International Journal of Analytical, Experimental and Finite Element Analysis (IJAEFEA), Issue. 2, Vol. 4, June 2017.
e-ISSN: 2394-5141, p-ISSN: 2394-5133, pp 27-32
DOI:10.26706/IJAEFEA.2017.2.4.27-32

Parametric Optimization of WEDM for Inconel-718 by using Taguchi - A Review

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Abstract*—Non tradition machining like EDM- Electro Discharge machine has no physical cutting forces present between the work piece and machining tool, high accuracy in metal removal process using thermal energy by generating a spark to erode the work piece. The work piece must be a conductive electricity material which is submerged into the dielectric fluid for better erosion. EDM has numerous application in die cavity casting with large components, small diameter whole having depth and various complex holes and other precision part. Inconel-718, a high strength, thermal resistant Nickel-based alloy, is mainly used in the aircraft industries. Inconel-718 has extreme toughness and work hardening characteristics of the alloy. The various notable works in the field of WEDM is reviewed in this paper and prominence given to Inconel-718.*

Index terms- *Electrical Discharge Machining (EDM), Inconel 718, WEDM, MRR, Taguchi method.*

I. INTRODUCTION

In the mechanical and innovative development, advancement of harder and hard to machine materials, which find wide application in aviation, atomic designing and different businesses inferable from their high quality to weight proportion, hardness and warmth resistance qualities has been seen. New advancements in the field of material science have prompted new designing metallic materials, composite materials and cutting edge earthenware production having great mechanical properties and warm attributes and also adequate electrical conductivity with the goal that they can promptly be machined by start disintegration. Non-traditional machining has grown out of the need to machine these exotic materials. Due towork-hardening nature of Inconel 718 have relatively poor machinability in the conventional machining process while EDM has advantages like reduced machining stresses, lesser work-hardening effects and lesser metallurgical damage, therefore EDM is a preferred for material removal process of Inconel-718 Mr.Somnath M. Kale and Mr.D.S.Khedekar [11].

Taguchi method**: -** uses a special set of arrays called orthogonal arrays. These standard exhibits indicate the method for leading the negligible number of tests which could give the full data of the considerable number of elements that influence the execution parameter. The crux of the orthogonal arrays method lies in choosing the level combinations of the input design variables for each experiment.

The design of an experiment involves the following steps

- Selection of independent variables
- Selection of number of level settings for each independent variable
- Selection of orthogonal array
- Assigning the independent variables to each column
- Conducting the experiments
- Analyzing the data
- Inference

A. Principal of EDM

The principle of EDM is to use the eroding effect of controlled electric spark discharges on the electrodes. It is thus a thermal erosion process. The spark are made in a dielectric fluid, by and large water or oil, between the work piece and a cathode, which can be considered as the cutting apparatus. There is no mechanical contact between the electrodes during the whole process. Since erosion is produced by electrical discharges, both electrode and work piece have to be electrically conductive. Thus, the machining process consists in successively removing small volumes of work piece material, molten or vaporized during a discharge. The volume removed by a single spark is small, in the range of 10^6-10^4 mm3, but this basic process is repeated typically 10'000 times per second. Figure 1 explain the process of erosion due to a single EDM discharge. First, voltage is applied between the electrodes. This ignition voltage is typically 200 V. The breakdown of the dielectric is initiated by moving the electrode towards the work piece. This will expand the electric field in the gap, until the point that it achieves the essential incentive for breakdown. The location of breakdown is generally between the closest points of the electrode and of the work piece, but it will also depend on particles present in the gap. When the breakdown occurs, the voltage falls and a current rises abruptly. The presence of a current is possible at this stage, because the dielectric has been ionized and a plasma channel has been created between the electrodes. The release current is then kept up, guaranteeing a consistent barrage of particles and electrons on the terminals. This will cause strong heating of the work piece material (but also of the electrode material), rapidly creating a small molten metal pool at the surface. A small quantity of metal can even be directly vaporized due to the heating. During the discharge, the plasma channel expands. Therefore, the radius of the molten metal pool increases with time.

The distance between the electrode and the work piece during a discharge is an important parameter. It is estimated to be around 10 to 100 μ m. (increasing gap with increasing discharge current). At the end of the discharge, current and voltage are shut down. The plasma implodes under the pressure imposed by the surrounding dielectric. Consequently, the molten metal pool is strongly sucked up into the dielectric, leaving a small crater at the work piece surface.

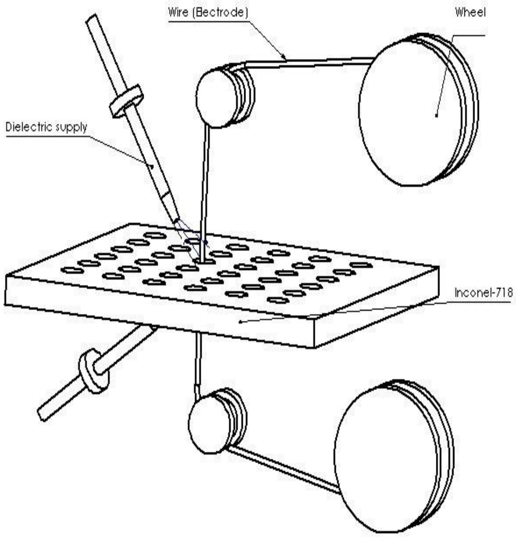

Figure 1: Schematic of WEDM Process

II. Literature Review

Mr. Somnath M. Kale and Mr. D. S. Khedekar (2016) studied on "Optimization of Process parameters in EDM for Machining of Inconel 718 using Response Surface Methodology", and conclusions are drawn describe the relation of various machining parameters and theireffects on output parameters while machining of Inconel 718.Current is most affecting parameters for both MRR and TWR. Material removal rate and tool wear rate increases as the current and pulse on time increases. While material removal rate and tool wear rate decreases as the voltage increases. The optimal values of process parameters which have composite desirability 0.54 are current 41.11 (A), voltage 80(V) and pulse on time 500 (µs) [11].

Sushil Kumar Choudhary and Dr. R. S Jadounb (2014) studied on Current Advanced Research Development of Electric Discharge Machining. Electrical discharge machining (EDM) process is one of the most commonly used non-conventional precise material removal processes. Electrical discharge machining (EDM) is a process for shaping hard metals and forming deep complex shaped holes by arc erosion in all kinds of electro-conductive materials. In work piece and electrode the Erosion pulse discharge create. This removes the unwanted material from the parent metal through melting and vaporizing in presence of dielectric fluid. As of late, EDM analysts have investigated various approaches to enhance EDM Process parameters, for example, Electrical parameters, Non-Electrical Parameters, device Electrode based parameters and Powder based parameters. This new research shares the same objectives of achieving more efficient metal removal rate reduction in tool wear and improved surface quality. This paper reviews the research work carried out from the inception to the development of die-sinking EDM, Water in EDM, dry EDM, and Powder mixed electric Discharge Machining. Within the past decade & also briefly describing the Current Research technique Trend in EDM, future EDM research direction [12].

Rajmohan et al. (2012) investigated the effect of EDM parameters such as pulse on time, pulse off time, voltage and current on material removal rate in 304 stainless steel. The experiments were carried out as per design of experiments approach using L9 orthogonal array. Signal to noise ratio and ANOVA is used to analyse the effect of the parameters on MRR. The current and pulse off time are the most significant machining parameter for MRR in EDM of 304 stainless steel. For higher MRR, the recommended parametric combination is pulse on time at level 1, pulse off time at level 2, voltage at level 2 and current at level 2, for EDM of 304 stainless steel [8].

Dubey and Yadav (2010) studied an hybrid approach of Taguchi method (TM) and principal component analysis (PCA) for multi-objective optimization (MOO) of pulsed Nd:YAG laser beam cutting (LBC) of nickel-based super alloy (SUPERNI 718) sheet to achieve better cut qualities within existing resources. The three-quality characteristics kerf width, kerf deviation (along the length of cut), and kerf taper have been considered for simultaneous optimization. The input parameters considered are assist gas pressure, pulse width, pulse frequency, and cutting speed. Initially, single-objective optimization has been performed using TM and then the signal-to-noise (S/N) ratios obtained from TM have been further used in PCA for multi-objective optimization. The results of MOO include the prediction of optimum input parameter level and their relative significance on multiple quality characteristics (MQC). The responses at predicted optimum parameter level are in good agreement with the results of confirmation experiments conducted for verification tests. The author concluded that, In single-objective optimization using TM, pulse width, and cutting speed is the significant factor for kerf width and kerf deviation, respectively, while both pulse frequency and cutting speed are significant for kerf taper. In multi-objective optimization, the loss in some quality characteristics is always possible as compared to single objective optimization but overall quality is improved. In present case, the kerf width deteriorates slightly but other two quality characteristics kerf deviation and kerf taper have been improved considerably [1].

e-ISSN: 2394-5141, p-ISSN: 2394-5133, pp 27-32
DOI:10.26706/IJAEFEA.2017.2.4.27-32

Yan et al. (2002) investigated the study precision micro holes in borosilicate glass using micro EDM combined with micro ultrasonic vibration machining. Because of its excellent anodic bonding property and surface integrity, borosilicate glass is usually used as the substrate for micro-electro mechanical systems (MEMS). For building the communication interface, micro-holes need to be drilled on this substrate. However, a micro-hole with diameter below 200 µm is difficult to manufacture using traditional machining processes. To solve this problem, a machining method that combines micro electrical-discharge machining (MEDM) and micro ultrasonic vibration machining (MUSM) is proposed herein for producing precise micro-holes with high aspect ratios in borosilicate glass. In the investigations described, a circular micro-tool was produced using the Micro EDM process. This tool was then used to drill a hole in glass using the Micro USM process. The experiments showed that using appropriate machining parameters; the diameter variations between the entrances and exits (DVEE) could reach a value of about 2 µm in micro-holes with diameters of about 150 µm and depths of 500 µm. In the roundness investigations, the machining tool rotation speed had a close relationship to the degree of micro hole roundness. Micro-holes with a roundness value of about 2 µm (the max. radius minus the min. radius) could be obtained if the appropriate rotational speed was employed.

For drilling micro-holes with high aspect ratios in borosilicate glass, a working method combining MEDM with MUSM was developed. Because the micro-tool was not dismantled from the clamping apparatus through varied working processes, a good tool concentricity level could be maintained in the machining procedures. Highly accurate micro-holes with diameters of about 150 µm and depth of 500µm were manufactured via the MUSM method. The experiments revealed that the DVEE is influenced by the slurry concentration, ultrasonic vibration amplitude or rotational speed of the micro-tool. Values of these parameters exist at which DVEE is a minimum. Larger or smaller values cause DVEE to increase. Furthermore, smaller particle sizes or micro-tool feed rates produced better DVEE. In the MUSM processes, the micro-hole roundness had a close relationship to the micro-tool rotational speed. Experiments show the rotational speed effect on roundness is similar to the rotational speed effect on DVEE. Hence, for better micro-hole roundness, choosing the proper rotational speed is important. Moreover, the surface roughness of micro-holes was clearly affected by the size of the abrasive particles. Results obtained show that a finer surface roughness could be obtained when smaller abrasive particle sizes were used [14].

Diver et al. (2004) reported the development of a new technique which enables reverse tapered holes to be produced using micro EDM. A reverse tapered hole increases the co-efficient of discharge of the hole. Tapered holes with 100 µm diameter at electrode entry and 160µm diameter at electrode exit can be produced with this technique. The quality of the holes produced is examined using a novel 3D impression technique, as well as SEM, surface roughness, and 3D optical measurements. The work presented in this paper has shown that high quality reverse tapered holes can be produced, showing excellent hole form, with hole diameter variation within 3µm and cycle times similar to standard EDM for straight holes. The *k*-factor values up to $k = 6.5$ have been produced. The quality of hole surface finish has been maintained at $Ra = 0.3$µm. The results have shown that the process is repeatable and stable. The solution can be applied to existing equipment without the need for a major retrofit. The results have shown that holes with a neck effect have been eliminated. One main application area is for diesel fuel injection nozzles to improve emissions from diesel engines without the need for higher injection pressures or smaller diameter holes. The developed method has not only enabled tapered holes to be produced but has also improved the general hole form and diameter consistency seen with standard EDM [2].

Shankarsingh et al. (2004)reports the results of an experimental investigation carried out to study the effects of machining parameters such as pulsed current on material removal rate, diameteral overcut, electrode wear, and surface roughness in electric discharge machining of En-31 tool steel (IS designation: T105 Cr 1 Mn 60)hardened and tempered to 55 HRc. The work material was ED machined with copper, copper tungsten, metal and aluminum anodes by differing the beat current at turn around extremity. Investigations indicate that the output parameters of EDM increase with the increase in pulsed current and the best machining rates are achieved with copper and aluminium electrodes. For the En-31 work material, copper and aluminum anodes offer higher MRR. Diameteral overcut created on En-31 is similarly low when utilizing copper and aluminum cathodes, which might be favored for En-31 when low diameter overcut (higher dimensional precision) is the prerequisite.Copper and copper–tungsten electrodes offer comparatively low electrode wear for the tested work material. Aluminium electrode also shows good results while brass wears the most, of all the tested electrodes. Of the four tried anode materials, Cu and Al cathodes create similarly high surface harshness for the tried work material at high estimations of streams. Copper–tungsten anode offers similarly low estimations of surface harshness at high release streams giving great surface complete for tried work material. Copper is nearly a superior terminal materials as it gives better surface complete, low diameteral overcut, high MRR and less anode wear for En-31 work material, and aluminum is by copper in execution, and might be favored where surface complete is not the prerequisite [10].

Puertas et al. (2004) found that The adequate selection of manufacturing conditions is one of the most important aspects to take into consideration in the die-sinking electrical discharge machining (EDM) of conductive ceramics, as these conditions are the ones that are to determine such important characteristics as: surface roughness, electrode wear (EW) and material removal rate, among others. In this work, an examination was completed on the impact of the components of power (i), beat time (ti) and obligation cycle (η) over the recorded mechanical attributes.The ceramic used in this study was a cemented carbide or hard metal such as 94WC–6Co.With this work, it has been confirmed that the technique of design of factorial experiments, combined with techniques of multiple linear regression, can be successfully applied to modelling the functions which depend on various variables.In order to carry out this study, some technological variables such as: surface roughness (evaluated by means of the *R*a parameter), the volumetric electrode wear and material removal rate (MRR) were selected. These technological variables were studied in relation to design factors such as: the level of intensity supplied by the EDM machine generator (*I*), pulse time (*t*i) and duty cycle (η). In all the response variables used in this work, second-order models were selected as the curvature tests for the first-order models showed evidence of the existence of pure quadratic effects for the factors. In the case of the *R*a parameter the most influential factors were intensity, followed by the pulse time factor, while the duty cycle factor was not significant at the considered confidence level.In the case of electrode wear, it was also seen that the intensity factor was the most influential, followed by its own pure quadratic effect and the interaction effect of intensity and pulse time. Finally, in the case of material removal rate, it was observed that the most influential factor was once again intensity, followed by the duty cycle factor, the pulse time factor and the interaction effect of the first two [7].

Luis et al. (2007) studied that the adequate selection of process parameters is an especially important factor to take into account. These conditions will determine technological properties, such as surface roughness, material removal rate (MRR) and electrode wear (EW). By means of the technique of design of experiments (DOE), as well as techniques of multiple linear regressions, it is possible to obtain technological tables that will allow the programming of the numerical control units used by the EDM machine tools. This is done by employing two different machining strategies in order to achieve a specific surface quality on the parts: one that minimizes the electrode wear and the other that maximizes the material removal rate, that is to say, the process speed. In this work, a methodology is developed to work out the values of technological tables employed in the programming of die sinking EDM machine tools for the particular case of conductive ceramic materials. In order to confirm its validation, the results of the methodology proposed in this work have been compared to those obtained by non-linear optimization. A series of technological tables have been calculated that allow the users of the EDM process, within finish stages, to select the most appropriate values for the process parameters allowing them to achieve a certain surface quality on their parts. This has been done taking into consideration two different machining strategies: a machining strategy that minimizes the electrode wear and the other that maximizes the material removal. In order to carry out an assessment of the values of the tables, mathematical models obtained from statistical techniques of factorial design of experiments and multiple linear regression have been used. These polynomials model the behavior of variables of the EDM process, such as surface roughness, electrode wear and material removal rate, in function of design factors of intensity, pulse time and duty cycle [5].

Seong Min et al. (2007) studied the influences of electrical pulse duration on the machining properties in micro EDM. The parameters were selected from the simple equation for the material removal rate and the experiments have been carried out for various EDM pulse conditions. Voltage, current, and on/off time of the pulse were selected as experimental parameters based on a simple equation for the material removal rate. The pulse condition is particularly focused on the pulse duration and the ratio of off-time to on-time, and the machining properties are reported on tool wear, material removal rate, and machining accuracy. Voltage, current, and pulse on/off time of the EDM power are main parameters to make decision of the material removal rate. Voltage and current are proportional to the material removal rate. On the contrary, current is only proportional in the case of tool wear rate. In the measurement of the gap between a tool and a machined surface, it is increased with an increase of voltage and current. But it is inversely proportional to the length of pulse-on time. The duration of pulse on/off time considerably affects machining properties such as material removal rate, tool wear rate, and machining accuracy. A comparatively shorter pulse on duration is profitable to make accurate machining with a higher removal rate and a lower tool wear rate [9].

Kanlayasiri et al. (2007) presented an investigation of the effects of machining variables on the surface roughness of wire-EDMed DC53 die steel. In this study, the machining variables investigated were pulse-peak current, pulse-on time, pulse-off time, and wire tension. Analysis of variance (ANOVA) technique was used to find out the variables affecting the surface roughness. Assumptions of ANOVA were discussed and carefully examined using analysis of residuals. Quantitative testing methods on residual analysis were used in place of the typical qualitative testing techniques. Results from the investigation demonstrate that heartbeat on time and heartbeat crest current are huge factors to the surface unpleasantness of wire-EDMed DC53 kick the bucket steel. The surface harshness of the test example increments when these two parameters increment. In conclusion, a numerical model was created utilizing different relapse strategy to detail the beat on time and heartbeat top current to the surface unpleasantness. The developed model was validated with a new set of experimental data, and the maximum prediction error of the model was less than 7%.Influences of wire-EDM machining variables on surface roughness of newly developed DC 53 die steel were investigated in this paper. The machining variables included pulse-on time, pulse-off time, pulse-peak current, and wire tension. The variables affecting the surface roughness were identified using ANOVA technique. Assumptions of ANOVA were tested using residual analysis. Quantitative testing methods were employed in place of the typical qualitative testing techniques. After careful testing, none of the assumptions was violated. Results showed that pulse-on time and pulse-peak current were significant variables to the surface roughness of wire-EDMed DC53 die steel. The surface roughness of the test

e-ISSN: 2394-5141, p-ISSN: 2394-5133, pp 27-32
DOI:10.26706/IJAEFEA.2017.2.4.27-32

specimen became larger when these two variables were increased. Finally, a mathematical model was developed using multiple regression method to formulate the pulse-on time and pulse-peak current to the surface roughness. The created demonstrate indicated high expectation exactness inside the test locale. The maximum prediction error of the model was less than 7%, and the average percentage error of prediction was less than 3%. Future research will be performed on optimization of wire-EDM machining variables for DC 53 tool steel [3].

Tai et al. (2007) did an investigation into the drilling of a deep micro holes with the depth of 320μm in tool steel SKD61 by the Micro-EDM process. The electrode with the diameter of 26μm is machined by the method of wire electro discharge grinding (WEDG). Optical microscopy, scanning electron microscopy, and co focal laser scanning microscopy techniques are used to determine the influence of the process parameters upon hole enlargement, electrode wear rate, material removal rate, wear ratio, and the observed surface topography. The consequences of the examination uncover the ideal parameter settings for the Micro-EDM machining of a high angle proportion small scale gap are as per the following: (1) a heartbeat voltage in the vicinity of 60 and 100 V, (2) a capacitance between 80 pF and 220 pF. At long last when the profundity surpasses 200 μm, the state of the small scale opening nearly winds up noticeably decreased because of the corner wear of the cathode and the optional release at the edge of the gap.The pulse voltage influences the hole enlargement, Electrode Wear Ratio (EWR) and Material Removal Rate (MRR). In order to guarantee a stable and precise machining operation, its value should be specified within the range of 60 to 100 V. The value of the EWR generally increases at elevated capacitance. However, when the capacitance is smaller than a value of 20 pF, the value of the EWR is seen to increases due to the problems involved in stray capacitance and flushing away the increased volume of debris. The material removal rate increases as the pulse voltage increases. However, the material removal rate is negative related to pulse capacitance. The Micro-EDM and conventional EDM processes generate similar surface topographies. The chief difference between the two is that the effect of reducing the pulse energy in the former technique is to leave a random series of clearly visible, overlapping craters on the machined surface. The diameter of the craters decreases as the capacitance decreases. When the voltage is small together with the capacitance is smaller than 20 pF, the diameter of the crater is in the contrary increased owing to the stray capacitance in the circuit. The state of the smaller scale opening nearly ends up plainly decreased as a result of the corner wear of the terminal and the optional release at the edge of the gap as the profundity surpasses 200μm [13].

III. Parameters Of EDM

A. Process Parameters

- Current
- Gap between Electrode and work piece
- Pulse ON time
- Pulse OFF time

B. Performance Parameters- these parameters can be optimizing by changing different process parameters. Some important performance parameters are as fallows-

- Material removal rate (MMR) - MRR is volumetric amount of work piece material removed per unit time.MMR a performance measure for the erosion rate of the work piece. MMR decides time required for completion of operation.
- Tool wear rate (TWR)- can be expressed as the volumetric amount of tool electrode material removed per unit time. TWR is a commonly taken into account when considering the geometrical accuracy of the machined feature.
- Heat affected zone.
- Surface quality (SQ).
- Recast layer thickness Sushil Kumar Choudhary and Dr. R.S Jadounb [12].

IV. Summary Of The Literature Review

- For drilling micro-holes with high aspect ratios in borosilicate glass, a working method combining Micro Electrical Discharge Machining with Micro Ultrasonic Machining was developed.
- A new technique was developed to produce reverse tapered micro holes using EDM, to a production standard that could be applied to real products in industry. Tapered holes with 100μm diameter at electrode entry and 160μm diameter at electrode exit can be produced with this technique.
- The study reported the results of an experimental investigation carried out to study the effects of machining parameters such as pulsed current on material removal rate, diameteral overcut, electrode wear, and surface roughness in electric discharge machining of En-31 tool steel (IS designation: T105 Cr 1 Mn 60) hardened and tempered to 55 HRc.
- The study revealed the influence of intensity, pulse time and duty cycle on surface roughness, material removal rate and tool wear rate on hard metal such as 94WC-6Co.
- The investigation stated that the adequate selection of process parameters is an especially important factor to take into account. These conditions will determine technological properties, such as surface roughness, material removal rate (MRR) and electrode wear (EW). By means of the technique of design of experiments (DOE), as well as techniques of multiple linear regressions, it is possible to obtain technological tables that will allow the programming of the numerical control units used by the EDM machine tools.
- The influences of electrical pulse condition on the machining properties in micro EDM were investigated which included voltage, current and pulse on/off time.
- The study presented an investigation of the effects of machining variables on the surface roughness of wire-ED Med DC53 die steel. In this study, the machining variables investigated were pulse-peak current, pulse-

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on time, pulse-off time, and wire tension. Analysis of variance (ANOVA) method was utilized to discover the factors influencing the surface unpleasantness.There was investigation done on the use of micro EDM process in drilling of the micro holes in SKD61 tool steel. The present results confirm that the process is assuredly capable of meeting the machining requirements of micro holes providing that the process parameters are correctly specified.

- A versatile process of electrical discharge machining (EDM) using magnetic force assisted standard EDM machine was developed. The effects of magnetic force on EDM machining characteristics were explored. Moreover, this work adopted an L18 orthogonal array based on Taguchi method to conduct a series of experiments, and statistically evaluated the experimental data by analysis of variance (ANOVA).
- An hybrid approach of Taguchi method (TM) and principal component analysis (PCA) was applied for multi-objective optimization (MOO) of pulsed Nd: YAG laser beam cutting (LBC) of nickel-based superalloy (SUPERNI718) sheet to achieve better cut qualities within existing resources.
- An overview of the process parameters, material removal rate, types of generators, dielectric fluids and the minimum machinable size of the diameter were discussed.
- The study reported the effects of EDM parameters such as pulse on time, pulse off time, voltage and current on material removal rate in 304stainless steel.

V. Conclusion

As what world cannot deny today, practical is not as perfect as theory which due to large number of variable and the uncertain nature of the process, even highly skilled operator finds it difficult in achieving optimal performance of machining. Even most micro EDM machine today has process control, but selecting and maintaining optimal parameter setting is still an extremely difficult job which must be addressed. The study will consist of obtaining an appropriate parameter settings and optimizing the responses i.e. maximizing the material removal rate and minimizing tool wear rate and Taguchi method will be used for this purpose. As the objectives are conflicting, PCA will be used further for multi objective optimization.

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