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Experimental Invetigation of Machining Parameters for EDM Using U-shaped Electrode of AISI P20 tool steel

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The correct selection of manufacturing conditions is one of the most important aspects to take into consideration in the majority of manufacturing processes and, particularly, in processes related to Electrical Discharge Machining (EDM). It is a capable of machining geometrically complex or hard material components, that are precise and difficult-to-machine such as heat treated tool steels, composites, super alloys, ceramics, carbides, heat resistant steels etc. being widely used in die and mold making industries, aerospace, aeronautics and nuclear industries.

AISI P20 Plastic mould steel that is usually supplied in a hardened and tempered condition. Good machinability, better polishability, it has a grooving rang of application in Plastic moulds, frames for plastic pressure dies, hydro forming tools These steel are categorized as difficult to machine materials, posses greater strength and toughness are usually known to create major challenges during conventional and non- conventional machining. The Electric discharge machining process is finding out the effect of machining parameter such as discharge current, pulse on time and diameter of tool of AISI P20 tool steel material. Using U-shaped cu tool with internal flushing. A well-designed experimental scheme was used to reduce the total number of experiments. Parts of the experiment were conducted with the L18 orthogonal array based on the Taguchi method. Moreover, the signal-to-noise ratios associated with the observed values in the experiments were determined by which factor is most affected by the Responses of Material Removal Rate (MRR), Tool Wear Rate (TWR) and over cut (OC).

Chapter 1

Introduction of EDM

1.1 Background of EDM

The history of EDM Machining Techniques goes as far back as the 1770s when it was discovered by an English Scientist. However, Electrical Discharge Machining was not fully taken advantage of until 1943 when Russian scientists learned how the erosive effects of the technique could be controlled and used for machining purposes.

When it was originally observed by Joseph Priestly in 1770, EDM Machining was very imprecise and riddled with failures. Commercially developed in the mid 1970s, wire EDM began to be a viable technique that helped shape the metal working industry we see today. In the mid 1980s.The EDM techniques were transferred to a machine tool. This migration made EDM more widely available and appealing over traditional machining processes.

The new concept of manufacturing uses non-conventional energy sources like sound, light, mechanical, chemical, electrical, electrons and ions. With the industrial and technological growth, development of harder and difficult to machine materials, which find wide application in aerospace, nuclear engineering and other industries owing to their high strength to weight ratio, hardness and heat resistance qualities has been witnessed. New developments in the field of material science have led to new engineering metallic materials, composite materials and high tech ceramics having good mechanical properties and thermal characteristics as well as sufficient electrical conductivity so that they can readily be machined by spark erosion. Non-traditional machining has grown out of the need to machine these exotic materials. The machining processes are non-traditional in the sense that they do not employ traditional tools for metal removal and instead they directly use other forms of energy. The problems of high complexity in shape, size and higher demand for product accuracy and surface finish can be solved through non-traditional methods. Currently, non-traditional processes possess virtually unlimited capabilities except for volumetric material removal rates, for which great advances have been made in the past few years to increase the material removal rates. As removal rate increases, the cost effectiveness of operations also increase, stimulating ever greater uses of nontraditional process. The Electrical Discharge Machining process is employed widely for making tools, dies and other precision parts.

EDM has been replacing drilling, milling, grinding and other traditional machining operations and is now a well established machining option in many manufacturing industries throughout the world. And is capable of machining geometrically complex or hard material components, that are precise and difficult-to-machine such as heat treated tool steels, composites, super alloys, ceramics, carbides, heat resistant steels etc. being widely used in die and mold making industries, aerospace, aeronautics and nuclear industries. Electric Discharge Machining has also made its presence felt in the new fields such as sports, medical and surgical, instruments, optical, including automotive R&D areas.

1.2 Introduction of EDM -

Electro Discharge Machining (EDM) is an electro-thermal non-traditional machining Process, where electrical energy is used to generate electrical spark and material removal mainly occurs due to thermal energy of the spark.

EDM is mainly used to machine difficult-to-machine materials and high strength temperature resistant alloys. EDM can be used to machine difficult geometries in small batches or even on job-shop basis. Work material to be machined by EDM has to be electrically conductive.

1.3 Principle of EDM –

In this process the metal is removing from the work piece due to erosion case by rapidly recurring spark discharge taking place between the tool and work piece. Show the mechanical set up and electrical set up and electrical circuit for electro discharge machining. A thin gap about 0.025mm is maintained between the tool and work piece by a servo system shown in fig 1.1.

Both tool and work piece are submerged in a dielectric fluid .Kerosene/EDM oil/deionized water is very common type of liquid dielectric although gaseous dielectrics are also used in certain cases.

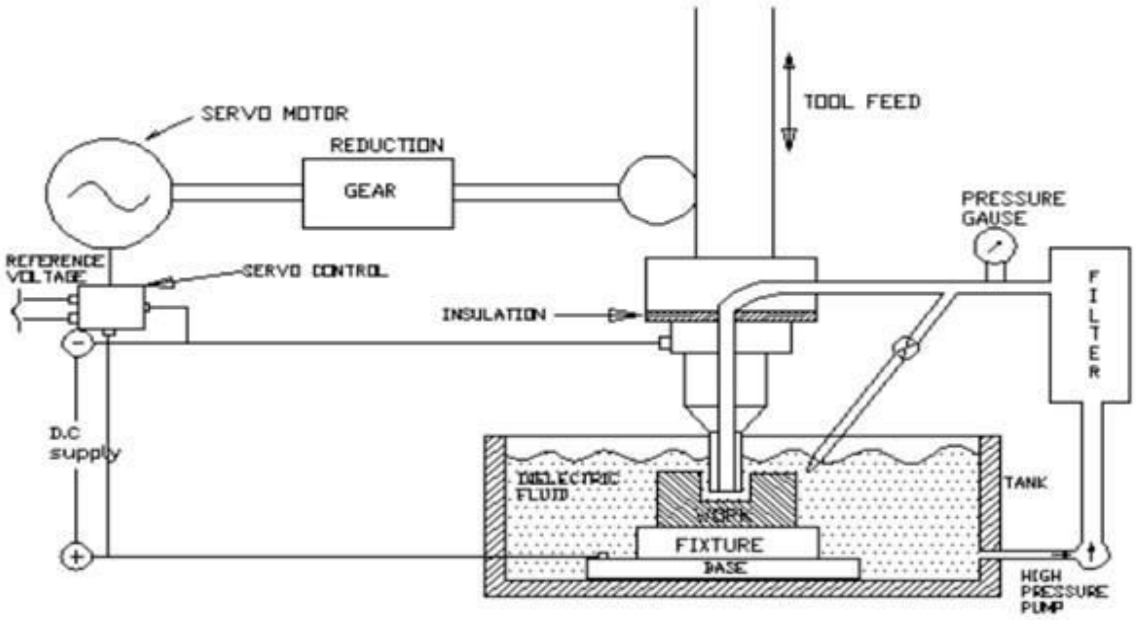

Figure1. 1 Set up of Electric discharge machining

This fig.1.1 is shown the electric setup of the Electric discharge machining. The tool is mead cathode and work piece is anode. When the voltage across the gap becomes sufficiently high it discharges through the gap in the form of the spark in interval of from 10 of micro seconds. And positive ions and electrons are accelerated, producing a discharge channel that becomes conductive. It is just at this point when the spark jumps causing collisions between ions and electrons and creating a channel of plasma. A sudden drop of the electric resistance of the previous channel allows that current density reaches very high values producing an increase of ionization and the creation of a powerful magnetic field. The moment spark occurs sufficiently pressure developed between work and tool as a result of which a very high temperature is reached and at such high pressure and temperature that some metal is melted and eroded.

Such localized extreme rise in temperature leads to material removal. Material removal occurs due to instant vaporization of the material as well as due to melting. The molten metal is not removed completely but only partially

As the potential difference is withdrawn as shown in Fig. 1.2, the plasma channel is no longer sustained. As the plasma channel collapse, it generates pressure or shock waves, which evacuates the molten material forming a crater of removed material around the site of the spark.

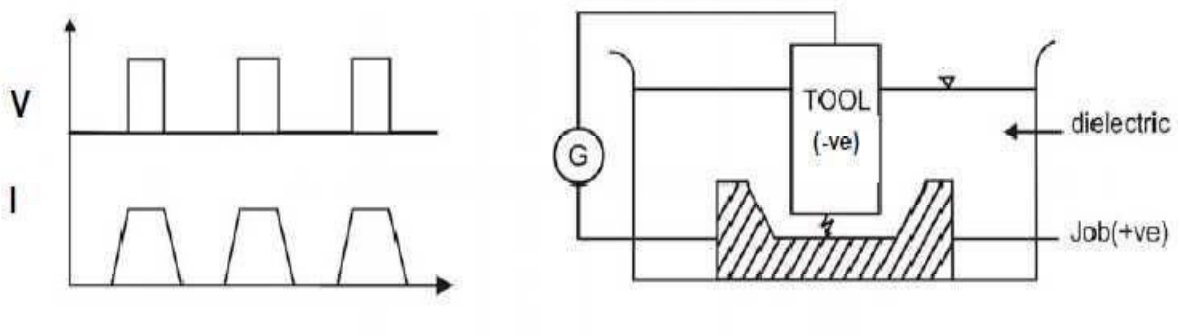

Figure1. 2 Working principle of EDM process

1.4 Types of EDM –

Basically, there are two different types of EDM:

1.4.1) Die-sinking

1.4.2) wire-cut.

1.4.1Die-sinking EDM –

In the Sinker EDM Machining process, two metal parts submerged in an insulating liquid are connected to a source of current which is switched on and off automatically depending on the parameters set on the controller. When the current is switched on, an electric tension is created between the two metal parts. If the two parts are brought together to within a fraction of an inch, the electrical tension is discharged and a spark jumps across. Where it strikes, the metal is heated up so much that it melts. Sinker EDM, also called cavity type EDM or volume EDM consists of an electrode and workpiece submerged in an insulating liquid such as, more typically, oil or, less frequently, other dielectric fluids. The electrode and workpiece are connected to a suitable power supply. The power supply generates an electrical potential between the two parts. As the electrode approaches the workpiece, dielectric breakdown occurs in the fluid, forming a plasma channel, and a small spark jumps.

These sparks usually strike one at a time because it is very unlikely that different locations in the inter-electrode space have the identical local electrical characteristics which would enable a spark to occur simultaneously in all such locations. These sparks happen in huge numbers at seemingly random locations between the electrode and the workpiece. As the base metal is eroded, and the spark gap subsequently increased, the electrode is lowered automatically by the machine so that the process can continue uninterrupted. Several hundred thousand sparks occur per second, with the actual duty cycle carefully controlled by the setup parameters.

1.4.2 Wire-cut EDM –

Wire EDM Machining (also known as Spark EDM) is an electro thermal production process in which a thin single-strand metal wire (usually brass) in conjunction with de-ionized water (used to conduct electricity) allows the wire to cut through metal by the use of heat from electrical sparks. a thin single-strand metal wire, usually brass, is fed through the workpiece, submerged in a tank of dielectric fluid, typically deionized water. Wire-cut EDM is typically used to cut plates as thick as 300mm and to make punches, tools, and dies from hard metals that are difficult to machine with other methods.

Wire-cutting EDM is commonly used when low residual stresses are desired, because it does not require high cutting forces for removal of material. If the energy/power per pulse is relatively low (as in finishing operations), little change in the mechanical properties of a material is expected due to these low residual stresses, although material that hasn't been stress-relieved can distort in the machining process. Due to the inherent properties of the process, wire EDM can easily machine complex parts and precision components out of hard conductive materials.

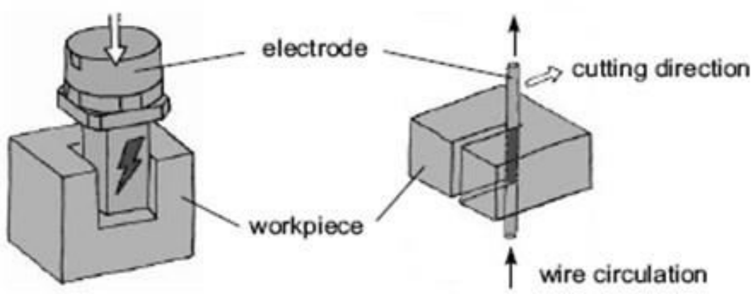

Figure1. 3 Die sinking & wire cut EDM Process

1.5 Important parameters of EDM

(a) **Spark On-time (pulse time or Ton):** The duration of time (μs) the current is allowed to flow per cycle. Material removal is directly proportional to the amount of energy applied during this on-time. This energy is really controlled by the peak current and the length of the on-time.

(b) **Spark Off-time (pause time or Toff):** The duration of time (μs) between the sparks (that is to say, on-time). This time allows the molten material to solidify and to be wash out of the arc gap.

This parameter is to affect the speed and the stability of the cut. Thus, if the off-time is too short, it will cause sparks to be unstable.

(c) **Arc gap (or gap):** The Arc gap is distance between the electrode and workpiece during the process of EDM. It may be called as spark gap. Spark gap can be maintained by servo system (fig no.-1).

(d) **Discharge current (current Ip):** Current is measured in amp Allowed to per cycle. Discharge current is directly proportional to the Material removal rate.

(e) **Duty cycle (τ):** It is a percentage of the on-time relative to the total cycle time. This parameter is calculated by dividing the on-time by the total cycle time (on-time pulse offtime).

$$\tau = \underline{\hspace{2cm}}$$

(f) **Voltage (V):** It is a potential that can be measure by volt it is also effect to the material removal rate and allowed to per cycle. Voltage is given by in this experiment is 50 V.

(g) **Diameter of electrode (D):** It is the electrode of Cu-tube there are two different size of diameter 4mm and 6mm in this experiment. This tool is used not only as a electrode but also for internal flushing.

(h) **Over cut** – It is a clearance per side between the electrode and the workpiece after the marching operation.

1.6 Characteristics of EDM

EDM specification by mechanism of process, metal removal rate and other function that shown in this table no .1

Table1.1 Specification on EDM

Mechanism of process	Controlled erosion (melting and evaporation) through a series of electric spark
Spark gap	0.010- 0.500 mm
Spark frequency	200 – 500 kHz
Peak voltage across the gap	30- 250 V

Metal removal rate (max.)	5000 mm^3/min
Specific power consumption	2-10 W/mm^3/min
Dielectric fluid	EDM oil, Kerosene liquid paraffin, silicon oil, deionized water etc.
Tool material	Copper, Brass, graphite, Ag-W alloys, Cu-W alloys .
MRR/TWR	0.1-10
Materials that can be machined	All conducting metals and alloys.
Shapes	Microholes, narrow slots, blind cavities
Limitations	High specific energy consumption, non conducting materials can't be machined.

1.7 Dielectric fluid

In EDM, as has been discussed earlier, material removal mainly occurs due to thermal evaporation and melting. As thermal processing is required to be carried out in absence of oxygen so that the process can be controlled and oxidation avoided. Oxidation often leads to poor surface conductivity (electrical) of the work piece hindering further machining. Hence, dielectric fluid should provide an oxygen free machining environment. Further it should have enough strong dielectric resistance so that it does not breakdown electrically too easily but at the same time ionize when electrons collide with its molecule. Moreover, during sparking it should be thermally resistant as well.

The dielectric fluid has the following functions:

(a) It helps in initiating discharge by serving as a conducting medium when ionised, and conveys the spark. It concentrates the energy to a very narrow region.

(b) It helps in quenching the spark, cooling the work, tool electrode and enables arcing to be prevented.

(c) It carries away the eroded metal along with it.

(d) It acts as a coolant in quenching the sparks.

The electrode wear rate, metal removal rate and other operation characteristics are also influenced by the dielectric fluid.

The dielectric generally fluid used are transformer on silicon oil, EDM oil, kerosene (paraffin oil) and de-ionized water are used as dielectric fluid in EDM. Tap water cannot be used as it ionizes too early and thus breakdown due to presence of salts as impurities occur. Dielectric medium is generally flushed around the spark zone. It is also applied through the tool to achieve efficient removal of molten material.

In this experiment using the Commercial grade EDM oil (specific gravity= 0.763, freezing point= 94˚C) was used as dielectric fluid are used it is using as coolant and medium of workpiece and tool during the process of erosion.

1.8. Flushing method-

Flushing is the most important function in any electrical discharge machining operation. Flushing is the process of introducing clean filtered dielectric fluid into the spark gap. There are a number of flushing methods used to remove the metal particles efficiently.

This experiment is using the internal flushing with the Cu U- shaped tool shown in the fig no. 1.4.

Figure 1. 4 Flushing of U-tube Cu electrode

1.9. Tool Material-

Tool material should be such that it would not undergo much tool wear when it is impinged by positive ions. Thus the localized temperature rise has to be less by tailoring or properly choosing its properties or even when temperature increases, there would be less melting. Further, the tool should be easily workable as intricate shaped geometric features are machined in EDM.

Thus the basic characteristics of electrode materials are:

1. High electrical conductivity – electrons are cold emitted more easily and there is less bulk electrical heating.
2. High thermal conductivity – for the same heat load, the local temperature rise would be less due to faster heat conducted to the bulk of the tool and thus less tool wear.
3. Higher density – for the same heat load and same tool wear by weight there would be less volume removal or tool wear and thus less dimensional loss or inaccuracy.
4. High melting point – high melting point leads to less tool wear due to less tool material melting for the same heat load.
5. Easy manufacturability.
6. Cost – cheap.

The followings are the different electrode materials which are used commonly in the industry:

1. Graphite
2. copper
3. Tellurium copper – 99% Cu + 0.5% tellurium
4. Brass

In this experiment are using the Cu tool U-shaped tool with internal flushing system this tool material can be eroded by U shaped.

1.10. Design variable-

Design parameter, process parameter and constant parameter are following ones,

Design parameters –

1. Material removal rate.
2. Tool wear rate
3. Over cut (OC)

Machining parameter –

1. Discharge current (Ip)
2. Pulse on time (Ton)
3. Diameter of U-shaped tool

Constant parameter-

1. Duty cycle
2. Voltage
3. Flushing pressure
4. Polarity

1.11. Workpiece material-

It is capable of machining geometrically complex or hard material components, that are precise and difficult-to-machine such as heat treated tool steels, composites, super alloys, ceramics, carbides, heat resistant steels etc.

There are different types of tool material are using the EDM method. And the tool steel contains carbon and alloy steels that are particularly well-suited to be made into tools. Their suitability comes from their distinctive hardness, resistance to abrasion, their ability to hold a cutting edge, and/or their resistance to deformation at elevated temperatures (red-hardness). Tool steel is generally used in a heat-treated state. Tool steels are made to a number of grades for different applications. In general, the edge temperature under expected use is an important determinant of both composition and required heat treatment. The higher carbon grades are typically used for such applications as stamping dies, metal cutting tools, etc.

In this experiment are using AISI P-20 plastic mould tool steel material.

1.12 Application of EDM –

1. The EDM process is most widely used by the mould-making tool and die industries, but is becoming a common method of making prototype and production parts, especially in the aerospace, automobile and electronics industries in which production quantities are relatively low.

2. It is used to machine extremely hard materials that are difficult to machine like alloys, tool steels, tungsten carbides etc.
3. It is used for forging, extrusion, wire drawing, thread cutting.
4. It is used for drilling of curved holes.
5. It is used for internal thread cutting and helical gear cutting.
6. It is used for machining sharp edges and corners that cannot be machined effectively by other machining processes.
7. Higher Tolerance limits can be obtained in EDM machining. Hence areas that require higher surface accuracy use the EDM machining process.
8. Ceramic materials that are difficult to machine can be machined by the EDM machining process.
9. Electric Discharge Machining has also made its presence felt in the new fields such as sports, medical and surgical, instruments, optical, including automotive R&D areas.
10. It is a promising technique to meet increasing demands for smaller components usually highly complicated, multi-functional parts used in the field of micro-electronics.

1.13 Advantages of EDM

(a) Any material that is electrically conductive can be cut using the EDM process.
(b) Hardened workpieces can be machined eliminating the deformation caused by heat treatment.
(c) X, Y, and Z axes movements allow for the programming of complex profiles using simple electrode.
(d) Complex dies sections and molds can be produced accurately, faster, and at lower costs. Due to the modern NC control systems on die sinking machines, even more complicated work pieces can be machined.
(e) The high degree of automation and the use of tool and work piece changers allow the machines to work unattended for overnight or during the weekends
(f) Forces are produced by the EDM-process and that, as already mentioned, flushing and hydraulic forces may become large for some work piece geometry. The large cutting forces of the mechanical materials removal processes, however, remain absent.
(g) Thin fragile sections such as webs or fins can be easily machined without deforming the part.

1.14 Limitation of EDM –

(a) The need for electrical conductivity – To be able to create discharges, the work piece has to be electrically conductive. Isolators, like plastics, glass and most ceramics, cannot be machined by EDM, although some exception like for example diamond is known. Machining of partial conductors like Si semi-conductors, partially conductive ceramics and even glass is also possible.

(b) Predictability of the gap - The dimensions of the gap are not always easily predictable, especially with intricate work piece geometry. In these cases, the flushing conditions and the contamination state of differ from the specified one. In the case of die-sinking EDM, the tool wear also contributes to a deviation of the desired work piece geometry and it could reduce the achievable accuracy. Intermediate measuring of the work piece or some preliminary tests can often solve the problems.

(c) Low material removal rate- The material removal of the EDM-process is rather low, especially in the case of die-sinking EDM where the total volume of a cavity has to be removed by melting and evaporating the metal. With wire-EDM only the outline of the desired work piece shape has to be machined. Due to the low material removal rate, EDM is principally limited to the production of small series although some specific mass production applications are known.

(d) Optimization of the electrical parameters - The choice of the electrical parameters of the EDM-process depends largely on the material combination of electrode and work piece and EDM manufactures only supply these parameters for a limited amount of material combinations. When machining special alloys, the user has to develop his own technology.

Chapter 2

Literature survey

Introduction-

In this chapter search few selected research paper related to EDM with effect of metal MRR, TWR, OC, surface roughness (SR) workpiece material, we are broadly classified all the paper in to five different category, i.e. paper related to material related workpiece or tool, tubular electrode, tool design, some paper related to Effect of multiple discharge and rest of the paper related to CNC.

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2.1 Workpiece and tool material-

Dhar and Purohit [1] evaluates the effect of current (c), pulse-on time (p) and air gap voltage (v) on MRR, TWR, ROC of EDM with **Al–4Cu–6Si alloy–10 wt. % SiC_P composites**. This experiment can be using the PS LEADER ZNC EDM machine and a cylindrical brass electrode of 30 mm diameter. And three factors, three levels full factorial design was using and analyzing the results. A second order, non-linear mathematical model has been developed for establishing the relationship among machining parameters. The significant of the models were checked using technique ANOVA and finding the MRR, TWR and ROC increase significant in a non-linear fashion with increase in current.

Karthikeyan et .al [2] has presented the mathematical molding of EDM with **aluminum-silicon carbide particulate composites**. Mathematical equation is Y=f(V, I, T). And the effect of MRR, TWR, SR with Process parameters taken in to consideration were the current (I), the pulse duration (T) and the percent volume fraction of SiC (25 μ size). A three level full factorial design was choosing. Finally the significant of the models were checked using the ANOVA. The MRR was found to decrease with an increase in the percent volume of SiC, whereas the TWR and the surface roughness increase with an increase in the volume of Sic. it shown the graph between interactive effect of the percent volume of Sic and the current on MRR Fig 2.1.

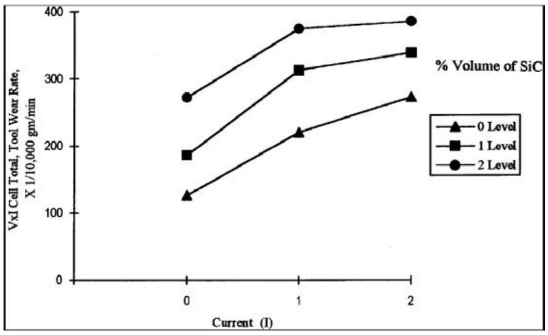

Figure 2.1 Graph between interactive effect of Sic and Current on MRR

Tool electrode material such as **Al–Cu–Si–Tic composite** produced using powder metallurgy (P/M) technique and using workpiece material CK45 steel was shown by **Taweel** [3]. The central composite second-order rotatable design had been utilized to plan the experiments, and RSM was employed for developing experimental models. Composite electrode is found to be more sensitive to peak current and Pulse on time then conventional electrode. And Fig 2.2. had shown the multi response optimization result for maximum MRR and minimum TWR.

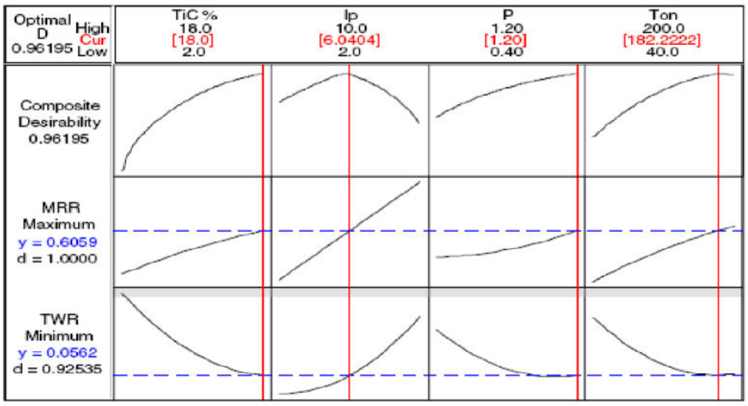

Figure 2.2 Multi Response optimization for Max. MRR and Min.TWR

B.Mohan and Satyanarayana [4] evolution the of effect of the EDM Current, electrode marital polarity, pulse duration and rotation of electrode on metal removal rate, TWR, and SR, and the EDM of **Al-Sic with 20-25 vol. % SiC**, Polarity of the electrode and volume present of SiC, the MRR increased with increased in discharge current and specific current it decreased with increasing in pulse duration. Increasing the speed of the rotation electrode resulted in a positive effect with MRR, TWR and better SR than stationary. The electric motor can be used to rotate the electrode(tool) AV belt was used to transmit the power from the motor to the electrode Optimization parameters for EDM drilling were also developed to summarize the effect of machining characteristic such as MRR, TWR and SR.

The effects of the machining parameters (MRR, TWR and SR) in EDM on the machining characteristics of **SKH 57** high-speed steel were investigated by **Yan-Cherng** et.al [5]. Experimental design was used to reduce the total number of experiments. Parts of the experiment were conducted with the L18 orthogonal array based on the Taguchi method. Moreover, the signal-to-noise ratios associated with the observed values in the experiments were determined by ANOVA and F -test. The relationship of MRR and SR with pulse duration graph in different peak current is as shown in Fig. 2.3. During the experiment MRR increases with peak current MRR initially increased to a peak at around 100 µs, and then fell.

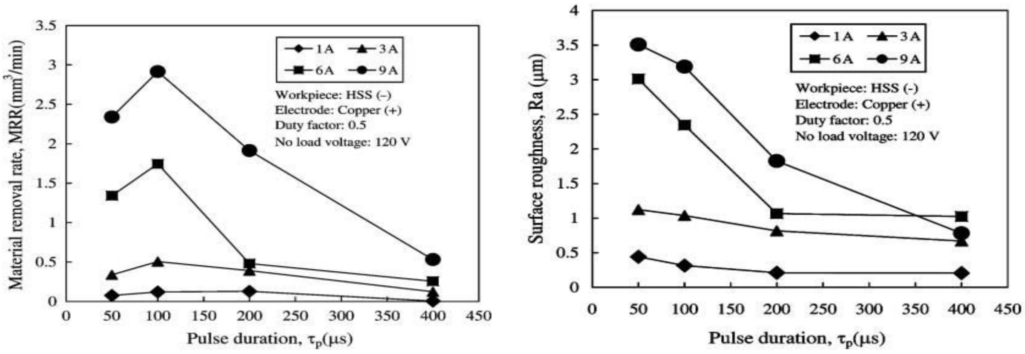

Figure 2.3 MRR and surface roughness with pulse duration graph

J. Simao et al [6] was developed the surface modification using by EDM, details are given of operations involving powder metallurgy (PM) tool electrodes and the use of powders suspended in the dielectric fluid, typically aluminum, nickel, titanium, etc. experimental results are presented on the surface alloying of **AISI H13** hot work tool steel during a die sink operation using partially sintered WC / Co electrodes operating in a hydrocarbon oil dielectric. An L8 fractional factorial Taguchi experiment was used to identify the effect of key operating factors on output measures (electrode wear, workpiece surface hardness, etc.). With respect to micro hardness, the percentage contribution ratios (PCR) for peak current, electrode polarity and pulse on time. Even so, the very low error PCR value (for micro hardness ~6%) implies that all the major effects were taken into account.

P. Narender Singh et al. [7] discuss the evolution of effect of the EDM current (*C*), Pulse ON-time (*P*) and flushing pressure (*F*) on MRR, TWR, taper (*T*), ROC, and surface roughness (SR) on machining as-cast **Al-MMC with 10% SiCp** . And use of metal matrix composites. ELEKTRAPULS spark erosion machine was used for the purpose and jet flushing of the dielectric fluid, kerosene, was employed. Brass tool of diameter 2.7mm was chosen to drill the specimens. An L27 OA, for the three machining parameters at three levels each, was opted to conduct the experiments. ANOVA was performed and the optimal levels for maximizing the responses were established. Scanning electron microscope (SEM) analysis was done to study the surface characteristics.

A. Soveja et al [8] have defined the experimental study of the surface laser texturing of **TA6V alloy**. The influence of the operating factors on the laser texturing process has been studied using two experimental approaches: Taguchi methodology and RSM. Empirical models have been developed. They allowed us to determine a correlation between process operating factors and performance indicators, such as surface roughness and MRR. Results analysis shows that the laser pulse energy and frequency are the most important operating factors. Mathematical models, that have been developed, can be used for the selection of operating factors' proper values in order to obtain the desired values of the objective functions.

Biing Hwa et al. [9] has discuss the investigates the feasibility and optimization of a rotary EDM with ball burnishing for inspecting the machinability of **Al_2O_3/6061Al composite** using the Taguchi method. Three ZrO_2 balls attached as additional components behind the electrode tool offer immediate burnishing following EDM. Three observed values machining rate, surface roughness and improvement of surface roughness are adopted to verify the optimization of the machining technique. Design of tool electrode is Cupper ring shaped BEDM as shown in Fig 2.4. This B-EDM process approaches both a higher machining rate and a finer surface roughness. Furthermore, the B-EDM process can achieve an approximately constant machining rate.

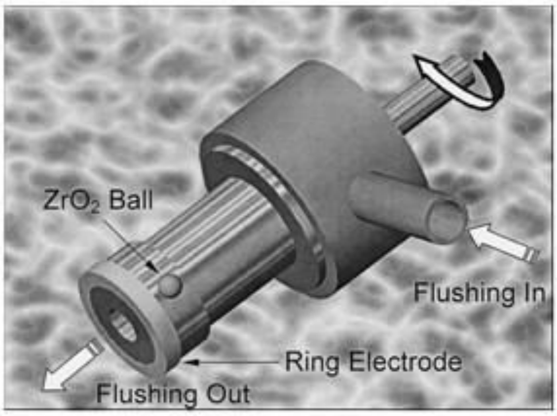

Figure 2.4 Design of Cu ring tool shaped B-EDM

Yan-Cherng Lin et al. [10] has reported that Electrical Discharge Energy on Machining of **Cemented Tungsten Carbide** using an electrolytic copper electrode. The machining parameters of EDM were varied to explore the effects of electrical discharge energy on the machining characteristics, such as MRR, EWR, and surface roughness. Moreover, the effects of the electrical discharge energy on heat-affected layers, surface cracks and machining debris were also determined. The experimental results show that the MRR increased with the density of the electrical discharge energy. The EWR and diameter of the machining debris were also related to the density of the electrical discharge energy. When the amount of electrical discharge energy was set to a high level, serious surface cracks on the machined surface of the cemented tungsten carbides caused by EDM were evident

Lee and X.P.Li [11] showed the effect of the machining parameter in EDM of tungsten carbide on the machining charatercteristics. The EDM process with tungsten carbide better machining performances is obtaining generally with the electrode as the cathode and the workpiece is anode. Tool with negative polarity give the higher material removal rate, lower tool wear and better surface finish. High open circuit voltage is necessary for tungsten carbide due to its high malting point and high hardness value and cupper tungsten as the tool electrode material with tool electrode material with negative polarity. This study confirms that there exists an optimum condition for precision machining of tungsten carbide although the condition may vary with the composing of martial, the accuracy of the machine and other other external factor.

Puertas and Luis[12] has define the optimization of machining parameter for EDM of **Boron carbide** of conductive ceramic materials. It is these conditions that determine such important characteristics as surface roughness, electrode wear, and MRR. In this article, a review of the state of art of the die-sinking EDM processes for conductive ceramic materials, as well as a description of the equipment used for carrying out the experiments, are presented. Also, a series of mathematical models will be devised using design of experiments techniques combined with multiple linear regression, which will allow us, while only performing a small number of experiments, to select the optimal machining conditions for the finishing stage of the EDM process.

Wang and Lin [13] discuss the optimization of W/Cu composite martial are used the Taguchi method. **W/Cu composites** are a type of cooling material highly resistant to heat corrosion produced through powder metallurgy. The Taguchi method and L18 orthogonal array to obtain the polarity, peak current, pulse duration, duty factor, rotary electrode rotational speed, and gapload voltage in order to explore the material removal rate, electrode wear rate, and surface roughness. The influenced of each variable and optimal processing parameter will be obtained through ANOVA analysis through experimentation to improve the process.

Tsai et al [14] have working martial of graphite, copper and copper alloys are widely using EDM because these materials have high melting temperature, and excellent electrical and thermal conductivity. The electrodes made by using powder metallurgy technology from special powders have been used to modify EDM surfaces in recent years, to improve wear and corrosion resistance. Electrodes are made at low pressure (20 MPa) and temperature (200 °C) in a hot mounting machine According to the experimental results, a mixing ratio of Cu–0wt%Cr and a sinter pressure of 20 MPa obtained an excellent MRR. Moreover, this work also reveals that the composite electrodes obtained a higher MRR than Cu metal electrodes. The recast layer was thinner and fewer cracks were present on the machined surface.

Study of parameter in EDM by using the RSM, the parameter like MRR, TWR, gap size and SR and relevant experimental data were obtained through experimentation by Sameh S. Habib[15]. They are using **Al/Sic composites** material and shown the correlations between the cutting rates, the surface finish and the physical material parameters of this process made it difficult to use. Optimal combination of these parameters was obtained for achieving controlled EDM of the workpiece and finding the MRR increases with an increase of pulse on time, peak current and gap voltage and MRR decreases with increasing of Sic%.

2.2 EDM with tubular electrode-

Saha and Choudhury [16] Study the process of dry EDM with **tubular** copper tool electrode and mild steel workpiece. Experiments have been conducted using air and study the effect of gap voltage discharge current, pulse-on time, duty factor, air pressure and spindle speed on MRR, surface roughness (Ra) and TWR. Empirical models for MRR, Ra and TWR have then been developed by performing a designed experiment based on the central composite design of experiments. Response surface analysis has been done using the developed models. ANOVA tests were performed to identify the significant parameters. The dry EDM attachment has shown the experimental result in Fig 2.5, and finding the Flow characteristic of air in the inter-electrode gap affects the MRR and the surface roughness (Ra). There exists an optimum number of airflow holes (in the tool) for which the MRR is highest and the Ra is lowest.

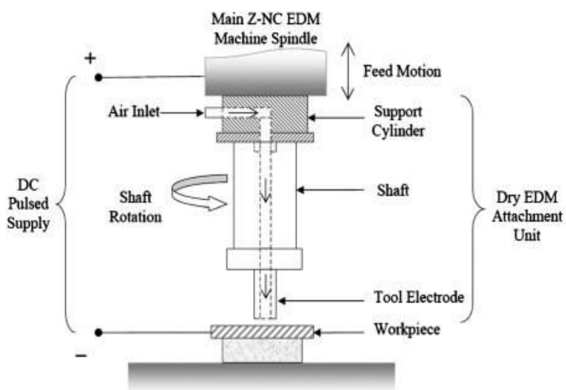

Figure 2.5 Experimental set-up

In the process of milling EDM machining of complex cavities with simple **cylindrical or** tubular electrodes was shown by **Bleys** et al. [17]. Milling EDM requires compensation of the tool electrode wear. Existing wear compensation methods are mostly based on off-line prediction of tool wear. New wear compensation method, incorporating real-time wear sensing based on discharge pulse evaluation. Tool wear is continuously evaluated during machining, and the actual wear compensation is adapted on the basis of this real-time wear evaluation. As a solution to this problem, a new wear compensation method is developed, based on real-time tool wear sensing. Simulations and experiments show the potential of the new method.

In this method for pipe electrode for a small hole for EDM or electrode magazine for replacing quickly a pipe electrode small-hole electric discharge machining to make a small-hole in a work by electric discharge machining was developed by **Suzuki** [18] they have to make replacement of a pipe electrode, an electrode magazine containing an electrode guide in which the pipe electrode is accommodated is replaced by using means. The electrode magazine has a self-position maintenance tip for maintaining the position taken by the electrode until then while the electrode magazine is removed from the electrode discharge machine and resuming the electrode discharge from the position after the electrode magazine is attached again to the electric discharge machine.

Lin and Han [19] presented the study about **tube electrode** for an EDM drilling includes a stabilizer block and a mover. The stabilizer block has a concaved in shaped supporting wall that parallels to the traveling path of a tube electrode, and has a plurality of apertures interconnected to air vacuuming connections to suck air. The move is connected to the stabilizer block for approaching the tube electrode. Suction force pushes the tube electrode against the supporting wall to achieve stabilization of the tube electrode. The stabilizer block further has a sensor to detect whether the tube electrode is seated into the stabilizer block or not and to measure the available length of the tube electrode before or after drilling.

2.3 EDM tool design –

Sohani et al. [20] discussed about sink EDM process effect of **tool shape and size factor** are to be considering in process by using RSM process parameters like discharge current, pulse on-time, pulse off-time, and tool area. The RSM-based mathematical models of MRR and TWR have been developed using the data obtained through central composite design. The analysis of variance was applied to verify the lack of fit and adequacy of the developed models. The investigations revealed that the best tool shape for higher MRR and lower TWR is circular, followed by triangular, rectangular, and square cross sections. From the parametric analysis, it is also observed that the interaction effect of discharge current and pulse on-time is highly significant on MRR and TWR, whereas the main factors such as pulse off-time and tool area are statistically significant on MRR and TWR.

Zhon and Han [21] worked on servo system for EDM, adaptive control of with self turning regulator a new EDM adaptive control system which directly and automatically regulates tooldown-time has been developed. Based on the real-time-estimated parameters of the EDM process model, by using minimum-variance control strategy, the process controller, a self-tuning regulator, was designed to control the machining process so that the gap states follow the specified gap state. With a properly selected specified gap states, this adaptive system improves the machining rate by, approximately, 100% and in the meantime achieves a more robust and stable machining than the normal machining without adaptive control. This adaptive control system helps to gain the expected goal of an optimal machining performance.

2.4 Effect of multiple discharges of EDM-

The EDM process e workpiece generated by the superposition of **multiple discharges**, as it happens during an actual EDM operation, by Izquierdo et al. [22] diameter of the discharge channel and material removal efficiency can be estimated using inverse identification from the results of the numerical model. An original numerical model for simulation of the EDM process has been presented. The model generates EDM surfaces by calculating temperature fields inside the workpiece using a finite difference-based approach, and taking into account the effect of successive discharges.

Wei Bin et al. [23] has study about electrical discharge machining with multiple holes in an electrically conductive work piece, includes an electrical discharge machine for rotatable mounting a first electrode, and at least one electrical discharge unit for rotatable mounting at least one second electrode. The electrical discharge machine includes a driver and a controller, the driver is desirably coupled to the electrical discharge machine and the electrical discharge unit for rotating the first electrode and the at least one second electrode, and the controller is desirably coupled to the electrical discharge machine and the at least one electrical discharge unit for controlling a supply of electrical energy from the first electrode and second electrode to the workpiece.

Kunge et al. [24] evolution the effect of MRR and EWR study on the powder mixed electrical discharge machining (PMEDM) of cobalt-bonded tungsten carbide (WC-Co) has been carried out. In the PMEDM process, the aluminum powder particle suspended in the dielectric fluid disperses and makes the discharging energy dispersion uniform; it displays multiple discharging effects within a single input pulse. This study was made only for the finishing stages and has been carried out taking into account the four processing parameters: discharge current, pulse on time, grain size, and concentration of aluminum powder particle for the machinability evaluation of MRR and EWR. The RSM has been used to plan and analyze the experiments. Notice that the residuals generally fall on a straight line implying that the errors are normally distributed. Furthermore, this supports adequacy of the least squares fit. The MRR generally increases with an increase of Aluminum powder concentration.

2.5 CNC Electric discharge machining-

Ding and Jiang [25] presented the work on CNC EDM machining of free-form surfaces requires tool paths that are different from those used in mechanical milling although in geometry both processes are described by the similar model of intersection between the rotating tool and the Workpiece. Special requirements on tool paths demanded by CNC EDM machining are studied and a two-phase tool path generation method for 4-axis CNC EDM rough milling with a cylindrical electrode is developed. The solid model of the workpiece and interface between the electrode as shown in **Fig 2.6** And finding the Discharge gap compensation, electrode wear compensation and many other factors have to be considered in the tool path generation process.

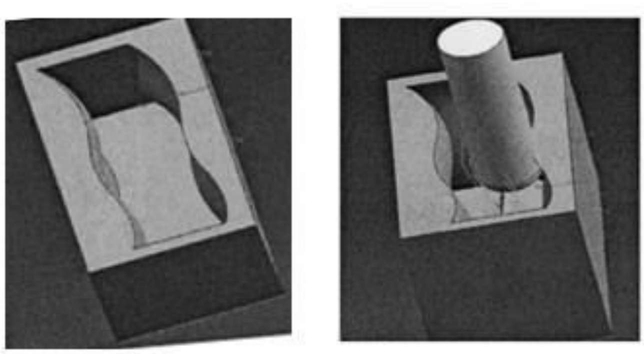

Figure 2.6 Solid model of workpiece and interference between work and tool

Bleys et al. [26] has discuss about CNC contouring EDM with a rotating cylinder and or tubular electrode necessitates compensation of the tool electrode wear in CNC milling operation is based on off-line tool wear simulation prior to machining. Tool wear can therefore be compensated in one dimension, by continuously moving the tool downward, On-line estimation of tool wear is used for combining anticipated compensation with real-time compensation. This extends the scope of milling EDM to the machining of blanks of which the exact shape is not known in advance.

Study about Variable structure system (VSS) with the large proportional gains can suddenly hold the electrode at the appropriate position was shown by Fang chang [27] for design process of the VSS is presented according to a practical gap control system for an EDM. This advantage can provide high performance on the nonlinear and time-varying gap condition during eroding process. The practical experimental results of an EDM with the VSS controller show a decrease of machining time, compared to the time required by the conventional proportional controlled EDM. And experimental result obtain from the commercial CNC EDM indicate that the eroding speed of control EDM with VSS faster than speed with force P control system.

Chang and Chiu [28] presented the electrode wear compensation of EDM of the scanning process with using the robust gap control is applied to compensate for electrode wear in an electric discharge scanning (ED-Scanning) process. This control compensates for the wear without reference to the wear ratio of the electrodes. As the tool moves horizontally from part (a) to part (b) as shown in **Fig 2.7,** compensation for wear they are discharge occur in gap and the material is then removed .The electrode must be moved from Z_2 to Z_1 and maintain the depth of removal at a layer. Finally During scanning the robust controller can compensate for wear on the bottom of the electrode without a complex calculation.

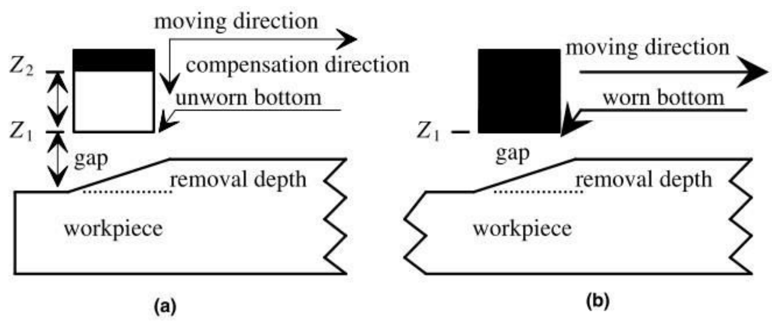

Figure 2.7 Compensation for wear during scanning of a layer

Ziada and Koshy [29] Study about the process Rotating Curvilinear Tools for EDM of Polygonal Shapes with Sharp Corners, Flushing of the inter-electrode gap is of critical importance in the performance of electrical discharge sinking operations. When the provision of flushing holes in the tool or the Workpiece is impractical, effective flushing is best realized by inducing a relative motion between the electrodes. This innovative scheme enables the machining of regular as well as non-regular polygonal shapes with sharp corners. Experimental results from implementing this concept on a **4-axis CNC EDM** machine tool are presented.

Study on reducing contour errors for CNC EDM was shown by **Shieh and lee** [30] they are proposed control, scheme consists of three portions. First, the step control performs position loop controller for each individual axis. Second, control error calculations suitable for control system analysis and design are used, and third, cross-coupling control is used to control contour error. Under the control of the proposed scheme, the stability of the system is studied for both linear and circular trajectories. The experimental results of a CNC EDM show that the proposed scheme is effective to improve contouring performance and ready for practical implementation.

2.6 Objective of the present work-

From the research papers in this classification, it is observed that few works has been reported on EDM on the material Al-Sic, EN-19, SKH 57, AISI H13, AISI D2 tool steel, and various composite materials. Study on EDM of different material and different mathematical model can be use to validated the experimental results.

The objective of the present work is an attempt to finding feasibility of machining AISI P-20 tool steel using U-shaped tubular copper electrode and internal flushing. The machining parameter selected for discharge current, pulse on time, and diameter of the tool using Taguchi design approach analyzing the responses MRR, TWR, and over cut.

Chapter 3
Experimental work

Introduction

In this chapter we are going to discuss about the experimental work which is consist about formation of the L-18 orthogonal array based on Taguchi design, orthogonal array is reduces the total on of experiment, in this experiment total 18 run. And Experimental set up, selection of workpiece, tool design, and taking all the value and calculation of MRR, TWR, and OC.

3.1 Experimental set up

For this experiment the whole work can be down by Electric Discharge Machine, model ELECTRONICA- ELECTRAPULS PS 50ZNC (die-sinking type) with servo-head (constant gap) and positive polarity for electrode was used to conduct the experiments. Commercial grade EDM oil (specific gravity= 0.763, freezing point= 94˚C) was used as dielectric fluid. With internal flushing of U-shaped cu tool with a pressure of 0.2 kgf/cm^2 .Experiments were conducted with positive polarity of electrode. The pulsed discharge current was applied in various steps in positive mode.

The EDM consists of following major part as shown in the chapter Appendix (Fig 5.1)

3.1.1 Dielectric reservoir, pump and circulation system.
3.1.2 Power generator and control unit.
3.1.3 Working tank with work holding device.
3.1.4 X-y table accommodating the working table.
3.1.5 The tool holder.
3.1.6 The servo system to feed the tool.

3.1.1 Dielectric reservoirs pump and circulation system - Dielectric reservoirs and pump are used to circulate the EDM oil for every run of the experiment and also used the filter the EDM oil. Dielectric reservoir is shown in Fig 3.1.

Figure 3.1 Dielectric reservoir

3.1.2 Power generator and control unit - The power supply control the amount of energy consumed. First, it has a time control function which controls the length of time that current flows during each pulse; this is called "on time." Then it is control the amount of current allowed to flow during each pulse. These pulses are of very short duration and are measured in microseconds. There is a handy rule of thumb to determine the amount of current a particular size of electrode should use: for an efficient removal rate, each square inch of electrode calls for 50 A. Low current level for large electrode will extend overall machine time unnecessarily. Conversely, too heavy a current load can damage the workpiece of electrode.

The control unit is control the all function of the machining for example of Ton, Ip, duty cycle, putting the values and maintain the workpiece the tool gap. The control unit is shown in this Fig 3.2.

Figure 3.2 Control unit of EDM machine

3.1.3 Working tank with work holding device– All the EDM oil kept in the working tank working tank is used to the supply the fluid during the process of machining.

3.1.4 X-y table accommodating the working table_– They_are used to the moment of the workpiece form X and Y direction.

3.1.5 The tool holder – The tool holder hold the tool with the process of machining. The tool holder with workpiece and tool as shown in Fig 3.3

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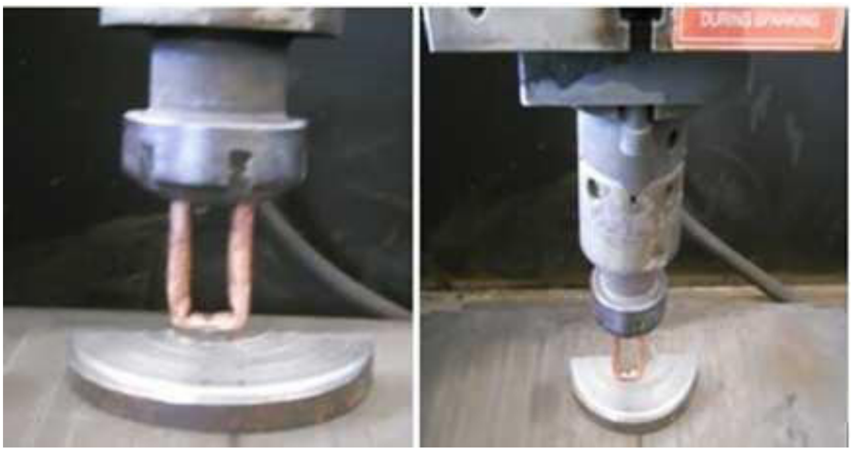


Figure 3.3 Tool holder with Workpiece and tool

3.1.6 The servo system to feed the tool - The servo control unit is provided to maintain the pre determined gap. It senses the gap voltage and compares it with the present value and the different in voltage is then used to control the movement of servo motor to adjust the gap.

3.2 Selection of the work piece-

It is capable of machining of hard material component such as heat treated tool steels, composites, super alloys, ceramics, carbides, heat resistant steels etc. The higher carbon grades are typically used for such applications as stamping dies, metal cutting tools, etc. AISI grades of tool steel is the most common scale used to identify various grades of tool steel. Individual alloys within a grade are given a number; for example: A2, O1, D2, P20 etc.

In this experiment using AISI P20 tool steel material this **P-20 tool** steel material is a pre hardened high tensile tool steel which offers ready machine ability in the hardened and tempered condition, therefore does not require further heat treatment. Subsequent component modifications can easily be carried out.

Plastic mould steel (P-20 tool steel) that is usually supplied in a hardened and tempered condition. Good machine ability, better polish ability, compared to DIN 1.2312 (AISI P20+S). Plastic mould steel is used growing range of to Plastic moulds, frames for plastic pressure dies, hydro forming tools. And their composition of the tool is listed in this Table: 3.1, 3.2, 3.3 and 3.4.

Table 3.1 Composition of AISI P-20 tool steel material

Elements	Weight limit %	Actual weight %
C	0.28-0.40	0.40
Mn	0.60-1.00	1.00
Si	0.20-0.80	0.40
Cr	1.40-2.00	1.20
Mo	0.30-0.55	0.35
Cu	0.25	0.25
P	0.03	0.03
S	0.03	0.03

Table 3.2 AISI P20 tool steel categories

Category	Steel
Class	Tool steel
Type	General mold steel
Designations	Germany : DIN 1.2330 United States : ASTM A681 , UNS T51620

Table 3.3 Mechanical properties of P20 steel

Properties		Conditions T (°C)
Density	7.85x1000 kg/m^3	25
Poisson's Ratio	0.27-0.30	25
Elastic Modulus	190-210Gpa	25

Table 3.4 Thermal Properties of P20 tool steel material

Properties		Conditions T (°C)
Thermal Expansion (10^{-6}/ºC)	12.8	20-425 more

AISI P20 tool steel material and after machining workpiece and the Cu U-shaped tool. As showing Fig 3.4 and the workpiece shows 18 total no. of experiments doing in this job.

Figure 3.4 P-20 workpiece before and after machining with tool

3.3 Tool Design- The tool design for Electric discharge machining for using Cu, brass, Al alloys silver tungsten alloys etc. In this experiment using the copper tool electrode and the design of cupper tool is a U- shaped with internal flashing. Shapes of the tool same cavity produced in the workpiece. Using the U-shaped tool so U-shaped cavity produced on the workpiece. The design of the tool in showed in Fig 3.5 and 3.6.

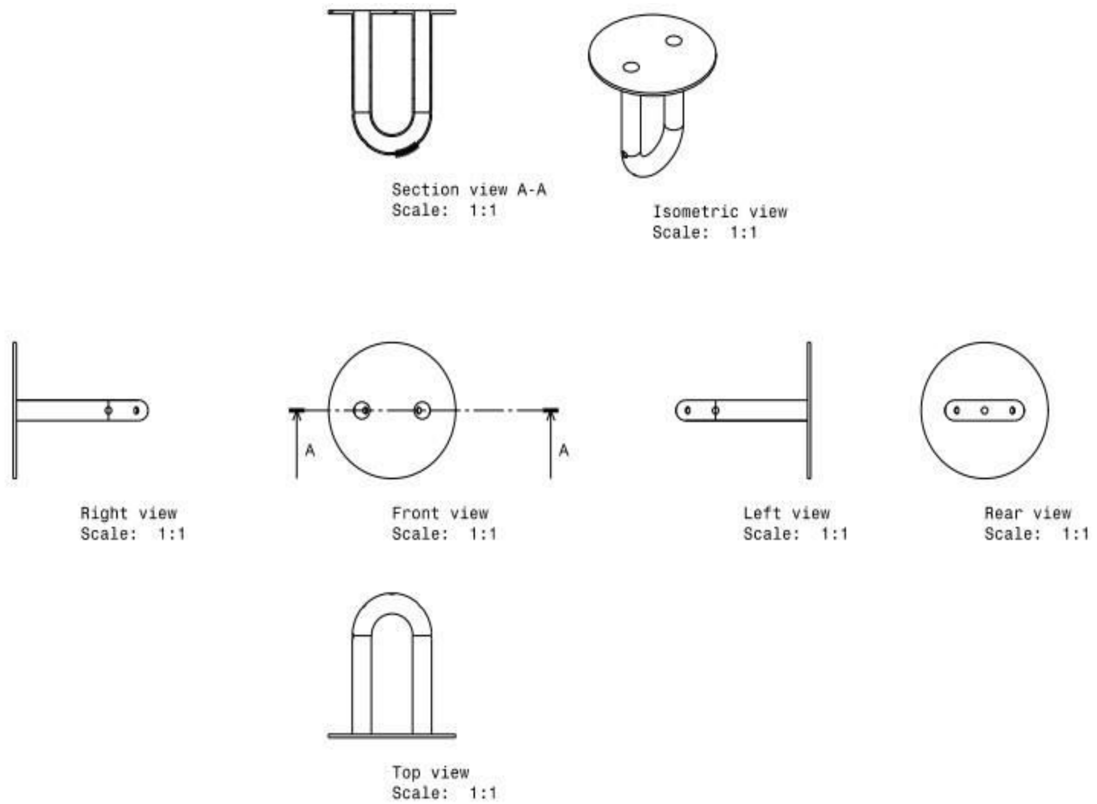
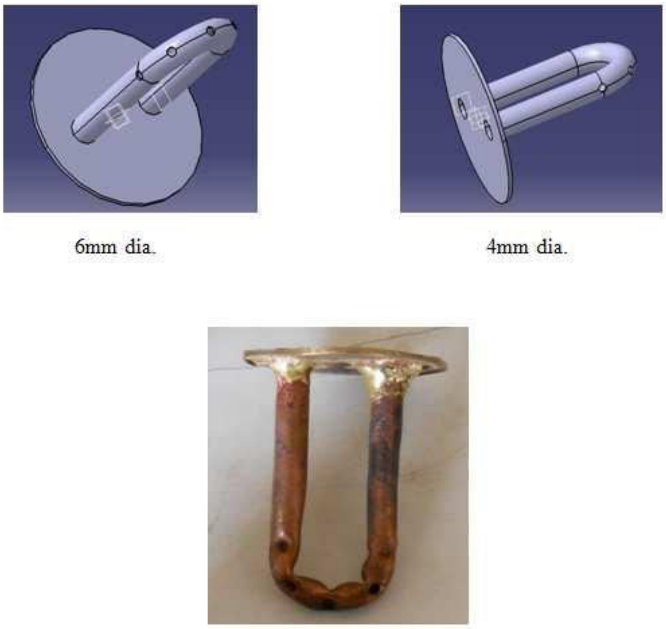


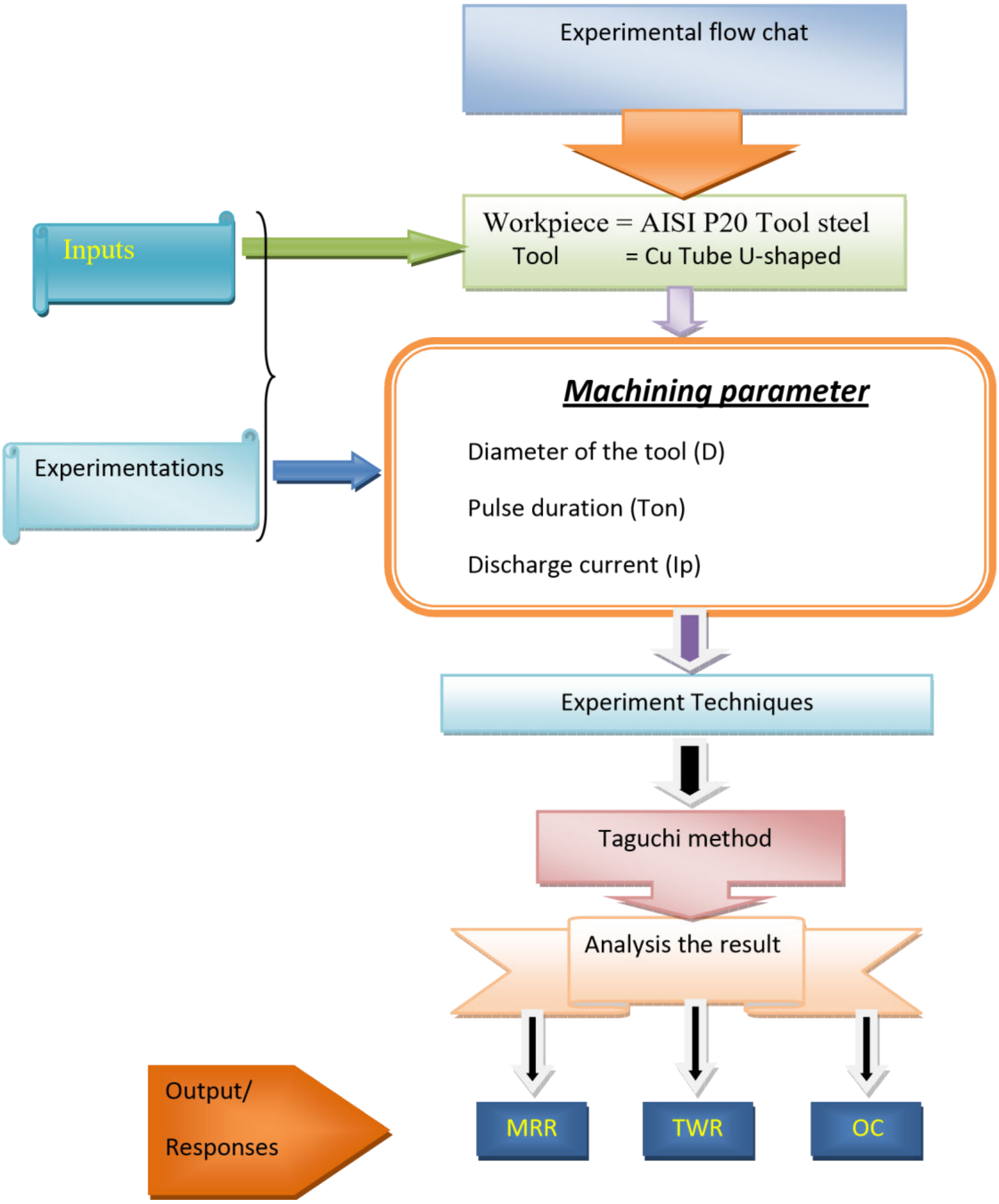
Figure 3.5 U - Tube Copper tool design



6mm dia. 4mm dia.

Figure 3.6 U-shaped Copper tool

3.4 Flow chart of experiment



3.5 Mechanism of MRR

The mechanism of material removal of EDM process is most widely established principle is the conversion of electrical energy it into thermal energy. During the process of machining the sparks are produced between workpiece and tool .Thus each spark produces a tiny crater, and crater formation shown in this Fig 3.7 in the material along the cutting path by melting and vaporization, thus eroding the workpiece to the shape of the tool.

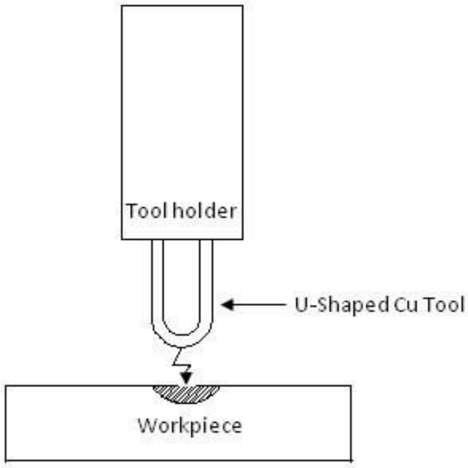


Figure 3.7 Crater formation in EDM process

It is well-known and elucidated by many EDM researchers by Roethel et.al [31] that Material Removal Mechanism (MRM) is the process of transformation of material elements between the work-piece and electrode. The transformation are transported in solid, liquid or gaseous state, and then alloyed with the contacting surface by undergoing a solid, liquid or gaseous phase reaction.

3.5.1 Evaluation of MRR-

The material MRR is expressed as the ratio of the difference of weight of the workpiece before and after machining to the machining time and density of the material.

MRR= .... (3.1)

Whereas Wjb = Weight of workpiece before machining.

Wja = Weight of workpiece after machining.
t = Machining time = 1.00 hr.

ρ = Density of AISI P20 steel material =7.84gm/cm^3

3.6 Mechanism of Tool wears-

Tool wear is an important factor because if affects dimensional accuracy and the shape produced. Tool wear is related to the melting point of the materials. Tool wear is affected by the precipitation of carbon from the hydrocarbon dielectric on the electrode surface during sparking. By Mohri et al. [32] Also the rapid wear on the electrode edge was because of the failure of carbon to precipitate at difficult to reach regions of the electrode.

3.6.1 Evaluation of tool wear rate

TWR is expressed as the ratio of the difference of weight of the tool before and after machining to the machining time. That can be explain this equations

TWR = ________ …………………(3.2)

Whereas Wtb = Weight of the tool before machining.

Wta = Weight of the tool after machining.

t = Machining time (In this experiment the machining time is one hour).

3.7 Mechanism of over cut -

It is the discharge by which the machined hole in the work piece exceeds the electrode size and is determined by both the initiating voltage and the discharge energy. During the process of machining EDMed cavity produced are always larger than the electrode this deference (size of electrode and cavity) is called Over Cut (OC). It becomes important when close tolerance components are required to be produced for space application and also in tools, dies and moulds for press work (Singh and Maheshwari [33]).

3.7.1 Evaluation of over cut

OC is expressed as half the difference of diameter of the hole produced to the tool diameter that is shown in these equations.

OC = ______ ……………………….(3.3)

Whereas Djt = diameter of hole produced in the workpiece

Dt = Diameter of tool

3.8 Taguchi design

Dr. Genichi Taguchi is regarded as the foremost proponent of robust parameter design, which is an engineering method for product or process design that focuses on minimizing variation and/or sensitivity to noise. When used properly, Taguchi designs provide a powerful and efficient method for designing products that operate consistently and optimally over a variety of conditions. Taguchi proposed several approaches to experimental designs that are sometimes called "Taguchi Methods." These methods utilize two-, three-, four-, five-, and mixed-level fractional factorial designs. Taguchi refers to experimental design as "off-line quality control" because it is a method of ensuring good performance in the design stage of products or processes.

3.9 Taguchi design experiments in MINITAB

MINITAB provides both static and dynamic response experiments in a static response experiment; the quality characteristic of interest has a fixed level. The goal of robust experimentation is to find an optimal combination of control factor settings that achieve robustness against (insensitivity to) noise factors. MINITAB calculates response tables and generates main effects and interaction plots for:-

Signal-to-noise ratios (S/N ratios) vs. the control factors.

Means (static design) vs. the control factors.

A Taguchi design or an orthogonal array the method is designing the experimental procedure using different types of design like, two, three, four, five, and mixed level. In the study, a three factor mixed level setup is chosen with a total of eighteen numbers of experiments to be conducted and hence the OA L18 was chosen. This design would enable the two factor interactions to be evaluated. As a few more factors are to be added for further study with the same type of material, it was decided to utilize the L18 setup, which in turn would reduce the number of experiments at the later stage. In addition, the comparison of the results would be simpler.

The levels of experiment parameters electrode diameter (D), spark on time (Ton), and discharge current (Ip) are shown in Table 3.5 and the design matrix is depicted in Table 3.6.

Table 3.5 Machining parameters and their level

Machining parameter	Symbol	Unit	Level		
			Level 1	Level 2	Level 3
Electrode diameter	(D)	mm	4	6	
Spark on time	(Ton)	μs	50	500	1000
Discharge current	(Ip)	A	1	3	5

3.10 Conduct of Experiment –

P20 Tool steel material particulate was using U-shaped Copper tube tool with 4mm and 6mm diameter. And the PS 50ZNC (die-sinking type) of EDM machine are used. Commercial grade EDM oil (specific gravity= 0.763, freezing point= 94˚C) was used as dielectric fluid. Internal flushing with U-shaped copper tool with internal flushing was used to flush away the eroded materials from the sparking zone. In this experiment voltage and duty cycle is kept constant is 50 v and 8. For a three factor are tackled with a total number of 18 experiments performed on die sinking EDM.

The calculation of material removal rate and tool wear rate by using electronic balance weight machine as shown in Fig 5.2. This machine capacity is 300 gram and accuracy is 0.001 gram. And the over cut measurement can be using tool maker microscope as shown in Fig 5.3 this machine accuracy is 0.0001 mm .

3.11 Design matrix and Observation table

Table 3.6 Design matrix and Observation table

Run	Dia (mm)	Ip (A)	Ton (μs)	Wt of Workpiece (gm)		Wt. of Tool (gm)		Cavity dia. (mm)
				Wjb	Wja	Wtb	Wta	Djt
1	4	1	50	266.510	266.220	18.976	18.974	5.724

2	4	1	500	266.220	266.109	18.974	18.970	5.393
3	4	1	1000	266.109	266.093	18.970	18.969	4.736
4	4	3	50	266.093	264.914	18.969	18.941	5.882
5	4	3	500	264.914	264.483	18.941	18.926	5.743
6	4	3	1000	264.488	264.395	18.926	18.925	5.445
7	4	5	50	264.395	262.983	18.925	18.836	5.895
8	4	5	500	262.983	262.146	18.836	18.827	5.785
9	4	5	1000	262.146	262.061	18.827	18.801	5.964
10	6	1	50	81.783	81.491	22.214	22.196	6.143
11	6	1	500	81.922	81.783	22.224	22.214	6.089
12	6	1	1000	81.955	81.922	22.225	22.224	6.071
13	6	3	50	3841.0	3840.0	22.240	22.238	6.158
14	6	3	500	82.769	82.245	22.238	22.233	6.130
15	6	3	1000	82.245	81.955	22.233	22.225	6.144
16	6	5	50	269.264	267.862	22.196	22.187	6.180
17	6	5	500	267.862	266.807	22.187	22.161	6.136
18	6	5	1000	266.807	266.510	22.161	22.173	6.024

3.12 Conclusion-

Experiments were conducted according to Taguchi method by using the machining set up and the designed U-shaped tubular electrodes with internal flushing. The control parameters like diameter of electrode (D) , discharge current (Ip) and pulse duration (Ton) conductivity were varied to conduct 18 different experiments and the weights of the work piece and Tool and dimensional measurements of the cavity were taken for calculation of MRR , TWR and over cuts.

Chapter 4
Result and discussion

Introduction –

In This chapter are related about influences of MRR, TWR, and OC and finding the result which factors discharge current , pulse duration, diameter of Cu tool , is most important with help of Taguchi method.

4.1 Response table –

The response table for MRR, TWR and OC are shown in Table 4.1 along with the input factors.

Table 4.1 Response table

Run	Dia (mm)	Ip (A)	Ton (μs)	MRR (mm^3/min)	TWR (gm/min)	OC (mm)
1	4	1	50	1.0400	0.0170	0.8620
2	4	1	500	0.2360	0.0030	0.6965
3	4	1	1000	0.0360	0.0006	0.3680
4	4	3	50	3.9890	0.0660	0.9410
5	4	3	500	0.9040	0.0150	0.8715
6	4	3	1000	0.7970	0.0130	0.7225
7	4	5	50	2.9980	0.0400	0.9295
8	4	5	500	1.7770	0.0290	0.8790
9	4	5	1000	0.8000	0.0030	0.9820
10	6	1	50	0.6140	0.0103	0.1435
11	6	1	500	0.2950	0.0040	0.0895
12	6	1	1000	0.0700	0.0010	0.0710
13	6	3	50	3.0000	0.0500	0.5790
14	6	3	500	1.1120	0.0180	0.5650
15	6	3	1000	0.9738	0.0356	0.5720
16	6	5	50	2.9700	0.0490	0.5900
17	6	5	500	2.2390	0.0370	0.5680

18	6	5	1000	1.3000	0.0105	0.5120

4.2 Influences on MRR

The S/N ratios for MRR are calculated as given in Equation 4.1. Taguchi method is used to analysis the result of response of machining parameter for larger is better criteria.

LB: η 10 log _Σ! yi] . . . . (4.1)

Where η denotes the S/N ratios calculated from observed values, yi represents the experimentally observed value of the i^{th} experiment and n=1 is the repeated number of each experiment in L-18 OA is conducted.

The analysis of variances for the factors is shown in Table 4.2 which is clearly indicates that the diameter of the tool is not important for influencing MRR and Ip and Ton are the most influencing factors for MRR and as well as the interaction Ip x Ton is significant (shown in bold). And other factors are not significant .The delta values are Dia. of tool, Ton and Ip are 1.1493, 15.0841 and 18.3901 respectively, depicted in Table 4.3. The case of MRR, it is "Larger is better", so from this table it is clearly definite that Ip is the most important factor then Ton and last is dia. of the tool.

Table 4.2 Analysis of Variance for S/N ratios for MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Dia	1	5.94	5.94	5.944	3.38	0.140
Ip	2	1222.40	1222.40	611.198	347.29	**0.000**
Ton	2	683.05	683.05	341.524	194.06	**0.000**
Dia*Ip	2	2.17	2.17	1.087	0.62	0.584
Dia*Ton	2	30.98	30.98	15.491	8.80	0.034
Ip*Ton	4	163.28	163.28	40.820	23.19	**0.005**
Residual Error	4	7.04	7.04	1.760		
Total	17	2114.86				

Table 4.3 Response for S/N Rations Larger is better (MRR)

Level	Diameter	Ip	Ton
1	-2.1459	-13.1689	6.1093
2	-0.9966	3.2340	-1.8508
3		5.2212	-8.9721
Delta	1.1493	18.3901	15.0841
Rank	3	1	2

During the process of Electrical discharge machining, the influence of various machining parameter like Ip, Ton and Diameter of tool has significant effect on MRR, as shown in main effect plot for S/N ratio of MRR in Fig 4.1. The discharge current (Ip) is directly proportional to MRR in the range of 1 to 3A. This is expected because an increase in pulse current produces strong spark, which produces the higher temperature, causing more material to melt and erode from the work piece. Besides, it is clearly evident that the other factor does not influence much as compared to Ip and similar conclusions were shown by Ghoreishi and Tabari [34]. But, with increase in discharge current from 3A to 5A MRR increases slightly. However, MRR decreases monotonically with the increase in pulse on time.

The diameter of the tool has no significant effect on MRR. The interaction plot of MRR is shown in Fig 4.2, where each plot exhibits the interaction between three different machining parameters like Ip, Ton and dia. of tool. This implies that the effect of one factor is dependent upon another factor. It is also confirmed by the ANOVA table (Table 4.2).

It is well known fact that the spark energy increases with Ton and hence, MRR increases with Ton in the range of 300 to 400 µs. MRR usually increases with Ton up to a maximum value after which that it starts to decrease. This is due to the fact that with higher Ton, the plasma formed between the Inter electrode gap (IEG) actually hinders the energy transfer and thus reduces MRR. In this experiment the value of pulse durations are 50, 500 and 1000 µs which miss the peak values. So, the plotted graph of pulse duration vrs MRR, as show decreasing trend only.

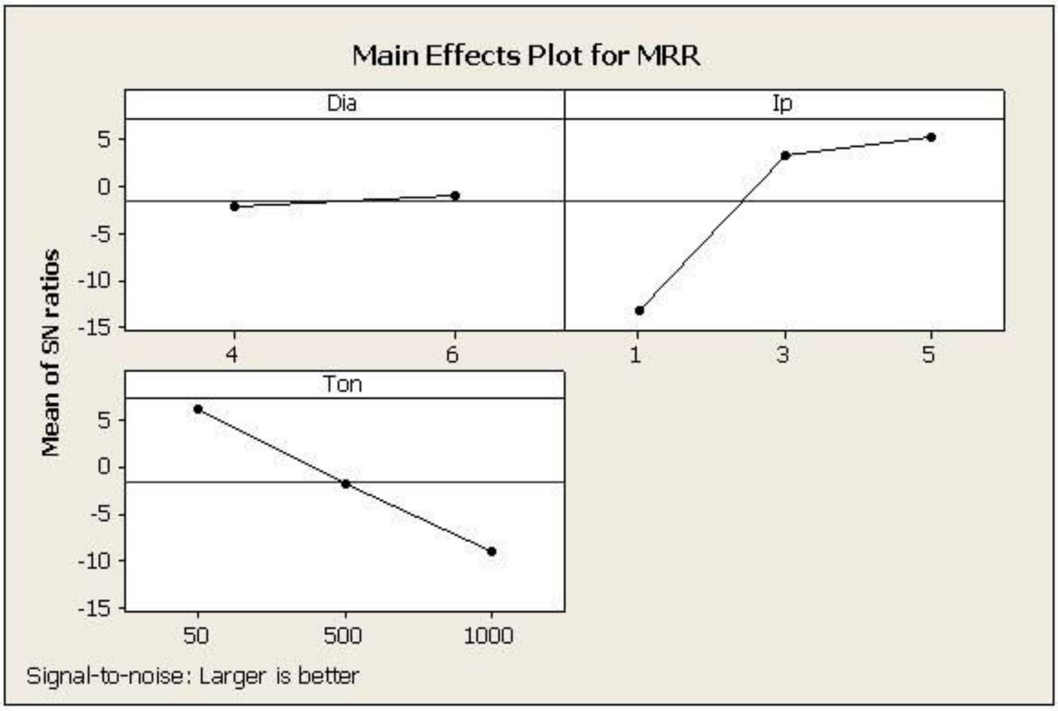


Figure 4.1 Main effect plot for S/N ratios (MRR)

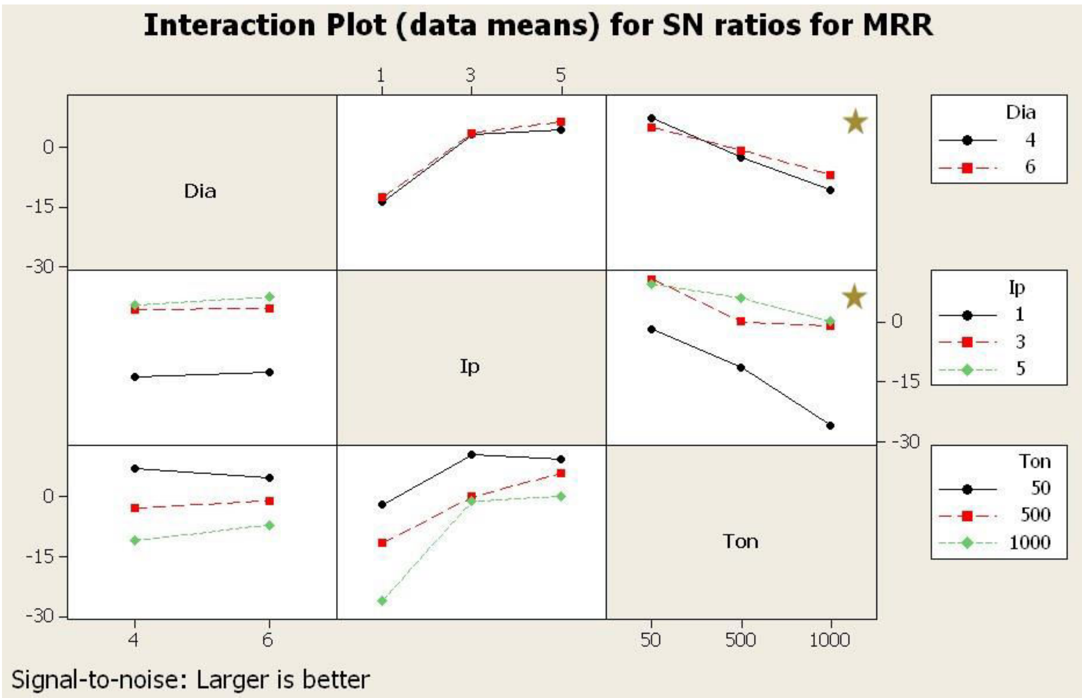


Figure 4.2 Interaction plot for MRR

4.2.1 Model Analysis of MRR

The coefficients of model for S/N ratios for MRR are shown in Table 4.4. The parameter R^2 describes the amount of variation observed in MRR is explained by the input factors. R^2 = 99.7 % indicate that the model is able to predict the response with high accuracy. Adjusted R^2 is a modified R^2 that has been adjusted for the number of terms in the model. If unnecessary terms are included in the model, R^2 can be artificially high, but adjusted R^2 (=98.6 %.) may get smaller. The standard deviation of errors in the modeling, S= 1.327. Comparing the p-value to a commonly used α-level = 0.05, it is found that if the p-value is less than or equal to α, it can be concluded that the effect is significant (shown in bold), otherwise it is not significant. Table 4.4 Estimated Model Coefficients for SN ratios

Term	Coef	SE Coef	T	P
Constant	-1.5712	0.3127	-5.025	**0.007**
Dia 4	-0.5747	0.3127	-1.838	0.140
Ip 1	-11.5976	0.4422	-26.227	**0.000**
Ip 3	4.8052	0.4422	10.866	**0.000**
Ton 50	7.6805	0.4422	17.369	**0.000**
Ton 500	-0.2796	0.4422	-0.632	0.562
Dia*Ip 4 1	0.0519	0.4422	0.117	0.912
Dia*Ip 4 3	0.3973	0.4422	0.898	0.420
Dia*Ton 4 50	1.7636	0.4422	3.988	**0.016**
Dia*Ton 4 500	-0.3827	0.4422	-0.865	0.436
Ip*Ton 1 50	3.5404	0.6254	5.661	**0.005**
Ip*Ton 1 500	1.8758	0.6254	3.000	**0.040**
Ip*Ton 3 50	-0.1346	0.6254	-0.215	0.840
Ip*Ton 3 500	-2.9316	0.6254	-4.688	**0.009**
S=1.327	R-Sq=99.7%		R-Sq(adj)=98.6%	

The residual plot of MRR is shown in Fig 4.3. This layout is useful to determine whether the model meets the assumptions of the analysis. The residual plots in the graph and the interpretation of each residual plot indicate below:

a. Normal probability plot indicates the data are normally distributed and the variables are influencing the response. Outliers don't exist in the data, because standardized residues are between -2 and 2.
b. Residuals versus fitted values indicate the variance is constant and a nonlinear relationship exists as well as no outliers exist in the data.
c. Histogram proves the data are not skewed and not outliers exist.

d. Residuals versus order of the data indicate that there are systematic effects in the data due to time or data collection order.

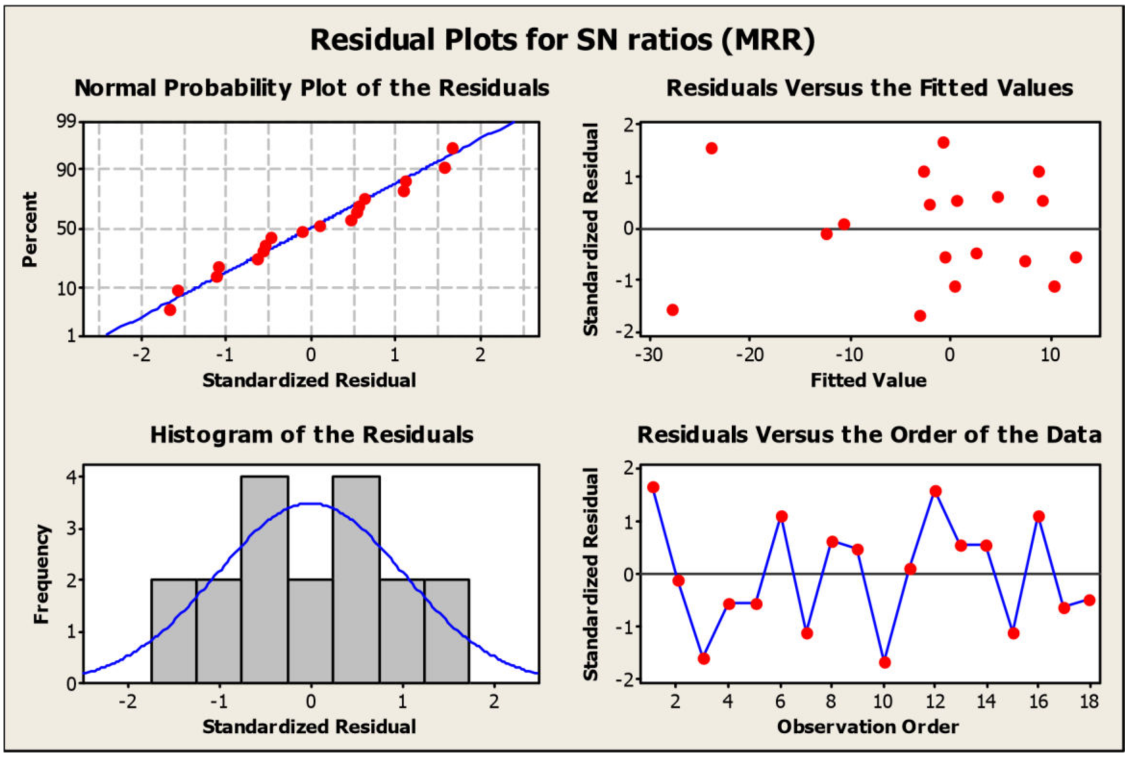


Figure 4.3 Residual plot for MRR

4.3 Influences on TWR

The S/N ratios for TWR are calculated as given in Equation 4.2. Taguchi method is used to analysis the result of response of machining parameter for smaller is better (SB) criteria.

SB:" 10log #_∑#'! $% & . . . . (4.2)

The analysis of variances for the factors are Dia, Ip , Ton, and IpxTon as shown in Table 4.5 is clearly indicate that the diameter of the tool is not important for influencing TWR and the value of Ip and Ton is most effected the TWR and as well as interaction Ip x Ton significant are shown in bold and otherwise not significant. The delta values are Dia. of tool, Ip and Ton are

2.81, 18.36 and 17.04 respectively, in Table 4.6. The case of TWR Smaller is better, so from this table it is clearly definite that Ip is the most important factor then Ton and last is dia.of the tool.

Table 4.5 Analysis of Variance for TWR

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Dia	1	35.46	35.46	35.465	17.02	**0.015**
Ip	2	1185.01	1185.01	592.506	284.31	**0.000**
Ton	2	871.24	871.24	435.618	209.03	**0.000**
Dia*Ip	2	12.42	12.42	6.209	2.98	0.161
Dia*Ton	2	71.66	71.66	35.828	17.19	**0.011**
Ip*Ton	4	243.68	243.68	60.921	29.23	**0.003**
Residual Error	4	8.34	8.34	2.084		
Total	17	2427.81				

Table 4.6 Response Table for Signal to Noise Ratios Smaller is better (TWR)

Level	Diameter	Ip	Ton
1	39.70	49.66	29.82
2	36.89	31.28	38.20
3		33.93	46.86
Delta	2.81	18.36	17.04
Rank	3	1	2

During the process of EDM, the influence of various machining parameter like Ip, Ton and Diameter of tool has significant effect on TWR , as shown in main effect plot for S/N ratio of TWR in Fig 4.4. Increasing in the discharge current from 1 to 3 A the tool wear rate is decreasing, but discharge Current in the range of 3 to 5 A the tool wear rate is increasing. Because of Ip increases the pulse energy increases and thus more heat energy is produced in the tool work piece interface, leads to increase the melting and evaporation of the electrode. One can interpret that Ip has a significant direct impact on TWR By Dhar and Purohit [1]. And pulse on time is directly proportional to the tool wear rate. And diameter of the tool has no significant effect on TWR. The interaction plot of TWR is shown in Fig 4.5, where each plot exhibits the interaction between three different machining parameters like Ip Ton and dia. of tool. This implies that the effect of one factor is dependent upon another factor. It is also confirmed by the ANOVA table (Table 4.5).

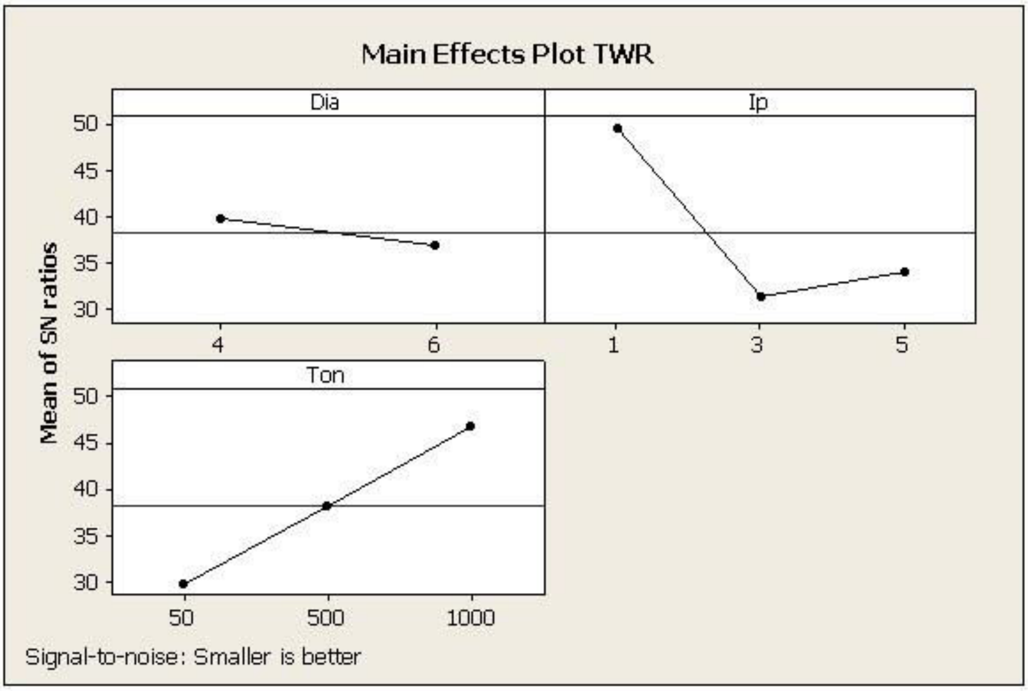


Figure 4.4 Main effect plot for SN ratios (TWR)

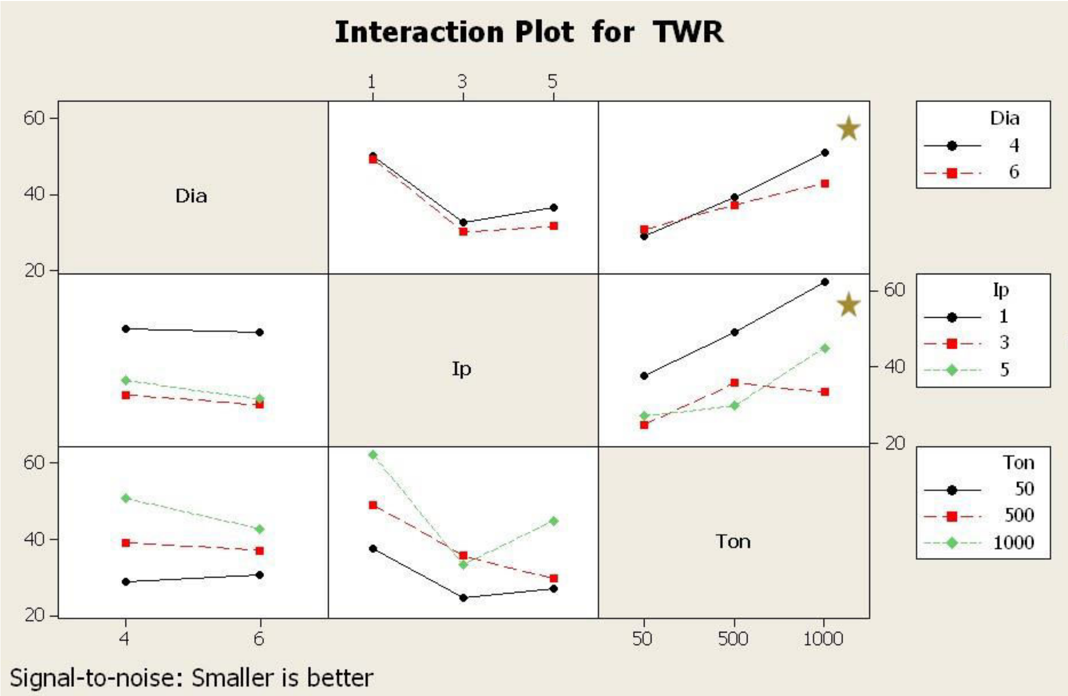


Figure 4.5 Interaction plot for TWR

4.3.1 Model Analysis of TWR

The coefficients of model for S/N ratios for TWR are shown in Table 4.7. The parameter R^2 (amount of variation)= 99.7% , Adj R2 = 98.5% , and standard deviation of error in the molding S= 1.444. And comparing the p value (less than 0.05) it can be concluded that the effect is significant (shown in bold), otherwise it is not significant.

Table 4.7 Estimated Model Coefficients for SN ratios (TWR)

Term	Coef	SE Coef	T	P
Constant	38.2922	0.3403	112.537	**0.000**
Dia 4	1.4037	0.3403	4.125	**0.015**
Ip1	11.3724	0.4812	23.633	**0.000**
Ip3	-7.0097	0.4812	-14.567	**0.000**
Ton 50	-8.4723	0.4812	-17.607	**0.000**
Ton 500	-0.0960	0.4812	-0.199	0.852
Dia*Ip 4 1	-0.9731	0.4812	-2.022	0.113
Dia*Ip 4 3	-0.0833	0.4812	-0.173	0.871
Dia*Ton 4 50	-2.2372	0.4812	-4.649	**0.010**
Dia*Ton 4 500	-0.3706	0.4812	-0.770	0.484

Ip*Ton 1 50	-3.6251	0.6805	-5.327	**0.006**
Ip*Ton 1 500	-0.3604	0.6805	-0.530	0.624
Ip*Ton 3 50	2.0048	0.6805	2.946	**0.042**
Ip*Ton 3 500	4.4999	0.6805	6.612	**0.003**
S = 1.444	R-Sq = 99.7%		R-Sq(adj) = 98.5%	

The residual plot of TWR is shown in Fig 4.6. This residual plot in the graph and the interpretation of each residual plot indicate below.

a) Normal probability plot indicate outlines don't exist in the data, because standardized residues are between -2 and 2.
b) Residuals versus fitted values indicate the variation is constant.
c) Histogram shows the data are not skewed and not outline exist.
d) Residual versus order of the data indicate that systematic effects in the data due to time of data collection order.

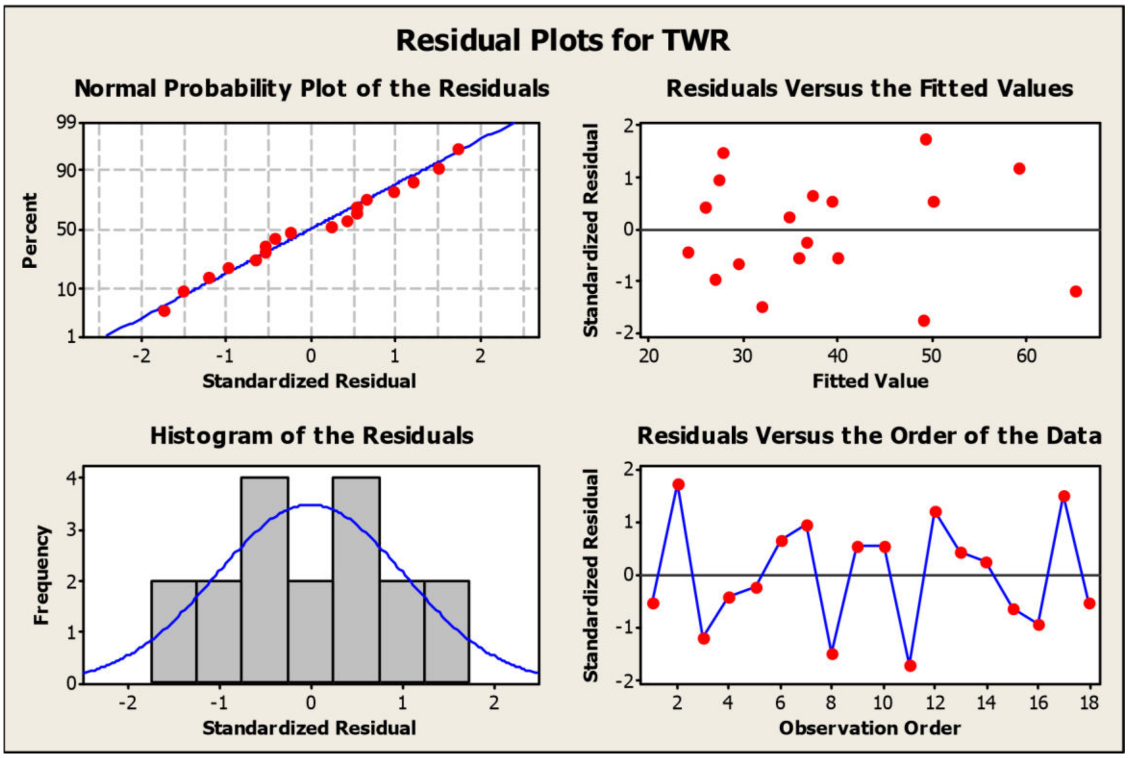


Figure 4.6 Residual Plots for TWR

4.4 Influences on over cut –

The S/N ratios for OC are calculated as given in Equation 4.2. Taguchi method is used to analysis the result of response of machining parameter for smaller is better (SB) criteria.

The analysis of variances for the factors are Dia, Ip , Ton, and IpxTon as shown in Table 4.8 is clearly indicate that the interaction factors Ton x Dia. and Ton x Ip is not significant for OC and the value of Ip is most influencing of OC and also Dia. of tool is significant (shown in bold). The delta values are Dia. of tool, Ip and Ton are 7.900, 9.449 and 2.777 respectively, in Table 4.6. The case of OC Smaller is better, so from this table it is clearly definite that Ip is the most important factor then dia.of the tool and last is Ton.

Table 4.8 Analysis of Variance for SN ratios (OC)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Dia	1	280.812	280.812	280.812	242.40	**0.000**
Ip	2	345.662	345.662	172.831	149.19	**0.000**
Ton	2	23.182	23.182	11.591	10.01	**0.028**
Dia*Ip	2	144.814	144.814	72.407	62.50	**0.001**
Dia*Ton	2	0.965	0.965	0.482	0.42	0.685
Ip*Ton	4	24.310	24.310	6.077	5.25	0.069
Residual Error	4	4.634	4.634	1.158		
Total	17	824.379				

Table 4.9 Response for S/N Rations smaller is better (Over cut)

Level	Diameter	Ip	Ton
1	2.175	12.319	4.774
2	10.074	3.184	6.049
3		2.871	7.551
Delta	7.900	9.449	2.777
Rank	2	1	3

The over cut between the dimension of the electrode and the size of the cavity it is inherent to the EDM process which is unavoidable though adequate compensation are provided at the tool design. To achieve the accuracy, minimization of over cut is essential. Therefore factors affecting of over cut is essential to recognize. The over cut are effect to each parameter such as diameter of tool, discharge current and pulse on time, the main effect plot for S/N ratios shown by Fig 4.7 for over cut . This graphs are represent the diameter of tool is directly proportional to the over cut. Increasing in the discharge current from 1 to 3 A the OC is decreasing, with increase in discharge current from 3A to 5A the OC increasing slightly. Whereas, OC increases monotonically with the increase in pulse on time. Because which is responsible for production of spark of tool and workpiece interface. it is given previous researchers Jeswani [35]. And The interaction plot of OC is shown in Fig 4.8, where each plot exhibits the interaction between three different machining parameters like Ip Ton and dia. of tool. This implies that the effect of one factor is dependent upon another factor. It is also confirmed by the ANOVA table (Table 4.8).

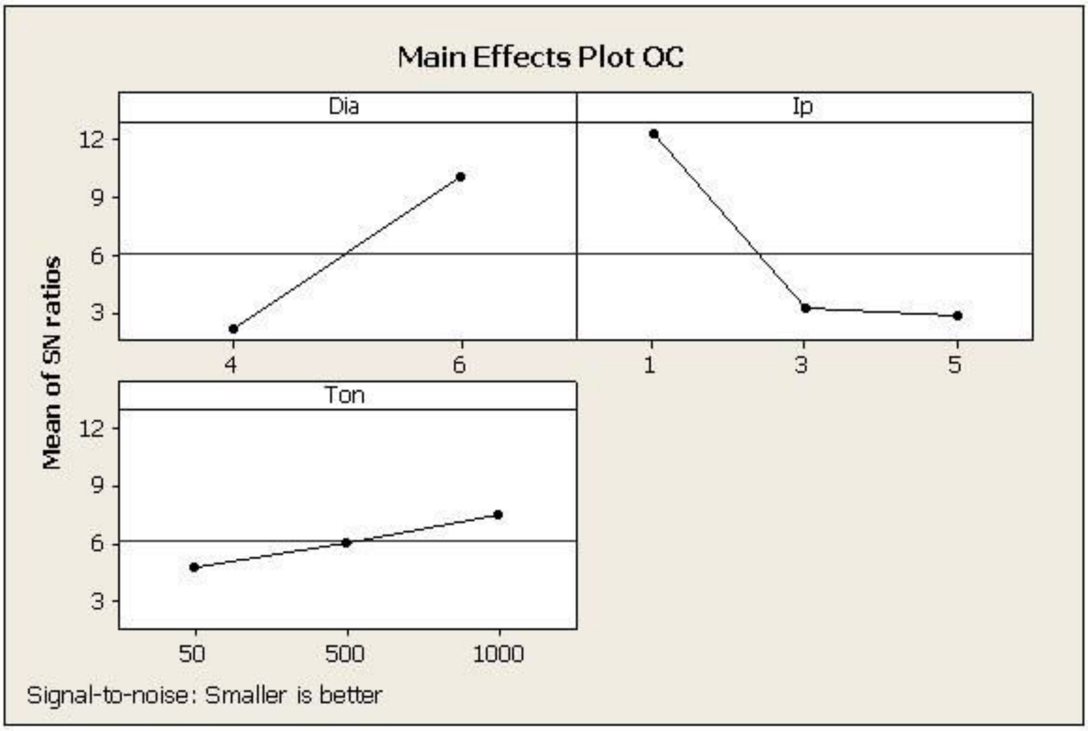


Figure 4.7 Main effect plots for over cut

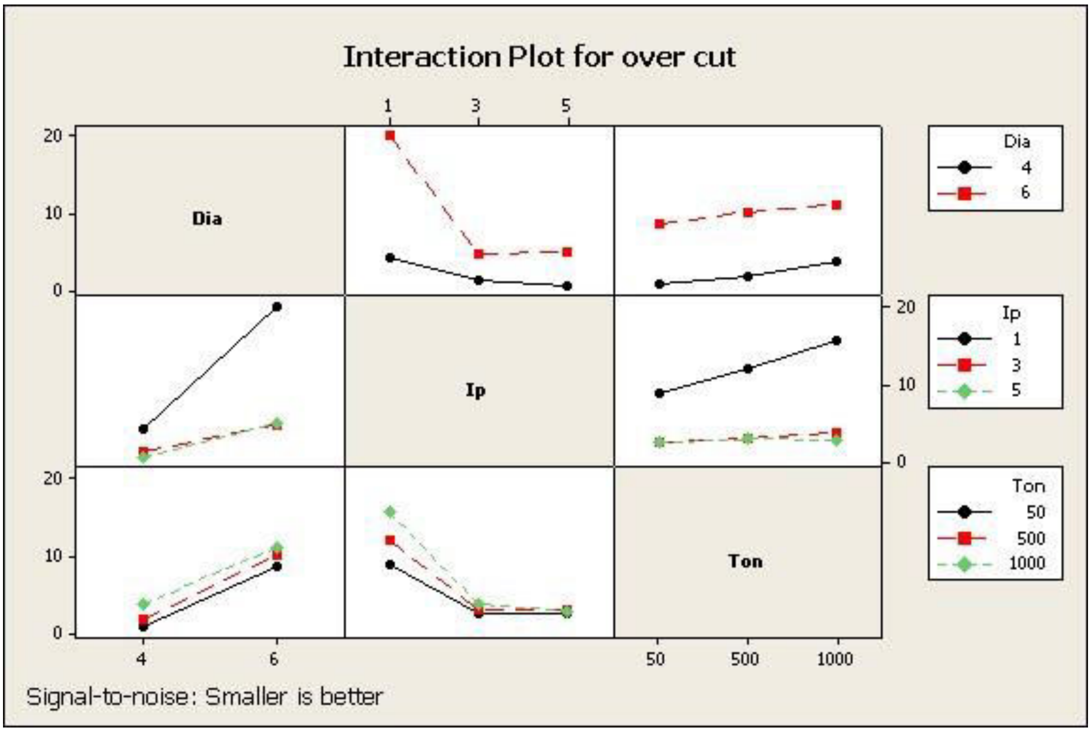


Figure 4.8 Interaction plot for over cut

4.4.1 Model Analysis of OC

The coefficients of model S/N ratios for over cut shown in table 4.10 and parameter result are standard deviation of error S=1.076, amount of variation R^2 = 99.4% and R2 (adj.) = 97.6%. And comparing the P value is less than or equal to 0.05 it can be concluded that the effect is significant (shown in bold), otherwise not significant.

Table 4.10 Estimated Model Coefficients for SN ratios (OC)

Term	Coef	SE Coef	T	P
Constant	6.12461	1.022	5.993	0.000
Dia 4	-3.94977	1.022	-3.865	0.005
Ip 1	6.19469	1.445	4.286	0.003
Ip 3	-2.94067	1.445	-2.035	0.076
Ton 50	-1.35038	1.445	-0.934	0.377
Ton 500	-0.07594	1.445	-0.053	0.959
Dia*Ip 4 1	-3.99804	0.3588	-11.144	0.000

Dia*Ip 4 3	2.28120	0.3588	6.358	0.003
Dia*Ton 4 50	-0.00677	0.3588	-0.019	0.986
Ip xTon 1 50	-1.89252	2.044	-0.926	0.382
Ip x Ton 1 500	-0.19081	2.044	-0.093	0.928
Ip x Ton 3 50	0.80375	2.044	-0.393	0.704
Ip xTon 3 500	-0.03116	2.044	-0.015	0.988
S = 1.076	R-Sq = 99.4%		R-Sq = 97.6%	

The residual plot for over cut is shown in fig 4.9. This residual plot in the graph for normal probability plot indicates the data are normally distributed and variables are influencing the response. And the Residuals versus fitted value indicate the variation is constant. And the Histogram proved the data are not skewed and not outline exist. And Residual versus order of the data indicates that there are systematic effects in the data due to time or data collection order.

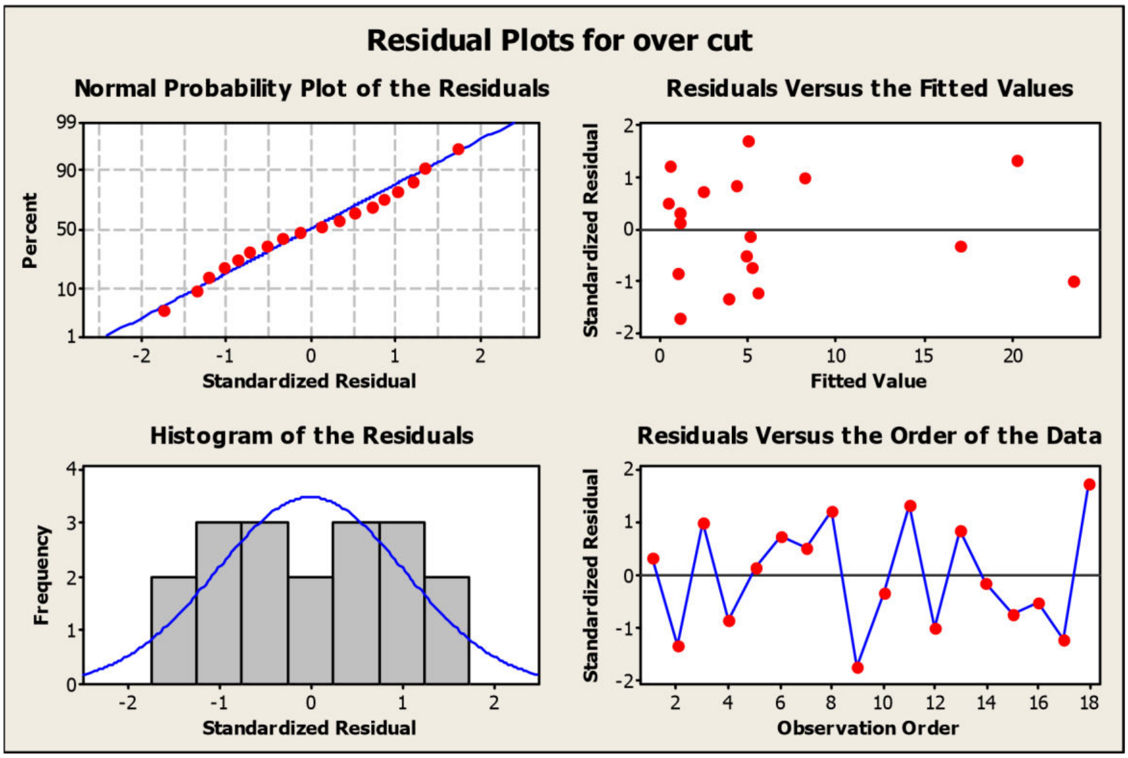


Figure 4.9 Residual Plots for over cut

4.5 Conclusion

Experiments were conducted according to Taguchi method by using the machining set up and the designed U-shaped tubular electrodes with internal flushing. Finding the result of MRR discharge current is most influencing factor and then pulse duration time and the last is diameter of the tool. In the case of Tool wear rate the most important factor is discharge current then pulse on time and after that diameter of tool. In the case of over cut the most important factor of discharge current then diameter of the tool and no effect on pulse on time

Chapter 5
Conclusion

In the present study on the effect of machining responses are MRR, TWR and OC of the AISI P20 plastic mould steel component using the U-Shaped cu tool with internal flushing system tool have been investigated for EDM process. The experiments were conducted under various parameters setting of Discharge Current (Ip), Pulse On-Time (Ton), and diameter of the tool. L-18 OA based on Taguchi design was performed for Minitab software was used for analysis the result and theses responses were partially validated experimentally.

(1). Finding the result of MRR discharge current is most influencing factor and then pulse duration time and the last is diameter of the tool. MRR increased with the discharge current (Ip). As the pulse duration extended, the MRR decreases monotonically

(2). In the case of Tool wear rate the most important factor is discharge current then pulse on time and after that diameter of tool.

(3) In the case of over cut the most important factor of discharge current then diameter of the tool and no effect on pulse on time .

Chapter 6
Appendix

Introduction –

In this chapter we are discuss about experimental used machine and equipment and which propose are used.

Machine and Equipment

This Electrical discharge machine (EDM) was used to machine on for conducting the Experiments. This machine model ELECTRONICA- ELECTRAPULS PS 50ZNC (die-sinking type) with servo-head (constant gap).

Figure 5.1 Die Sinker EDM Model: PS 50ZNC

Weighing machine

Precision balance was used to measure the weight of the workpiece and tool. This machine capacity is 300 gram and accuracy is 0.001 gram and Brand: SHINKO DENSHI Co. LTD, JAPAN, Model: DJ 300S.

Figure 5.2 Electronic Balance weight machine

Tool maker microscope

This machine was used to measure the overcut which was occurs during EDM. This Tool maker microscope Make : Carl Zeiss, Germany and Accuracy : 0.001 mm.

Figure 5.3 Tool maker microscope

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