Analysis of Two Phase Flow of Electrolyte In Electro Chemical Machining by Using Computational Fluid Dynamics

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Abstract- *Electrochemical machining is a non-conventional machining process which is used to machine difficult-to-machine materials such as super alloys, Ti-alloys, stainless steel etc. The basic working principle of ECM is reverse electroplating due to which the material removal takes place atom by atom by the process of electrolysis. In this process, we have many problems to overcome such as complexity of tool geometry and its effect on various parameters, prediction of electrolyte flow pattern and its impact etc. A two phase assumption in ECM comprising of brine as the primary phase along with formation of hydrogen bubbles as the secondary phase and the subsequent analysis may provide a real insight into the complex ECM process. In this project work, the two phase flow of electrolyte is analyzed by using Computational Fluid Dynamics. Computational Fluid Dynamics is considered to be the most powerful tool for analyzing the flow of fluid. The analyzing is concluded by comparing the results through the contours. The software used for the analysis is ANSYS. Various process parameters like temperature, velocity profile are evaluated from the simulated environment.*

Keywords- ECM; electrolysis; electroplating; CFD Analysis; material removal rate; two Phase flow

I. INTRODUCTION

It is very difficult to machine a high strength, heat-resistant material into complex shapes by conventional techniques, but such materials can be effectively machined by electrochemical machining (ECM) method. Therefore it stemmed the requirement of electrochemical machining process in many industries. ECM is an electrochemical process in which the work piece acts as an Anode and the tool acts as a Cathode. An electrolyte generally sodium chloride or sodium nitrate with a velocity of 5-50 m/s is supplied through the concentric hole in the cathode and it falls over the anode surface, a small gap of 0.05 - 0.8 mm is provided in between the two electrodes. When a small voltage of 5-30 V is applied across the inter electrode gap, a high current density of the order of 5 - 100 A/cm^2 is producing which results in dissolution of metal from anode (work -piece) electrochemically and gas generation occurs at cathode-tool electrode[1]. Allowing the electrolyte to flow through the inter-electrode gap to remove the solid and gaseous products as well as the heat generated caused by the passes of current and electrochemical reactions. The rates of electrochemical dissolution depend strongly on the temperature. The energy losses in the gap are large but the heat can be removed by high flow of electrolyte and, thus, depends on the geometry. Accordingly the temperature at the anode surface is not exactly known, it can be in the range from 40 to $85^{O}C$[2]. The ECM method is quite effective and accurate to obtain a required shape of work-piece within a given tolerance on the shape and dimensions using the cathode–tool electrode with a shape which is geometrically close to the final shape of the work piece[3].

ECM is the controlled removal of metal by anodic dissolution in an electrolytic cell in which the work piece is the anode and the tool is cathode. Electrochemical machining is developed on the principle of Faradays and Ohm. In this process, an electrolyte cell is formed by the anode (work-piece) and the cathode (tool) in the midst of a following electrolyte. The metal is removed by the controlled dissolution of the anode according to the well-known Faradays law of electrolysis. Two electrodes which are placed closely with a gap of about 0.5 mm and immersed in an electrolyte which is a solution of sodium chloride (common salt)[4].

The high current densities promote rapid generation of metal hydroxides and gas bubble in the small spacing between the electrodes. These become a barrier to the electrolyzing current after a few seconds. To maintain a continuous high density current, these products of machining must be continuously removed. This is achieved by circulating the electrolyte at a high velocity through the gap between the electrodes. It is also to be noted that the machining gap size increases as the metal is removed. The larger gap leads to a decrease in the metal removal rate[5].

Therefore to maintain a constant gap between the tool and work-piece, the cathode (tool) should be advanced towards the anode (work) at the same rate at which the metal is removed.

The servo system controls the tool motion relative to the work piece to follow the desired path. It also controls the gap width within such a range that the discharge process can continue. If tool electrode moves too fast and touches the work piece, short circuit occurs. Short circuit contributes little to material removal because the voltage drop between electrodes is small and the current is limited by the generator. If tool electrode moves too slowly, the gap becomes too wide and electrical discharge never occurs. Another function of servo system is to retract the tool electrode when deterioration of gap condition is detected[6].

Analysis of single phase flow in Electro Chemical Machining process has been long evaluated by various researchers. However, it is an established fact that real ECM processes are multi-phasic. A two phase assumption in ECM comprising of brine as the primary phase along with formation of hydrogen bubbles as the secondary phase and the subsequent analysis may provide a real insight into the complex ECM process[7]. As discussed above, the secondary phase consists of hydrogen bubbles which are generated because of the reaction taking place at cathode.

More amount of hydrogen bubbles are generated if the electrolyte is subjected to boiling because of the high heat generated in the IEG. This secondary phase affects various process parameters like current density distribution, volume fraction of brine, velocity pattern of brine etc. Therefore, it is highly desirable to study the second phase and its effect on overall machining process in order to accurately design the tool shape and predict the MRR. Good range of research has been carried out so far on mathematical modeling and simulation of ECM processes[8].

Electrochemical machining is a non-conventional machining process which is used to machine difficult-to-machine materials such as super alloys, Ti-alloys, stainless steel etc. The basic working principle of ECM is reverse electroplating due to which the material removal takes place atom by atom by the process of electrolysis. In this process, we have many problems to overcome such as complexity of tool geometry and its effect on various parameters, prediction of electrolyte flow pattern and its impact etc[9].

A two phase assumption in ECM comprising of brine as the primary phase along with formation of hydrogen bubbles as the secondary phase and the subsequent analysis may provide a real insight into the complex ECM process. In this project work, the two phase flow of electrolyte is analyzed by using Computational Fluid Dynamics. Computational Fluid Dynamics is considered to be the most powerful tool for analyzing the flow of fluid. The analyzing is concluded by comparing the results through the contours. The software used for the analysis is ANSYS. Various process parameters like temperature, velocity profile are evaluated from the simulated environment.

II. MODEL GENERATION

The flow and thermal analysis was performed when the flow parameters such as inlet velocity of flow, density & viscosity of the electrolyte and material properties such as density, thermal conductivity and specific heat for the copper and iron were provided. The heat generated per unit volume of the inter-electrode gap was dependent on the current density and temperature (as the electrical conductivity of electrolyte was temperature dependent). Because of heating, the temperature of the electrolyte is increased so that heat transferred through the walls of electrodes by the conduction process.

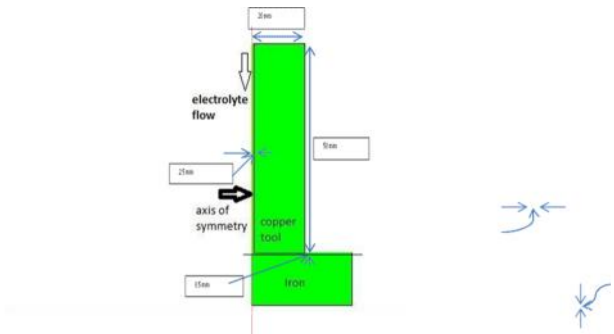

Figure 1: Physical model for CFD analysis

This construction can understand by taking the example of pen for easy manner. Pen has two cylinder layers. Outer layer is plastic, inner layer is refill. If we remove the refill it is visible as thick cylinder with hole. Through this hole electrolyte will flow. For easy construction this setup is divided symmetry. Then, the sketching of the flow path is very easy to us.

III. SOLID WORKS SOFTWARE

Solid works is a 3D mechanical CAD program that runs on Microsoft Windows which was developed by Solid Works Corporation. Solid works provides a full range of

integrated modeling, simulation, visualization; communication and validation tools that product designers need to develop better products faster and at lower cost.
Solid works enable the design engineer to:

- Precisely turn creative concepts into 3D designs
- Create the most ergonomic designs possible
- Produce design in iterations in less time
- Reduce prototyping time and cost

Solid works mechanical design automation software is a feature-based, parametric solid modeling design tool which advantage of the easy to learn windows TM graphical user interface. We can create fully associate 3-D solid models with or without while utilizing automatic or user defined relations to capture design intent. Parameters refer to constraints whose values determine the shape or geometry of the model or assembly. Parameters can be either numeric parameters, such as line lengths or circle diameters, or geometric parameters, such as tangent, parallel, concentric, horizontal or vertical, etc. Numeric parameters can be associated with each other through the use of relations, which allow them to capture design intent. A two phase assumption in ECM comprising of brine as the primary phase along with formation of hydrogen bubbles as the secondary phase and the subsequent analysis may provide a real insight into the complex ECM process. In this project work, the two phase flow of electrolyte is analyzed by using Computational Fluid Dynamics. Computational Fluid Dynamics is considered to be the most powerful tool for analyzing the flow of fluid. The analyzing is concluded by comparing the results through the contours. The software used for the analysis is ANSYS. Various process parameters like temperature, velocity profile are evaluated from the simulated environment.

As per the study carried out by Ratkovich, Chan, Berubeand and Nopens, more amount of hydrogen bubbles are generated if the electrolyte is subjected to boiling because of the high heat generated in the IEG. This secondary phase affects various process parameters like current density distribution, volume fraction of brine, velocity pattern of brine etc. Therefore, it is highly desirable to study the second phase and its effect on overall machining process in order to accurately design the tool shape and predict the MRR. Good range of research has been carried out so far on mathematical modeling and simulation of ECM processes. A brief review of existing literature is carried out.

Electrochemical machining is a non-conventional machining process which is used to machine difficult-to-machine materials such as super alloys, Ti-alloys, stainless steel etc. The basic working principle of ECM is reverse electroplating due to which the material removal takes place atom by atom by the process of electrolysis. In this process, we have many problems to overcome such as complexity of tool geometry and its effect on various parameters, prediction of electrolyte flow pattern and its impact etc.

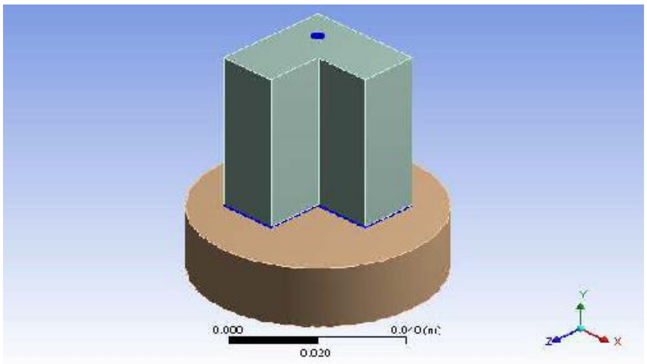

Figure 2: 3D Model

IV. MESHING

For CFD analysis by Fluent software, the model was first prepared and meshed in the Gambit and a mesh file was generated which is then reopened in fluent for the analysis where the element type and the boundary conditions were applied.

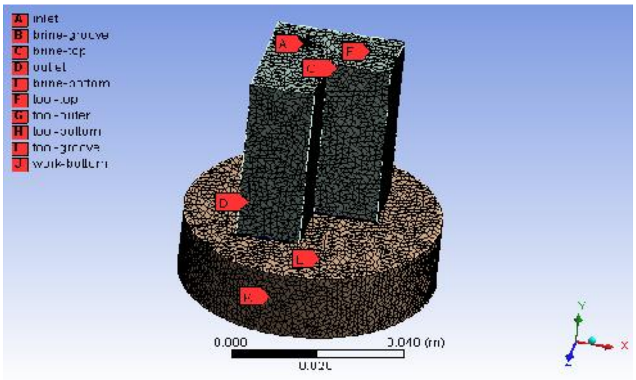

Figure 3: Elements after meshing

V. CFD ANALYSIS

Finite Element Analysis (FEA) is a computer-based numerical technique for calculating the strength and behavior of engineering structures. It can be used to calculate deflection, stress, vibration, buckling behavior and many other phenomena. It also can be used to analyze either small or large-scale deflection under loading or applied displacement. It uses a numerical technique called the finite element method (FEM).

Computational fluid dynamics (CFD) is a branch of fluid mechanics that uses numerical analysis and data structures to solve and analyze problems that involve fluid flows. Computers are used to perform the calculations required to simulate the interaction of liquids and gases with surfaces defined by conditions. With high speed super computers,

Better solutions can be achieved. Ongoing research yields software that improves the accuracy and speed of Complex simulation scenarios such as transonic or turbulent flows. Initial experimental Validation of such software is performed using a wind tunnel with the final validation coming in full-scale testing, e.g. flight tests.

Like solving any problem analytically, you need to define (1) your solution domain, (2) the physical model, (3) boundary conditions and (4) the physical properties. You then solve the problem and present the results. In numerical methods, the main difference is an extra step called mesh generation. This is the step that divides the complex model into small elements that become solvable in an otherwise too complex situation. Below describes the processes in terminology slightly more attune to the software. The layout of ANSYS Fluent workbench used for CFD analysis.

Build Geometry Construct at three dimensional representation of the object to be modeled and test educing the work plane coordinates system within ANSYS.

Define Material Properties Now that the part exists, define a library of the necessary materials that compose the object (or project) being modeled. This includes thermal and mechanical properties.

Generate Mesh At this point ANSYS understands the makeup of the part. Now define how the Modeled system should be broken down into finite pieces. The geometry of meshing in ANSYS fluent.

Define Boundary Conditions Once the system is fully designed, the last task is to burden the system with constraints, such as physical loadings or boundary conditions.

Obtain Solution This is actually a step, because ANSYS needs to understand within what state (steady state, transient… etc.) the problem must be solved. This can be achieved by using the ANSYS Fluent software

VI. RESULTS AND DISCUSSION

Fluent software contains the broad, physical modeling capabilities needed to model flow, turbulence, heat transfer and reactions for industrial applications. These range from air flow over an aircraft wing to combustion in a furnace, from bubble column stool platforms, from blood flow to semiconductor manufacturing and from clean room design to wastewater treatment plants. Fluent spans an expansive range, including special models, with capabilities to model in-cylinder combustion, aero-acoustics, turbo machinery and multiphase systems. Fluent also offers highly scalable, high-performance computing (HPC) to help solve complex, large-model computational fluid dynamics (CFD) simulations quickly and cost-effectively.

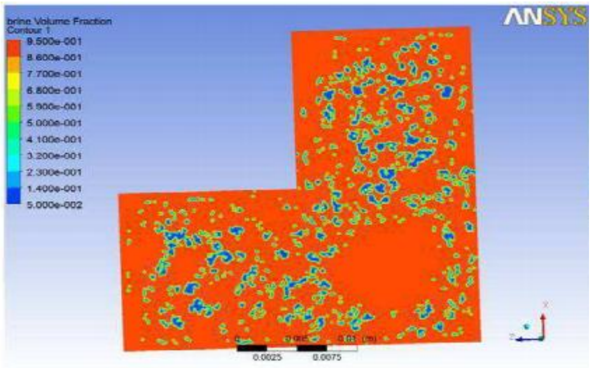

Figure 4: Volume Contour Fraction of Brine

Volume fraction pattern of brine in the IEG for a standard 40m/s inlet electrolyte velocity is shown. It depicts that the brine volume fraction is continuously reduced from the outlet point of the groove towards the boundaries of the contact area. The reduction in volume fraction of brine has the potential to reduce MRR and may affect the heat transfer rates.

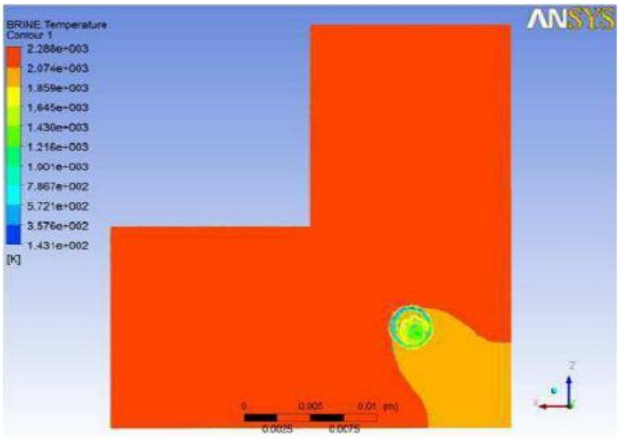

Figure 5: Temperature Contour

The same is consistent with the temperature contour as shown, which shows that, highest temperature occurs near the outlet of the groove and it goes on decreasing outwards. This may be attributed to the increase in hydrogen volume fraction. As hydrogen has very low convective heat transfer coefficient than brine solution, so transfer of heat is inhibited resulting in temperature rise.

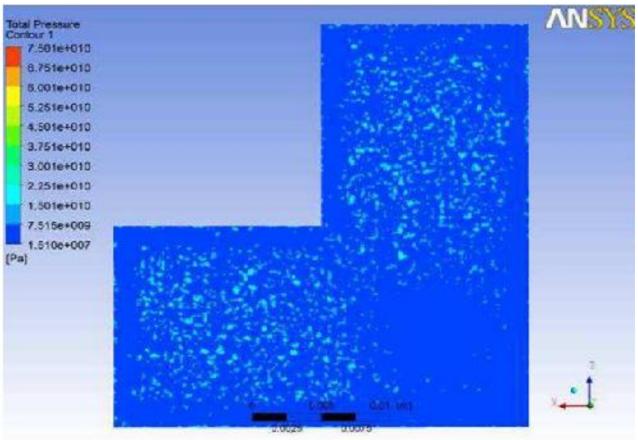

Figure 6: Static Pressure Contour

Ideally the enhanced velocity should increase the pressure drop and a reduced static pressure contour towards the boundary should be obtained. However, the pressure contour shows numerous nucleus high pressure zones towards the boundary despite of enhanced velocity. This is due to the cavitation phenomena occurred there with increased bubbling of hydrogen gas.

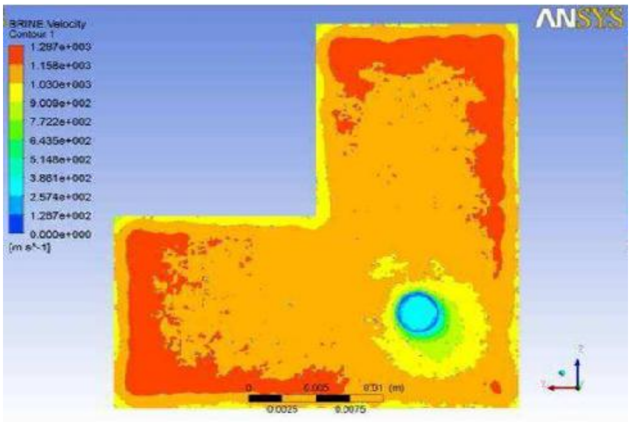

Figure 7: Velocity Contour

The velocity contour is crystal clear that velocity of two phase electrolyte is increased from the groove to the boundary partly due to reduction in area of flow and partly due to formation of hydrogen bubbles resulting in more turbulence. The intensity of bubble formation and its effect on surface finish is another grey area in the domain of ECM which should be investigated in further research.

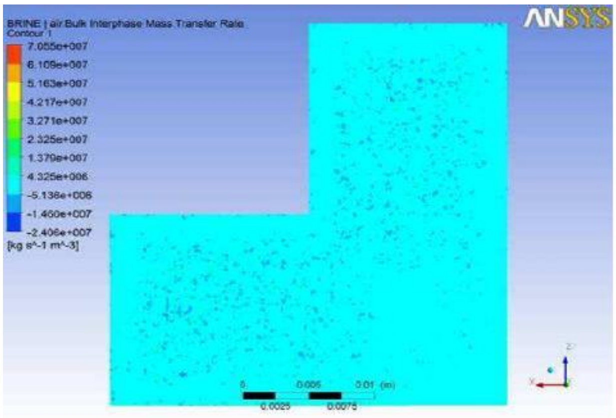

Figure 8: Inter-Phase mass transfer

The contour for inter-phase mass transfer. It may be seen that for the existing tool geometry and a fixed electrolyte flow rate, increased amount of bulk inter-phase mass transfer rate resulting in hydrogen bubbles is obtained away from the groove towards the boundary in closely spaced nucleus sites.

VII. CONCLUSION

In present work, since there is electrical energy source, so according to Joule's heating effect, the heat is generated in the process, and hence the electrolyte temperature rises. This analysis predict the maximum temperature reached and also predict that the inlet flow velocity required for the process corresponding to a particular value of current density, so that boiling of electrolyte shouldn't take place.

The main conclusions are various process parameters like volume fraction profile, velocity profile, turbulent pattern of electrolyte flow in the Inter Electrode Gap (IEG) etc. have been evaluated from the simulated environment. The results indicated hydrogen bubbles generation which in turn reduces the volume fraction of brine. Reduced brine volume fraction decreases MRR and may also affect the surface finish. Besides the temperature at the boundaries are increased substantially due to reduced convective heat transfer as hydrogen bubbles posses substantially low convective heat transfer coefficient.

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