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OPTIMIZATION OF MACHINING PARAMETERS OF ELECTROCHEMICAL MACHIINING - A REVIEW

Rahul Bansal[1], P. Sudhakar Rao[2], Amritbir Singh[3]

[1,3]*M. E. scholar, Department of Mechanical Engineering, National Institute of Technical Teachers Training and Research, (NITTTR), Chandigarh*

[2]*Assistant professor, Department of Mechanical Engineering, National Institute of Technical Teachers Training and Research, (NITTTR), Chandigarh*

Abstract: *Electrochemical machining (ECM) is the most widely used advanced machining process which provides an economical and effective method for shaping high strength and high resisting materials into sophisticated shapes, such as turbine blades, hip-joint implants and micro-components. Influence of various process parameters such as applied voltage, electrolyte concentration, tool feed rate and electrolyte flow rate are optimized to improve the material removal rate and surface roughness. Electrochemical micromachining (EMM) is an advancement of ECM which is used for high precision machining in the order of microns. In the present work, reviews are conducted based on ECM and EMM experimental investigations. Various optimization tools like Taguchi, Response surface methodology (RSM), as well as prediction tools like artificial neural network (ANN), are also implemented.*

Index Terms: *ECM, EMM, Taguchi, ANN, Grey Relational Analysis*

I. INTRODUCTION

1. Electrochemical machining (ECM)

Electrochemical machining is one of the most potential non-traditional machining processes used for removing material from the workpiece. These processes are non-traditional in the sense that they do not use any traditional tools for metal removal and instead they directly use other forms of energy. These methods are generally used to overcome the problems of high complexity in shape, size and higher demand for product accuracy and surface finish [1]. Since material removal takes place at the atomic level, ECM can produce a mirror finish surface. It is generally used for mass production and for machining extremely hard materials that are difficult to machine using conventional methods [2].

In non-traditional machining, the processes are majorly divided into four categories. Thermal oriented, e.g. Electric Discharge Machining (EDM), Laser Beam Machining (LBM), and Electron beam machining (EBM), etc., which may cause thermal alteration of the machined surface, Mechanical oriented, e.g. Ultrasonic machining (USM), Abrasive Jet machining (AJM) etc., while some are thermal free processes, e.g. Chemical machining and Electrochemical Machining.

Electrochemical machining is a material removal process similar to electro plating and is based the Faraday's law of electrolysis. In this process, the work piece (anode) and the ECM tool (cathode) of an electrolytic cell with a salt solution are used as an electrolyte. When adequate electrical energy is achieved between the tool and the work piece on the application of high amperage direct current between the two electrodes, positive metal ions leave the work piece. Since electrons are removed from the work piece, oxidation reaction occurs at the anode. A reduction reaction occurs as the electrolyte accepts these electrons. This charge exchange between the cathode and anode in an aqueous solution of electrolyte helps to machine specific areas of workpiece. Hence the metal removal is obtained by anodic dissolution of the work piece [3]. Regular flow of electrolyte is flushed in the gap between the tool and the work piece to remove the unwanted machining products which otherwise would grow to create a short circuit between the electrodes. The tool is advanced into the work piece for the machining to be carried out. The removed material is precipitated from the electrolyte solution in the form of metal hydroxide. The schematic diagram of Electro-Chemical Machining is shown in the following figure 1.

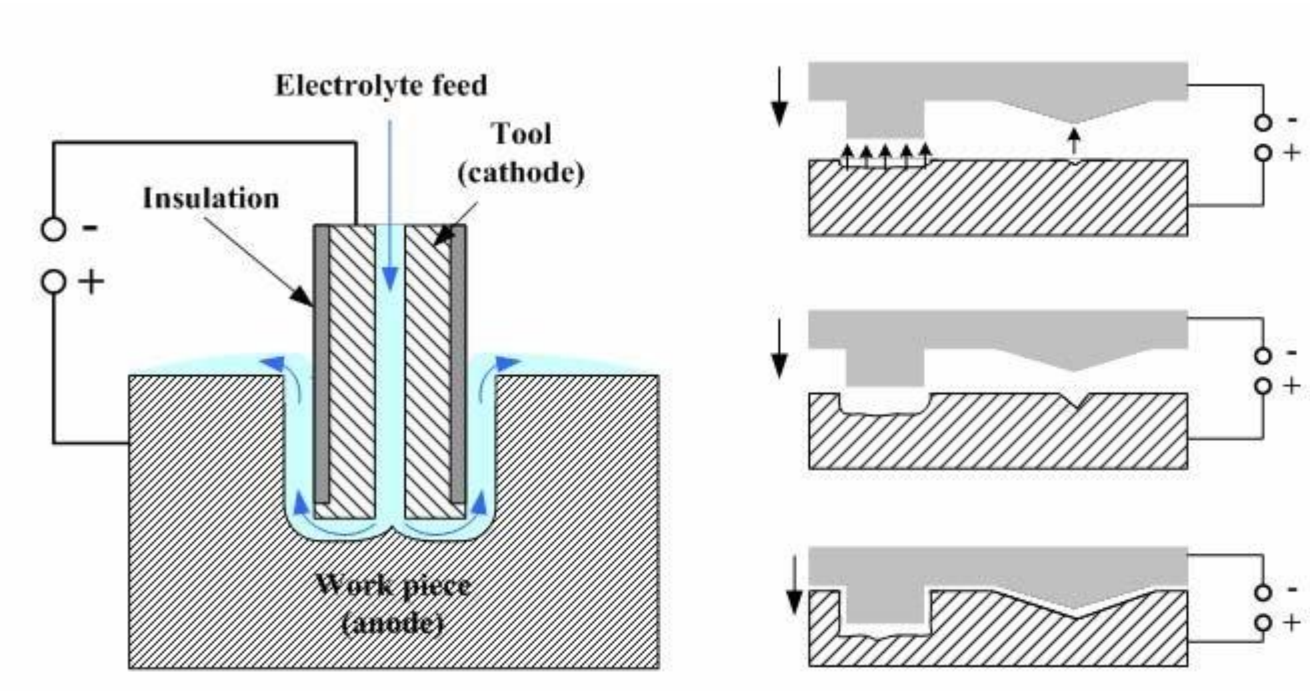

Fig. 1: Schematic view of Electro-Chemical Machining [3]

2. Electrochemical Micromachining (EMM)

When Electrochemical machining process is used for fabrication of microstructures it is known as Electrochemical Micromachining (EMM). Micromachining technology plays an important role in the miniaturization of components and it refers to very small amount of material removal of dimensions ranging from 1 to 999 µm [1]. The process variables of the EMM system such as nature of power supply, electrolyte, micro tool design, and temperature, etc. should be optimally controlled as discussed by J. Kozak et al. [4].

ECM process is widely used to cut odd-shaped angles, curved surfaces and cavities in hard and exotic metals, such as Titanium aluminides, Inconel, Nickel, Cobalt, and rhenium alloys with excellent surface quality [5]. Since the electrolyte used is acidic in naure, it leads to the corrosion of tool, workpiece and equipment [6]. Since, ECM is such vast and fast-growing field, many researchers have worked on it. Some of the reviews of their research are as follows.

II. LITERATURE BASED ON ELECTROCHEMICAL MACHINING

Singh and Shukla [7] analyzed the two performance parameters i.e. MRR and overcut, using the Black Hole algorithm for ECM process. BHA provided the optimum solution with a smaller number of trials and less computational time. For the considered ECM process, the MRR obtained using BHA increased from 0.8230 g/min to 1.6922 g/min which was very significant improvement and overcut decreased from 0.2706 mm to 0.1063 mm.

Asokan et al. [8] proposed a practical method to determine the optimal machining parameters for ECM based on multiple regression models and Artificial Neuron Network (ANN) model. Machining parameters such as current, voltage, flow rate, and gap depend on operator's technologies and experience. MRR and surface roughness were obtained as responses from the ECM process, which were combined to have a single objective as grey relational grade by the application of grey relational analysis. The author further stated that the geometry, condition, and accuracy of the machined surface depend on the electrolyte salt type concentration, machining gap, pulse power supply setting, flow velocity, and flow profile.

Chakradhar and Gopal [9] presented the optimization of process parameters for electrochemical machining of EN-31 steel using grey relation analysis. The process parameters considered were electrolyte concentration, feed rate and applied voltage which were optimized with performance characteristics including material removal rate, overcut, cylindricity error and surface roughness. The optimal process parameters that yielded the best combination of process variables were electrolyte concentration at 15 %, feed at 0.32 mm/min and voltage at 20 V. As a result, the target performance characteristics, i.e. material removal rate was maximized and the overcut, cylindricity error and surface roughness were minimized through this method.

Rao and Padmanabhan [10] studied the application of Taguchi method for the optimization of process parameters like voltage, feed rate and electrolyte concentration. Also, orthogonal arrays of Taguchi, the signal-to-noise (S/N) ratio, the analysis of variance (ANOVA), and regression analyses were employed to find the optimal process parameter levels and to analyze the effect of these parameters on metal removal rate values. It is noted that the metal removal rate increase with voltage, feed rate and electrolyte concentration in electrochemical machining.

Nayak and Tripathy [11] observed that Taguchi technique can be used to optimize the surface roughness and MRR. Experiment result of MRR and Surface Roughness was predicted by the Multi-Layer Feed Natural Network (MFNN) and Least square support vector machine (LSSVM). EN19 tool steel material was used as the workpiece for experiments. Experimental setup included a low voltage source which was applied across two electrodes with a small gap size (0.1 mm – 0.5 mm) and with a high current density around 2000 A/cm^2. Electrolytes $NaCl+H_2O$ flow through the gap with a velocity of 20-30 m/s.

Klocke et al. [12] investigated the machinability of selected modern titanium and nickel- based alloys for aero engine components. Using the research platform at WZL and with the associated ECM tool the results of feed rate – current density curves for several titanium and nickel-based alloys were examined. Experimental results were compared according to Faraday's law of electrolysis, which established a relation between the feed rate as a function of current density and external flushing was compared to the theoretical dissolution behavior. SEM and EDX analysis were used to examine the surface properties in terms of the rim zone. This analysis proved that there was no kind of affected zone or foreign atoms diffused from the electrolyte.

Senthil Kumar et al. [13] studied the effect of input parameters such as MRR and Surface Roughness (Ra) on die sinking Electrochemical Machining process. The electrolyte used for experimentation was afresh aqueous solution of sodium nitrate ($NaNO_3$) with varying electrolyte concentration and workpiece used was LM25AL/10%SiCp composite. Response Surface Methodology (RSM) was used to find an empirical relationship between process parameters and responses in ECM process. Analysis of variance (ANOVA) was also used to indicate the level of significance of machining parameters. Experiments proved that MRR is influenced by applied voltage and tool feed, whereas surface roughness was affected by electrolyte concentration.

Bisht et al. [14] performed experimentation to optimize the MRR and surface roughness. An experiment was conducted on mild steel and aluminum by optimizing four machining parameters i.e. Voltage, Electrolyte flow rate, Tool feed rate and current using Taguchi orthogonal array with three levels of machining parameters and also with the help of software Minitab 15. The MRR was considered as the quality characteristics with the concepts of "The larger the better" and surface roughness was considered with the concepts of "The smaller the better". The author concluded by stating that Electrolyte flow rate for mild steel and current for aluminum alloy are the most significant machining parameters.

Thanigaivelana et al. [15] described the Electrochemical Micromachining (EMM) of stainless steel with acidified sodium nitrate. A 160 μm thick conical tip shape tool electrode was used to conduct all the experiments on a stainless plate with thickness 200 μm. Using scheme of experiments involving various parameters, such as machining voltage, pulse on time and electrolyte concentration, the performance of acidified sodium nitrate and sodium nitrate on EMM were compared.

Mogilnikov et al. [16] discussed the diamond electrochemical grinding (DECMG) method of machining of rectangular ceramic metal - tungsten base plates with their vacuum fastening on the table of the machine-tool. An aqueous solution of Na_2HPO_4 and Na_2CO_3 with additives was used as an electrolyte. Thus, using delicate working conditions of DECMG including change of electrode operating voltage from 2.5 to 5 V and regulating volume of aqueous solution supplied to machining area we obtain the required performance of ceramic metal-tungsten plates, such as linear dimensions, surface roughness, structure of surface layers, reflection power, zero-defect quality, and durability.

Ningsong et al. [17] observed that Wire electrochemical machining (WECM) can be used for the fabrication of Titanium and titanium alloys. Axial electrolyte flushing process is used for removing electrolysis products and renewing electrolyte in WECM. Taguchi experiment was also conducted to optimize the machining parameters, such as the optimal combination level of the machining parameter was electrolyte 2.5% NaCl+2.5% $NaNO_3$, 5 mm nozzle workpiece distance, 87 m/s electrolyte flow rate, 18V working voltage and 1.8 mm/min wire feed rate, machining voltage, electrolyte concentration etc. The machining productivity of wire electrochemical machining could be improved by multi-wire electrochemical machining.

Yong and Ruiqin [18] analyzed a tapered hole, shaped by ECM after a straight cylindrical pilot hole was drilled by EDM for fuel jet nozzles. A type of polyimide tube is used to insulate the electrode. To keep the correct position of tool electrode for sequential machining, same electrode guide is used for non-insulated electrode for EDM and insulated electrode for ECM. The diameter variances in ECM with pulse voltage, tool electrode feeding speed, pulse duration and duty ratio were investigated experimentally.

Rath and Biswas [19] analyzed various process parameters like volume fraction profile, velocity profile, turbulent pattern of electrolyte flow in the Inter Electrode Gap (IEG) etc. using Computational Fluid Dynamics (CFD). Though ECM is highly efficient non-conventional machining process, still there are some challenges in ECM like generation of hydrogen bubbles and its effect on MRR, complexity of tool geometry and its effect on various process parameters, prediction of electrolyte flow pattern and its impact etc.

Surekar et al. [20] conducted an experimental process to optimize machining parameters which affected the MRR of Hastelloy c-276. Three parameters used in experiments were feed rate, electrolyte flow rate and voltage. Taguchi L9 orthogonal array was used for parameter setting during the experimental runs. In this paper, the author observed that the best combination for material removal was high feed rate at minimum electrolyte flow rate and maximum voltage. Thus, he concluded that the feed rate is the most affecting parameter to the material removal rate.

III. CONCLUSIONS AND FUTURE SCOPE

ECM today is widely used for machining operations of materials used in extreme conditions of temperature, friction, and corrosion. Some recent developments in various aspects of ECM and EMM are discussed in this paper. Various advancements are being conducted to spread ECM processes into new areas of modern technologies, such as Micromachining, and Diamond electrochemical grinding etc. It can be observed that ECM finds majority of its applications in deburring and hole drilling, and EMM can be used to machine either a single hole or a series of holes with the same characteristics. Thus, it can be concluded that Machining performance can be evaluated by considering MRR, overcut as a response which effects with various process parameter like voltage inter- electrode gape, machining time etc.

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