, a decrease in frequency is observed after the addition of the PVC layer, of approximately 1235 Hz. In the other two models of stepped cylindrical concentrators, larger in size compared to the first two conical concentrators, a decrease in frequency of approximately 472 Hz for the application realised with the transducer of 40 kHz, and 215 Hz for the manufacturing of the surface where was used the transducer with a frequency of 20 kHz is observed.

Table 3. The influence of Polyamide

	Frequency without Polyamide [Hz]	Frequency with Polyamide [Hz]	Eigenfrequency with Polyamide [Hz]
Model 1_40 kHz	43642	42862	40019
Model 2_40 kHz	43645	43011	40002
Model 3_40 kHz	42842	42554	40048
Model 4_40 kHz	42884	42595	40035

In the case of adding the polyamide layer, for the first two models there is a decrease in frequency of 780 Hz and 634 Hz, respectively. In contrast, for the other two the drop is around 288-289 Hz.

Table 4. The influence of Polyethylene

	Frequency without Polyethylene [Hz]	Frequency with Polyethylene [Hz]	Eigenfrequency with Polyethylene [Hz]
Model 1_40 kHz	43642	42952	40040
Model 2_40 kHz	43645	42949	40017
Model 3_40 kHz	42842	42576	40069
Model 4_40 kHz	42884	42616	40007

kHz			
-----	--	--	--

In the case of polyethylene, the values show a decrease in frequency of 690 Hz and 696 Hz, respectively, for the first two models, and for models three and four, the decrease is 266-268 Hz.

Table 5. The influence of Epoxy resin X238

	Frequency without Epoxy resin X238 [Hz]	Frequency with Epoxy resin X238 [Hz]	Eigenfrequency with Epoxy resin X238 [Hz]
Model 1_40 kHz	43642	42810	40041
Model 2_40 kHz	43645	42814	40038
Model 3_40 kHz	42842	42522	40019
Model 4_40 kHz	42884	42563	40054

The addition of epoxy resin X238 brings a decrease of approximately 831-832 Hz, for the first two models and 320-321 Hz, for the other two analyzed concentrators.

4. DEPENDENCE OF EIGENFREQUENCY IN RELATION TO THE THICKNESS OF ISOLATING MATERIAL

After the analysis presented in the previous chapters, graphs were made for some of the developed models, so as to highlight the way of increasing the frequency for each individual material, the thickness of the protective material layer increasing from 0.5 to 1 mm. It is observed that for all analyzed concentrator models, when applying each protective material around the ultrasonic chain, the greater its thickness, the more the frequency tends to decrease.

The influence of the material thickness is almost the same for all models, so in the next figure is exposed one of the developed graph.

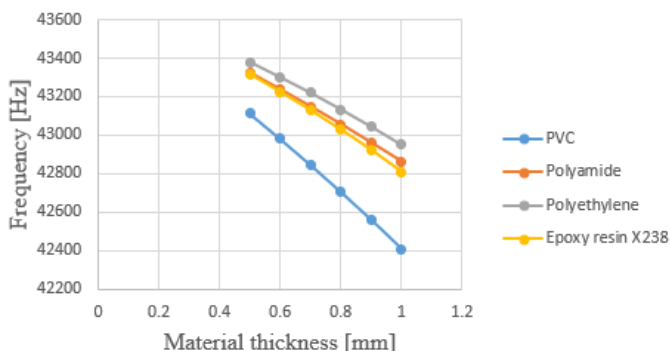


Figure 11. Relation between frequency-material thickness

5. CONCLUSIONS

In this article, the steps followed to perform the modeling in the COMSOL Multiphysics program were indicated. Considering that during electrochemical processing, the tool must be isolated from the electrical environment, the influence of

applying a layer of PVC, polyamide, polyethylene or paint (resin epoxy) was exposed.

The mechanical and chemical properties of all applied materials were considered and at the same time their influence on the resonance frequency was analyzed in detail. Following the studies carried out with the help of the COMSOL program, it is found that materials such as PVC and paint lead to a considerable decrease in the frequency of approximately 831-1235 Hz for the conical concentrator models, respectively 320-472 Hz for the cylindrical concentrator models in steps.

The other two materials analyzed, polyamide and polyethylene, lead to a decrease of 690-780 Hz, for the conical concentrators, and of 266-289 Hz, for the stepped cylindrical concentrators.

Further research will be approached aiming at experimental validation of the results obtained by numerical simulation.

6. REFERENCES

- [1]. Marinescu, N.I., Ghiculescu, D., Popa, Liliana, Pirnau, C. Marinescu Roxana, Ene Gabriela Marina, *Procese tehnologice cu fascicule, oscilații și jeturi*, Volumul 3, TEHNOLOGII CU UNDE ULTRASONICE, ISBN 978-606-23-0984-8, Editura Printech, Cod CNCSIS 54, București, (2019).
- [2]. Hassan El-Hofy, *Vibration-assisted electrochemical machining: a review*, The International Journal of Advanced Manufacturing Technology, (2019).
- [3]. Minghao L., Yong L., et. al., *Theoretical and experimental study on micro ultrasonic-assisted electrochemical drilling with high speed electrode*, The International Journal of Advanced Manufacturing Technology, (2020).
- [4]. Hinduja S., Kunieda M., Modelling of ECM and EDM processes, *CIRP Annals - Manufacturing Technology*, (2013).
- [5]. Wataru N., Hisashi N., et. al., *Improvement of ECM Characteristics by Applying Ultrasonic Vibration*, INTERNATIONAL JOURNAL OF PRECISION ENGINEERING AND MANUFACTURING Vol. 13, No. 7, pp. 1131-1136, (2012).
- [6]. Singh H., Jain P. K., *Influence of ultrasonic vibrations on process performance of electrochemical honing*, Int J Adv Manuf Technol, (2016).
- [7]. Tarlochan S., Akshay D., et. al., *Experimental investigations of energy channelization behavior in ultrasonic assisted electrochemical discharge*

machining, Journal of Materials Processing Tech. 293, (2021).

[8]. Peng T., Wang K., et. al., *Effect of ultrasonic vibration object on machining performance of wire electrochemical micromachining*, The International Journal of Advanced Manufacturing Technology 116:281–291, (2021).

[9]. Jin W., Wei C., et. al., *Ultrasonically assisted electrochemical micro drilling with sidewall-insulated electrode*, Proc IMechE Part B:J Engineering Manufacture, Vol. 230(3) 466–474, (2016).