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PARAMETRIC OPTIMIZATION IN MACHINING ON NIMONIC 75 ALLOY USING ELECTRICAL DISCHARGE MACHINING

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ABSTRACT

The increasing demands of machining of complex shape geometries and their high surface finish and has further strengthened the need of non-traditional machining processes. Among various process, EDM has been explored to large extent towing to surface finish and MRR are of crucial importance in the field of machining processes .Taguchi's optimization technique, in order to optimize the cutting parameters in EDM for super alloys. The objective of the effect of EDM parameters on MRR, Surface finish for machining NIMONIC75 alloy. In this present study super alloy is used as a work piece, copper or copper Alloy Like Brass used as a tool and distilled water is used as a dielectric fluid For experimentation, Taguchi's orthogonal array will be followed by ANOVA to identify the most significant factor .This would followed by developing empirical relation and optimization study.

Nimonic75 (Nickel chromium base Alloys) is the most commonly used alloy. His basic chemical composition is Ni,Cr,Ti,C,Si,Cu,Fe,and Mn. Nimonic75 is significantly stronger than other commercially pure nimonic whilst still retaining the same stiffness and thermal properties. Nimonic75 extensively used in Gas-turbine engines Heat-treating equipment and fixtures Nuclear engineering aerospace, medical, marine and chemical processing.

KEYWORD: *NIMONIC 75, EDM, SURFACE FINISHING, ANOVA, & TAGUCHI TECHNIQUE*

1. INTRODUCTION

1.1 BACKGROUND OF RESEARCH

The developments in manufacturing industries have led to the demands for advanced materials Such as composites, ceramics and super alloy, having high hardness, toughness and impact resistance. Challenges encountered during conventional machining of such materials are complex shape, high precision, surface quality and machining costs. Conventional machining processes include turning, boring, milling, shaping, broaching, slotting, grinding and many more. However, there arises difficulties in machining of advanced materials through conventional machining processes. The production of fine holes and intricate shape profile in thin and brittle jobs is very difficult by conventional methods.

1.1.1Ceramics

Ceramic is an inorganic non-metallic solid made up of either metal or non-metal compounds that have been shaped and then hardened by heating to high temperatures. In general, they are hard, corrosion-resistant and brittle .Ceramics can be divided into two classes: traditional and advanced Traditional ceramics include clay products, silicate glass and cement; while advanced ceramics consists of carbides (Sic), pure oxides (Al_2O_3), nitrides (Si_3N_4) and non-silicate glasses and many others. Ceramic offers many advantages compared to other materials. It tougher and stiffer than steel. additional heat and corrosion resistant than metals and polymers, less dense than most metals and their alloys.
The applications of ceramic materials are:

1. Teeth of human mouth
2. Space shuttle tiles
3. Glassware and windows
4. Ceramic tiles, lenses and home electronics
5. Spark plugs, pressure sensors, Thermistors and vibration sensors


Fig 1.1 Glassware& window

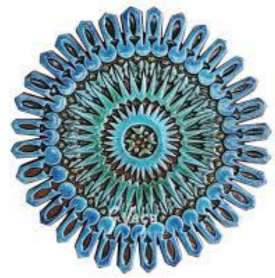


Fig 1.2 Ceramic tiles

Fig. 1.1: Component made of ceramic materials

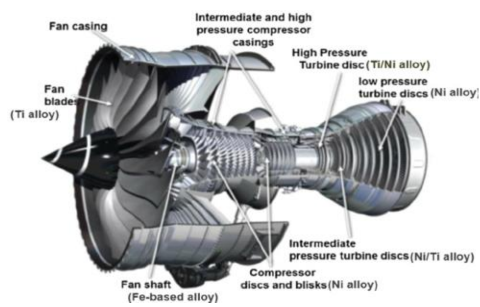
1.1.2Composites

It is a combination of two or more distinct materials, each of which retain its own individual properties, to create a new material with properties that cannot be achieved by any of the components acting alone. Using this definition, it can be determined that a wide range of engineering materials falls into this category. Composites made, from glass, graphite, Kevlar, boron or silicon carbide fibers in polymeric matrices had been studied extensively because of their application in aerospace and space vehicle technology, matrix material which forms the continuous phase. The composites are broadly classified in metal matrix (MMC) ceramic matrix composite (CMC) and polymer matrix (PMC) composites.

The applications of composite materials are

1. Sport good such as golf stick, racket, baseball strike
2. Aerospace components such as
3. Marine application such as wing, spoiler, winglet
4. Automobile components such as muffler, brake
5. Rotating blade sleeves in a helicopter.


Aerospace component



Rotating blade sleeve in a helicopter

Fig. 1.3: Component made of composite materials

1.1.3Super Alloys

A super alloys due to better multiple functional characteristics such as excellent mechanical strength, resistance to thermal creep deformation, good surface stability and resistance to corrosion or oxidation. Super-alloys find a vast range of application in the aerospace, nuclear and chemical industries. Super alloys are difficult to machine by conventional machine process due to their high hardness and brittleness. This calls for non-conventional Machining processes.

1.2 NON-CONVENTIONAL MACHINING

The non-conventional machining methods came into existence due to the need of higher accuracies and quality of surface finish, and the impediments in conventional machining of hard and difficult-to-machine materials. The increasing utility of such materials in the modern industry has forced research engineers to develop non-conventional machining methods, so as to have full advantage of these costly materials.

The use of such costly and hard-to-machine material is quite common in the aircraft industry, research equipment, nuclear plants, missile technology, sophisticated equipments, manufacturing industries etc. To meet the requirements of such industries, whereas on one hand newer materials are developed at an equivalent time, variety of newer machining strategies are evolved for machining of these materials. These machining methods are known as Unconventional or Nontraditional Machining Methods.

1.2.1Mechanical Processes

In mechanical processes, metal removal takes place either by the mechanism of easy shear or by erosion mechanism wherever high speed particles are used as transfer media and pneumatic/hydraulic pressure acts as a source of energy. It include ultrasonic machining (USM), water jet machining (WJM) and abrasive jet machining (AJM) etc. The schematic diagram of abrasive jet machining.

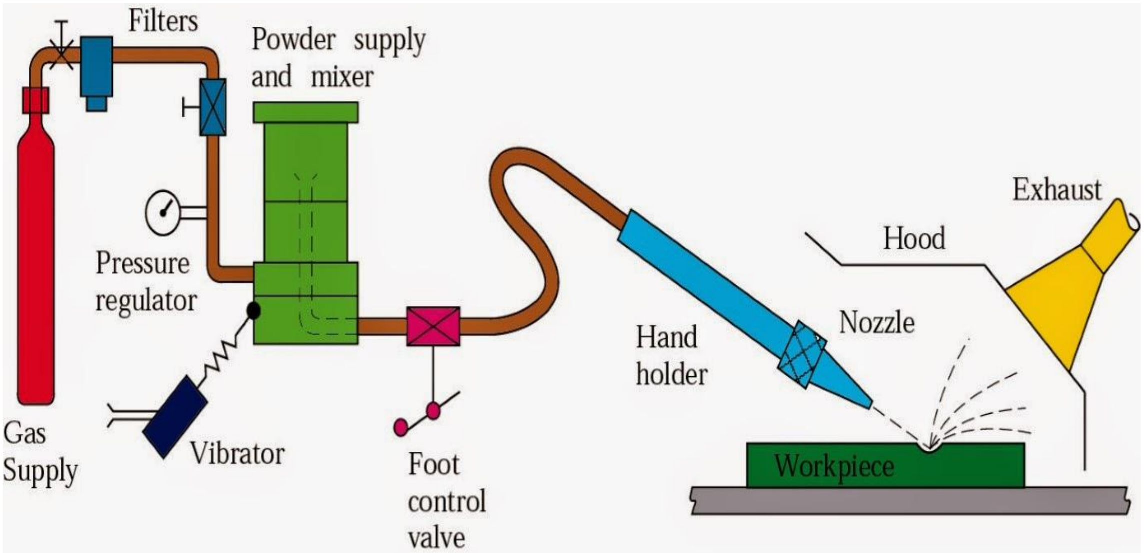


Fig.1.4: Abrasive jet machining (After Ingulli, C.N 1967)

1.2.2Electrochemical Processes

In Electrochemical processes removal of metal by the mechanism of ion displacement. High current is needed because the supply of energy. Electrolyte acts as transfer media. It includes electro-chemical machining (ECM), electro-chemical grinding (ECG) etc. A well-equipped diagram of ECM process is shown in fig. 1.5.

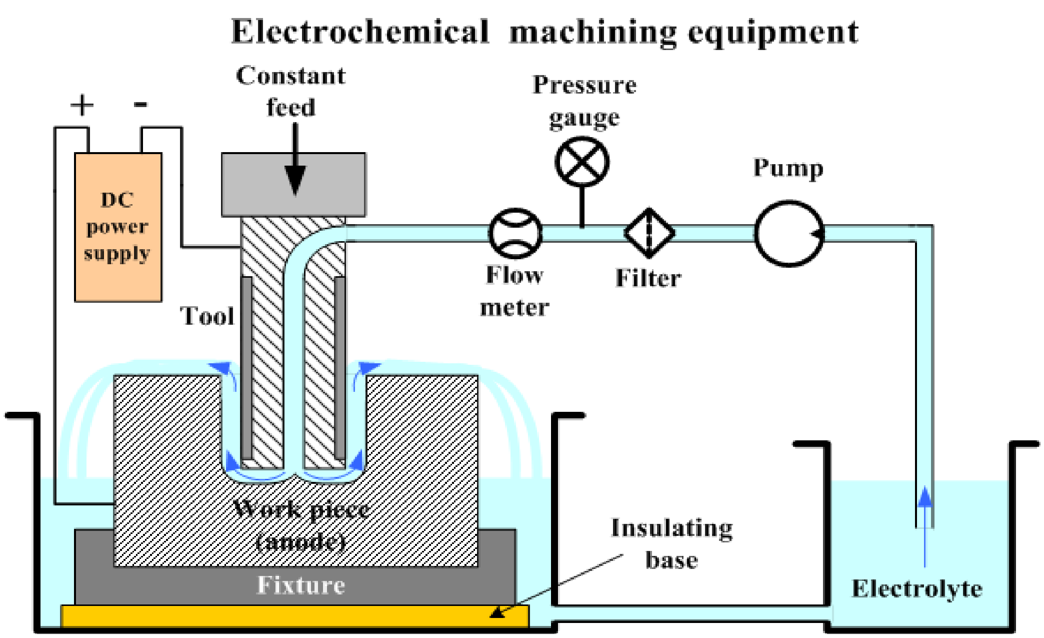


Fig.1.5: electrochemical machining (After Ghosh, A. 1997)

1.2.3 Chemical Processes

Chemical processes involve the application of resistant material (acidic or alkaline in nature) to certain portions of the work surface. The desired amount 3 of material is removed from the remaining area of the work piece by the subsequent application of an etching that converts the work piece material into a dissolvable metallic salt. It conclude chemical machining (CHM) and photochemical machining (PCM).

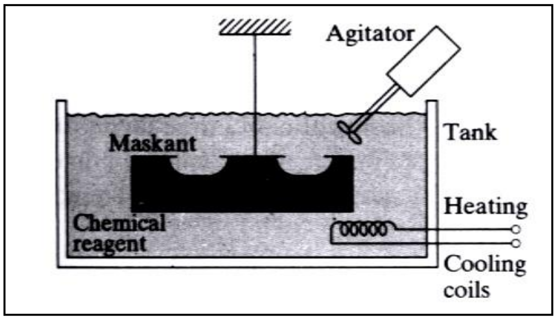


Fig.1.6: Chemical machining (After M. Langworthy 1994)

1.3 THERMAL PROCESS

In this processes involve the application of very thin, intense local heat. Higher melting and vaporization from the small areas on the surface of the work piece removes material. The source of energy used amplifies light, ionized material and high voltage. Examples of thermal process are Electric Discharge Machining (EDM) and its variants such as WEDM, Laser Beam Machining (LBM), Ion Beam Machining (IBM) and Plasma Arc Machining (PAM)

1.4 EDM PROCESS PARAMETER

1.4.1 Discharge voltage

Discharge voltage in EDM is related to the spark gap and break-down strength of the dielectric.Before current can flow, the open gap voltage increases until it has created an ionized path through the dielectric.

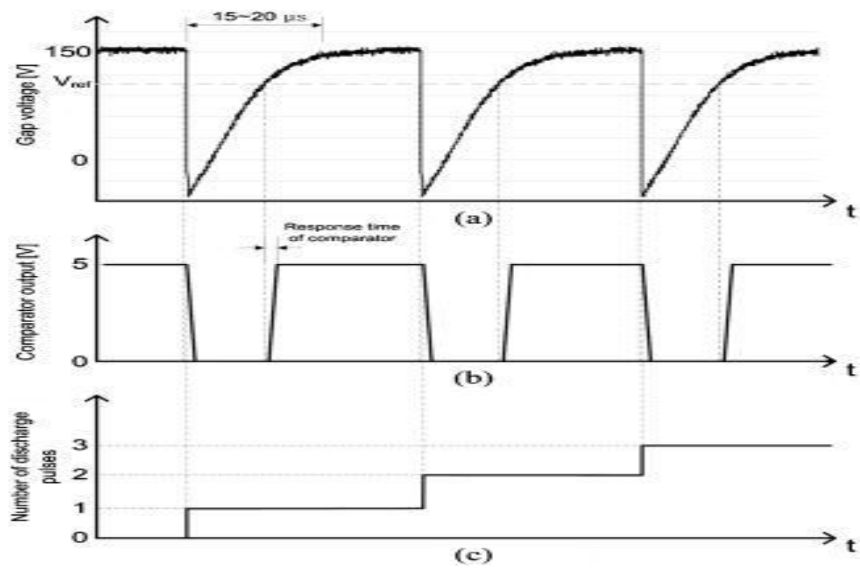


Fig.1.7 Actual profile of a single EDM pulse

The preset voltage determines the width of the spark gap between the leading edge of the electrode and work material. Higher voltage settings, increase the gap, which improves the flushing condition and helps to stabilize the cut. Material removal rate (MRR), tool wear rate (TWR) and surface roughness (SR) increases, by increasing open circuit voltage, because electric field strength increases.

1.4.2Peak current

The amount of power used in Elctrodischarge machining measured in units of amperage and is the most important machining parameter in EDM. During each on- time pulse, the current increases until it reaches a present level, which is expressed as the peak current. Higher current will improve the material removal rate (MRR), but at the cost of surface finish and tool wear.

1.4.3 Pulse duration

Each cycle are an on-time and off-time that is expresses in units of microseconds. Metal removals are directly proportional to the amount of energy applied during the on-time. This energy is controlled by the peak amperage and the length of the one-time. Pulse on-time is commonly referred to as pulse duration and pulse off-time is called a pulse interval. With a longer pulse duration, more work material will be melted away. The resulting crater will be broader and deeper than a crater produced by shorter pulse duration. These large craters will create a rougher finish. Extended pulse duration also allows more heat to sink into the work material and spread, which means the recast layer will be larger and the heat affected zone will be deeper. However, the excessive pulse duration can be counterproductive. Once that point is reached, increasing the duration further causes the electrode to grow from plating build–up. Cycle has completed when sufficient pulse interval is allowed before the start of the next cycle. If the interval is too short, the ejected work piece material will not be swept away by the flow of die electric and fluid will not be de-ionized. It is cause the next spark to be unstable. Unstable condition causes erratic cycling and retraction of the advancing servo.

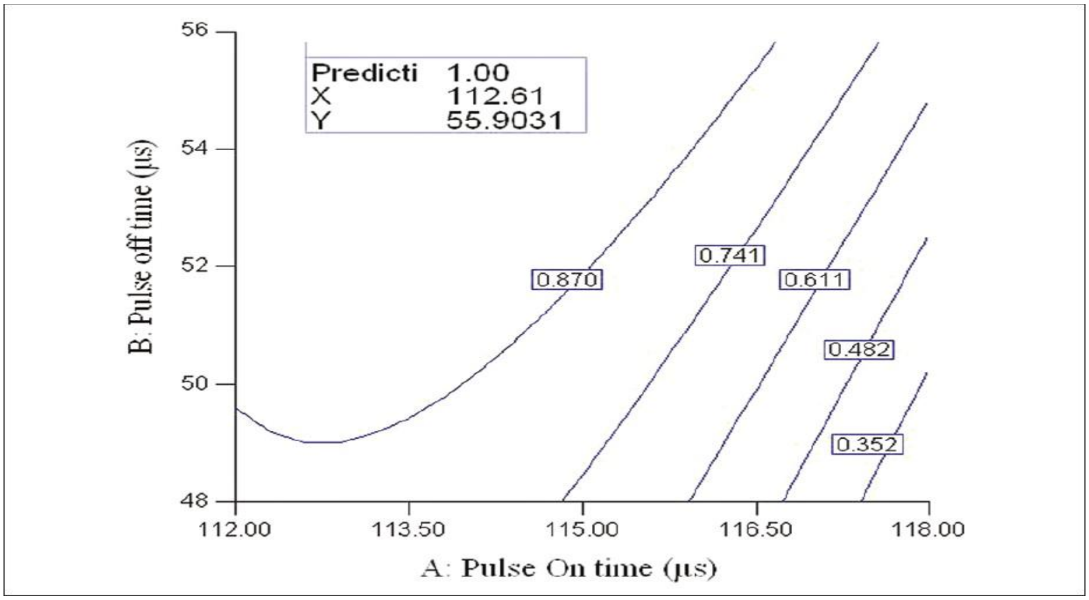


Fig.1.8 Pulse on time and pulse off time

1.4.4 Pulse Waveform

Pulse shapes is normally rectangular but generators with other pulse shapes have also been developed. Types of generator introduce an initial pulse of high voltage but low current and of a few microseconds duration. Before the main pulse, which facilitates ignition. For our research, we have used the rectangular waveform.

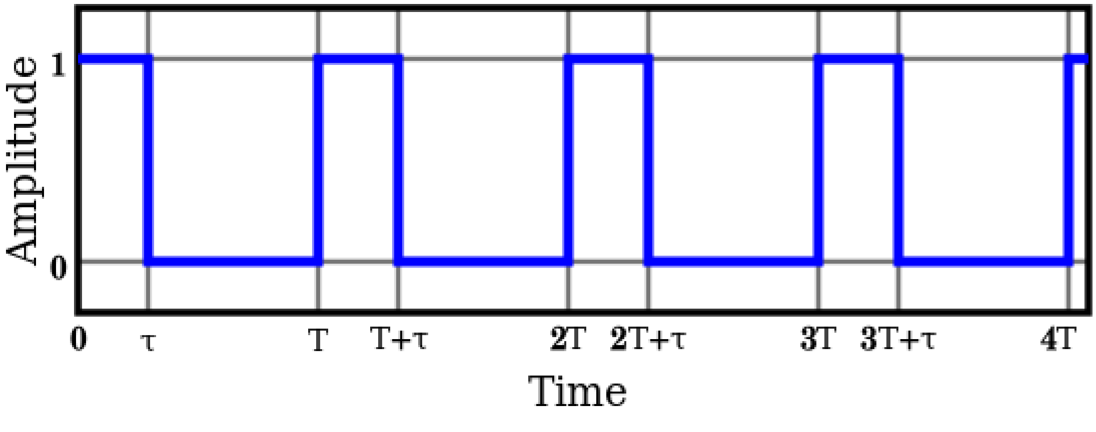


Fig.1.9 pulse waveform

1.4.5 Polarity

The polarity of the electrode can be positive or negative. The current passing through the gap creates higher temperatures causing material evaporation at both electrode sports.

This effects causes minimum wear to the tool electrode and becomes of importance under finishing operations with shorter on-times. However, while running longer discharges, the early electron process predominance changes in positron process (proportion of ion flow increases with pulse duration), resulting in high tool wear. In general, polarity is determined by experiments and is a matter of tool material, work material, current density and pulse length combination. A typical ratio is swing ratio is a swing pulse for every 15 standard pulses. In our experimentation, straight polarity is used, i.e., work material act as the positive terminal and tool electrode acts as the negative terminal.

1.4.6Electrode gap

The tool servo mechanism is of considerable importance in the efficient working of EDM, and its function is to control responsively the working gap to the set value. Mostly electrochemical (DC or stepper motor) and the electro hydraulic system is used, and are normally designed to respond to average gap voltage. This reaction speed be high in order to respond to short circuits or open gap conditions. The Gap width is not measured directly but can be inferred from the average gap voltage. Servo head automatically controls the gap between the tool electrode and the work piece.

2. DESIGN OF EXPERIMENT (DOE)

Design of experiment techniques enables designers to determine simultaneously the individual and interactive effects of many factors that could affect the output results in any design. Physical process and computer simulation models are also conducted by design of experiment in which purposeful changes are made to the in variables of a system or process and the effects on response variables are measured. Design of Experiments are powerful tool to achieve manufacturing cost savings minimizing process variation and reducing rework scrap and the need of inspection. Factorial designs allow judgment of the sensitivity it to each factor and also to the combined effect of two or more factors. Design of experiment method has been successfully applied to several ballistic missiles defense sensitivity studies to maximize the amount of information with a minimum number of computer simulation runs. In a highly competitive world of testing and evaluation an efficient methodology for testing many factors is needed.

2.1 Taguchi Technique

Taguchi constructed special set of general design for factorial experiments that covers many applications. The orthogonal arrays with number of experiment, factors and levels for each special design orthogonal arrays. Use of these arrays help us to determine numbers of experiments needed for a given set of factors.

2.2 The Theory and Philosophy of Taguchi Approach

Taguchi approach and its contribution to excellent quality control in the manufacturing industries. His concept has developed engineers to see quality as a yard stick in their design of product and process. The philosophy which based on three fundamental concept has been greatly caused the better application and development of technology and techniques in many industries. The three concepts are:

1. Quality should be designed into the product and not in its inspection.
2. To achieve the quality it is best to minimize the deviation from the target and product shall be designed to be insensitive to the uncontrollable environmental factors.
3. The cost of quality is measured as a function of deviation from the standard and the losses should measure the system-wide.

2.3 Taguchi Rule for Manufacturing

Taguchi realize that the best opportunity to eliminate variation is during, the design of a products and its manufacturing process. Consequently its developed a strategy for quality engineering, that can be used in both contexts. The process has three stages:

1. System Design
2. Parameter (measure) Design
3. Tolerance Design

2.4Taguchi Quality Loss Function

In Taguchi loss function the fraction of products outside the specified limits as the measure of quality though it is a good measure of the loss due to Scrap. It dejectedly fails as a forecaster of customer satisfaction. An ideal on target value is achieved in terms of the deviation of a design parameter through a quality loss function. The heart of Taguchi method is his definition of the nebulous and elusive term quality as the characteristics that avoid loss to the Society from the time the product is shipped. Loss is measured in terms of monetary units and is related to quantifiable product characteristic.

Taguchi´s loss function can be expressed in terms of the quadratic relationship: —

$L = k\,(y-m)^2$ eq. (3.1)

"y" is the critical performance parameter value and "L" is the loss associated with a particular parameter "y", "m" is the nominal value of the parameter specification, "k" is a constant that depends on the cost at the specification limits signal-to-noise ratio.

2.5Signal to Noise Ratio

Noise factor are those that are either too hard or uneconomical to control even though they may cause unwanted variation in performance. It has been observed that on goal performance generally satisfies the user best, and targets are often inadequate under the acceptable range of product quality. Strengthening the product and process design is important for different stakeholders like manufacturers, suppliers and consumers. As variability exists in all operation, it is desirable to create products and processes that are not very sensitive to factors that are not controllable. The taguchi method is an approach to strong design. Definition of a loss function contained in the taguchi method. This loss function formulation is influenced by the type of quality characteristic under consideration, that is, lower-is-best, higher-is-best, or nominal-is-best. Apart from this, a performance measurement has been defined based on the type of quality selected. The measures of such performance, which are commonly referred to as signal-to-noise (S / N) ratios, are used to determine the optimal settings of controllable factors. Typically, a two-step process is adopted in the Taguchi method. In the first step, the S/N ratio is maximized, whereas in the second step, using an adjustment factor that does not affect the S/N ratio, the mean response is adjusted to meet the target value, where appropriate. There we three signal-to-noise ratios

1- Lower-the-better
2- Higher-the-better
3- Nominal-the-best

A high value of S/N ratio implies that the signal is much higher than the random effects of noise factors. Process operation consistent with highest S/N ratio always yields optimum quality with minimum variation. The equation for calculating S/N ratio for lower-is-better (for TWR and SR), higher-is-better (for MRR), or nominal-is-best are as:

(i) Lower is better (for example, TWR and SR)

$$\frac{S}{N_{LB}} = -10 \log \left(\frac{1}{r}\sum_{t=1}^{r} y_t^2\right)$$

(ii) Higher is better (for example, MRR)

$$\frac{S}{N_{HB}} = -10 \log \left(\frac{1}{r}\sum_{t=1}^{r} \frac{1}{y_t^2}\right)$$

(iii) Nominal is best (for example, a mating part in an assembly)

$\frac{S}{N_{NB}} = -10 \log \text{Ve}$ (Variance only)

$\frac{S}{N_{NB}} = -10 \log \left(\frac{\text{Vm}-\text{ve}}{rVe}\right)$(Mean and variance)

Where

y = observation data, r = total number of repetitions in trail, y = t^{th}response

Ve =variance due to error, V_m=variance due to mean

3. EXPERIMENTAL DESIGN

In the present research work, L_9 orthogonal array has been chosen for the purpose of investigation. The number of treatment condition is equal to the number of row in orthogonal array and must be equal to or greater than the degree of freedom of different parameters considered. As per Taguchi experimental design philosophy a set of three levels assigned to each process parameter has two degree of freedom (DOE). This gives a total of 8 degree of freedom for four process parameters namely peak current, pulse-on time, and pulse off time selected in present study. The total degree of freedom for the three factors is

8. So, the array selected fulfils the criterion for selection of array. Experimental layout of L_9 **(3^3)** orthogonal array used in present work is shown in Table 3.1.

Table 3.1: Experimental lay out using L9 (3^3) orthogonal array

Run	Peak Current I_p(A)	Pulse-ON time T_{on} (µs)	Pulse of time(µs)
1	9	30	2
2	12	30	3
3	15	30	4
4	12	60	2
5	15	60	3
6	9	60	4
7	15	90	2
8	9	90	3
9	12	90	4

3.1 EXPERIMENTAL PROCEDURE

The experimentation was conducted to study the effect of various machining parameters on electrical discharge machining process which is based on L9 orthogonal array. Each experimental runs as per orthogonal array were repeated twice in order to reduce experimental error. Thus total experiments performed were 9X3 =27. CPC kerosene is used as Dielectric throughout the tests.

Following steps were followed in the cutting operation

1. The tool was made vertical with the help of upper and lower guide block.
2. The work piece was mounted and clamped on the work table.
3. A reference point on the work piece was set for setting work co-ordinate system (WCS). The programming was done with the reference to the WCS.

The reference point was defined by the ground edges of the work piece.

Then after setting the wire electrode and the work piece the input process parameters viz. peak current (I_p), pulse-on-time (T_{on}) , Gap voltage(V) were set according to levels from the control panel of the machining and other parameters were kept constant throughout the experiments. A straight machining of 2mm depth was made on specimens of 8 x 40mm x 60mm x 8mm that is presented by the following fig. 4.5 or fig.4.6.

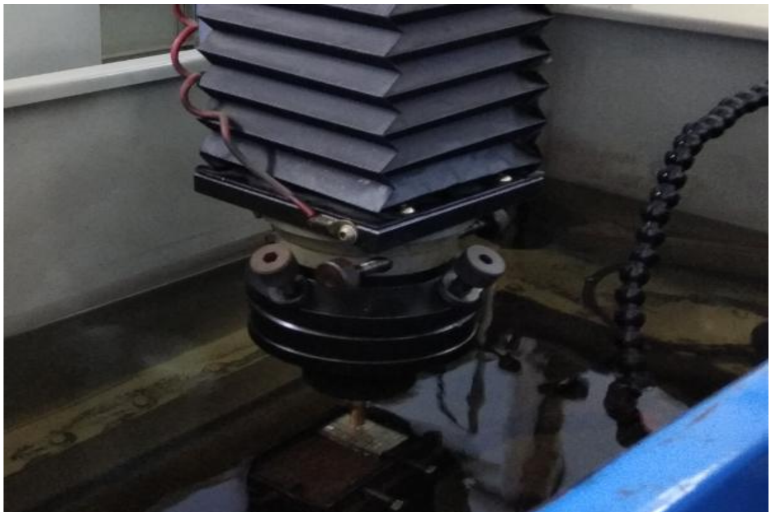


Fig. 3.1 Plate material blank during machining on EDM machine

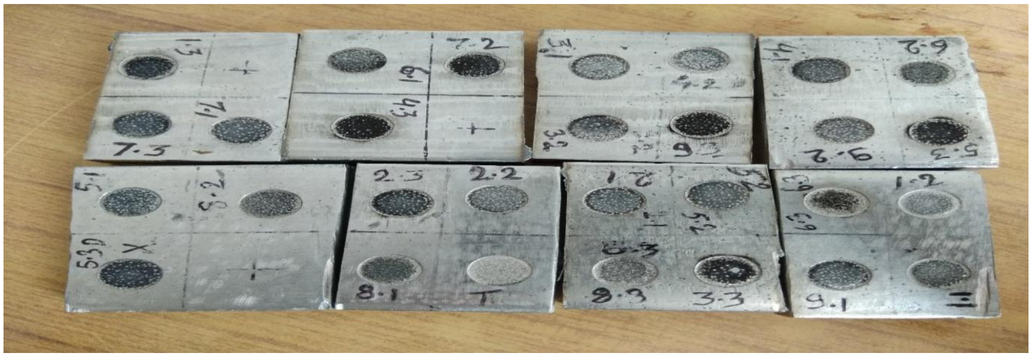


Fig. 3.2: Specimen cut by EDM machine after experimentation

Table 3.2 Experimental results of present work.

S. no.	Gap voltage(V)	Pulse on time(μs)	Peak current (A)	Material removal rate (gm/min)			MRR average	Surface roughness (μm)			Average SR
				Trial 1	Trial 2	Trial 3		Trial 1	Trial 2	Trial 3	
1	40	90	6	0.01989	0.02442	0.02634	0.02355	2.2	2.6	2.13	2.31
2	40	120	9	0.02631	0.03621	0.03931	0.03394	1.8	1.8	2.0	1.87
3	40	150	12	0.01295	0.02963	0.03600	0.02619	2.73	3.27	2.33	2.78
4	50	90	9	0.02270	0.03241	0.04578	0.03363	2.13	2.13	2.0	2.09
5	50	120	12	0.01518	0.02755	0.01956	0.02070	2.53	2.27	2.27	2.36
6	50	150	6	0.01036	0.02019	0.01140	0.01398	2.93	2.8	2.95	2.89
7	60	90	12	0.03375	0.04461	0.03399	0.03745	2.27	2.27	2.5	2.35
8	60	120	9	0.02406	0.02277	0.02542	0.02408	2.87	2.6	2.93	2.8
9	60	150	6	0.03809	0.03421	0.02960	0.03397	2.2	2.47	2.07	2.25

3.2 Main effects plots for S/N Ratio of Metal Removal Rate (MRR)

The main effects plot for S/N ratio of Metal Removal Rate

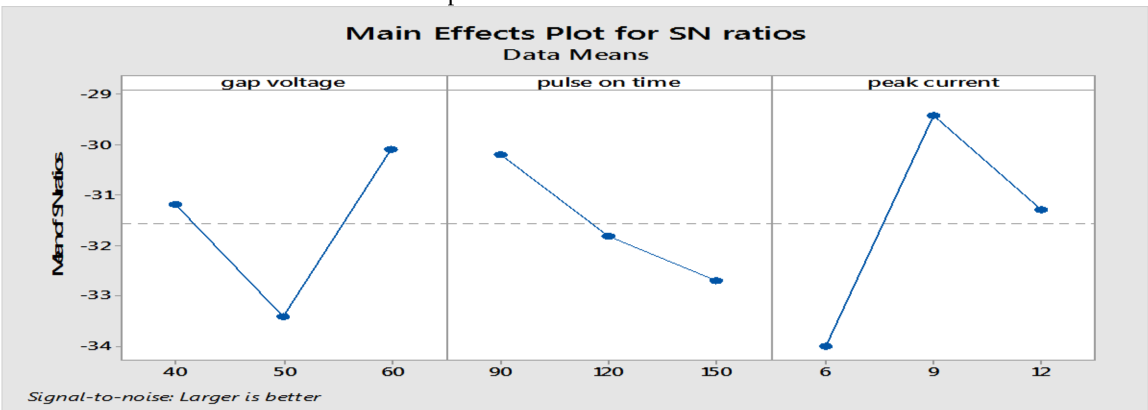
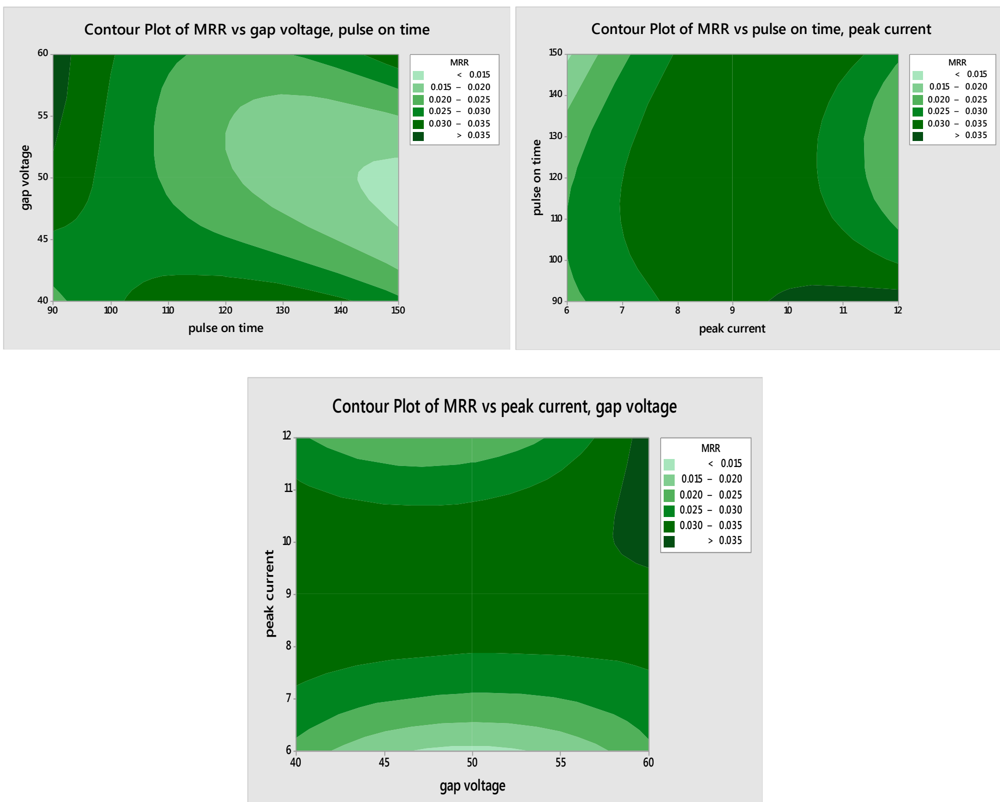


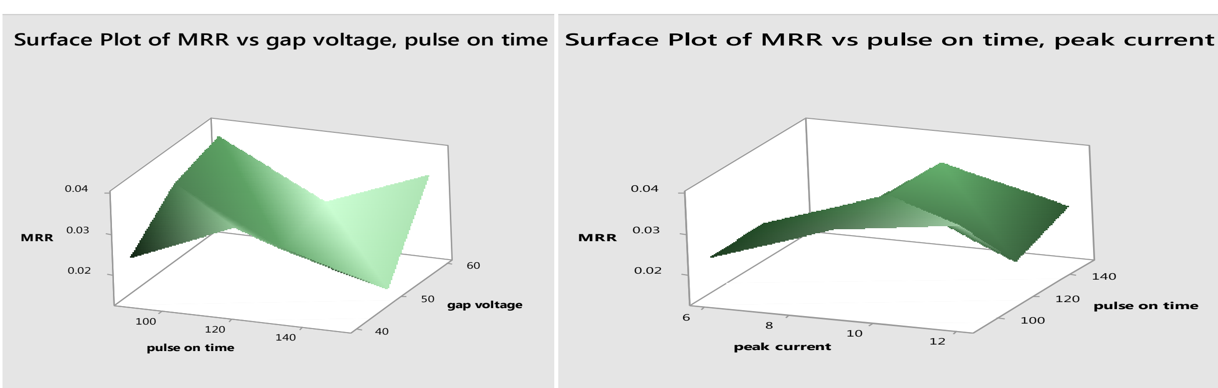
Figure 3.3: Main effects plots for S/N Ratio of Metal Removal Rate (MRR) on Nimonic 75

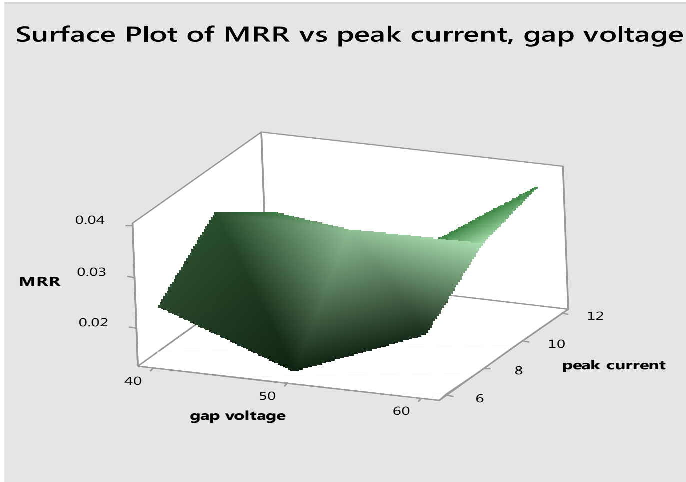
From the above figure 3.3 in subplot 1, it is observed that when the value of voltage increases from 40V to 50V the value of MRR decrease and from 50V to 60Vthe value of MRR increases. The reason for this is being that at higher voltage rating the higher of energy per unit discharge is released causing more metal erosion and hence MRR increase. Maximum MRR obtained at voltage value of 60V The S/N ratio clearly shows that the value of MRR is more at 60V. In subplot 2, it is observed that when pulse on time increase from 90µs to 120µs the value of MRR also decrease higher rate and pulse on time increase from 120µs to 150µs the value of MRR also decrease. Subplot 3 shows that when the value of pick current increases from 6A to 9A MRR first increase but when further increase from 9A to 12A its decrease. Optimal value is 9A for higher MRR.

3.3 Contour plots for MRR



3.4 Surface plot for MRR





4. CONCLUSIONS AND FUTURE SCOPE

When gap voltage increases from 50 to 60V MRR increases from 0.02 to 0.04 gm/min.

- On increasing pulse on time 100 to 120µs, MRR increases from 0.02 to 0.03 gm/min. But pulse on time increases from 120 to 140µs then MRR also decreases from 0.03 to 0.02gm/min.
- Peak current increases from 6 to 8 A then MRR also increases from 0.02 to 0.03 gm/min. But on increasing peak current from 8-11 A then MRR slightly increases from 0.03-0.035 gm/min while on increasing peak current from 11-12A the MRR deceases from 0.035-0.01gm/min.
- Peak current is having most significant effect on MRR as it followed by gap voltage and pulse on time having least effect.
- On increasing pulse on time 100-120µs, SR decreases from 2.5-2.0 µm but SR increases from 2-2.75 µm when pulse on time increases from 120-145µs.
- When gap voltage increases from 40-50V then SR increases from 2.5-3.5 µm but gap voltage increases from 50-55V SR also increases from 2.5-3.5 µm when gap voltage increases 50-60V SR decreases from 3.5-2.7 µm.
- When peak current increases from 6-9 A then SR decreases from 2.25-2.0 µm but when peak current increases 9-12 A then SR also increases from 2-2.5 µm.
- Peak current is having most significant effect on SR followed by pulse on time and gap voltage having.

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