International Journal of Engineering Innovation & Research
Volume 3, Issue 3, ISSN: 2277 – 5668

CFD Analysis of Electrolyte Flow Pattern in Pulse Electrochemical Machining

Anamika Mishra
Research Scholar,
Mechanical Engineering Department
Bharti Vidyapeeth Deemed University
College of Engineering, Pune-43
Email: anamika_mishra@hotmail.com

D. B. Jadhav
Assistant Professor,
Mechanical Engineering Department
Bharti Vidyapeeth Deemed University
College of Engineering, Pune-43

P. V. Jadhav
Associate Professor,
Production Engineering Department
Bharti Vidyapeeth Deemed University
College of Engineering, Pune-43

Abstract **− ECM emerges out to be one of the major non conventional machining techniques based on Faraday's laws of electrolysis, highly efficient due to its zero tool wear characteristic. Occurrence of passivation is the major problem faced in ECM. In the present work, study of the flow pattern of electrolyte has been performed so that, the machining variable distribution can be predicted accurately thus passivation can be minimized.**

A tool was modeled in Pro-E design modeler. This problem is considered as steady state with turbulence model. The model was simulated for various inlet pressures. The results obtained showed that the flow velocity decreases when electrolyte moves towards the work piece and it increases at the outlet. The pressure is minimum at the inlet and maximum at the inter-electrode gap. Turbulence model also depends upon kinetic energy and eddy dissipation rate. The increase in turbulent kinetic energy increases the surface roughness.

Keywords **− ECM, CFD, Flow Pattern, Hole Making Process, Pulse ECM.**

I. INTRODUCTION

Electrochemical machining is one of the most potential non conventional machining techniques used to machine high strength, heat resistant material. It is considered a reverse of electroplating, based on the principal of electrolysis. As there no contact between tool and work piece at the time of machining it results in zero tool wear. It has been widely used in the automobile industries, turbo-machinery aerospace, aeronautics, defense and medical industries because of its various advantages like negligible tool wear, high precision machining in difficult-to-cut materials, lower thermal and mechanical stress on work piece etc. Though there are few disadvantages such as hydrogen bubble generation and its effect on Material Removal Rate (MRR), complexity of tool geometry and its effect on various process parameters, prediction of electrolyte flow pattern and its impact etc. which have been investigated by various researchers. In complicated work piece it is very difficult to know the machining variables distribution within the inter electrode gap (IEG). Study of the flow pattern of electrolyte can predict the machining variable distribution accurately and thus passivation can be avoided which is the major drawback in electrochemical machining of complicated shapes [1]. Many researchers have presented experimental and analytical studies related to material removal mechanism and current density distribution in ECM using different tool shapes and different software, but they couldn't predict the flow pattern accurately [2]. In complicated work piece, it's very difficult to deduce the machining variables within the IEG. So there is a need to understand parameters related to flow pattern. Once the flow pattern is known, then it's easy to design the tool and avoid passivation. With this background and the art of literature studied, the salient objective of the present study is the analysis of the flow pattern of electrolyte.

II. ELECTROCHEMICAL MACHINING SETUP

In Electrochemical Machining (ECM), a high current, low voltage DC power supply connects a conducting tool and work piece. The shaped tool is connected to the negative (-ve) terminal and work piece to the positive (+ve) which are cathode and anode respectively. A conducting electrolyte flows through a small gap that is maintained between the tool and work piece, thus providing the necessary path for electrolysis. As the direction of electron flow is from work piece to the tool, material removal is from the work piece in a reverse image of the tool. The several components of ECM setup as shown in the fig.1.

A. Work-Piece

Work-piece is a conducting material which acts as an anode. It is connected to the positive terminal of the pulse power supply. Generally materials with very high value of hardness or a very low value of machinability are used as work-piece materials in ECM as it removes material independent of the hardness.

B. Tool

Tool acting as cathode is connected to the negative terminal. Tool material used for electrochemical machining should have good electrical and thermal conductivity, easy machinability, resistance to chemicals, good stiffness and be easily obtainable. The most commonly used tool materials are copper, brass, stainless steel etc.

C. Electrolyte

Electrolyte is a conducting fluid which plays a very vital role in electrochemical machining. An electrolyte in electrochemical machining completes electrical circuit allowing the passage of current (i.e. acts as a conductor), sustains the required electrochemical reactions and acts as a coolant and carries away the waste products. The selection of the electrolyte is based upon the work-piece material, the tool material and the application. Also, it must have a good chemical stability. Apart from these, it should be inexpensive, safe, and as non corrosive as possible.

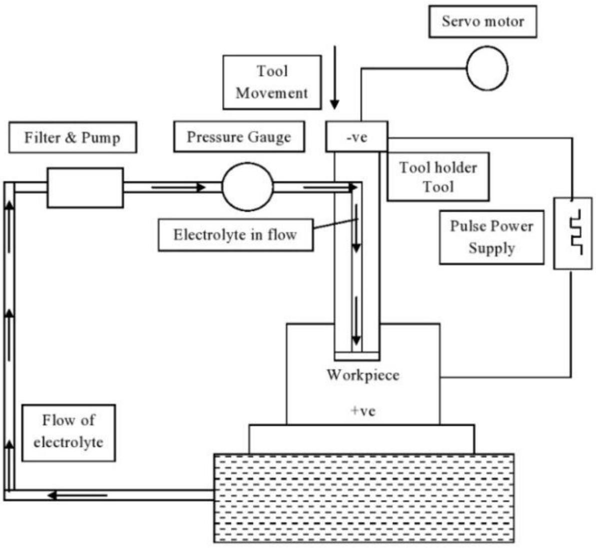

Fig.1. Schematic diagram of various elements of ECM setup

D. Power Supply

Pulse DC power supply with low value of voltage and high value of current is used to minimize the loss of electricity. Current of the order of 50-40,000 A and voltage of order 4-30 V is generally applied to overcome the resistance at the gap.

III. CRITICAL PARAMETERS

A. Tool Feed Rate:

A low feed rate will produce a large overcut and conversely a high feed rate will reduce the amount of overcut.

B. Electrolyte Flow Rate:

A sufficient electrolyte flow between the tool and the work piece is necessary to carry away the heat and the products of machining and to assist the machining process at the required feed rate and producing a satisfactory surface finish

C. Material Removal Rate:

Material removal is based on principle of electrolysis. If the density of the anode material is ρ, the volumetric removal rate is given by,

$$Q = AIt/\rho ZF \quad cm^3/sec$$

Whereas for alloys the charge required to remove all *i-th* element in the volume υ is given by the equation[4].

$$Q = \frac{100}{\rho F}\left(\frac{1}{\sum_i\left(\frac{x_i Z_i}{A_i}\right)}\right) \text{cm}^3\text{/amp-sec}$$

D. Voltage Drop:

The applied voltage is necessary to overcome the potential drop or voltage drop between the electrodes.

E. Current density:

The ECM removal rate is controlled by the current density When the gap size is too small there is a danger of short circuit if it is too large then current density reduced which resulting in a poor surface finish and also decrease in a material removal rate [3].

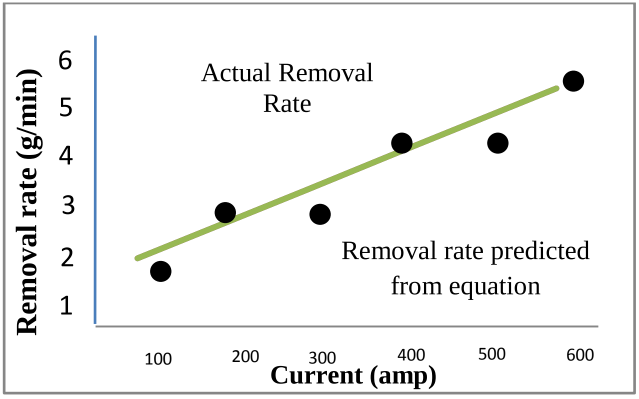

Fig.2. Removal rate versus current[4]

F. Surface finish:

A very good surface finish is desired after ECM. The surface finish of the work piece is affected by the current density and electrolyte velocity. As the current density is increased, the feed rate increases, the overcut is reduced and the surface finish is improved [3].

IV. METHODOLOGY & SOFTWARE

The methodology will work out to achieve the above-mentioned objectives is as follows:

1) Designing of tool with PRO-E Design Modeller: A circular hollow tool of copper is designed using Pro-E design modeler to analyze the flow pattern of the electrolyte.
2) Meshing of model with ANSYS Mesh Module ICEM CFD 14.5
3) Analysis of the problem with ANSYS (ICEM 14.5, Fluent 14.5, CFD-Post 14.5)
4) Observations of results and discussions.

A. Modelling & simulation

To machine the work piece into required shape, tool should be designed properly. The shape of the tool affects the critical parameters of machining and also affects the MRR.

Geometrical modelling: The modeling is done using PRO-E Design modeler. The model used for the simulation study under consideration in the present work is cylindrical shaped with a central through hole having a diameter of 2 mm and height 100 mm. The centre of the hole is fixed at (0, 0, 0) on XYZ coordinate. A cubical block having 100 mm length, 35 mm width and 5 mm height is used as work piece. Model of work-piece is shown in Figure 3. Electrolyte used for this simulation is $NaNO_3$ solution. The electrolyte starts flowing with a constant diameter from the inlet of the tool. 3-D view of the tool is shown in Figure 4. The complete physical model of work-piece-tool set up is as shown in figure 5.

Importing model to ANSYS: Model prepared in the Pro-E cannot be directly opened in the ANSYS. It has to be converted into a compatible format like IGES or STEP/STP for further processing. Pro-E model of the tool and work-piece assembly is firstly converted into STEP/STP format and then imported to ANSYS ICEM CFD14.5.

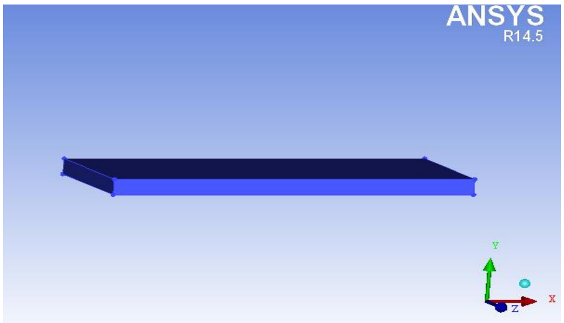

Fig.3. Model of the work-piece used for simulation study

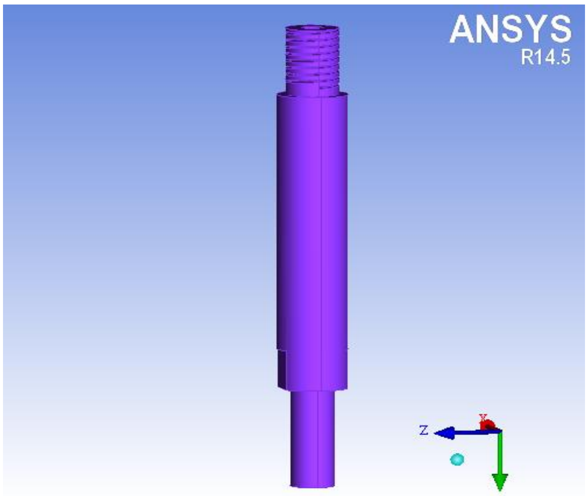

Fig.4. 3-D view of tool for simulation study

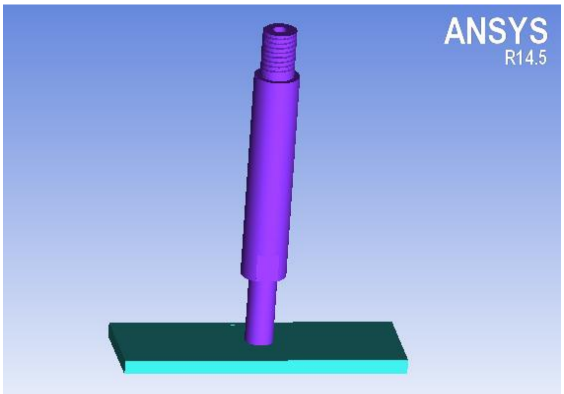

Fig.5. Physical model of work-piece-tool set up

Geometry checking: After importing the geometry to the ICEM CFD we repair the Geometry to check the errors like any incomplete surfaces, holes and gaps etc, by build diagnostic topology. These errors should be rectified as FLUENT does not tolerate such errors. After rectifying all the errors we can proceed further for part naming.

Part naming and material points: After importing the model from the ProE parts are assigned the name for identify. Material points are created to indicate the fluid volume or solid volume. Different names of the parts shown in the model tree. This fig 6 shows the different parts and their names.

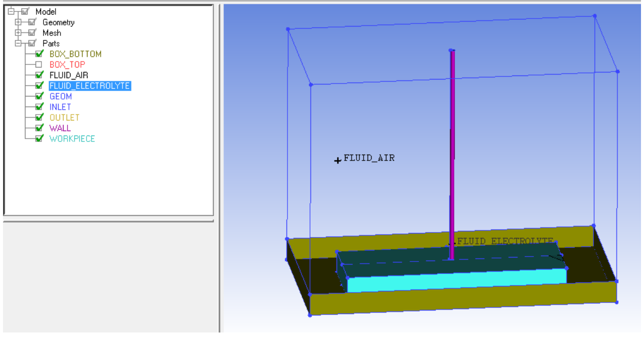

Fig.6. Model with part naming

B. Meshing:

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. After importing the geometry and part naming we set the parameters for meshing. Firstly we have to decide which type of meshing we are going to do (a) Structured mesh, or (b) Unstructured mesh based on the application and complexity of the geometry. In the present work unstructured mesh is used as the model is not too complex and it also takes less time for calculation and analysis. The quality of mesh is a relevant factor in the case of appropriate geometry of the model and accuracy of the results. This can be expressed in terms of orthogonal quality. If the value of orthogonal quality is > 0, mesh quality is good and it gives better results. At the same time if it is < 0, mesh gives bad results. Tetrahedron elements are used for meshing the geometry. It generally provides more automatic solutions with ability to add mesh controls to improve accuracy in critical region. Hexahedral meshes generally give more accurate results but are difficult to generate and time consuming for analysis [17]. We select the part mesh set up to set the proper mesh size for different parts of the model for capturing the proper physic and important features involved in that. The box structure outside the tool work piece setup is generated to capture the air volume which is present in atmosphere.

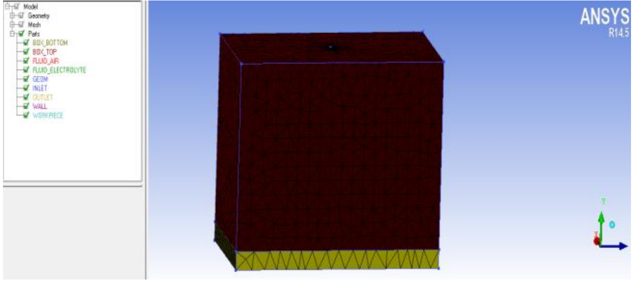

Fig.7. Meshed box model with part naming

Next important step was to create prism elements over the wall surface as the flow pattern of the electrolyte is to be analysed so layer is created only over the electrolyte fluid volume After meshing we check the mesh for the different kind of errors which can create problems at the time of analysis in FLUENT. Errors which can create problem at the time of analysis are as follows [17]:

(a) Duplicate elements (b) Uncovered faces (c) Missing internal faces (d) Volume orientation (e) Surface orientation (f) Hanging elements (g) Multiple edges (h) Triangle boxes (i) Single edges (j) Non-manifold vertices (k) Unconnected vertices.

Errors related to multiple edges are and unconnected vertices are ignored as they do not create any problem while importing the model to FLUENT.

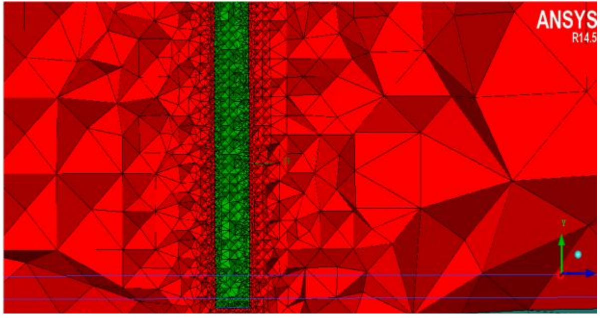

Fig.8. Volume mesh at cut plane

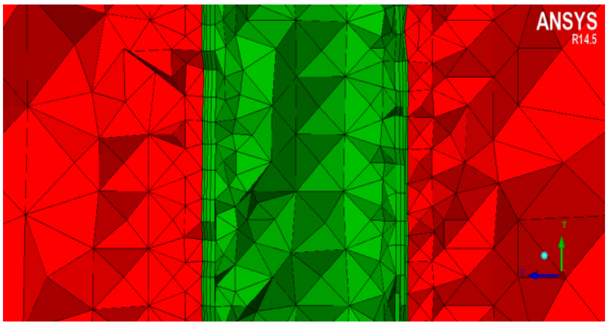

Fig.9. Prism layer at wall surface

C. Boundary conditions

Meshing done in ICEM is then imported in FLUENT in .msh file extension. Before setting the boundary conditions it is necessary to set proper dimensional units. So that proper results are achieved.

Model: In model setup we activate multiphase mode for volume of fluids, as we are considering two volumes: air and electrolyte. Energy equation is also activated as temperature profile is required in present work. We are working on 4000+ Reynolds number so it is a turbulent flow. In turbulent flow model we have two options k-ϵ and k-Ω. We select k-ϵ model for standard wall function as it accurately predicts the spreading rate of both planar and round jets and also provides superior performance for flows involving rotation, boundary layers under strong adverse pressure gradients, separation, and recirculation.

Material: In material setup we create material to be used as solid and fluid volumes as in our work copper and steel as solid material for tool and work-piece respectively and electrolyte and air as a fluid material are used. Air as a fluid volume is defined as it is present in the atmosphere and electrolyte as it circulates inside tool.

The input values for analysis are as:

For inlet zone we select type as pressure-inlet and box bottom as pressure-outlet.

In inlet conditions the pressure of 1.0, 1.2 and 1.4 kg/cm^2 accordingly are inserted. In specification method we give intensity as 5 and hydraulic diameter as 0.02 m. For inlet thermal conditions temperature of air is taken as ambient temperature i.e. 300 k.

The outlet is set as a interior type, box-bottom set as pressure-outlet, the gauge pressure at the outlet surface will be "0". In specification method we give backflow intensity as 5 and backflow hydraulic diameter as 0.02 m.

V. RESULTS & DISCUSSIONS

This deals with the analysis of the results of the three models generated in ANSYS Fluent as modelling. It shows the crucial parameters affecting overall machining process of ECM in terms of contours from which we can predict the variation of these parameters in the IEG and their effects.

It also describes the various experimental results we have obtained from the experiment performed.

A. Critical parameters analyzed in simulation:

Volume Fraction Profile

Figures 10, 11, 12 show the volume fraction profiles, generated at different pressure. The inlet pressure for this simulation study was taken as 1.0 kg/cm^2, 1.2 kg/cm^2 and 1.4 kg/cm^2 respectively. The volume fraction contours shown are the volume fraction of sodium nitrate electrolyte between IEG.

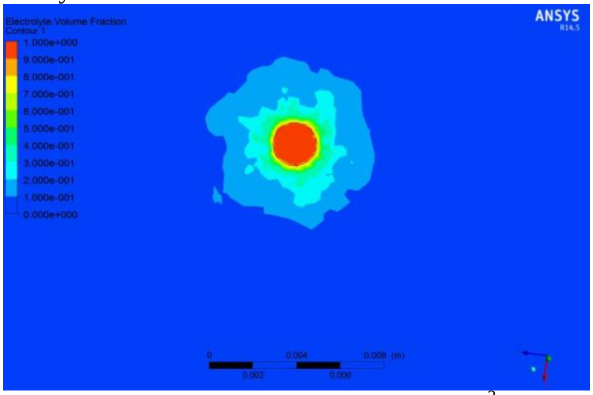

Fig.10. Volume fraction at 1.0 kg/cm^2

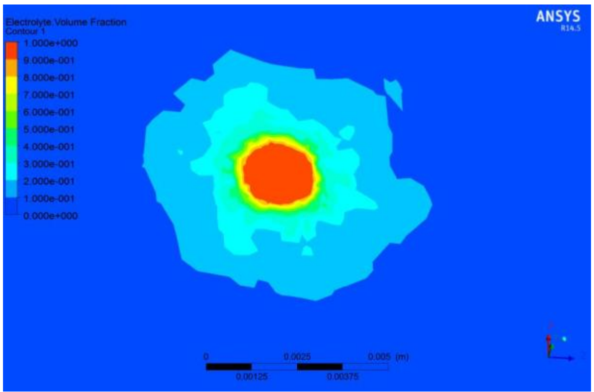

Fig.11. Volume fraction at 1.2 kg/cm^2

As in figure the volume fraction of the electrolyte is higher at the center of the hole and decrease at the outer side. The value of the volume fraction for model at different pressure will be different.

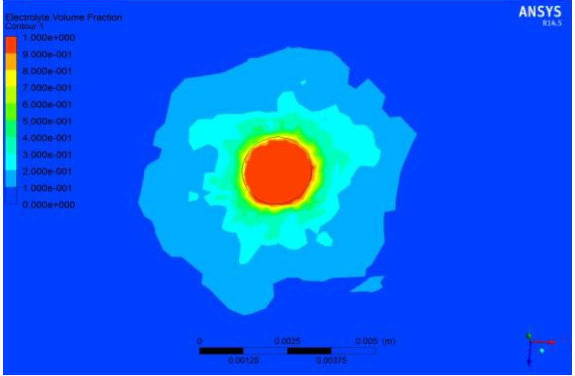

Fig.12. Volume fraction at 1.4 kg/cm^2

Velocity Profile

Figures 13, 14 and 15 show the velocity profile for model at inlet pressure 1.0 kg/cm^2, 1.2 kg/cm^2 and 1.4 kg/cm^2 respectively.

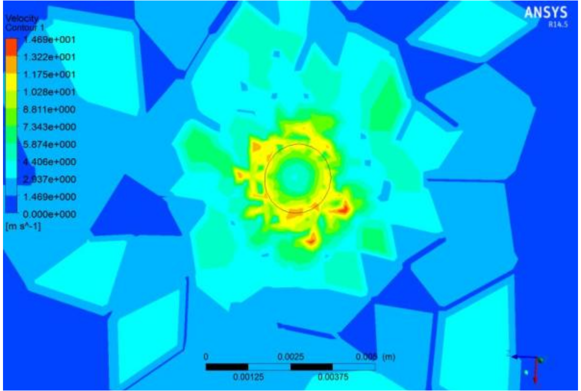

Fig.13. Velocity Profile at 1.0 kg/cm^2

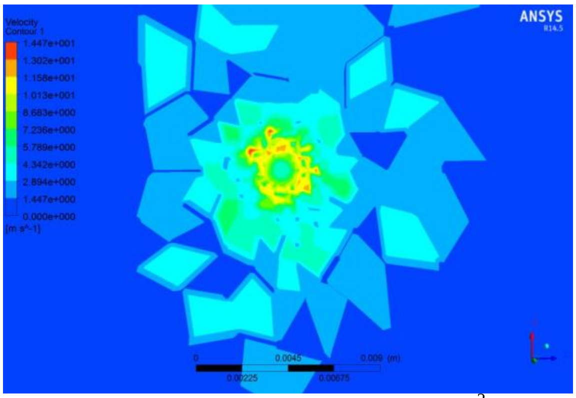

Fig.14. Velocity Profile at 1.2 kg/cm^2

The velocity profile at 1.0 kg/cm^2 pressure is as shown in Fig.13 which indicates that velocity of electrolyte increases from the hole to the boundary due to reduction in area of flow. The velocity of the electrolyte within the IEG is 10.03 m/s, which is less than the outlet velocity. So as the fluid flows towards the work-piece the velocity decreases. There is a slight change in velocity within IEG at different pressure.

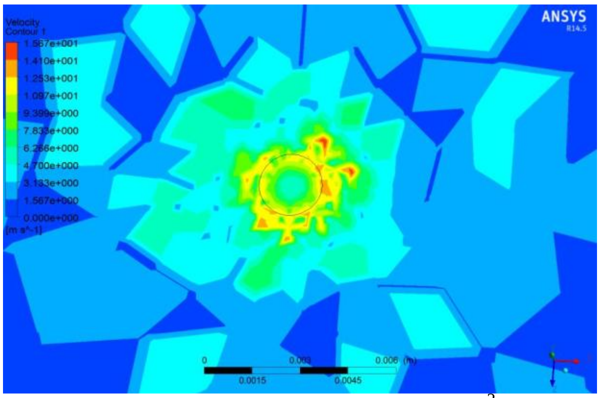

Fig.15. Velocity Profile at 1.4 kg/cm^2

Pressure Profile

Figures 16, 17 and 18 describes the pressure contours for model with different inlet pressure 1.0 kg/cm^2, 1.2 kg/cm^2 and 1.4 kg/cm^2 respectively in the inter electrode gap on the plane of work-piece.

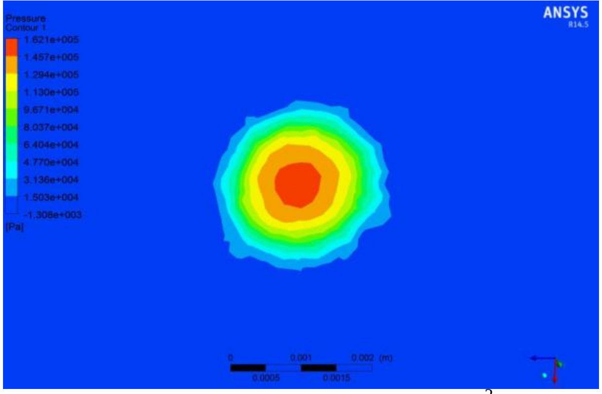

Fig.16. Pressure profile at 1.0 kg/cm^2

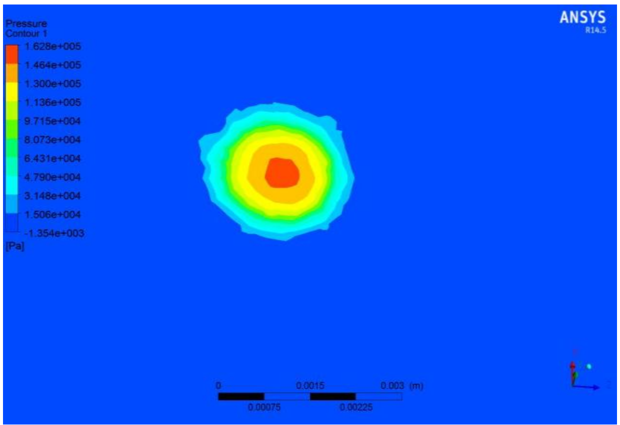

Fig.17. Pressure profile at 1.2 kg/cm^2

The above pressure profiles describe the variation in pressure at the IEG on the plane of machining area. As all cases shows that pressure is higher at the center of the hole and decreases towards the boundary. The pressure increases from the inlet to outlet. The pressure within the IEG will be higher as compare to inlet pressure.

Turbulent Kinetic Energy Profile

Figures 19, 20 and 21 show the turbulent kinetic energy contour within the IEG for model with different pressure.

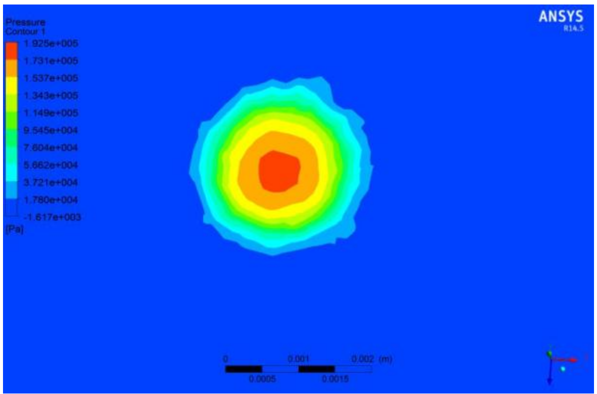

Fig.18. Pressure profile at 1.4 kg/cm^2

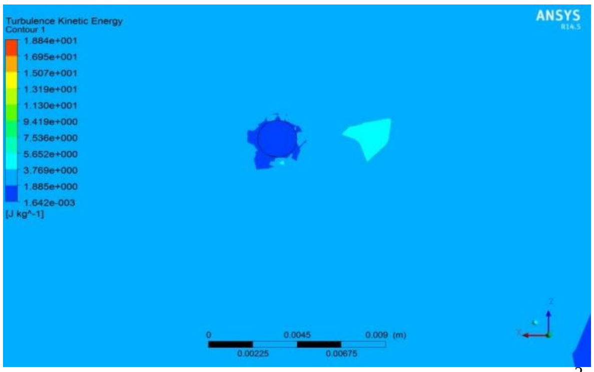

Fig.19. Turbulence kinetic energy profile at 1.0kg/cm^2

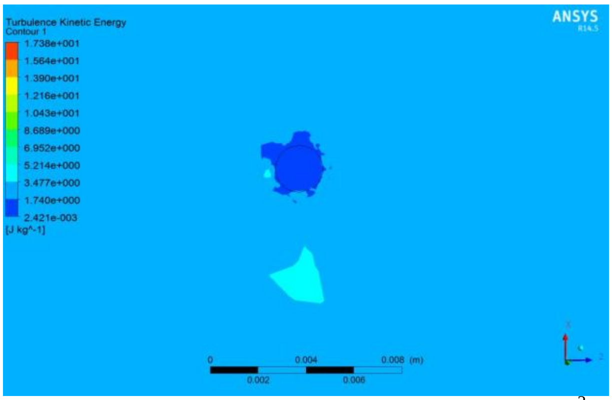

Fig.20. Turbulent kinetic energy profile at 1.2kg/cm^2

Turbulence in the k-ε model depends on turbulent kinetic energy (k) and turbulent eddy dissipation (ε). Turbulence is directly related to the surface roughness. If the turbulence within the IEG is more, then the roughness of the machined surface will also be more. Turbulent kinetic energy determines the energy in the turbulence. Turbulent kinetic energy produced by fluid shear, friction or buoyancy or through external forcing at low frequency eddy scale. The minimum value of the turbulence kinetic energy is 5.101×10^{-1} m^2/s^2 which is at the outlet of electrolyte with 1.0 kg/cm^2 pressure. The maximum value of the kinetic energy is 2.7533m^2/s^2 which will be within the IEG at 1.4 kg/cm^2 pressure. Minimum kinetic energy within the IEG is 2.2638m^2/s^2 at 1.4 kg/cm^2 pressure. So as shown in the figure 20 turbulence is less so there is less turbulent kinetic energy.

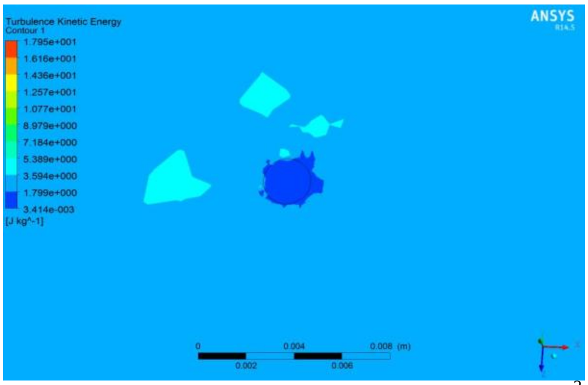

Fig.21. Turbulence kinetic energy profile at 1.4kg/cm^2

Turbulent Eddy Dissipation Profile

Turbulent eddy dissipation gives the quantitative measurement of the turbulence. Figs. 22, 23 and 24 represent the profiles of turbulent eddy dissipation for model within the pressure range 1.0 -1.4 kg/cm^2.

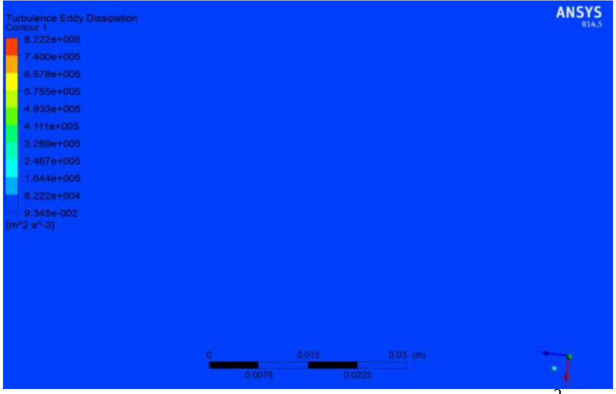

Fig.22. Turbulent eddy dissipation at 1.0 kg/cm^2

The value of turbulent eddy dissipation is almost constant. It is very less within the IEG. The turbulence also depends upon the eddy dissipation rate. At the pressure 1.0 kg/cm^2 the minimum value of eddy dissipation is 4. 230×10^3 m^2/s^3 within IEG and the maximum value of the dissipation rate is 4.735×10^3 m^2/s^3 which is at the outlet.

Fig.5.14 shows the minimum value of dissipation rate is 4.218×10^3 m^2/s^3 within the IEG and the maximum value is 4.735×10^3 m^2/s^3 at the outlet of the electrolyte. In fig 24 the value of dissipation rate within IEG is 5.189×10^3 m^2/s^3 which is at maximum.

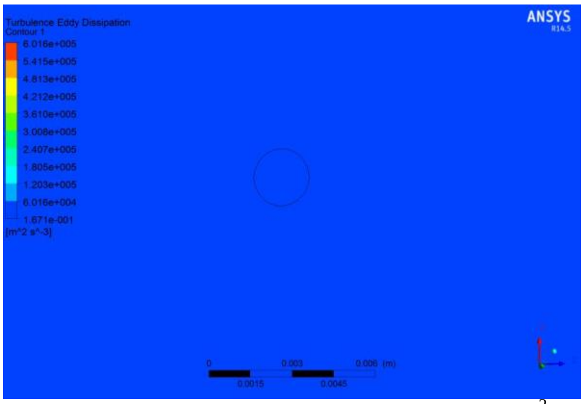

Fig.23. Turbulent eddy dissipation at 1.2 kg/cm^2

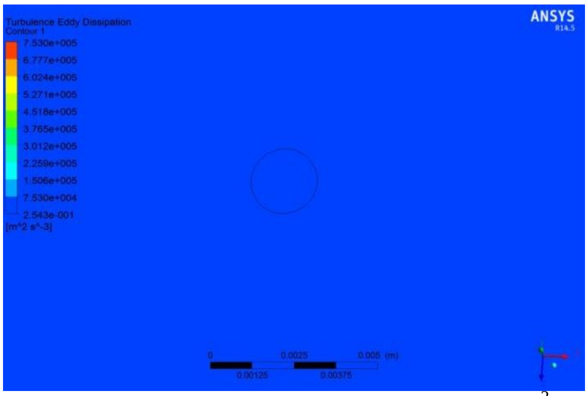

Fig.24. Turbulent eddy dissipation at 1.4 kg/cm^2

VI. CONCLUSIONS

Three dimensional two phase flow pattern analysis of electrochemical machining with circular (hollow) tool provides fundamental idea of velocity distribution, pressure pattern, turbulence etc. in the IEG. A cubical stainless steel work piece, circular copper tool and 15% sodium nitrate solution as electrolyte were considered in this analysis. Tool was modeled using Design Modeler of PRO-E and analyzed in ANSYS FLUENT 14.5. To get consistent and good results, model was meshed with Fine mesh resolution. Model is analyzed with inlet pressure of 1.0 kg/cm^2, 1.2 kg/cm^2 and 1.4 kg/cm^2 respectively.

6.1. Major conclusions:

1) The flow velocity decreases when electrolyte moves towards the work-piece and it increases at the outlet.
2) The pressure is minimum at the inlet and maximum in the inter-electrode gap.
3) The increase in turbulent kinetic energy increases the surface roughness.
4) Turbulence model is also depends upon the eddy dissipation rate.

REFERENCES

[1] Usharani Rath "Two phase flow analysis in electrochemical machining for l-shaped tool: A CFD APPROACH". *M.tech project report (2013).* National Institute of Technology, Rourkela, Odisha, India.

[2] Baburaj, M. "CFD analysis of flow pattern in electrochemical machining for L-shaped tool". *M.Tech project report (2012).* National Institute of Technology, Rourkela, Odisha, India.

[3] Benedict, Gary F. Nontraditional Manufacturing Processes, Marcel Dekker, Inc. 270 Madison Avenue, New York.

[4] Ghosh, A. and Mallik, A.K., (2010). Manufacturing Science Second Edition, *East-West Press Private Limited,* New Delhi, India

[5] Sekar T., Marappan R "Improving Material Removal Rate of Electrochemical Machining by Using Rotating Tool"

[6] H. S. Beravala1, R. S. Barot, A. B. Pandey, G. D. Karhadkar (2011) "Development of Predictive Mathematical model of process parameters in ElectroChemical Machining Process". *National conference on recent trends in engg. & technology.*

[7] Rama Rao. S, Padmanabhan. G (2012) "Application of Taguchi methods and ANOVA in optimization of process parameters for metal removal rate in electrochemical machining of Al/5%SiC composites". *International journal of engineering research and applications,* Vol. 2, pp. 192-197.

[8] Suresh H. Surekar, Sudhir G. Bhatwadekar, Wasudev G. Kharche, Dayanand S. Bilgi (2012) "Determination Of Principle Component Affeting Material Removal Rate In Electrochemical Machining process". *International journal of engineering science and technology,* Vol. 4, pp. 2402-2408.

[9] J. Pattavanitch, S. Hinduja, J. Atkinson (2010) "Modelling of the electrochemical machining process by the boundary element method". *CIRP Annals – Manufacturing technology,* Vol. 59, pp. 243-246.

[10] M.H. Wanga, D. Zhub (2009) "Simulation of fabrication for gas turbine blade turbulated cooling hole in ECM based on FEM". *Journal of material processing technology,* Vol. 209, pp. 1747-1751.

[11] Mohan Sen, H.S. Shan (2005) "A review of electrochemical macro- to micro-hole drilling processes". *International Journal of Machine Tools & Manufacture,* Vol. 45, pp. 137–152.

[12] Evgueny I. Filatov (2001)"The numerical simulation of the unsteady ECM process". *Journal of Materials Processing Technology,* Vol. 109 pp. 327-332.

[13] Jerzy Kozak (2001) "Computer simulation system for electrochemical shaping*". Journal of Materials Processing Technology,* Vol. 109, pp. 354-359.

[14] Upendra Behera , P.J. Paul , S. Kasthurirengan , R. Karunanithi , S.N. Ram , K. Dinesh , S. Jacob () "CFD analysis and experimental investigations towards optimizing the parameters of Ranque–Hilsch vortex tube".

[15] Rui Wu, Danwen Zhang and Juan Sun (2011) "3-D Flow Field of Cathode Design for NC Precision Electrochemical Machining Integer Impeller Based on CFD". *Research journal of applied sciences, engineering and technology,* Vol. 3, pp.1007-1013.

[16] Krishna Mohan Singh1, R. N. Mall (2013) "Analysis Of Optimum Corner Radius Of Electrolyte Flow Path In ECM Using CFD". *International journal of engineering research & technology,* Vol. 2, pp. 617-635.

[17] Sian, S. "CFD analysis of flow pattern in electrochemical machining". *B.Tech. Project Report (2011),* National Institute of Technology Rourkela, Odisha, India.

[18] Ansys Training Manual Inventory Number: 002600, 1st Edition ANSYS Release: 12.0, published date: 28April 2009.

AUTHOR'S PROFILE

Anamika Mishra
was born in Kanpur on 14th October 1993. She has completed Bachelor of Technology in Mechanical Engineering from Baba Saheb Dr. Bhim Rao Ambedkar College of Agricultural Engineering & Technology (Faculty of Technology: Chandra Sekhar Azad University, Kanpur). She has Masters of Technology (CAD/CAM) from Bharti Vidyapeeth Deemed University College of Engineering, Pune.

Dattatray B. Jadhav
is Assistant Professor in the Department of Mechanical Engineering, Bharati Vidyapeeth University College of Engineering, Pune, Maharashtra, India. He has 9 years of teaching experience in the college level engineering education since 2005. He has published four papers in international journals and one paper in international conferences. His area of Interest is Non-traditional Manufacturing Processes.

Pradeep V. Jadhav
is Associate Professor in the Department of Production Engineering, Bharati Vidyapeeth University College of Engineering, Pune, Maharashtra, India. He has 11 years of teaching experience in the college level engineering education since 2003. He has published three papers in international Journals, one national journal and ten papers in international conferences. His area of Interest is Advanced Manufacturing Processes.