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Experimental Study on Pulse Electrochemical Machining of Inconel 718

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Abstract:- The properties of the Inconel 718 super alloy are used in the manufacturing of aircraft components, due to high hardness and toughness machining of such alloy by conventional machining process is difficult. To overcome this, nonconventional techniques are used, from which electrochemical machining (ECM) is good alternative. Electrochemical Machining (ECM) is a nonconventional manufacturing process widely employed in various industries due to its precision in shaping complex, detailed components. This study focuses on exploring and optimizing the key machining parameters in ECM to enhance machining efficiency and surface finish quality of Inconel 718. The research methodology involves a systematic experimental investigation, employing a series of controlled tests on an ECM machine. The controllable process parameters selected which are current, voltage and duty cycle. The aim is to comprehend the nuanced influence of these variables on material removal rate (MRR) and overcut and to investigate optimum level of process parameter. The analysis shows that the duty cycle and current are most influencing factor for controlling depth of overcut and for improving MRR, but excessive high duty cycle can be counterproductive which results in increased heat generation because continuous current flow generates heat in the electrolyte and work piece.

Keywords:- *Inconel 718; Electrochemical Machining; Electrolyte; Taguchi Method; Process Optimization.*

I. INTRODUCTION

Inconel 718 is a nickel-chrome base super alloy. It can sustain high working temperatures of up to 700°C.The main component of the material are nickel(50-55%), chromium(17-21%), niobium(4.75-5.5%). It has more desirable properties which are applicable in manufacturing of high working temperature components in aerospace industry. Electrochemical Machining (ECM) stands as a transformative process in modern manufacturing, offering high-precision material removal capabilities without inducing mechanical stress or heat-related deformities. The optimal control and understanding of ECM parameters hold pivotal significance in harnessing its potential for achieving superior machining efficiency and surface quality. The literature surrounding ECM underscores its foundation in electrochemical dissolution mechanisms. The process involves controlled material removal through electrolysis, where complex interactions between the work piece, tool, and electrolyte determine the efficiency of material removal. Understanding these fundamental principles is critical to navigating the complexities of ECM parameter optimization.

Extensive research has been committed to unravelling the complex details in relationships between ECM parameters and machining outcomes. Voltage, electrolyte composition, tool feed rate, and electrode gap have been recognized as key influencers affecting Material Removal Rate (MRR), surface finish, and dimensional accuracy. The exploration of these parameters has been instrumental in advancing ECM capabilities.

A significant stride in ECM literature involves the application of statistical techniques and optimization methodologies. Studies have employed approaches like Design of Experiments (DOE) and Taguchi analysis methodology to model and optimize ECM parameters. These statistical methods aim to navigate the intricate parameter space to achieve superior machining performance.

Challenges persist in the ECM domain, ranging from tool wear and electrolyte degradation to achieving a harmonious balance between material removal rates and surface quality. Addressing these challenges presents avenues for future research, driving innovations in ECM processes and opening doors to various techniques and materials this review of ECM literature sets the context for the current investigation into experimental exploration and optimization of ECM machining parameters.

II. ELECTROCHEMICAL MACHINING OF INCONEL 718

A. Experimental Setup

In this study Inconel 718 plate is used for machining which is size of 150mm*100mm*3.2mm. During the machining process metal from workpiece is dissolved by using voltage pulse at high current density. The workpiece act as the anode and tool act as cathode and they are separated by a small gap of 10 µm. The main working elements of the pulse electrochemical machine (PECM) are cathode tool, tool feed mechanism, machining chamber, electrolyte storage tank, and pulse power supply unit. Figure 1 shows the experimental setup of ECM.

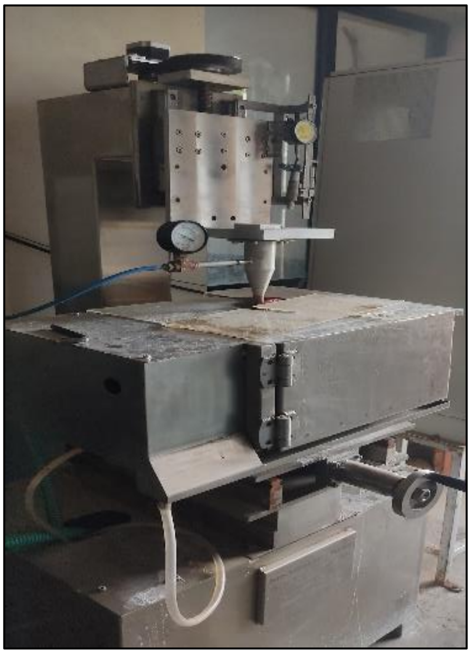

Fig 1 ECM Setup

- *Power Supply:*

A pulse power supply at constant voltage mode (0 – 30 V) with the output current in following ranges (0-33 Amp) Pulse on time range available from 5 to 2000µs with 1 µs rise and pulse off time in the range of 5-6000 µs are available for the experimentation. Fig. 2 represents the control panel of the pulse power supply.

- *Machining Chamber:*

Figure 2 shows the machining chamber. Machining of the workpiece can be performed in the machining chamber made up of SS 304 grade material. Workpiece was held firmly using the clamp made up of SS 304 material, workpiece is attached to positive terminal and tool is attached to negative terminal. Slurry formed during the machining was collected in the electrolyte tank.

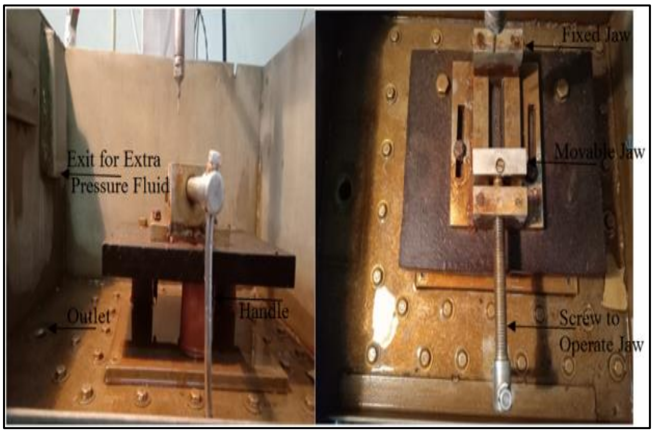

Fig 2 Machining Chamber

- *Tool Feed Mechanism:*

The mechanism provide vertical feed to the tool against the work piece during machining. Stepper motor, belt, pulley, lead screw and vernier caliper are the subcomponents of tool feed mechanism unit as shown in Figure 3.

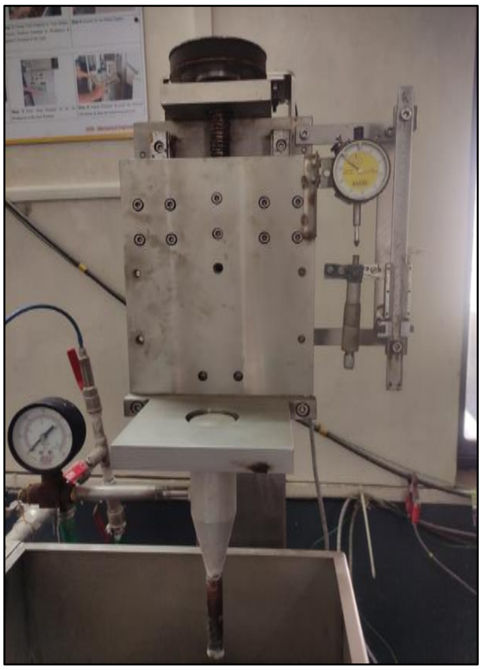

Fig 3 Tool Feed Mechanism

- *Tool:*

Copper is the most used materials for the manufacturing of tool electrode in ECM. High stiffness, thermal conductivity, low electrical resistivity and easiness in manufacturing makes the copper as the best material as compared to the other selected material. An insulating coating of Perspex, 120µm thick was applied along the full length of the tool. Figure 4 shows the copper tool having internal diameter of 3mm is used for machining.

Fig 4 Copper Tool

- *Electrolyte:*

Sodium Nitrate ($NaNO_3$) is used as electrolyte for the machining of Inconel 718. It readily dissociates into Na^+ and NO_3^- ions in solution, making it an excellent conductor of electricity ensuring efficient current flow and controlled material removal.

B. Machining Parameters

Table 1 show the machining parameters and their ranges selected for experimentation. Where Voltage, Current and Duty Cycle are input parameters. The parameters other than input parameters are kept constant.

Table 1 Machining Parameters

Sr No	Parameter	Range
1	Voltage(A)	16-20
2	Current(A)	6-10
3	Duty Cycle	3.5-5.5
4	Feed Range	0.4mm/min
5	Power supply(DC)	Continuous
6	Electrolyte Type	NaNO3
7	Tool Material	Copper
8	Electrolyte Temperature	20-30℃

- *Response Variables:*

- Material Removal Rate(MRR), g/min: It is defined as mass of drilled material per unit machining time (g/min)
- MRR= (Initial weight of workpiece - final weight of workpiece)/ machining time
- Depth of Overcut (mm): The difference between the size of the electrode diameter and size of the hole is called total depth of overcut.

III. DESIGN OF EXPERIMENT BY TAGUCHI METHOD

Design of Experiments (DOE), is a technique of designing the experimentation by varying the levels of the controllable factors in the process to investigate the effect of process parameter on output variables.

A. *Taguchi Approach*

The Taguchi method used to reducing the variation in a response of process through obtaining optimum process parameter. Taguchi method can analyze different input parameters by conducting low amount of experimentation also identify the most influencing input parameter on the response variables. The optimal settings for the independent variables can be estimated.

B. *Design of Experiment*

Design of Experimentation is devised by Taguchi method by using mini tab software.

- *Table 2 Contains Input Parameter and their Levels*

Table 2 Input Parameter

Sr No	Current	Voltage	Duty Cycle
1	6	16	3.5
2	8	18	4.5
3	10	20	5.5

- *Design Summary: Table 3 Contains List of Readings to be Conducted Obtained by Taguchi Array L9(3^3)*

Table 3 List of Readings

Sr. No.	Current (A)	Voltage (V)	Duty Cycle
1	6	16	3.5
2	8	18	4.5
3	10	20	5.5
4	6	16	4.5
5	8	18	5.5
6	10	20	3.5
7	6	16	5.5
8	8	18	3.5
9	10	20	4.5

IV. EXPERIMENTAL DETAILS

Table 4 specifies the values of MRR and Depth of overcut for each combination of levels obtained from experimentation.

Table 4 Calculated Values of MRR and Depth of Overcut

Sr. No.	Current (A)	Voltage (V)	Duty Cycle	MRR	Depth of Overcut
1	6	16	3.5	0.013	0.0650
2	8	18	4.5	0.0620	0.0600
3	10	20	5.5	0.0550	0.0990
4	6	16	4.5	0.0318	0.0540
5	8	18	5.5	0.0341	0.0662
6	10	20	3.5	0.0365	0.0900
7	6	16	5.5	0.0089	0.0910
8	8	18	3.5	0.0084	0.0660
9	10	20	4.5	0.0258	0.0480

A. *Process Optimization by Taguchi Method*

To investigate the optimum level of control factors which can improve the characteristics of MRR and Depth of overcut taguchi method uses the loss function technique to identify the fluctuating values of output parameter from required output. The value of this loss function is obtained by calculating signal-to-noise (S/N) ratio for each response variable.

Following are the process optimization results obtained by using Minitab software.

- *Taguchi Analysis: MRR vs Current Voltage Duty Cycle. Table 5 Shows the S/N Ratios for MRR.*

Table 5 S/N Ratio for MRR

Level	Current	Voltage	Duty Cycle
1	-29.02	-36.23	-36.00
2	-29.35	-31.67	-28.62
3	-38.10	-28.57	-31.85
Delta	9.08	7.66	7.37
Rank	1	2	3

- *Taguchi Analysis: Depth of Overcut vs Current Voltage Duty Cycle. Table 6 Shows the S/N Ratios for Depth of Overcut*

Table 6 S/N Ratio for Overcut

Level	Current	Voltage	Duty Cycle
1	22.76	23.30	22.76
2	23.28	23.88	25.39
3	23.60	22.46	21.50
Delta	0.85	1.42	3.89
Rank	3	2	1

V. RESULT AND DISCUSSION

Figure 5 shows the graph of MRR and Overcut over voltage and duty cycle when Current kept constant at 6A. During the ECM process current.

Fig 5 Inconel 718 Plate After Machining

Figure 6 shows the graph of MRR and Overcut over voltage and duty cycle when Current kept constant at 6A. During the ECM process current 6 A was kept constant, voltage and Duty cycle are increased by 16, 18, 20 and 3.5, 4.5, 5.5 respectively. The graph shows that with change in voltage and Duty cycle has enormous effect on MRR and overcut and with increase in voltage and duty cycle, MRR increases and overcut decrease up to 18V and 4.5DC further increase in voltage and duty cycle, MRR decrease and overcut increase.

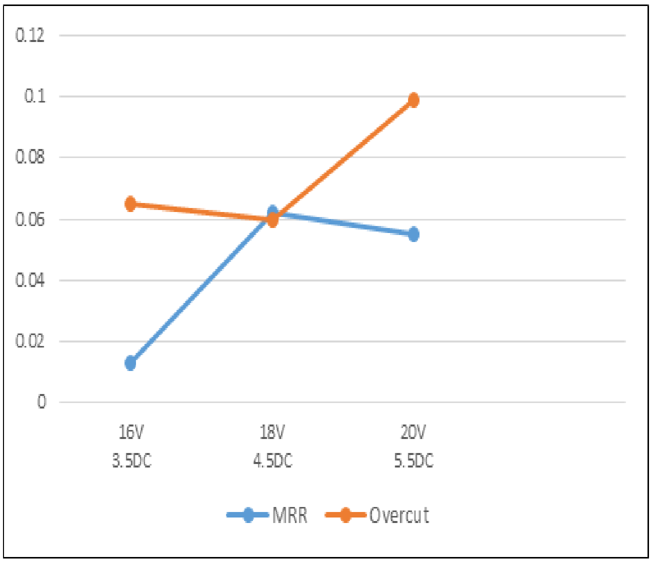

Fig 6 Current-6A

Figure 7 shows the graph of MRR and Overcut over voltage and duty cycle when current kept constant at 8A. By further increasing the current to 8 ampere and keeping it constant. Changing the voltage and Duty cycle which is 16V, 18V, 20V and 4.5, 5.5, 3.5 respectively. With this combination of readings MRR increases which is desirable but overcut goes on increasing which is undesirable.

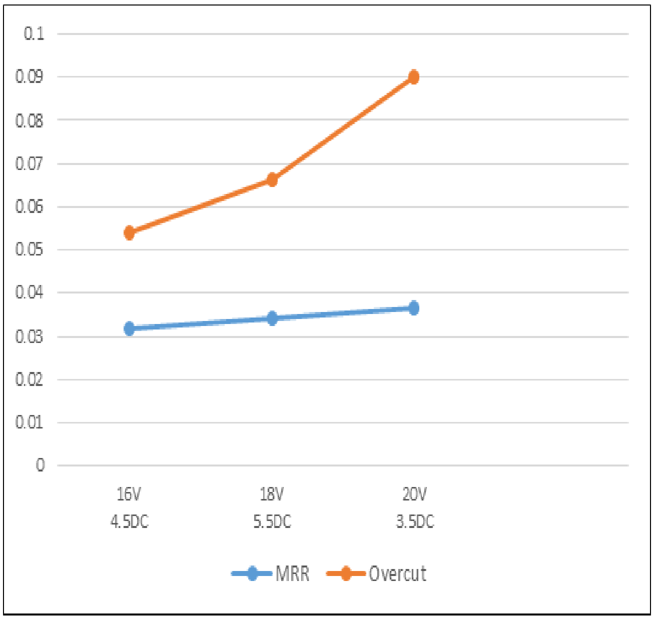

Fig 7 Current-8A

Figure 8 shows the graph MRR and Overcut over voltage and duty cycle when current kept constant at 10A and changing the voltages and duty cycle as 16, 18, 20 volt and 5.5, 3.5, 4.5 respectively, as determined in the DOE. With this combination of reading, it shows that MRR is very small and slightly decreasing at starting, treating it as noise value then it shows that MRR is increased when voltage and duty cycle get increased. With increasing voltage and high value of current overcut gets decreased.

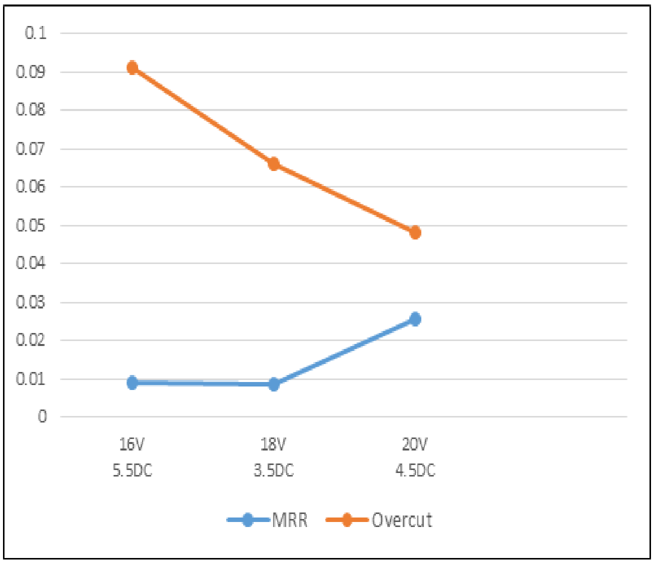

Fig 8 Current-10A

- *Identifying Optimum Process Parameter*

To investigate optimum input process parameter for machining of Inconel 718, Signal to Noise(S/N) ratio has been calculated for each response variables in the table 5 and table 6 by using loss function. Optimum process parameter and their level has identified to improve the process efficiency and characteristics of output parameters by analyzing following results obtained by using Minitab software.

- *Optimum Process Parameter for MRR:*

Figure 9 Show the graph of S/N ratio for MRR vs Current, Voltage and Duty cycle. For calculating the S/N ratio for Material Removal Rate the "larger-the-better" function was used. The factor levels which is having the highest S/N ratio were selected as optimum value. The optimum values to improve the MRR are as given in Table 7.

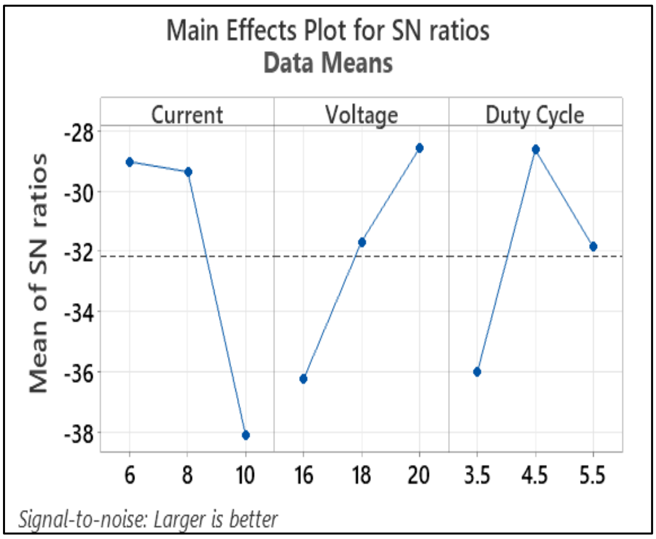

Fig 9 S/N Ratio for MRR

Table 7 Optimum Values for MRR

Parameter	Optimum value for MRR
Current	6
Voltage	20
Duty cycle	4.5

➢ *Optimum Process Parameter for Depth of Overcut:*

Figure 10 Show the graph of S/N ratio for MRR vs Current, Voltage and Duty cycle. For calculating the S/N ratio for Overcut the "smaller-the-better" function was used. The factor levels which is having the highest S/N ratio were selected as optimum value. The optimum values to improve the overcut are as given in Table 8.

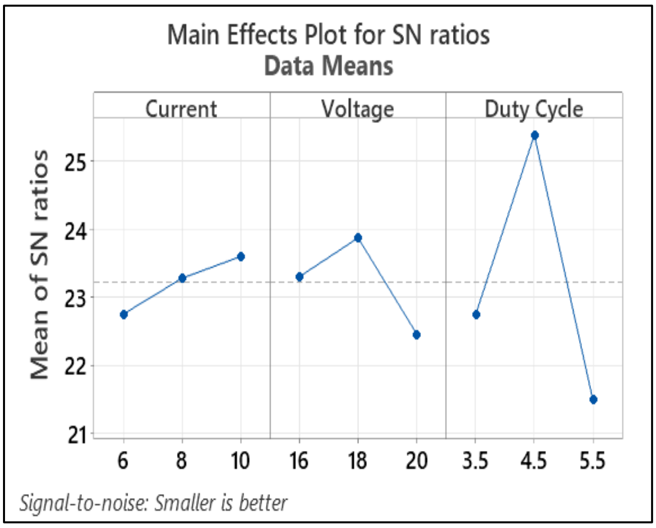

Fig 10 S/N Ratio for Overcut

Table 8 Optimum Values for Overcut

Parameter	Optimum value for Overcut
Current	10
Voltage	18
Duty cycle	4.5

VI. CONCLUSION

The "Experimental investigation of machining parameters in electrochemical machining (ECM) machine" project aimed to address the ECM machines low efficiency and poor surface quality. The project's primary objective was to improve the machining efficiency of Inconel 718 with ECM technology by experimenting and analysing ECM parameters. This study successfully investigated the influence of current, voltage, duty cycle on the performance of ECM machining. The following key findings provide valuable insights for parameters to achieve desired MRR and Depth of overcut.

- Increasing the current leads to a higher MRR. This is because more electrons flow through the electrolyte. Beyond a certain point, further increasing the current may not significantly improving the MRR, and is even harmful to MRR.
- Duty cycle is resulting in increase in MRR. But excessive high duty cycle can be counterproductive which results in increased heat generation because continuous current flow generates heat in the electrolyte and workpiece.
- Increasing voltage is leading to a higher MRR. This is because a higher voltage increases the electric field strength in the gap between the tool and workpiece. Increasing the voltage to much causes the harmful effects to MRR, and also the overcut gets hampered.
- Machining efficiency of Inconel 718 can be improved by selecting optimum values of current, voltage and duty cycle which are 6A, 20V and 4.5% respectively.
- Required depth of overcut can be achieved when current, voltage and duty cycle are as 10A, 18V and 4.5% respectively.

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