Thesis Report
On
MATHEMATICAL MODELLING OF MATERIAL REMOVAL RATE AND HARDNESS IN ELECTRIC DISCHARGE MACHINE BY DOE APPROACH

Submitted in the partial fulfillment of requirement for the award of the degree of

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IN

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CERTIFICATE

I hereby certify that the work which is being presented in this thesis entitled"**MODELLING OF MATERIAL REMOVAL RATE AND HARDNESS IN ELECTRIC DISCHARGE MACHINING BY DOE APPROACH"**, in partial fulfillment of the requirements for the award of **Master Of Engineering In Production And Industrial Engineering** submitted to Mechanical Engineering department of **Thapar University, Patiala,** is an authentic record of my own work carried with the supervision of *V.K.Singla*, Senior lecturer, MED, Thapar University, Patiala

The matter presented in this thesis has not been submitted for the award of any other degree of this or any other university.

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ABSTRACT

In last forty years there is tremendous research in machining and development in technology. With increase in comptetion in market and to attain high accuracy now a days the non-conventional machining are become lifeline of any industry. One of the most important non conventional machining methods is Electric discharge machining. Although productivity by EDM is low but its high accuracy, finishing, ability of machining any hard materials and to produce intricate shape increases its demand in market.

In thesis work literature has been studied in context to modeling of EDM. The equation of MRR and hardness has develop. In order to attain target and optimum results, taguchi method employed. The appropriate orthogonal array has been selected as per number and there levels to performs minimum experimentation

The approach of optimum and modeling of MRR and hardness for batch production has been applied because now days, many industry are following batch production. The three materials which are easily available in the market as one of the parameter En24, EN19, EN353 has been taken for experimentation work. The optimum value has been determined with the help of main effect plot and anova table to find out optimum value. But our anova table is not supporting any parameter but it is proved that how machining of batch production can be improve. Kerosene has been taken as dielectric fluid .With help of MINITAB software mathematical modeling has been foun out that is acceptable to experimental data also with help of fuzzy logic. The optimum value has been determined which is suitable for both MRR and hardness

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CHAPTER-1

INTRODUCTION

There has been a rapid growth in the development of harder and difficult to machine metals and alloys during the last two decades. Conventional edged tool machining is uneconomical for such materials and the degree of accuracy and surface finish attainable is poor .The advancing strength level would have a catastrophic effect on the total machining bill of there was no corresponding improvement in machining technology . In view of seriousness of this problem, Merchant (1960) emphasized the need for the development of newer concepts in metal machining. By applying a adopting a unified programmed and utilizing the result of basic and applied result it has now possible to process some of materials which were formerly considered to be unmachinable under normal conditions. The newer machining that developed is often called ‘modern machining processes or ‘non-traditional machining process’. The word unconventional is used in sense that the metal like tungsten, hardened stainless steel tantalum, some high strength steel alloys etc. are such that they can’t be machined by conventional method but require some special technique . The conventional methods in spite of recent advancements are inadequate to machine such materials from stand point of economic production.

The unconventional methods of machining have several specific advantages over conventional methods of machining. And these promise formidable tasks to be undertaken and set a new record in the manufacturing technology. These methods are not limited by hardness, toughness, and brittleness of the material and can produce any intricate shape on any work piece material by a suitable control over various physical parameter of the process.

In unconventional machining methods, there is no direct contact between the tool and work piece; hence the tool need not to be harder than work piece. Further, in spite of the recent technical advancement, the conventional machining processes are inadequate to produce complex geometries shapes in hard and temperature resistant alloy and die steels. Keeping these requirements into mind, a number of non conventional methods have been developed. Below give classification of machining process based on type of energy used, the mechanism of metal removal, the source of energy requirement.

- **Mechanical Energy (Mechanical Processes) :** In mechanical processes metal removal takes place either by a mechanism of simple shear or by erosion mechanism where high velocity particles are used as transfer or by erosion mechanism where high velocity particles are used as transfer media and pneumatic /hydraulic pressure acts as source of energy . it includes ultrasonic machining , water jet machining and abrasive jet machining etc .
- **Thermal Energy (Thermal Process):** Thermal processes involve the application of the application of very thin intense local heat. Here melting or vaporization from the small areas at he surface of the work piece removes material. The source of energy used is amplified light, ionized material and high voltage. Examples are laser beam machining , ion beam machining, plasma arc machining and electric discharge machining .
- **Electrical Energy (Electro chemical Processes):** Electrochemical processes involve removal of metal by mechanism of ion displacement. High current is required as the source of energy, and electrolyte acts as transfer media. It includes electro-chemical machining, electro chemical grinding etc.
- **Chemical Energy (Chemical processes):** Chemical processes involve the application of resistant material (acidic or alkaline in nature) to certain portion of the work piece . The desired amount of material is removed from the remaining area of the work piece by subsequent application of an etching that converts the work piece material into a dissolve metallic salt. It includes chemical machining and photochemical machining .

CHAPTER-2

ELECTRICAL DISCHARGE MACHINING

In 1970 the English scientist, Priestly, first detected the erosive effect of electrical discharge on metals. More recently, during research the soviet scientists, Lazarenko and lazarenko, decided to exploit the destructive effect of an electrical discharge and develop a controlled method of metal machining. In 1943 they announced the construction of the first spark erosion machine. The spark generator used in 1943 , known as lazarenko circuit , has been employed over many years in power supplies for EDM machines and an improved form is being used in many current applications.

The EDM process can be compared with the conventional cutting process, except that in this case , a suitable shaped tool electrode , with a precision controlled feed movement is employed in place of cutting tool , and the cutting energy is provided by means of short duration electrical pulses EDM has found ready application in the machining of hard metals or alloys which cannot be machined easily by conventional methods . It thus plays a major role in the machining of dies , tools , etc , made of tungsten carbide , setllites or hard steels . Alloys used in aeronautics industry, for example, hastalloy, nimoic, etc, could also be machined conveniently by this process. This process has added advantage of being capable of machining complicated component

The popularity of EDM process is due to the following advantages:

1. The process can be readily applied to electrical conductive materials. Physical and metallurgical properties of the work material , such as strength , toughness , microstructure , etc are no barrier to its application
2. During machining, the work piece is not subjected to mechanical deformation as there is physical contact between the tool and work. This makes process more versatile. As a result, slender and fragile jobs can be machined conventially.
3. Although the metal removal in this case is due to thermal effects, there is no heating in the bulk of the material.

4. Complicated die contours in hard materials can be produced to a high degree of accuracy and surface finish
5. Overall production rate compares well with the conventional process because it can dispense with operations like grinding
6. The surface produce by EDM consists of multitude of small crates. This may help in oil retention and better lubrication , specially for components where lubrication is a problem The random distribution of the craters does not result in an appreciable reduction in fatigue strength of the components machined by EDM
7. The process can be automated easily requiring very little attention from the operator

2.1 Description of EDM Controls

The various types of EDM (model no. T-3822M) as given in figure are listed below:

1. Rotary Switch (Mains)
2. Indicator Lamps (Three phase)
3. Rotary Switch (Pump)
4. Rotary Switch (Finish)
5. Rotary Switch (Current Range)
6. Rotary Knob (Current Adjust)
7. Ammeter (Gap current)
8. Rotary Switch (Duration)
9. Rotary switch (Base)
10. Indicator (Gap)
11. Rotary Potentiometer (Gap Control)
12. Toggle Switch (Soft Pulse)
13. Indicator Lamp (Spark)
14. Push Button (Spark)
15. Toggle switch (Auto flushing)
16. Rotary Potentiometer (Sparking Time)

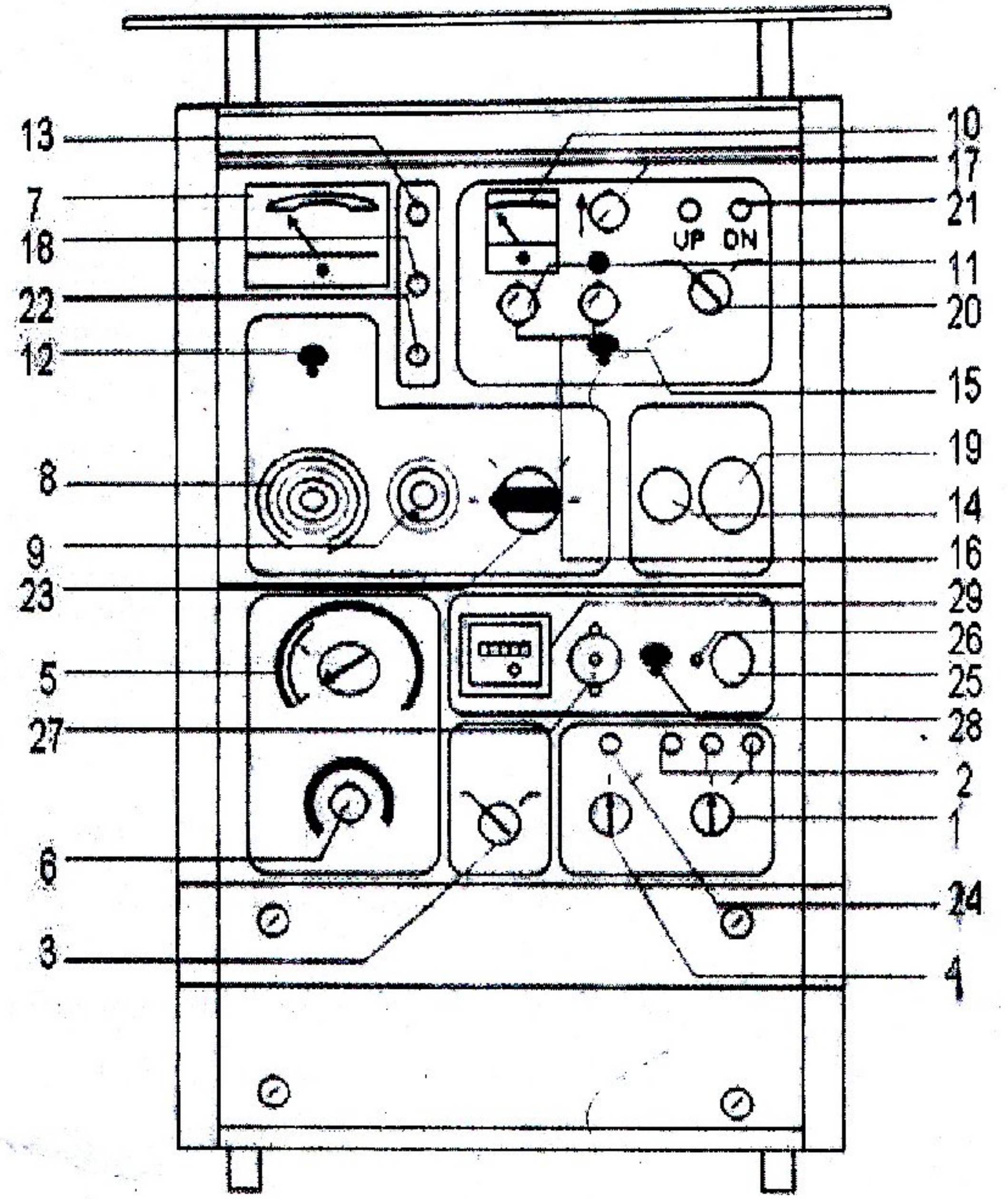


Figure 2.1 Indicating the controls of EDM (Model No. T-3822M)

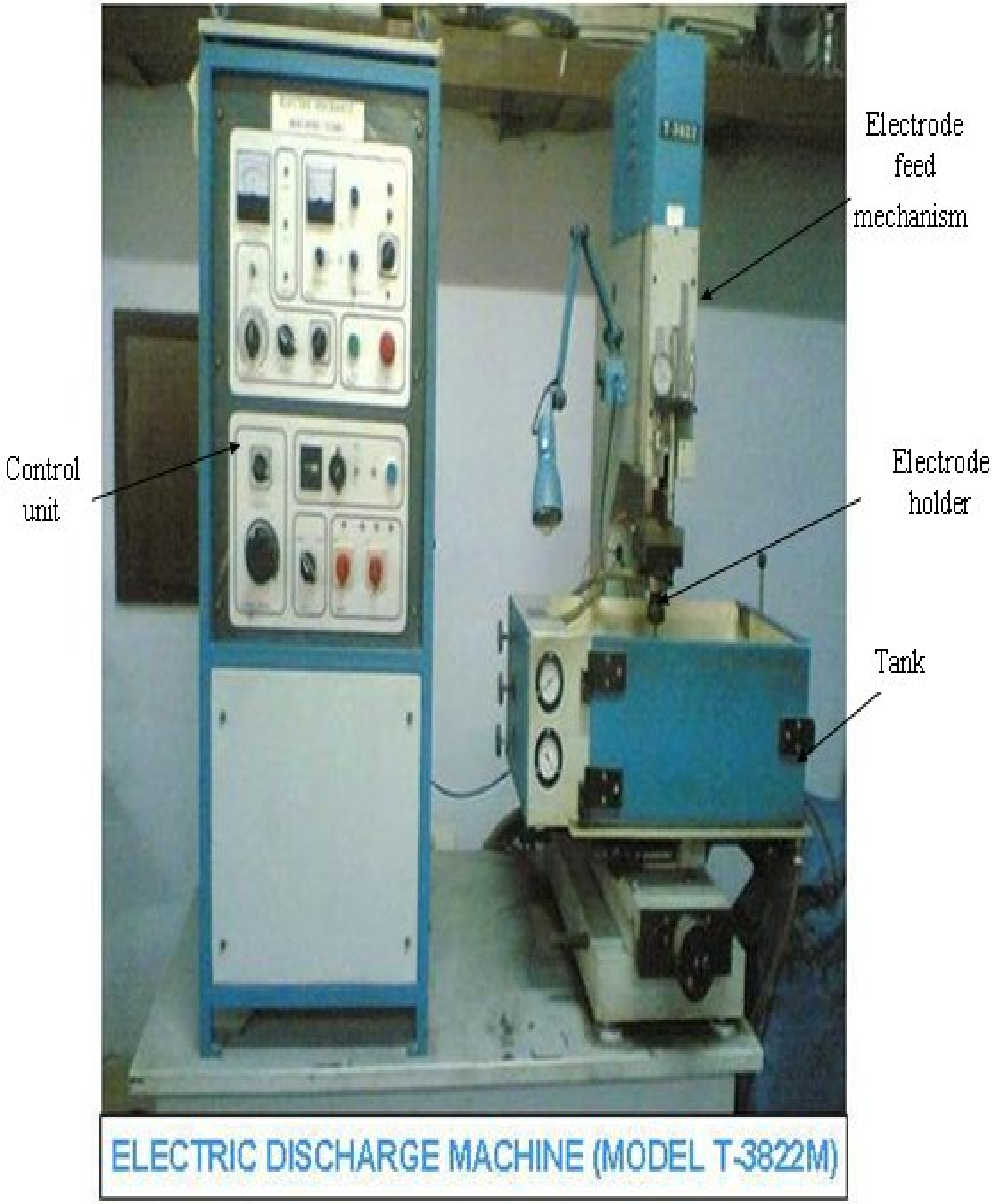


Figure 2.2 setup of electric discharge machining

16.Rotary Potentiometer (Lifting Time)
17. Indicator Lamp (OV/SP)
18. Push Button (Off)
19. Rotary Switch(AUT/MAN)
20. Push Button (UP/DN)
21. Indicator Lamp (Interlock)
22. Rotary Switch (Ignition)
23. Indicator Lamp (Pump ON).
24. Push Button (AUTOPOS)
25. Indicator Lamp (Pump On)
26. Piezo Ceramic Alarm (Buzzer)
27. Toggle Switch (Buzzer Select)
28. Decade counter (Hour Counter)

- **Rotary Switch (mains)**

This is main ON for total power supply (generator). IN position ‘1’, the supply is on and in the position ‘0’ the supply is off.

- **Indicator Lamps (Three Phase)**

There is three LED’s (light emitting diodes) indicating presence of three phase of main supply.

- **Rotary Switch (Finish)**

This has two positioning viz. NORMAL and MIRROR. The positioning MIRROR is selected only while polishing the job, while for all other setting, electrode and work piece material combinations the NORMAL position is to be selected.

- **Rotary Switch (Pump)**

This switch has two positions 0 and 1 and in position 1 the dielectric pump is started and in position ‘0’ pump is off

- **Rotary Switch (Current Range)**

This switch has three positions. The positions '1' through '3' increase machining current in steps of 4 amperes.

- **Rotary Knob (Current Adjust)**

This knob continuously adjusts machining current in the span of about four amperes. In Range '1', the current varies from 0.2 to 4 amperes approximately. Current is minimum when the knob is in fully counter clockwise (CCW) position and goes on increasing as the knob is turned in clockwise (CW) direction

- **Ammeter (Gap Current)**

This is a moving coil type ammeter indicating average machining current during the machining processes. This range provided is from 0 to 15 amps. Green band is up to 12 amps and the remaining is red band.

- **Rotary Switch (Base)**

This switch has 8 positions which are explained as given below:

Positions 8,7 - Roughing

Positions 7,6,5,4 - Semi-finishing

Position 5,4,3,2 - Finishing

Position - Super-finishing

To achieve good machining stability, the range of machining current are recommended for different positions of rotary switch, as given in table:

Base position	Machining Current Range
8	06 A to 12A
7	04 A to 12 A
6	03 A to 10 A
5	01 A to 08 A

4	0.5 A to 06 A
3	0.5 A to 04 A
2	0.1 A to 02 A
1	0.1 A to 01 A
	0.2

Table 2.1 : **Ranges of machining current with respect to switch ‘8’ (Base)**

- **Rotary Switch (Duration)**

This switch has 12 positions. The pulse duration can change from minimum (position 1) to maximum (position 12) in ‘12’ positions by switch ‘9’ (Duration) for each position of switch ‘8’ (Base). Thus one can obtain a full range of pulse duration from a minimum of 2 us to a maximum of 520 us which largely covers the duration reduces the machining rate with drastic reduction in the relative electrode tool wear. Too long pulse duration (duration position ‘10’ to ‘12’) with copper electrode and steel work piece results in excessive accumulation of carbon in the machining zone with a subsequent instability of the machining processes.

- **Indicator (Gap)**

Under healthy machining condition, the deflection is 1 to 1.5 divisions of its scale

- **Rotary potentiometer (Gap Control)**

This control adjusts the servo to change deflection of indicator ‘10’ (GAP). In CCW direction, the deflection goes on decreasing and vice versa

- **Toggle Switch (Soft Pulse)**

The function of this switch, when in position ‘1’ , is to smooth the discharge pulses which are very strong when the machining current is more than 2-3 amps . The purpose of this switch is to reduce arching tendency and ensure stable machining processes under these conditions.

Normally, soft pulse should be switched on (position 1) whenever the average machining current is greater than 2-3 amps .However , finishing ranges where the machining current is less than 2-3 amps ; putting off this switch improves the surface finish and also reduce the electrode – tool wear .

- **Indicator Lamp (Spark)**

This LED is ON when machining starts. It is turned OFF momentarily during lifting period of auto flush cycle or when the machining gap is short.

- **Push Button (Spark)**

Pressing of this push button (with indicator ‘18’ and ‘22’ OFF) starts the machining processes.

- **Toggle Switch (Auto flushing)**

This switch selects auto flushing (lifting during machine) in position ‘1’. In position ‘0’ auto flushing stops.

- **Rotary Potentiometer (Sparking Time)**

This controls adjusts lofting time Toggle Switch ‘15’ (Auto flushing) slecting .In CW direction, the sparking time goes on increasing .

- **Rotary Potentiometer (Lifting Time)**

This control adjusts lifting time with Toggle Switch ‘15’ (Auto flushing) selected. In CW direction, times goes on increasing

- **Indicator Lamp (OV/SP)**

This LED is ON under single phasing or over voltage condition of main input i.e. when the voltage of one or more of the 3 phase main input is above or below the safe working unit.

- **Push Button Red (OFF)**

The machining (sparking) or auto position function can be stopped by pressing this push button .

- **Rotary Switch (AUT/MAN)**

This switch selects one of the two modes of operation .Automatic and manual. In position 'AUT' either sparking or auto positioning can be started. In position 'MAN', the manual up and movement of quill is possible.

- **Push Button (UP/DN)**

This switch has center off position. This switch is 'MAN' position of switch (20). With UP and DN position of the switch, upward and downward movement of quill is possible.

- **Indicator Lamp (interlock)**

The LED is ON when level of dielectrics low in the working tank and causes interruption in the machining operation

- **Rotary Switch (Ignition)**

This is a 4 position switch .It controls the energy of ignition of discharge channel. This energy is maximum in position 1 of this switch and it decreases progressively as the switch is rotated from position 1 to 4. Excessive ignition of the discharge channel provokes arching tendency and instability of machining process. Hence, whenever the arching tendency is more or the panel meter GAP(in spite of adjusting the GAP control) is overshooting frequency , a higher position of switch ignition should be selected .

Current Range (Amps.)	**Duration Range**			
	1-3	4-5	6-8	9-12
6 A	2	3	4	4
2-6 A	2	3	¾	4
2 A	½	2/3	¾	4

Table 2.2: Indicating ignition positions for different durations and current ranges.

- **Indicator Lamp (Pump ON)**

This is ON when switch 4 above is in position 1 when dielectric pump is ON.

- **Push Button (AUTOPOS)**

This is useful in position of the job. For actuation of this control, switch 20 has to be in position AUTO. On pressing this push button 20, the quill starts down slowly. As the dielectric comes in the vicinity of the work piece, it maintains a constant gap at low voltage between the electrode and the work piece with weak sparking. The AUTOPOS can be stopped by pressing push button 19 or by operation of preset depth switch on machine head.

2.2 Spark Erosion machining process

Electrical discharge machining is the removal of the materials conducting electricity by electrical discharge between two electrodes, a dielectric fluid being used in the process. The aim of the process is controlled removal of material from the work piece.

2.2.1Sinking by EDM

In this case , the metal removal is affected by non stationary electrical discharges which are separated from each other which are separated from each other both spatially and temporarily . This process includes those EDM operations in which the average relative speed between the tool and work piece is coincident with the penetration speed in the work piece (fig 2.3)

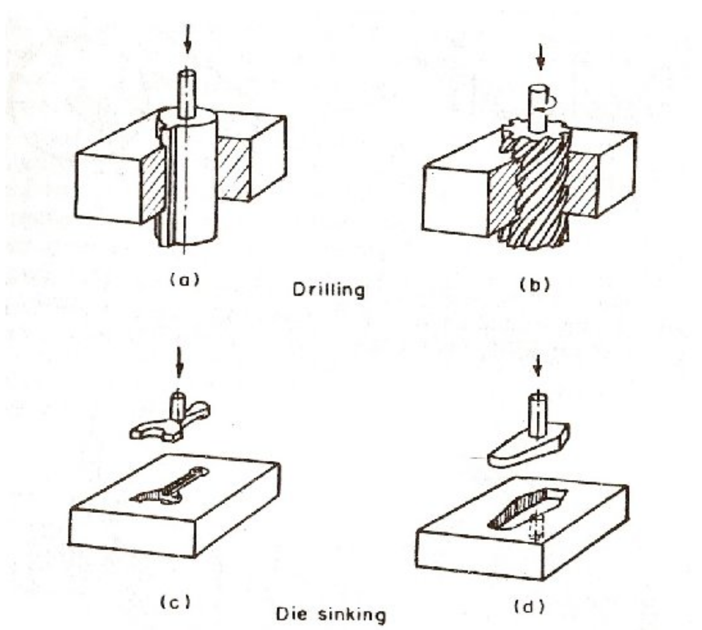


Figure 2.3 process of sinking by EDM

2.2.2 Cutting by EDM

It includes those machining operations where the work piece is cut off or notched. Fig 2.4 to 2.7 determines various EDM cutting operations.

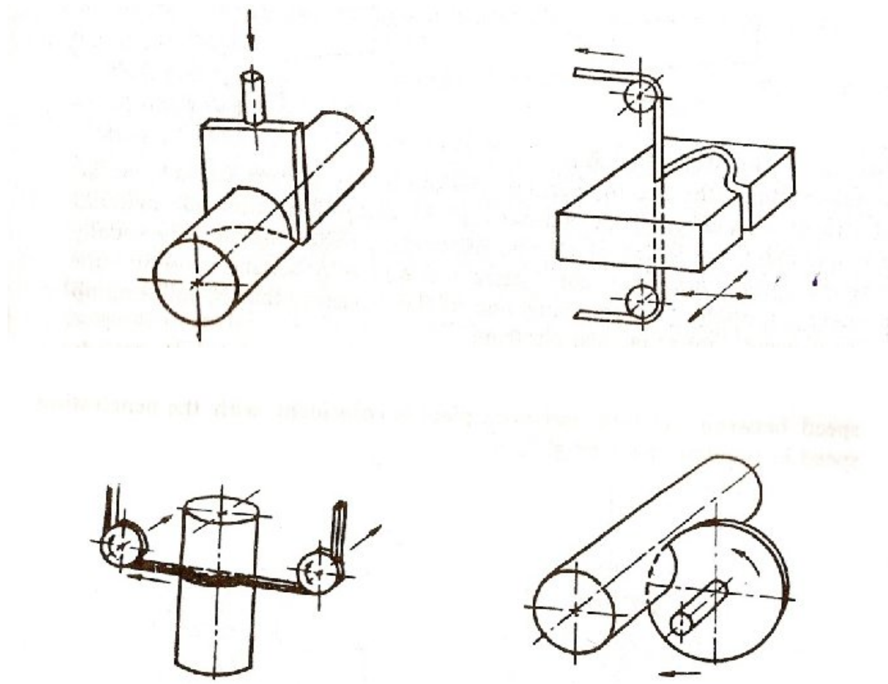


Figure 2.3 cutting by EDM

2.2.3 Grinding by EDM

Spark erosion grinding embraces the machining process made with an electrode rotating around an axis in addition to the normal electrode feed. The foems and arrangements for this process are shown in figure 2.8 to 2.11

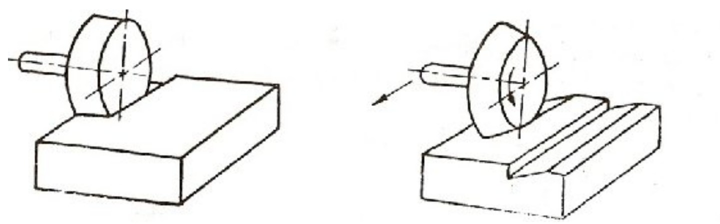


Figure 2.4 grinding by EDM

2.3 WORKING PRINCIPLE OF EDM PROCESS

Fundamentally, the electro sparking method of metal working involves an electric erosion effect which connotes the breakdown of electrode material accompanying any form of electric discharge. A necessary condition for producing a discharge in ionization of the dielectric, that is , splitting up of its molecules into ions and electrons.

Consider the case of a discharge between two electrodes through a gaseous or liquid medium . As soon as suitable voltage is applied across the electrodes, the potential intensity of the electric field between them builds up, until at some predetermined value , the individual electrons break loose from the surface of the cathode and are impelled towards the anode under influence of field forces . While moving in the inter electrode space, the electrons collide with the neutrals molecules of the dielectric, detaching electrons from them and causing ionization. At some time or other, the ionization becomes such that a narrow channel of continuous conductivity is formed. When this happen, there is a considerable flow of electrons along the channel to the anode, resulting in a momentary current impulse or discharge. The liberation of energy accompanying the discharge leads to the generation of extremely high temperature between 8000 degree Celsius and 1200 degree Celsius, causing fusion or partial vaporization of the metal and the dielectric fluid at the point of discharge. The metal in the form of liquid drops is dispersed into the space surrounding the electrodes by explosive pressure of the gaseous products in the discharge .This result in the formation of a tiny crater at the point of discharge in the work piece.

Comparatively less metal is eroded from the cathode as compared to the anode work due to the following reasons:

1. The momentum with which positive ions strike the cathode surface is much less than the momentum with the electron stream impinges on the anode surface

2. A compressive force is generated on the cathode surface by the spark which helps reduce tool wear.

Most of the EDM operations are conducted with electrodes immersed in the liquid dielectric. For example paraffin and the mechanism of sparking is similar to that described above except that the dielectrive is contaminated with the conductive particles. Furthermore, the particles removed from the electrodes due to the discharge fall in liquid, cool down and contaminate the area around the electrodes by forming colloidal suspensions of metal. These suspensions along with the products of decomposition of the liquid dielectric are drown to the space between the electrodes during the initial part of the discharge process and are distributed along the electric lines of force, thus forming current carrying bridges. Discharge then occurs along one of these bridges as a result of ionization.

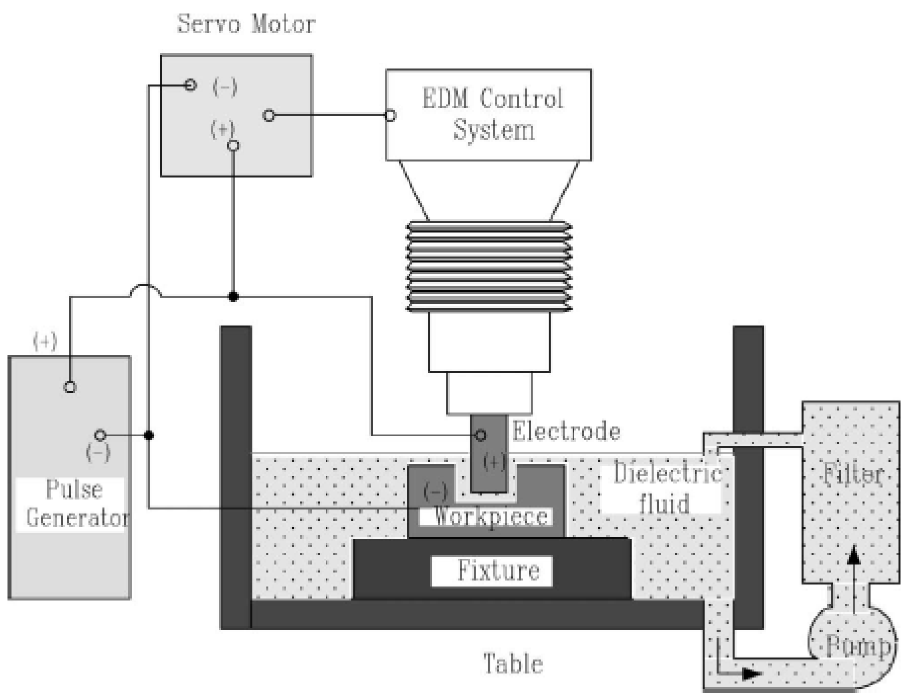


Figure 2.5 Typical set up for EDM.

2.4 SPARK EROSION GENERATORS

In EDM process, electrical energy in the form of short duration impulses are required to be supplied to the machining gap. For more this purpose, especially designed generators are employed . The generators for spark erosion are distinguished according to the way the voltage is transmitted and pulse is controlled, and also on characteristic of discharge.

On basis of these facts, generators for EDM can be classified into:

1. Relaxation generators
2. Rotary generators
3. Static pulse generator

2.4.1Relaxation generator

The relaxation generator or the r-c circuit was the first to be used in EDM. The circuit comprises of a d.c power source that charges a capacitor C across a resistance R. If condenser is initially uncharged and the d.c supply is switched on, a heavy current will flow into the circuit with the condenser voltage rising continuously as shown in figure 2.13. The condenser voltage at instant time *t* can describe by the relationship:

$$U_{i(t)} = U_s\left(1 - e^{\frac{-t}{RC}}\right) \ldots\ldots\ldots.(1)$$

Equation (1) predicts that the condenser voltage will approach the supply voltage with time constant equal to RC and after t= RC the condenser voltage will be 63% of the supply voltage. A discharge across the working gap will occur if U1/2(t) equals the breakdown voltage Ub of the dielectric within gap After the dielectric deionizes, the capacitor is recharged and cycle repeats itself

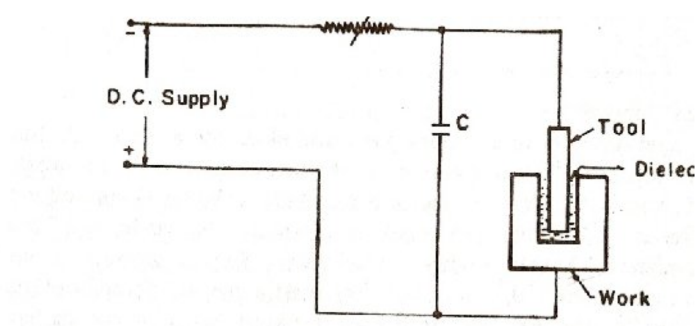


Figure 2.6 relaxation circuit

In practice, the spark gap is adjusted so that the discharge takes place corresponding to a gap voltage of about 0.72Us. Although a higher gap voltage would liberate much more energy, the time required to recharge the condenser increases. it has been found in an R-C circuit , that for a given condenser and breakdown voltage , there exists a certain value of r that will ensure correct length of the charging cycle.

In relaxation generator , the spark repetition rate , for a given supply voltage and capacitance , cannot be increased beyond a critical value and is determined by the speed at which the spark gap is deionized and clear of the debris after each discharge . Forced circulation of the dielectric through the gap is necessary if high metal removal rate is required. As the working gap is 0.025-0.050 mm , forced circulation is difficult , especially when large electrodes are involved . In such a case a lower erosion rate must be accepted than is possible with small size electrode .heir comparative cheapness, simplicity of design,

The fundamental advantage of this circuit are there comparative cheapness, simplicity of design, robustness and relatively extensive range of discharge . In spite of many modifications of relaxation circuits they are liable to result in high tool wear and slow metal removal rates compare with other rate type of generator

2.5 Electrode Feed Control

Since during operation both the work piece and tool get eroded, the feed control must maintain a movement of electrode towards the work piece at such a speed that the working gap and hence the sparking voltage remain unaltered. Actuation of the control drive is derived from an error indication signal obtained from an electrical sensing device responsive to either the gap voltage or working current or both. Servo mechanism affecting the movement of the electrode may be electric driven motor, solenoid operated or hydraulically operated or combination of these. Control mechanism is shown in figure 2.14. The axial movement of spindle is controlled through reduction gear box driven by a d.c shunt motor, which is reversible so that electrode can be withdrawn.

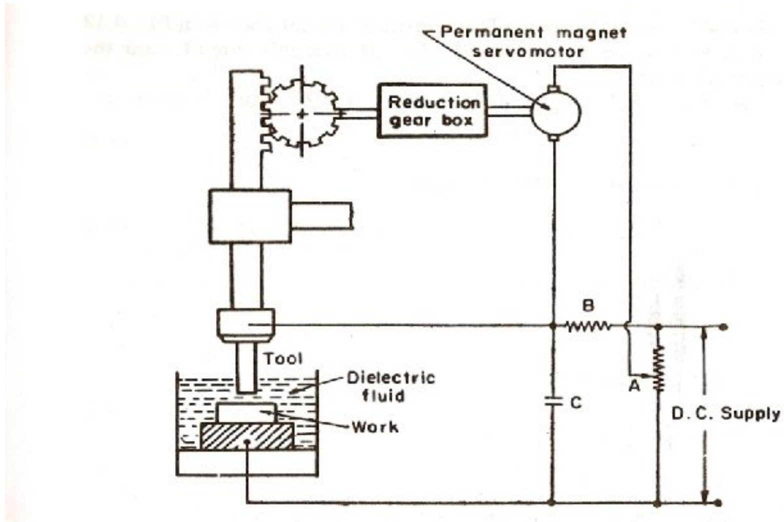


Figure 2.78 Electric feed control

The motor armature is connected across a bridge network , the arms of which consist of a potential divider A connected across the d.c supply , while other arm consist of ballast resistance B and condenser C of the charging circuit , the latter arms also being connected across the supply . The control gear work as follows

Assume the electrode to be initially widely spaced from the work piece and the current supply switched on to the condenser. This will cause the condenser to be charged and voltage will rise to approach the supply voltage. The supply voltage will therefore will prevail across one lower arm of bridging and .the voltage across the other arm will depend on the potentiometer setting, and if this setting is midway, then voltage across the bridge will be half the supply voltage .This voltage will tends to rotate the motor causing the electrode to close the gap. When the electrode reaches the correct position sparking takes place and the condenser rapidly charges and discharges so that a saw tooth wave form is produced across its terminals. The electrode will rend to move when the average value of this voltage equals that prevailing across lower limb of potentiometer. Under this condition the bridge, the bridge is balanced and there is no armature current. The electrode overshoots, the gap width will smaller and average condenser voltage will fall since the condenser will no longer be charge able to charge up to the specific voltage. The bridge is now unbalanced with reverse polarity so that motor reverse and widens the gap until correct position attained. If electrode touches the work, the condenser is short circuit, causing the supply voltage to appear across the blast resistance and electrode is lifted away from work piece.

2.5.1Power delivered by an R-C circuit

The power delivered in time t’ (average) would be obtained as

$$\frac{E}{t'} = W_{avg} = \frac{C}{2t_i}\left[Us\left\{1 - e^{\frac{-t}{RC}}\right\}\right] \ldots\ldots\ldots(2)$$

For maximum power deliver through the circuit

$$\frac{dw_{max}}{dx} = 0$$

where

$$X = \frac{t'}{RC}$$

For maximum power it is seen that x = 1.26

$$U_b = U_s(1 - e^{-1.26}) \ldots\ldots\ldots(3)$$

Or

$$\frac{U_b}{U_s} = 0.72$$

Thus it is seen that for maximum power delivery through the gap the break Down and supply voltage should follow the relationship given above

2.5.2 Material removal rate using relaxation circuit

Metal removal rate in EDM using relaxation circuit is proportional to the product of frequency of charging and energy delivered per spark i.e

$$f * \frac{1}{2} * C * U^2 \ldots\ldots\ldots(4)$$

Or

$$k_1 * f * \left(\frac{1}{2} * C * U^2{}_b\right) \ldots\ldots\ldots(5)$$

The metal removal rate is given by :

$$MRR = \frac{K}{2R} * U_b * \left[\frac{1}{\log \frac{1}{1-\frac{U_b}{U_s}}} \right] \dots\dots\dots(6)$$

From above equation it can be seen that for a given circuit the metal removal rate will increase with decreasing R. However R can not made very low because in that case arcing will occur instead of sparking and such a situation is determinately to the work surface finish . The minimum value of the resistance that will prevent arcing is known as critical resistance.

2.5.3 Critical resistance

If the equivalent inductance of discharging circuit is considered to be L, then from energy balance it is seen that

$$\frac{1}{2} L i^2{}_{d\ max} = \frac{1}{2} * C * U_b{}^2 \dots\dots\dots(7)$$

$$\text{where}, i_{d\ max} = \text{maximum discharge current} = \frac{U_c}{\sqrt{\frac{L}{C}}}$$

Uc= condenser voltage at instant of spark initiation

For purely inductive circuit

$$i_{d\ max} = \frac{U_R}{R_{min}} \dots\dots\dots\dots\dots\dots(8)$$

Equating above equation we get minimum value of the resistance R_{min} for a purely inductive circuit as

$$R_{min} = \frac{U_s}{U_c} * \sqrt{\frac{L}{c}} \dots\dots\dots\dots\dots(9)$$

$$\text{For} \quad \frac{U_s}{U_c} = 1, R_{min} = \sqrt{\frac{L}{C}}$$

In practice circuit is not purely inductive and hence this equation should be used with modification. The empirical relation has been found to yield better results

$$R_{min} \geq 30 * \sqrt{\frac{L}{C}} \quad \ldots\ldots\ldots\ldots(10)$$

2.6 Process Parameters

2.6.1 Discharge Voltage

Discharge voltage in the EDM is related to the spark gap and breakdown strength of the dielectric. Before current can flow, the open gap voltage increases until it creates an ionization path through the dielectric. Once the current starts to flow, voltage drops and stabilizes at the working gap level. The preset voltage determines the width of the spark gap between the leading edge of the electrode and work piece. Higher voltage settings increase the gap, which improves the flushing conditions and helps to stabilize the cut. MRR< TWR and surface roughness increases with increasing open circuit voltage because electric field strength increases.

2.6.2 Peak Current

This is the amount of power used in discharge 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 preset level, which is expressed as the peak current. Higher currents will improve MRR but at the cost of TWR and surface finish. Figure 2.15 shows effect of current on surface

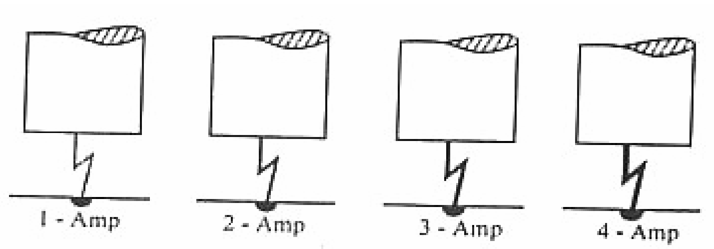


Figure 2.8 shows effect of current on surface

2.6.3 Pulse On-time & Off-time

Each cycle has an on-time and off-time that is expressed in units of microseconds. Since all the work is done during on-time, the duration of these pulses and the number of cycles per second are important. Metal removal is directly proportional to the amount of energy applied during the on-time. The energy is controlled by the peak current and the length of the pulse on-time. The resulting crater will be deeper and broader than a crater produced by a shorter on-time. Excessive on-times can be counter productive when the optimum on-time for each electrode-work material combination is exceeded, material rate starts to decrease.

The cycle is completed when sufficient off-time is allowed before the start of the next cycle. Off-time will affect the speed and stability of the cut. Shorter the off-time, the faster will be the machining operation. However, if the off-time is too short, the ejected work piece material will not be swept away by the flow of the dielectric and the fluid will not be deionized. This will cause the next spark to be unstable. Unstable conditions cause erratic cycling and retraction of the advancing servo. This slows down cutting more than long, stable off-times. Off-time must be greater than the deionization time to prevent continued sparking at one point.

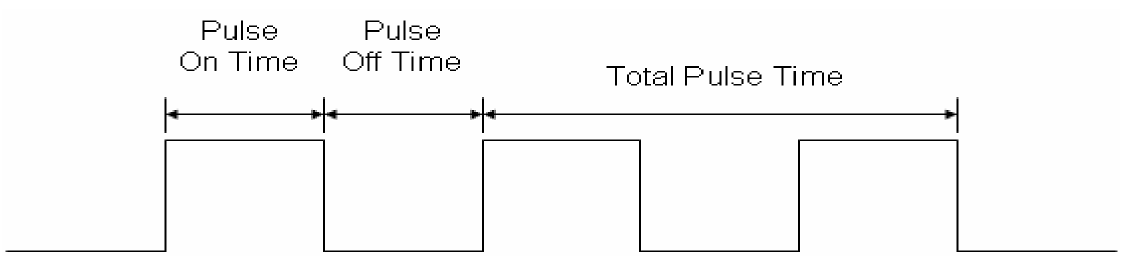


Figure 2.9 Concept of Pulse on Time and Pulse off Time

2.6.4 Polarity

The polarity of the electrode can be either positive or negative. The current passing the gap creates high temperatures causing material evaporation at both electrode spots. As the electron processes show quicker reaction, the anode material is worn out predominantly. This causes minimum wear to the tool electrodes and becomes of importance under finishing operations with shorter on-times. However while longer discharges, the early electron process predominance changes to positron process, resulting in high tool wear. In this experiment setup, positive polarity is selected. The recommended polarity for different tool-jobs is given in Table below:

Work material	Rougher	Finisher
Tool steel	+(*)	+ -
Stainless steel	+(*)	+ -
Aluminum	+ -	+ -
Titanium	-	-
Carbides	-	-
Copper	-	-

Table 2.3 Recommended Polarities for different Tool-Job pairs.

2.6.5 Electrode 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 of the set value. Mostly electro-mechanical systems are used. The most important requirements for good performance are gap stability and the reaction speed of the system; the presence of the backlash is practically undesirable.

2.6.6 Frequency

This is a measure of the number of times the current is turned on and off. During roughing, the 'on time' is increased significantly for high removal rates and fewer cycles per second, hence a lower frequency setting as shown in Figure 2.17. Frequency is distinct from the duty cycle, as this is a measure of efficiency.

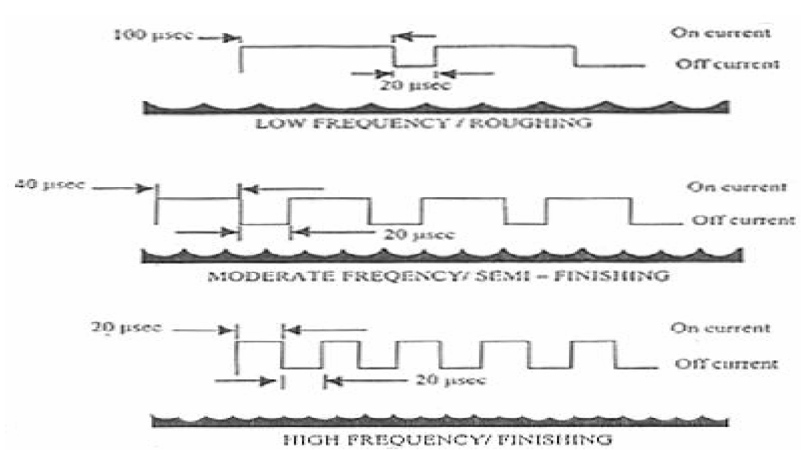


Figure 2.10 frequency setting

2.7 Dielectric Fluids

Dielectric fluid used in EDM should be:

1. Remain electrically non conductive until the required breakdown voltage is reached that is they should have high dielectric strength.
2. Breakdown electrically in shortest possible time once the breakdown voltage has been reached.
3. Quench the spark rapidly deionize the spark gap after discharge has occurred
4. Provide an effective cooling medium.
5. Have a good degree of fluidity
6. Be cheap and easily available
7. Light hydro carbons oil satisfies this condition. Table 2.4 compares performance of several dielectric fluids.

DIELECTRIC FLUID	MACHINING RATE	WEAR RATIO
50 viscosity ssu hydro carbon oil	39	2.8
Distilled water	54.6	2.7
Tap water	57.7	4.1
Tetraethylene glycol	102.9	6.8

Table 2.4 performance of several dielectric fluids.

2.8 Flushing

Flushing is defined as correct circulation of dielectric fluid between work piece and tool. Suitable flushing is necessary for highest machining efficiency

To start with dielectric should be fresh that is free from eroded particles and residue resulting from dielectric cracking and its insulation strength is high . With successive discharges dielectric gets contaminated, reducing its insulation strength and hence discharge can take place easily. If density of the particles becomes too high at certain points within the gap bridges are formed which lead to abnormal discharges and damage the tool as well as the work electrode .This build up of the wear debris is eliminated by flushing. Flushing can be achieved by one of following methods:

1. Injection flushing
2. Suction flushing
3. side flushing
4. Flushing by dielectric pumping

2.9 Suction Flushing

In this method dielectric is being suck either by tool electrode or work piece. Compared with injection flushing suction avoids tapering effects due to sparking via particles along side of electrode. Suction flushing through tool rather than work piece is more efficient

2.9.1 Side Flushing

When flushing hole cannot be drilled either in the work piece or the tool this type of flushing is employed. For the entire work area to be evenly flushed

2.9.2 Flushing by Dielectric pumping

Flushing is obtained by using electrode pulsation movement. When the electrode is raised the gap increases resulting in clean dielectric being sucked into mix with contaminated fluid and as electrode is lowered the particles are flushed out.

2.9.3Injection flushing

The dielectric fluid is injected into the working gap either through the work piece or tool. A hole is provided in the work piece or tool for this purpose.

2.10 Selection of Electrode Material

Four main factor determine the suitability of a material for use as an electrode

1. The maximum possible metal removal rate
2. Wear ratio
3. Ease with which it can be shaped or fabricated to the desired shape
4. Cost

Keeping in mind technical and economic consideration various material that can be used as tool

MATERIAL	WEAR RATIO	MATERIAL REMOVAL RATE	COST
Copper	low	high	high
Brass	high	high	low
Tungsten	lowest	low	high
Cast iron	low	low	low
Steel	high	low	low
Zinc alloys	high	high	low
Copper graphite	low	high	high

Table 2.5 Different elecrtode material

2.11 Surface Finish

The surface produced by the EDM process consists of a multitude of small craters randomly distributed all over the machined face. The quality of surface finish depends upon energy per spark. If energy content is higher deeper crater will result leading to poor surface. The surface roughness has been found to be inversely proportional to frequency of discharge.

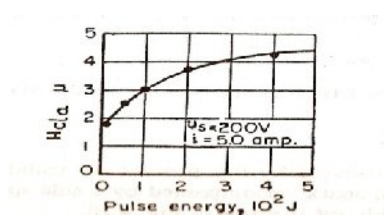


Figure 2.10 surface finish with craters

$H_{cla} = K * V^{0.5} * C^{0.31}$ …………… (1)

H_{cla} = Center line average value of the surface produced

CHAPTER-3

LITREATURE REVIEW

Taguchi methods are most recent additions to the tool kit of design, process, and manufacturing engineers and quality assurance experts. In contrast to stastical process control which attempt to control the factors that adversely effect the quality of production The significance of beginning quality assurance with an improved process or product design is not difficult to gauge .Taguchi method systematically reveal the complex cause and effect relationship between design parameter and performance . These lead to building quality performance into process and product before actual production begins .Taguchi method have rapidly attained prominence because wherever they have been applied, they lead to the major reductions into process and products before actual production begins .The foundation of quality depend upon two premises :

1. Society incurs a loss any time the performance of product is not on target .
2. Product and process design require a systematic development , progressing stepwise through system design , parametric design and finally tolerance design

The first point suggests that whenever the performance of a product deviates from its target performance, society suffer loss. Such a loss has two components: The manufacture incurs a loss when he repairs or rectified return or rejected product. The second point aims at quality engineering , a discipline that aims at engineering not only function but also quality performance into products and process .The following seven points highlight the distinguish feature of taguchi's approach which aimed at assuring quality :

1. Taguchi defined the term quality as the deviation from on target performance which appears to be first paradox. According to him the quality of a manufactured product is the total loss generated by that product to the society from the time it is shipped.
2. In a competitive economy continuous improvement (CQI) and cost reduction are necessary.

3. A CQI programmed include continuous reduction in the variation of product performance characteristic in their target values.
4. Customer loss attribute to the product performance variation is often proportional to the square of the deviation performance characteristic from its target value.
5. The finally quality and cost of a product manufactured depends primarily on the engineering design of the product and its manufacturing process.
6. Variation in the product depends primarily on the engineering design of the product and its manufacturing process.
7. Statically planned experiments can efficiently and reliably identify the settings of the product and process parameters that reduce performance variations.

Design of Experiments (DOE) is a powerful statistical technique introduced by R.A. fisher in England in 1920s to study the effect of multiple variables simultaneously DOE can highly effective when:

1. Optimize product and process design , study the effect of multiple factor on process .
2. Study the influence of individual factors on the performance and determine which factor has more influence, which one has less. It can also find which factor should have higher tolerance and which tolerance should be relaxed.

Qing Gao et al(2007) Electrical discharge machining (EDM) process, at present is still an experience process, wherein selected parameters are often far from the optimum, and at the same time selecting optimization parameters is costly and time consuming. In this paper, artificial neural network (ANN) and genetic algorithm (GA) are used together to establish the parameter optimization model. An ANN model which adapts Levenberg-Marquardt algorithm has been set up to represent the relationship between material removal rate (MRR) and input parameters, and GA is used to optimize parameters, so that optimization results are obtained. The model is shown to be effective, and MRR is improved using optimized machining parameters.

S. Assarzadeh and M. Ghoreishia new integrated neural network-based approach is presented for the prediction and optimal selection of process parameters in die sinking electro-discharge machining (EDM) with a flat electrode (planning mode). A 3–6–4–2-size back-propagation neural network is developed to establish the process model. The current (I), period of pulses (T), and source voltage (V) are selected as network inputs. The material removal rate (MRR) and surface roughness (Ra) are the output parameters of the model. Experimental data were used for training and testing the network. The results indicate that the neural model can predict process performance with reasonable accuracy, under varying machining conditions. The effects of variations of the input machining parameters on process performance are then investigated and analyzed through the network model. Having established the process model, a second network, which parallelizes the augmented Lagrange multiplier (ALM) algorithm, determines the corresponding optimum machining conditions by maximizing the MRR subject to appropriate operating and prescribed Ra constraints. The optimization procedure is carried out in each level of the machining regimes, such as finishing (Ra≤2 μm), semi-finishing (Ra≤4.5 μm), and roughing (Ra≤7 μm), from which, the optimal machining parameter settings are obtained. The optimization results have also been discussed, verified experimentally, and the amounts of relative errors calculated. The errors are all in acceptable ranges, which, again, confirm the feasibility and effectiveness of the adopted approach.

Ko-Ta Chiang (2008) Electric discharge machining (EDM) has achieved remarkable success in the manufacture of conductive ceramic materials for the modern metal industry. Mathematical models are proposed for the modeling and analysis of the effects of machining parameters on the performance characteristics in the EDM process of Al2O3+TiC mixed ceramic which are developed using the response surface methodology (RSM) to explain the influences of four machining parameters (the discharge current, pulse on time, duty factor and open discharge voltage) on the performance characteristics of the material removal rate (MRR), electrode wear ratio (EWR), and surface roughness (SR). The experiment plan adopts the centered central composite design (CCD). The separable influence of individual machining parameters and the interaction between these parameters are also investigated by using analysis of variance (ANOVA). This study highlights the development of mathematical models for investigating the influences of machining parameters on performance characteristics and the proposed mathematical models in this study have proven to fit and predict values of performance characteristics close to those readings recorded experimentally with a 95% confidence interval. Results show that the main two significant factors on the value of the material removal rate

(MRR) are the discharge current and the duty factor. The discharge current and the pulse on time also have statistical significance on both the value of the electrode wear ratio (EWR) and the surface roughness (SR).

Kuang-Yuan Kung et al (2007) In this article, a material removal rate (MRR) and electrode wear ratio (EWR) study on the powder mixed electrical discharge machining (PMEDM) of cobalt-bonded tungsten carbide (WC-Co) has been carried out. This type of cemented tungsten carbide was widely used as moulding material of metal forming, forging, squeeze casting, and high pressure die casting. 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 mach inability evaluation of MRR and EWR. The response surface methodology (RSM) has been used to plan and analyze the experiments. The experimental plan adopts the face-centered central composite design (CCD). This study highlights the development of mathematical models for investigating the influence of processing parameters on performance characteristics.

Ali Ozgedik and Can Cogun (2005) In this study, the variations of geometrical tool wear characteristics – namely, edge and front wear – and machining performance outputs – namely, work piece removal rate, tool wear rate, relative wear and work piece surface roughness – were investigated with varying machining parameters. Experiments were conducted using steel work pieces and round copper tools with a kerosene dielectric under different dielectric flushing conditions (injection, suction and static), discharge currents and pulse durations. The experiments have shown that machining parameters and dielectric flushing conditions had a large effect on geometric tool wear characteristics and machining performance outputs. Additionally, published research on tool wear is presented in detail in this study.

Yusuf Keskin et al (2006) Electrical discharge machining (EDM) is a nontraditional production method that has been widely used in the production of dies throughout the world in recent years. The most important performance measure in EDM is the surface roughness; among other measures material removal and tool wear rates could be listed. In this study, experiments were performed to determine parameters effecting surface roughness. The data obtained for performance measures have been analyzed using the design of experiments methods. A considerably profound equation is obtained for the surface roughness using power, pulse time, and spark time parameters. The results are discussed.

JI Renjiet et al , A new method which employs a group pulse power supply for electric discharge milling of the silicon carbide ceramic with the resistivity of 500 Ω·cm is presented. Due to the good machining stability and high pulse utilization, the material removal rate (MRR) can reach 72.9 mm3/min. The effects of high-frequency pulse duration, high-frequency pulse interval, peak voltage, peak current, polarity, rotate speed and group frequency on the process performance have been investigated. Also the EDMed surface microstructure is examined with a scanning electron microscope (SEM), an X-ray diffraction (XRD), an energy dispersive spectrometer (EDS) and a micro hardness tester. The results show that the conditions of smaller high-frequency pulse duration and pulse interval, higher peak voltage and peak current, and positive tool polarity are suitable for machining the SiC ceramic. The optimal rotate speed is 1090 r/min and the preferable group frequency is 730 Hz. In addition, there is a small quantity of iron on machined surface when machining with steel electrode. The average grain size of the EDMed surface is smaller than that of the unprocessed, and the micro hardness of machined surface is superior to that of the unprocessed.

Paulo Peças *and* Elsa Henriques (2007) The addition of powder particles to the electrical discharge machining (EDM) dielectric fluid modifies some process variables and creates the conditions to achieve a higher surface quality in large machined areas. This paper presents a new research work that aims to study the improvement in the polishing performance of conventional EDM when used with a powder-mixed-dielectric (PMDEDM). The analysis was carried out varying the silicon powder concentration and the flushing flow rate over a set of different processing areas and the effects in the final surface were evaluated. The evaluation was done by surface morphologic analysis and measured through some quality surface indicators. The results show the positive influence of the silicon powder in the reduction of crater dimensions, white-layer thickness and surface roughness. Moreover, it was demonstrated that an accurate control of the powder concentration and flushing flow is a requirement for achieving an improvement in the process polishing capability.

Young-Cheol Ahn and Young-Seup Chung (2002) The electrical discharge manufacturing process of a ceramic composite material consisting of alumina and titanium carbide has been modeled as an unsteady state mathematical model and solved by using Galerkin's implicit finite element method. For several selected currents and powers the spark melted and sublimated the work piece to form a crater which gradually expanded outwards. The size and shape of the crater anticipated by the computation were in good agreement with the scanning electron *micrograph* of the crater formed in an experiment. An increased electric current and duty factor would increase the material removal rate in expense of roughened surface and deteriorated mechanical properties.

Qing Gao et al (2007) In this paper, artificial neural network (ANN) and genetic algorithm (GA) are used together to establish the parameter optimization model. An ANN model which adapts Levenberg-Marquardt algorithm has been set up to represent the relationship between material removal rate (MRR) and input parameters, and GA is used to optimize parameters, so that optimization results are obtained. The model is shown to be effective, and MRR is improved using optimized machining parameters.

S. Assarzadeh et al (2007) a new integrated neural network-based approach is presented for the prediction and optimal selection of process parameters in die sinking electro-discharge machining (EDM) with a flat electrode (planing mode). A 3–6–4–2-size back-propagation neural network is developed to establish the process model. The current (I), period of pulses (T), and source voltage (V) are selected as network inputs. The material removal rate (MRR) and surface roughness (Ra) are the output parameters of the model. Experimental data were used for training and testing the network. The results indicate that the neural model can predict process performance with reasonable accuracy, under varying machining conditions. The effects of variations of the input machining parameters on process performance are then investigated and analyzed through the network model. Having established the process model, a second network, which parallelizes the augmented Lagrange multiplier (ALM) algorithm, determines the corresponding optimum machining conditions by maximizing the MRR subject to appropriate operating and prescribed Ra constraints. The optimization procedure is carried out in each level of the machining regimes, such as finishing ($Ra \leq 2$ μm), semi-finishing ($Ra \leq 4.5$ μm), and roughing ($Ra \leq 7$ μm), from which, the optimal machining parameter settings are obtained. The optimization results have also been discussed, verified experimentally, and the amounts of relative errors calculated. The errors are all in acceptable ranges, which, again, confirm the feasibility and effectiveness of the adopted approach.

B. Izquierdo et al (2008) In this paper a new contribution to the simulation and modelling of the EDM process is presented. Temperature fields within the workpiece generated by the superposition of multiple discharges, as it happens during an actual EDM operation, are numerically calculated using a finite difference schema. The characteristics of the discharge for a given operation, namely energy transferred onto the workpiece, diameter of the discharge channel and material removal efficiency can be estimated using inverse identification from the results of the numerical model. The model has been validated through industrial EDM tests, showing that it can efficiently predict material removal rate and surface roughness with errors below 6%.

M.K. Pradhan (2008) Response surface methodology was used to investigate the relationships and parametric interactions between the three controllable variables on the material removal rate (MRR). Experiments are conducted on AISI D2 tool steel with copper electrode and three process variables (factors) as discharge current, pulse duration, and pulse off time. To study the proposed second-order polynomial mode for MRR, they used the central composite experimental design to estimation the model coefficients of the three factors, which are believed to influence the MRR in EDM process. The response was modeled using a response surface model based on experimental results. The significant coefficients were obtained by performing analysis of variance (ANOVA) at 5% level of significance. It was found that discharge current, pulse duration, and pulse off time significant effect on the MRR. This methodology is very effectual, needs only 20 experiments to assess the conditions, and model sufficiency was very satisfactory as the coefficient of determination was 0.962.

Dawei Luy et al (2002) The approach presented in this paper takes advantage of both the Taguchi method and a fuzzy-rule based inference system, which forms a robust and practical methodology in tackling multiple response optimization problems. The paper also presents a case study to illustrate the potential of this powerful integrated approach for tackling multiple response optimization problems. The variance analysis is also an integral part of the study, which identifes the most critical and statistically significant parameters.

C. L. Lin (2002) In this paper, the use of the grey relational analysis based on an orthogonal array and fuzzy-based Taguchi method for optimising the multi-response process is reported. Both the grey relational analysis method without using the S/N ratio and fuzzy logic analysis are used in an orthogonal array table in carrying out experiments for solving the multiple responses in the electrical discharge machining (EDM) process. Experimental results have shown that both approaches can optimize the machining parameters (pulse on time, duty factor, and discharge current) with considerations of the multiple responses (electrode wear ratio, material removal rate, and surface roughness) effectively. It seems that the grey relational analysis is more straightforward than the fuzzy-based Taguchi method for optimising the EDM process with multiple process responses.

A Yahya et al (2003) this article presents a model of the EDM system for an Electrical Discharge Machine (EDM), which accurately predicts the material removal rate for particular electrodes and workpieces. A value for the material removal rate constant, α has been identified based on the empirical analysis carried out on the experimental data and compared with the simulation result from the model using the Matlab/Simulink simulation tool. The EDM controller is designed based on the TMS320LF2407 DSP microprocessor.

Y. S. Tarng (2000) an orthogonal array, the signal-to-noise ratio, multiresponse performance index, and analysis of variance are employed to study the performance characteristics in the submerged arc welding process. The process parameters, namely arc current, arc voltage, welding speed, electrode protrusion, and preheat temperature are optimised with considerations of the performance characteristics, including deposition rate and dilution. Experimental results are provided to confirm the effectiveness of this approach.

Ko-Ta Chiang et al (2007) The rapidly resolidified layer is formed by the resolidification of residual molten materials on the machined surface during the electric discharge machining (EDM) process. This study adopts a range of 4–29 wt% to change the silicon content in Al-Si alloy specimens to clarify the effect of silicon particles including the content, area fraction and intercept length of primary silicon particles on the performance of the rapidly resolidified layer during the EDM process. The layer thickness, surface roughness and ridge density on the rapidly resolidified layer are considered in the performance evaluation and explored by experiment. Experimental results indicate that the EDMed surface has a continuous ridge appearance and the effect of silicon particles including the content, area fraction and intercept length of primary silicon particles has the advantage of more ridge density. The rapidly resolidified layer thickness and surface roughness on the EDMed surface tend to increase with increasing the content and area fraction of the silicon particles.

S. H. Yeo (1999) This paper presents a methodology for the multi-objective analysis of the electric discharge machining (EDM) processes. A utility function was employed to determine the utility levels of various dielectrics by integrating the factors involving time, energy, quality and weighted mass. Using the utility function, the process or material with the highest rating represents the condition with the best match of all the key factors. It will therefore give a more balanced result, leading to savings in resources, which helps in protecting the environment.

CHAPTER-4

DESIGN OF STUDY

4.1 OUTLINE OF THESIS WORK

It is found already many work has been done in MRR and Surface finish but very little work has been done on optimization of MRR and Hardness according to batch production .Here I will try to find out optimum value In my thesis work I will try to find out optimal value of MRR and HARDNESS .For this I consult to many industries , they suggested that EN24,EN19,EN353 are cheaply available and widely used alloys .Taguchi method using design of experiments approach can be used to optimize a process Here we will to apply D.O.E approach for modeling of MRR in EDM process and . The various input parameters will be taken under experimental investigation and then model will be prepared then again experimentation work will be performed. The results obtain will be analyzed and the models will be produced by using MINITAB software. This will help in improving the life of work piece, material as well as the effective and efficient working of the EDM machining process. Tool material is of copper because of easy available in market and lower in cost

Various Input parameters

- Discharge Voltage
- Peak Current
- Pulse Waveform
- Pulse on-time
- Pulse off-time
- Pulse Frequency
- Polarity
- Electrode Gap
- Type of Dielectric flushing

After extensive research it has been found that above are important input parameters for studying material remove rate. As I am going to perform my work on model T-3822 and after literature review four main input parameters are **peak current, pulse on time, gap between work piece and electrode, material.** One parameter **polarity** is kept fixed for the whole experiment. Polarity has been fixed as **straight polarity** (electrode negative) for all the experiments because it is desirable setting for material transfer to occur. With straight polarity, the energy available per discharge at work surface is higher as compared to the tool electrode and consequently material removal rate is also higher.

4.2 Design of Experiment

The objective of this research work is to study MRR Surface properties such as Surface roughness and micro hardness the design variables can be summarized as follows:

a) Three levels of the gap have been used.

b) Three levels of peak current to be used; because the non-linear behavior of process parameters can only be studied if more than two levels of a parameter are used.

c) Three levels of pulse on-time to be used.

d) Three different materials.

For conducting the experiments, it has been decided to follow the Taguchi method of experimental design and an appropriate orthogonal array is to be selected after taking into consideration the above design variables. Out of the above listed design variables, the orthogonal array was to be selected for four design variables (namely peak current, pulse on-time, material .gap) which would constitute the orthogonal array.

The two most important outputs are material removal rate and hardness a the same have been selected as response parameters for this research work also . The effect of the variation in input process parameter will be studied on these two response parameters and the experimental data will be analyzed as per Taguchi method to find out the optimum machining condition and percentage contribution of each factor.

S.no	Machining Parameters	Fixed Value
1	Open Circuit Voltage	135 ± 5% Volts
2	Polarity	Straight
3	Depth of cutt	1 mm
4	Type of Di-electric	Kerosene
5	Electrode Quill Movement	10:4

Table 4.1 machining parameters

4.3 Selection of Orthogonal Array & Parameter Assignment

In this experiment, there are four parameters at three levels each. The degree of freedom(DOF) of a three level parameter is 2 (number of levels-1), hence total DOF for the experiment is 8. The DOF of the orthogonal array selected should have higher than that of total DOF of the experiment. .

Interaction	Units	DOF
Current (A)	Ampere	2
Material (B)	-	2
Pulse duration (C)	μ sec	2
Gap (D)	Mm	2

Table 4.2 degree of freedom as per level

Sum of all DOF is 8.So we will take L18 orthogonal array

Table 4.3 Standards L18 Orthogonal Array (Taguchi Design)

Exp no	Current	Material	Pulse duration	Gap
1	1	1	1	1
2	2	2	2	2
3	3	3	3	3
4	2	2	3	3
5	3	3	1	1
6	1	1	2	2
7	1	3	2	3
8	2	1	3	1
9	3	2	1	2
10	3	2	2	1
11	1	3	3	2
12	2	1	1	3
13	3	1	3	2
14	1	2	1	3
15	2	3	2	1
16	2	3	1	2
17	3	1	2	3
18	1	2	3	1

4.3.1Signal-to-noise ratio

Noise factors are those that are either too hard or uneconomical to control even though they may cause unwanted variation in performance. It is observed that on target performance usually satisfies the user best, and the target lies under acceptable range of product quality are often inadequate. If Y is the performance characteristic measured on a continuous scale when ideal or target performance is T then according to Taguchi the loss caused L(Y) can be modeled by a quadratic function as shown in equation (1)

$$L(Y) = K(Y - T^2) \dots \dots \dots (1)$$

The objective of robust design is specific; robust design seeks optimum settings of parameters to achieve a particular target performance value under the most noise condition. Suppose that in a set of statistical experiment one finds a average quality characteristic to be μ and standard deviation to be σ. Let desired performance be μ1 .Then one make adjustment in design to get performance on target by adjusting value of control factor by multiplying it by the factor (μ_0/μ) . Since on target is goal the loss after adjustment is due to variability remaining from the new standard deviation. Loss after adjustment shown in equation (2):

$$\mathbf{k}(\mu_0|\mu)^2\,\sigma^2 \dots \dots \dots (2)$$

The factor $\frac{\mu^2}{\sigma^2}$ reflects the *ratio of average performance* μ^2(which is the signal) and σ^2(*the variance* of performance) the noise. Maximizing $\frac{\mu^2}{\sigma^2}$ or S/N ratio therefore become equivalent to minimizing the loss after adjustment. Finding a correct objective function to maximize in an engineering design problem is very important. Depending upon the type of response, the following three types of S/N ratios are employed in practice:

Higher the Better

If the nominal value for a characteristic Y is best then designer should maximize the S/N ratio i.e:

(S/N)HB = -10 log (MSDHB)

Where

$$MSD_{HB} = \frac{1}{R}\sum_{j=1}^{R}\frac{1}{Y_j^{\,2}}$$

Lower the Better:

If the nominal value for a characteristic Y is best then designer should maximize the S/N ratio i.e.:

(S/N)LB = -10 log (MSDLB)

Where

$$\mathrm{MSD_{HB}} = \frac{1}{\mathrm{R}}\sum_{\mathrm{j}=1}^{\mathrm{R}}\mathrm{Y_j^2}$$

- In my thesis work MRR is considered *larger is better.* Value of MRR is measured by difference between initial and final weight after machining
- Hardness of specimen is considered as *smaller is better.* Hardness value is measured on Rockwell machine on C scale by using diamond intender

4.4 ANOVA (Analysis of Variance)

The purpose of the statistical analysis of variance (ANOVA) is to investigate which design parameter significantly affects the material removal rate and hardness. Based on the ANOVA, the relative importance of the machining parameters with respect to material removal rate and hardness is investigated to determine more accurately the optimum combination of the machining parameters.

Two types of variations are present in experimental data:

1. Within treatment variability
2. Observation to observation variability

So ANOVA helps us to compare variabilities within experimental data. In my thesis ANOVA table is made with help of **MINITAB 15** software. When performance varies one determines the average loss by statistically averaging the quadratic loss. The average loss is proportional to the *mean squared error* of Y about its target T. The initial techniques of the analysis of variance were developed by the statistician and geneticist R. A. Fisher in the 1920s and 1930s, and are sometimes known as Fisher's ANOVA or Fisher's analysis of variance, due to the use of Fisher's *F-distribution* as part of the test of statistical significance. Various formulas for ANNOVA:

- **Sum of square**

$$SS_A = \sum_{i=1}^{K_A}\left(\frac{A^2}{n}\right) - \sum_{i=1}^{N}\frac{y_i^{\,2}}{N}$$

- **Total sum of square deviation**

$$SS_T = \sum_{i=1}^{K_A} y_i^{\,2} - \frac{\sum_{i=1}^{N} y_i^{\,2}}{N}$$

- **Experimental error**

$$SS_e = SS_T - \sum SS_{factor}$$

- **Pure sum of square**

$$SS'_A = SS_A - (dof)_A \times MS_E$$

- **Mean of square**

$$MS_E = \frac{SS_E}{dof_e}$$

CHAPTER-5

EXPERIMENTAL ANALYSIS

Since in my thesis work there are four factors and three levels for each which are shown below:

LEVELS				
CONTROL FACTORS	1	ll	lll	Unit
Discharge current	3	4	5	amp
Material	EN24	EN19	EN353	-
Pulse duration	4	5	6	Micro second
Gap	0.3	0.4	0.5	mm

Table 5.1 Values of variables at different level

After deciding parameters and levels as shown above orthogonal array L18 decided as per degree of freedom of each factor and dof of interaction among the parameters. Data of parameter was collected in such a way that it shouldn't damage or cause any accident to operator and as per literature review and as per consultant with lab in charge. Now perform experiment as per orthogonal array (L18) on model T 3822, output like MRR and hardness is being given in tabulated form. After the experimental results have been obtained, analysis of the results was carried out analytically as well as graphically. Graphical analysis is done by MINITAB, shows interactions of all parameters. Then ANOVA of the experimental data has been done to calculate the contribution of each factor in each response. Then we calculated S/N ratio for MRR and hardness of specimens. Then we obtain optimal conditions has been calculated for MRR and hardness of specimen. The following table shows readings of MRR and HARDNESS at each experiment, it also shows S/N ratio for MRR and hardness at each experiments

Table 5.2 Experimental results and S/N ratios of MRR and HARDNESS

Exp no	Curent (A)	Material (B)	Pulse duration (C)	gap (D)	MRR(g/min)	S/N Ratio For MRR	Hardness(HRC)	S/N Ratio for hardness
1	3	EN24	4	0.3	0.560	-5.0362	70	-36.9019
2	4	EN19	5	0.4	0.420	-7.5350	71	-37.0251
3	5	EN353	6	0.5	0.150	-16.4781	59	-35.41704
4	3	EN19	6	0.5	0.420	-7.5350	69	-36.7769
5	4	EN353	4	0.3	0.390	-8.1787	67	-36.5214
6	5	EN24	5	0.4	0.400	-7.9588	71	-37.0251
7	4	EN24	5	0.5	0.460	-6.7448	63	-35.9868
8	5	EN19	6	0.3	0.420	-7.5350	65	-36.2582
9	3	EN353	4	0.4	0.380	-8.4043	72	-37.1466
10	5	EN353	5	0.3	0.080	-21.9382	73	-37.2664
11	3	EN24	6	0.4	0.450	-6.9357	67	-36.5214
12	4	EN19	4	0.5	0.600	-4.4369	79	-37.9525
13	4	EN353	6	0.4	0.450	-6.9357	72	-37.1466
14	5	EN19	4	0.5	0.660	-3.6091	69	-36.7769
15	3	EN24	5	0.3	0.690	-3.2230	67	-36.5214
16	5	EN19	4	0.4	0.500	-6.0205	65	-36.2582
17	3	EN353	5	0.5	0.540	-5.3521	66	-36.3908

18	4	EN24	6	0.3	0.650	-3.7417	70	-36.9019

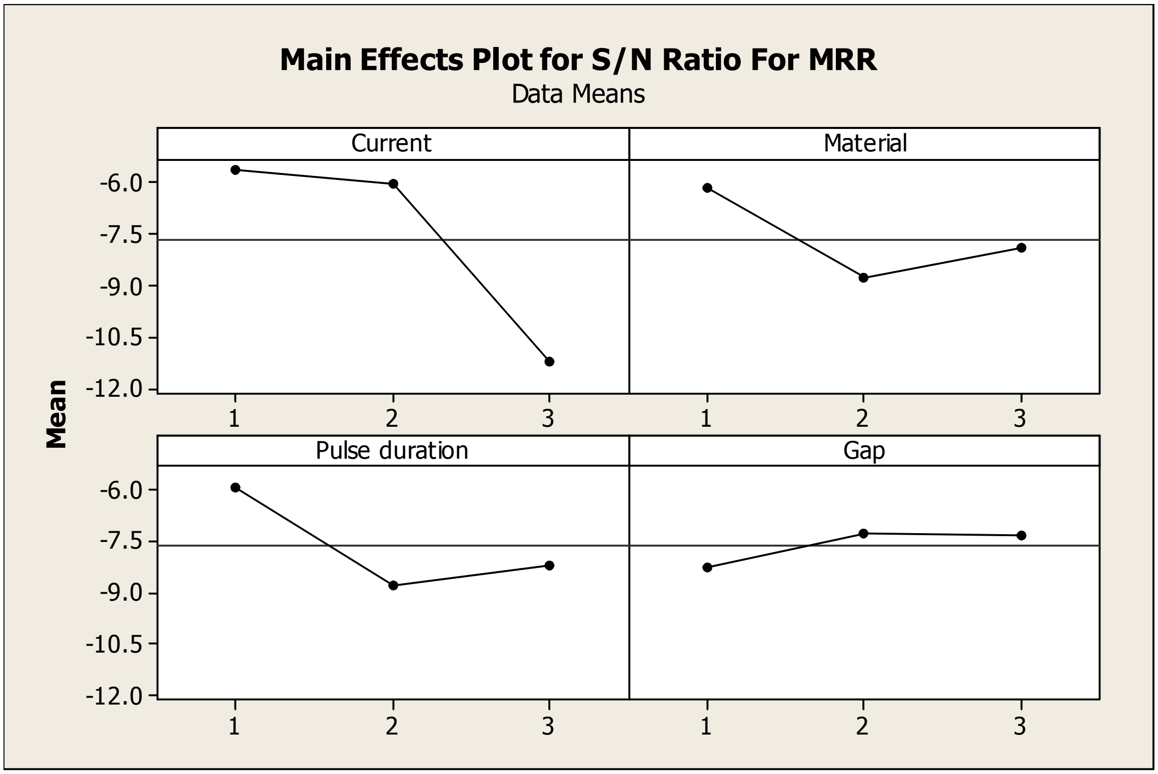
EN 353

EN 24

EN 19

Figure 5.1 Cuts on workpiece during machining

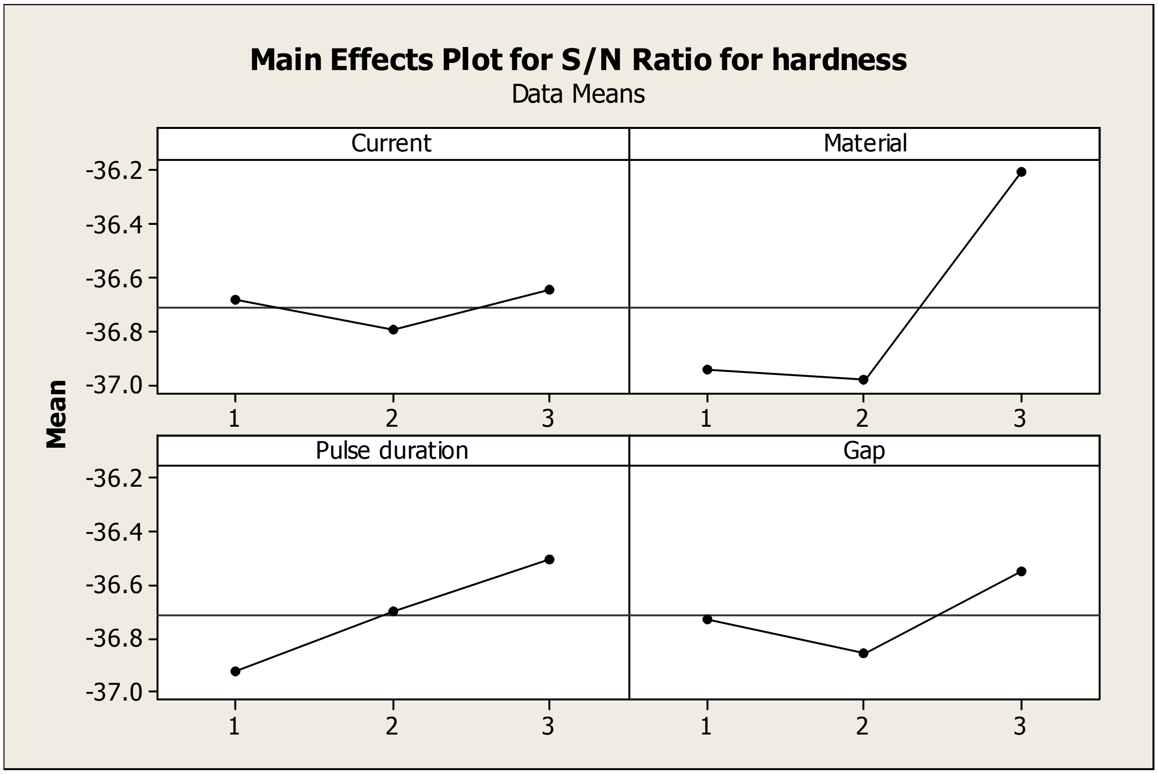
5.1Experimental results for MRR



Graph 5.1 effects of various factors on MRR

By using MINITAB software we obtain some interactions if we look at the graph we will observed that with increase in current MRR s/n ratio decreasing. Material removal rate decreases with pulse duration but after certain value of pulse duration there is increase in material removal rate , also with increase in gap there is increase in material removal rate this is because if gap is larger than optimum consequent reduction is not compensated for by an increase in energy per spark and hence power falls

5.2Experimental results for HARDNESS



Graph 5.2 various effects on hardness (lowest is better)

Graph above represent the effect of parameters on hardness of different materials. It can be seen that as value of machining parameters increases hardness is also increases .EN 353 is showing maximum hardness among all specimen. So it is clear that pulse duration and concentration of chromium has significant effect on hardness .moreover with increase in gap there is increase in hardness

5.3 ANOVA (Analysis of variance)

Since as already stated anova help us to identified which parameter is important for us after literature review following ANOVA table is obtained for MRR and HARDNESS .For ANOVA table I use MINITAB 15 software

PARAMETER	SS	DOF	VARIANCE	F TEST	F CRITICAL	C%
CURRENT	0.0705	2	0.03525	1.78	4.26	16.5
MATERIAL	0.1435	2	0.07175	3.62	4.26	33.6
PULSE DURATION	0.0307	2	0.01535	0.775	4.26	7.19
GAP	0.0039	2	0.00195	0.0098	4.26	0.91
ERROR	0.1782	9	0.0198			41.7
TOTAL	0.4268	19	0.022			100
E POOL	0.2833	17	0.06875			

Table 5.3ANNOVA TABLE OF MRR

From table 5.3 we can conclude that no parameter is significant for MRR in batch production because F critical is larger then F test for every parameter**.** Anova table is not supporting parameter in batch production.

PARAMETER	SS	DOF	VARIANCE	F TEST	F CRITICAL	C%	
CURRENT	33.4445	2	16.7222	0.5569	4.26	7.9	**NS**
MATERIAL	10.6066	2	5.3033	0.1766	4.26	2.5	**NS**
PULSE DURATION	33.9466	2	16.9733	0.565	4.26	8.02	**NS**
GAP	14.6132	2	7.3156	0.2436	4.26	3.4	**NS**
ERROR	330.2777	11	30.0252			78.09	
TOTAL	422.8941	19				100	
E POOL	422.8886	19	76.3396				

Table 5.4 ANNOVA TABLE OF HARDNESS

From table 5.4 we can conclude that no parameter is significant for hardness in batch production because F critical is larger then F test for every parameter**.** Anova table is not supporting parameter in batch production.

5.4CONFIRMATION TEST

From mean of each level of every factor we will construct response table for MRR and HARDNESS which are given below

LEVEL	A	B	C	D
1	-6.08	-5.60	-5.94	-8.27
2	-6.26	-6.11	-8.79	-7.29
3	-10.58	-11.21	-8.19	-7.35

Table 5.5 Response table for s/n ratio of MRR

From above main effect plot of MRR we can conclude the optimum condition for MRR is, A1 B1 C1 D2

LEVEL	A	B	C	D
1	-36.70	-36.64	-36.92	-36.72
2	-36.92	-36.84	-36.70	-36.85
3	-36.50	-36.64	-36.50	-36.55

Table 5.6 Response table for s/n ratio of HARDNESS

Similarly from graph of hardness we can say that optimal parameters are A3B3C3D3

After evaluating the optimal parameter settings, the next step of the Taguchi approach is to predict and verify the enhancement of quality characteristics using the optimal parametric combination. The estimated S/N ratio using the optimal level of the design parameters can be calculated:

$$\eta_{opt} = \eta_m + \sum_{i=1}^{o}(\overline{\eta_i} - \eta_m)$$

Where η_m is the total mean S/N ratio , $\overline{n_i}$ is the mean S/N ratio at optimum level and' **o'** is the number of main design parameter that effect quality characteristic. Based on the above equation the estimated multiresponse signal to noise ratio can be obtained. Below shows the confirmation experiment for material removal and hardness.

$$= -7.64 + (-6.08 + 7.64) + (-5.60 + 7.64) + (-5.94 + 7.64) + (-7.29 + 7.64)$$

Optimal value of MRR = **-2**

And the corresponding value of MRR = $y^2{}_{opt} = \frac{1}{10^{\frac{-n_{opt}}{10}}} = 0.63095$

$$y_{opt} = 0.79$$

Similarly optimal value of hardness can be obtained by:

$$= -36.71 + (-36.50 + 36.71) + (-36.64 + 36.71) + (-36.5 + 36.71) + (-36.55 + 36.71)$$

Optimal value of HARDNESS = **-36.06**

And corresponding value of hardness = $y^2{}_{opt} = 10^{\frac{-n_{opt}}{10}} = 4036.45$

$$y_{opt} = 63.5$$

After performing experiment again as per given optimum levels following result obtained

MRR	Optimal value of A1B1C1D2= 0.79	Experimental result of A1B1C1D1=0.90	Percentage change
			14%
HARDNESS	Optimal value of A3B3C3D3 = 63.5	Experimental result of A3B3C3D3 = 60.5	3%

Table 5.7 experimental and optimal result of MRR and HARDNESS

So we can say that there is 14% improvement in MRR and also hardness reduce with improvement of 3%.

CHAPTER-6

MATHEMATICAL MODELLING

6.1 INTRODUCTION TO REGRESSION ANALYSIS

The term multiple *regression* literally means stepping back toward the average. It was use by British mathematician Sir Francis Galton .Regression analysis is a mathematical measure of the of the average relationship between two or more variables in terms of the original units of the data. In regression analysis there are two types of variables. The value whose value is influenced or is to be predicted is called *dependent variable* and the variable which influences the values or is to be used for prediction is called *independent variable.* Regression analysis can be done in two ways;

- **Bivariate regression**
- **Multiple regression**

6.1.1 BIVARIATE REGRESSION:

Two variables X and Y may be related to each other or inexactly. In physical sciences, variables frequently have an exact relationship to each other. The simplest relationship can be expressed by

$$Y=a+bX$$

Where the values of the coefficient, **a** and **b,** determine respectively the precise height and steepness of the line. Thus coefficient *a* represent to as the *intercept* or constant, and coefficient *b* referred to as the *slope.*

In contrast, relationship between variables in social sciences is almost always inexact. The equation for a linear relationship between two social science variables would be written as:

$$Y=a+bX+e$$

Where *e* represents the presence of error

6.1.2 The least Squares Principle

In postulating relationship among social science variables, we commonly assume linearity. Of course this assumption is not always correct. Least square principle tells us or identified best line which can fit the model for example. The question arises out of all possible line we should choose. From the scatter plot we will calculated prediction error is calculated as:

Prediction error = observed error - predicted

Summing the prediction error for all observation would yield a total prediction error (TPE), total prediction error = (+3-3+4) = 4

$$b = \frac{\sum(X_i - \bar{X})(Y_i - \bar{Y})}{\sum(X_i - \bar{X})^2}$$

$$a = \bar{Y} - b\bar{X}$$

These values of a and b are our least square estimates

As we know **MULTIPLE REGRESSON ANALYSIS** is use when more than two parameters are used .in my thesis there are 4 parameters so I will consider multiple regression analysis. In multiple regressions analysis linear equation is given by:

$$y = a + bx_1 + CX_2 + \cdots NX_3$$

Where b, c etc are called partial slope .Some terms which are considered in multiple regressions are discussed below:

6.1.3 SAMPLING ERROR

When estimating a population parameter from a sample it is important not only to derive a specific value but also estimate the effect of the sampling error on the estimate. To accomplish this it is necessary to consider the concept of a sampling distribution for a regression coefficient. This could be easily understood as the distribution of estimates of the regression coefficient that would be result if sample of given size were drawn repeatedly from the population and coefficient calculated from each sample .Because coefficient estimated from random samples will deviate from populations values by varying amounts, the estimates , the estimates of the coefficient from a series of random samples of population will not be identical but instead will distribute themselves around a mean . the estimated standard deviation of the sampling distribution of a regression coefficients is known as a *standard error* and is denoted by '*s'*.

6.1.4 R^2

This is called ***coefficient of determination*** indicates explanatory power of any regression model. Its value lies between +1 and 0. It can also been shown that R –sq is the correlation between actual and predicted value. It will reach maximum value when dependent variable is perfectly predicted by regression equation.

6.1.5 MULTICOLLINEARITY

Multicollinearity means that none of that independent variable or linear variable is perfectly correlated with another independent variable or linear combination of other independent variable .In multiple regression if there is collinearity among variables , then regression surface not even define (because in multiple regression instead of two plane we will consider multiple plain) as there are infinite number of surface that fit the observation equally well and there fore it is impossible to drive unique estimates of the intercepts and partial slope coefficient for the regression

6.1.6 RESIDUAL ANALYSIS

The prediction errors from a regression model are also called residuals. Analysis of these residuals can help us to detect the violations of certain regression assumption. It helps us to identify OUTLIERS and to improve the model.

In my thesis work i try to compare between linear equation and polynomial equation with the help of RESIDUAL ANALYSIS and R-sq value. Model which will have less outliers and higher R-sq will be final model for MRR and hardness. For this I will again take the help of MINITAB 15

6.2FIRST ORDER LINEAR MODEL

With the help of Minitab 15 I developed polynomial model and also residual analysis as per given outputs

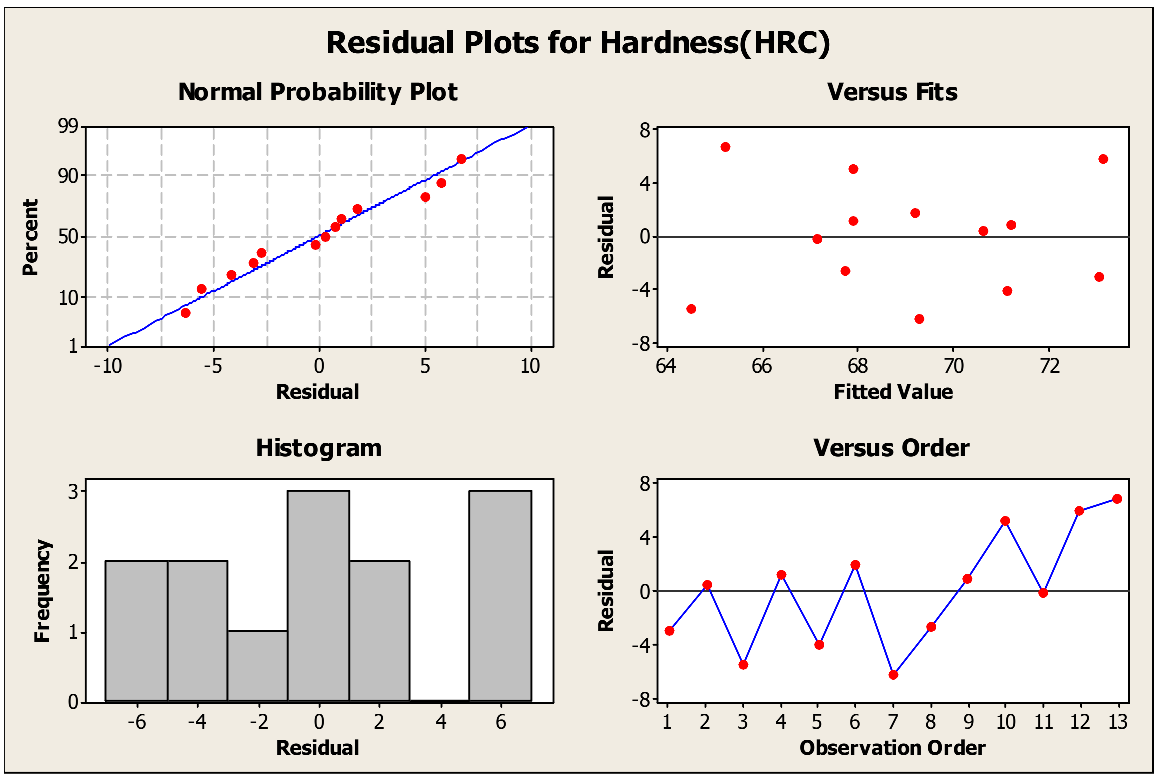
The regression equation of hardness is

Hardness (HRC) = 71.7 - 0.39 A + 10.5 B - 2.80 C - 3.0 D

S = 5.18868 R-Sq = 28.9% R-Sq (adj) = 0.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	87.54	21.89	0.81	0.551
Residual Error	8	215.38	26.92		
Total	12	302.92			



Graph 6.1 Residual analysis of hardness of first degree polynomial equation

With the help of Minitab 15 polynomial equation of first order MRR developed

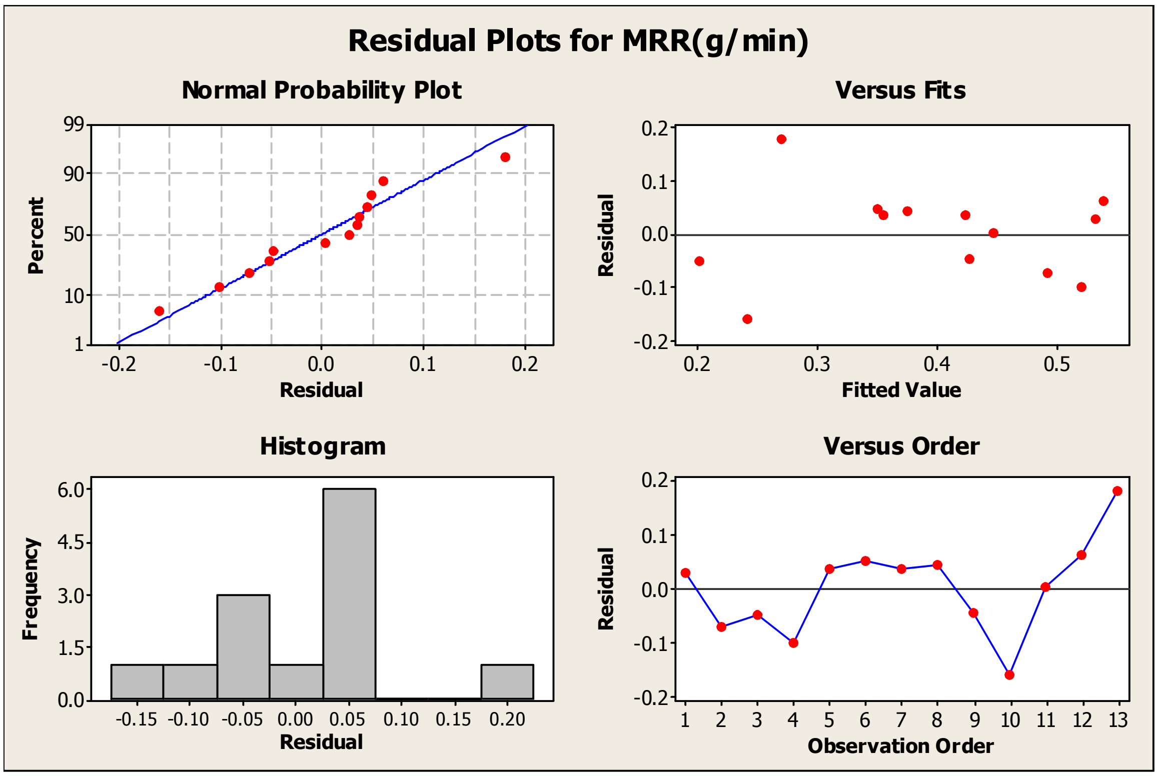
The regression equation of MRR

MRR (g/min) = - 0.089 - 0.0703 A + 0.716 B - 0.0441 C + 0.024 D

S = 0.106255 R-Sq = 62.5% R-Sq (adj) = 43.7%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	0.15045	0.03761	3.33	0.069
Residual Error	8	0.09032	0.01129		
Total	12	0.24077			



Graph 6.2 Residual analysis of MRR of first degree polynomial equation

6.3 SECOND ORDER LINEAR EQUATION

With the help of MINITAB 15 I developed second order polynomial equation and residual model both for MRR and HARDNESS

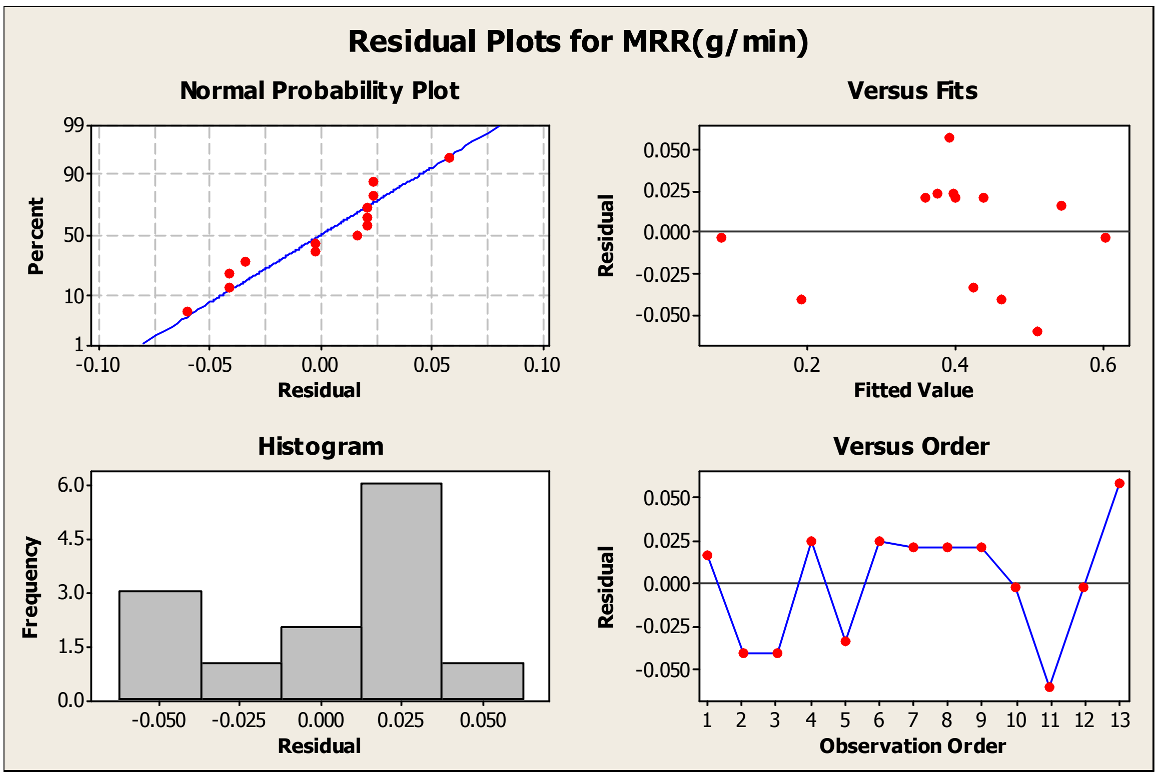
The regression equation MRR

MRR (g/min) = - 14.7 + 0.999 A + 23.4 B - 1.71 C + 4.85 D - 0.126 A2 - 8.21 B**2 + 0.167 C**2 - 6.16 D**2**

S = 0.0602136 R-Sq = 94.0% R-Sq (adj) = 81.9%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	8	0.226267	0.028283	7.80	0.032
Residual Error	4	0.014503	0.003626		
Total	12	0.240769			



Graph 6.3 residual analysis of MRR of second order degree polynomial equation

The regression equation of hardness is

Hardness (HRC) = 484 - 2.7 A - 697 B + 3.2 C + 305 D + 0.30 A2 + 259 B**2**

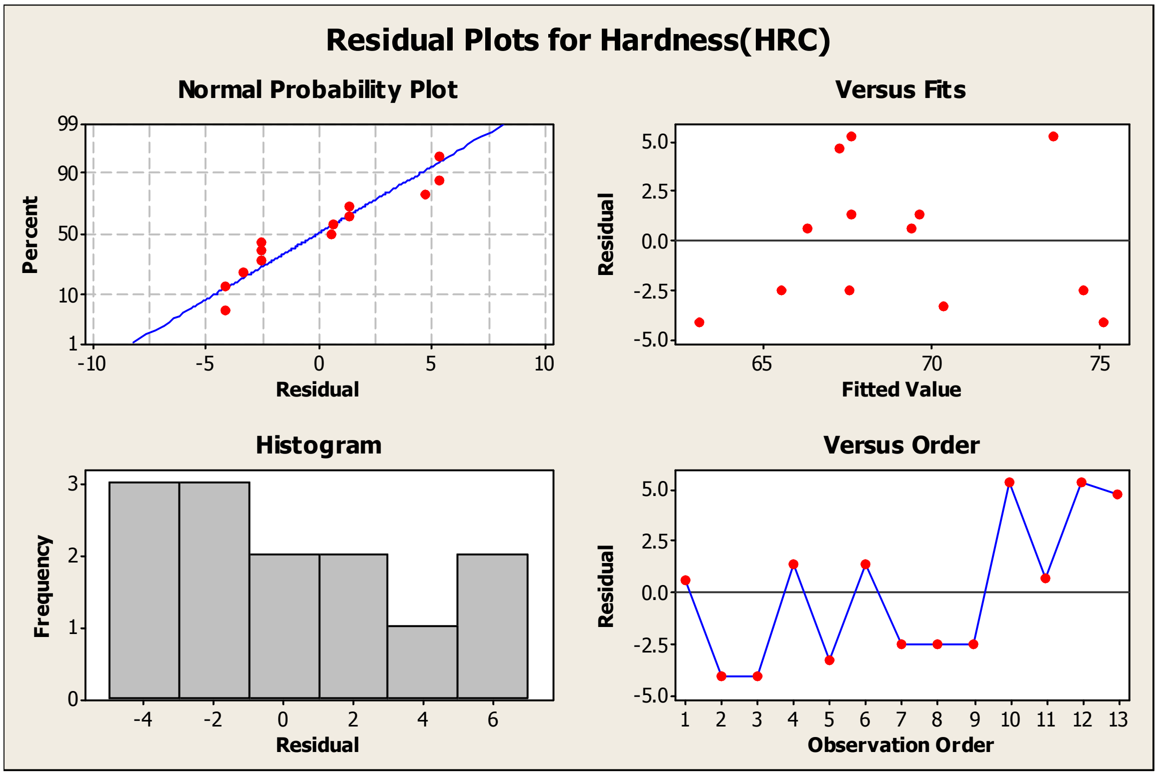
- 0.65 C2 - 385 D**2**

S = 6.09349   R-Sq = 51%   R-Sq (adj) = 0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	8	154.40	19.30	0.52	0.800

Residual Error	4	148.52	37.13
Total	12	302.92	



Graph 6.4 residual analysis of hardness of second degree polynomial equation

Now question arises that which model is perfect? There are two ways to solve this problem (1) **estimated standard error** (2) **coefficient of determination**

6.4 ESTIMATED STANDARD ERROR

For hardness: In linear equation of first degree an estimated of the error variance σ^2 is s^2 = 26.92 located in the analysis of variance at the interaction of error and MS. An estimate of σ, the standard deviation of the random variable is s = 5.18868. We expect the model to predict the percentage correct to within 2s or approximately 10 percentage points of true value

In second order equation of hardness an estimated of the error variance σ^2 is s^2 = 37.13 located in the analysis of variance at the interaction of error and MS An estimate of σ, the standard deviation of the random variable is s = 6.09349 or approximately 13 percentage points of its true value . This is not improvement

For MRR: In linear equation of first degree an estimated of the error variance σ^2 is s^2 = .01129 located in the analysis of variance at the interaction of error and MS. An estimate of σ, the standard deviation of the random variable is s = 0.16225 we expect the model to predict the percentage correct to within 2s or approximately 32 percentage points of true value

In second order equation of hardness an estimated of the error variance σ^2 is s^2 = 0.003626 located in the analysis of variance at the interaction of error and MS An estimate of σ, the standard deviation of the random variable is s = 0.0602136 or approximately 12.04 percentage points of its true value. Which is very much improvement

6.5 COEFFICIENT OF DETERMINATION

1.*For hardness :* if we compare R-sq of first order and second order then we will observe that R-sq of second order is **51%** while that of first order is **28.9%** .So there is very much improvement in R-sq . As already stated R-sq predicted power of fitness of model

2.*For MRR :* again if we compare R-sq of first order and second order then we will observe that **R-sq** of second order is **94%** as compare to **62.5%** of first order which is very much improvement in our model

R-sq is very strong factor to select any model .On the basis of that the model for MRR and hardness must be of second order .But there are some other factor which should keep in mind.

(1)Value of R-sq will increase if we increase parameters in equation .This can misguide us to take decision .Because there are some factor which can be add unnecessarily

(2)Consider the value of‘s’. In HARDNESS we can see there is no improvement in’s’ which again doubt whether we select second order equation or not? For this we perform RESIDUAL ANALYSIS

Residual analysis are to determine whether regression model is misspecified , whether there are unusual observation or outliers .The model assume that errors are independent and probability of distribution is normal with zero mean and constant variance.

6.6 CONCLUSIONS OF RESIDUAL ANALYSIS

HARDNESS: If we compare residual analysis for hardness between first order equation and second order equation then we will observe that both are following curvilinear but first order is in somewhat in better condition as compare to first order.

MRR: if we compare residual analysis for MRR between first order and second order equation then we will observe that second order following better trend as compare to first order .In second order there is less outliers as compare to first order .also histogram is approximately follows normal distribution as compare to first order

So finally our regression model for MRR is second order and HARDNESS is of first order .But if we see **P value in ANOVA table then we will observe that it is less than 0.05 which means our p value doesn't consider this model significant. According to me to get better model we need bigger sample size and some more parameters to be consider which were not consider in above experiment. But there is no multicollinearity in any model.**

6.7 FUZZY LOGIC

Fuzzy logic was first initiated by **Lotfi A .Zadeh** a professor of computer science at university of California, Berkley. Fuzzy logic tell value between True and False for example we know in computer science or in automation '0' and '1' are use for higher and lower value .But with the help of fuzzy logic we can find the value in between '0' and '1' .It work on human communication .He presented the concept of human approximate reasoning to make effective reasoning on the basis of available linguistic information. Fuzzy logic is made in such a way that it can accept all noise, imprecise input and easy to implement. Here Fuzzy logic is solved by MATLAB software. Till now we not getting that which value of MRR and HARDNESS is low and large .So we will use fuzzy logic which will improve optimum condition of MRR and HARDNESS.

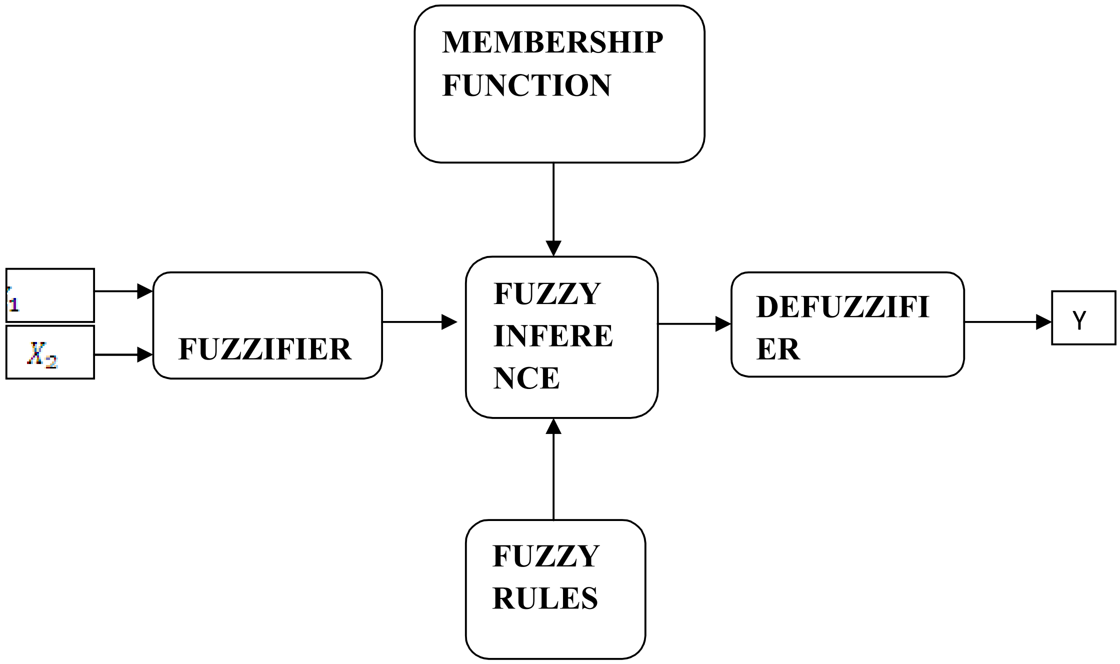


Figure 10.1 Block diagram of fuzzy inference system

Above block diagram represent the tools which are used in fuzzy logic. X_1 and X_2 are S/N ratios of MRR and HARDNESS which were obtained by orthogonal array and 'Y' is multi response performance index which is obtained after defuzzification

6.7.1FUZZYSETS

Fuzzy logic begins with fuzzy sets .Earlier there was a classical set which have a fixed value for but fuzzy sets can have partial value which tells us value at any instant. That is member of set can lie within a boundary or at a boundary. Fuzzy sets are made to make computer more logically initially there were two values 0and 1 .For example we can say person is tall and small if its height is 6 feet and 4 feet .But by this we doesn't comes to know if any person having height 5.5 feet then at which category he will be . Here we are using three fuzzy sets for MRR and HARDNESS

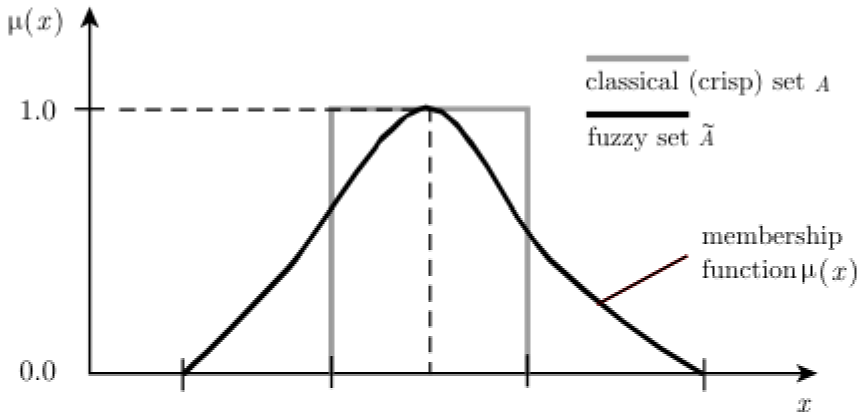


Figure 6.2 Difference between classical and fuzzy set

6.7.2 MEMBERSHIP FUCTIONS

These are represent by $\mu A(x)$ .It is defined how inputs point are mapped between 0 and 1. From above we can see the example of membership function. Membership function can represented either by *triangular, trapezoidal or by generalized bell curve*`. After extensive literature review in my work I prefer trapezoidal curve whose figure given below

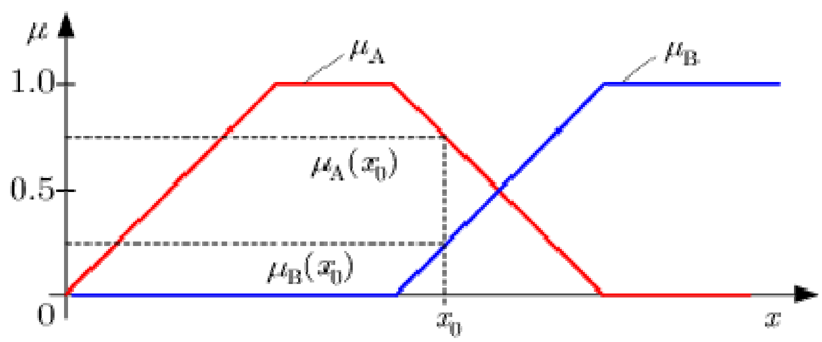


Figure 6.3 Trapezoidal form membership functions

Formula which will be used for formation of trapezoidal curve will be :

$$f(x,a,b,c) = \begin{cases} \frac{x-a}{b-a} a \le x \le b \\ 1, b \le x \le c \\ \frac{d-x}{d-c}, c < x \le d \\ 0, x > d \end{cases}$$

6.7.3 FUZZY RULES

Fuzzy use if then rules for example in our daily life we use to say that if temperature is more then 35 degree Celsius then it is hot . If then rules are use in same way as in C language .it consists of two input X_1 and X_2 and one output. The following nine fuzzy rule will be used:

Rule 1: if x_1 is A_1 and x_2 is B_1 then y is C_1 else

Rule 2: if x_1 is A_2 and x_2 is B_2 then y is C_2 else

:

Rule n: if x_n is A_n and x_n is B_n then y is C_{2n} else

6.7.4 FUZZY INFERENCE

Fuzzy inference is the process of formulating and mapping given input to an output using fuzzy logic. Fuzzy inferences are of two types: *MAMDANI TYPE* and *SUGENO TYPE.* In my thesis work and after literature review I prefer *mamdani* type inference .After fuzzifing the given inputs as per appropriate membership function we will get the result in between 0 and 1. We use some *LOGICAL OPREATIONS* like 'AND' 'OR' operations. In my thesis work I used AND operations which combine two antecedent.

Every statement has antecedent and consequent .For example ***if there is humidity*** then ***there will be rain.*** Here sentence is divided into two portion , portion before word 'then' is ANTCDENT and after 'then is COSEQUENT . So consequent is reshape after implications

6.7.5 DEFUZZIFICATION

It is a last step where output of fuzzy inference act as input to defuzzification .We can say that it gives us single value of aggregations of all outputs. in my thesis work CENTROID method has been used

6.8 MEMBERSHIP FUNCTION OF HARDNESS

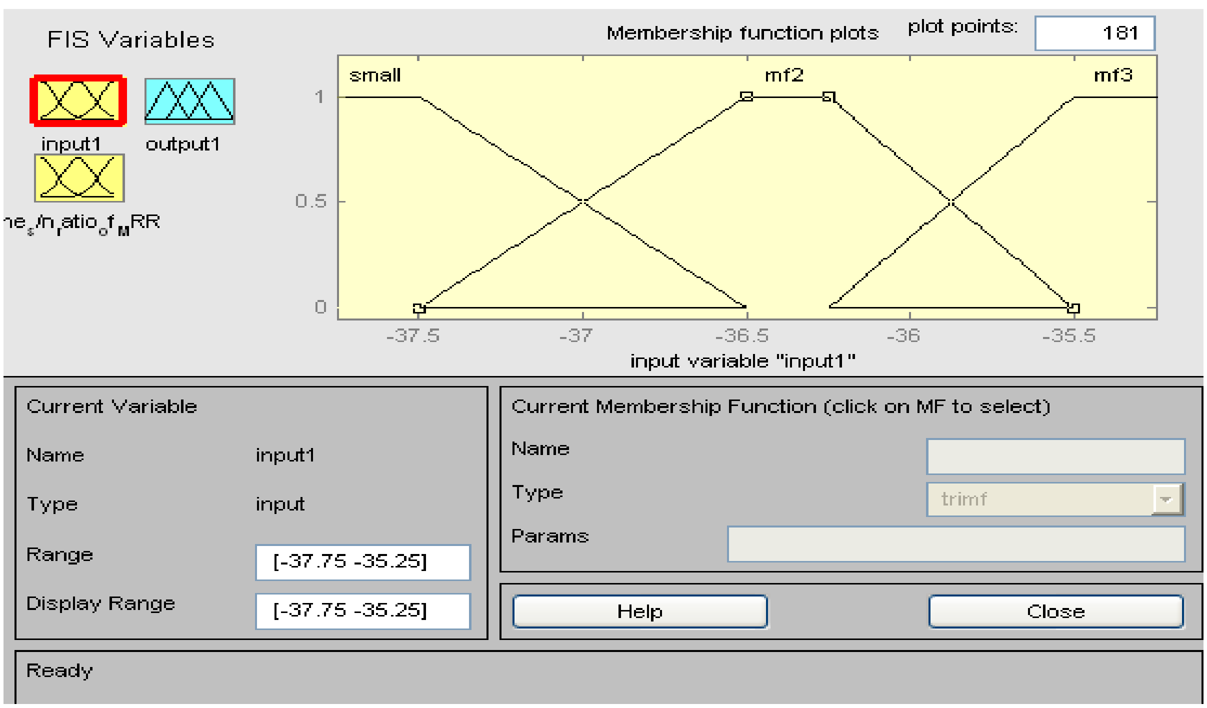
By using the formula of trapezoidal membership we obtain following outputs

$$Small = \begin{cases} 1 \; when \; x \leq 37.5 \\ \frac{-36.5-x}{-36.5+37.5} \; when -37.5 < x < -36.5 \\ 0 \; when \; x \geq -36.5 \end{cases}$$

$$Middle = \begin{cases} 0 \; when \; x \leq -37.5 and x \geq -35.5 \\ \frac{x+37.5}{-36.5+37.5} \; when -37.5 < x < -36.5 \\ \frac{-35.5-x}{-35.5+36.25} \; \text{when} -36.25 < \text{x} < -35.5 \\ 1 \; when -36.5 \leq x \leq -36.25 \end{cases}$$

$$Large = \begin{cases} 0 \; when \; x \leq -36.25 \\ \frac{x + 36.25}{-35.5 + 36.25} \; when - 36.25 < x < -35.5 \\ 1 \; when \; x \geq -35.5 \end{cases}$$

Now by using the S/N ratio obtained for HARDNESS will be kept in all above equation and then with the help of MATLAB software we will develop following membership function of HARDNESS as shown below:



Graph 6.5 membership functions of HARDNESS

6.9 MEMBERSHIP FUNCTIONS OF MRR

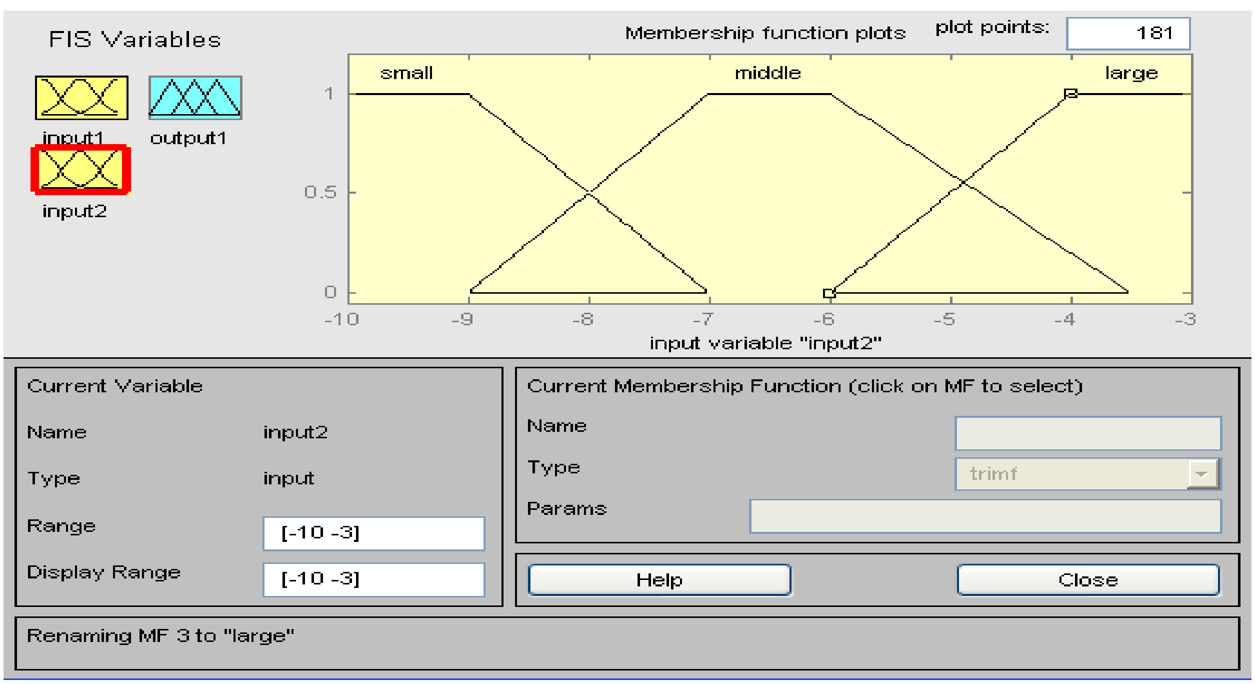
By using the formula for trapezoidal membership we obtain :

$$Small = \begin{cases} 1 \; when \; x \leq -9 \\ \frac{-36.5-x}{-36.5+37.5} \; when -9 < x < -7 \\ 0 \; when \; x \geq -7 \end{cases}$$

$$Middle = \begin{cases} 0 \; when \; x \leq -9 and x \geq -4 \\ \frac{x+9}{-7+9} \; when -9 < x < -7 \\ \frac{-4-x}{-4+6} \; when -6 \leq x \leq -4 \\ 1 \; when -7 \leq x \leq -6 \end{cases}$$

$$Large = \begin{cases} 0 \; when \; x \leq -6 \\ \frac{x+6}{-4+6} \; when -6 < x < -4 \\ 1 \; when \; x \geq -4 \end{cases}$$

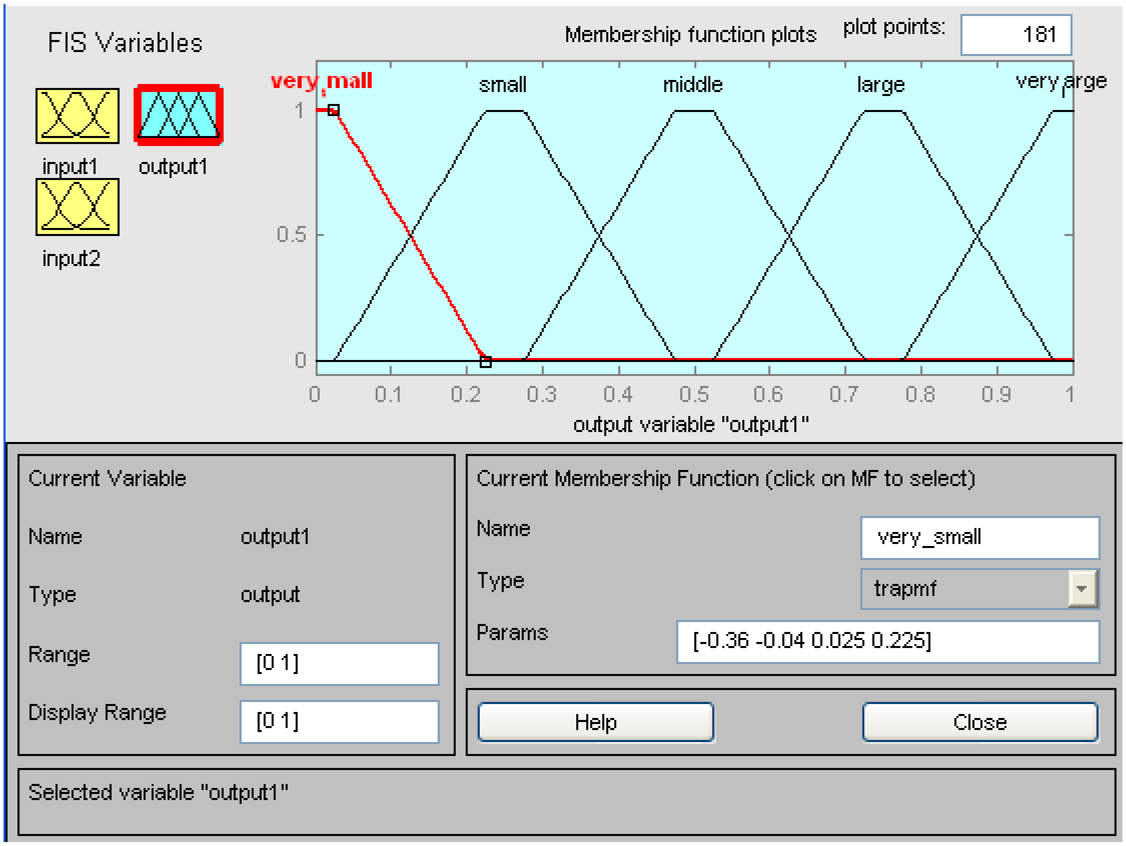
Now by using the S/N ratio obtained for MRR will be kept in all above equation and then with the help of MATLAB software we will develop following membership function of MRR as shown below:



Graph 6.6 Membership functions of MRR

6.10 MEMBERSHIP FUNCTION OF MULTI RESPONSE PERFORMANCE INDEX

Membership function of multi response performance index is use to defuzzifcation. The following figure is MRPI



Graph 6.7 Membership function of multi response performance index

Rules which are used to define relation between antscedent and consequent are:

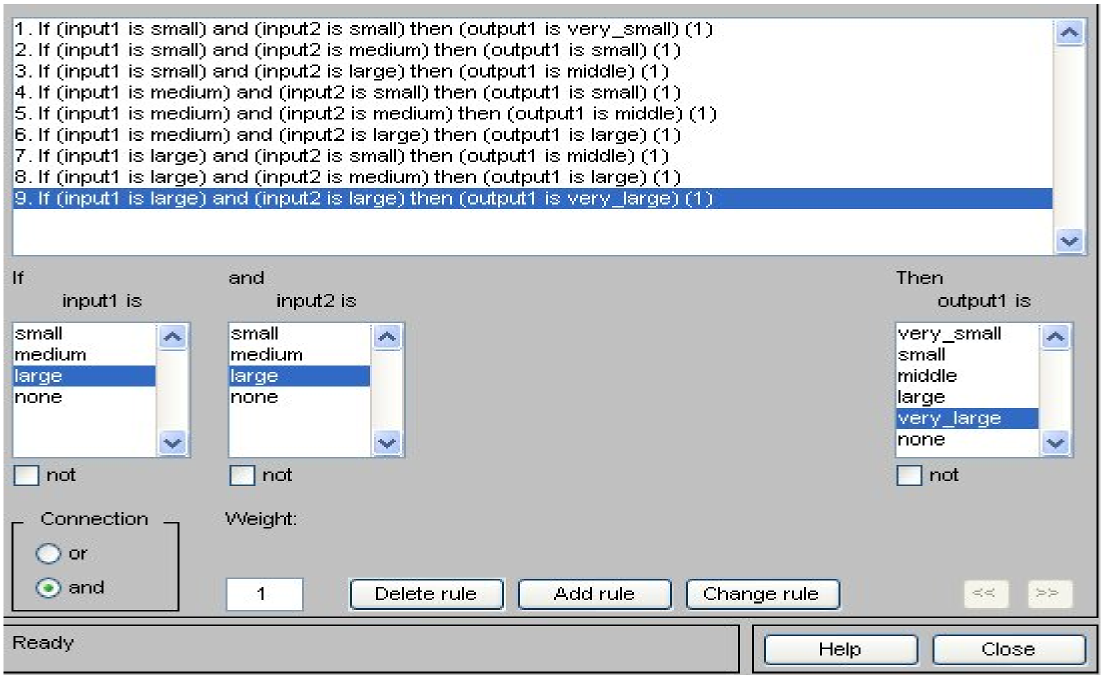


Figure 10.4 rules for membership function

Here weightage of each rule is equal that is one. After we will apply centroid method for defuzzification .The window below represent using MATLAB for defuzification

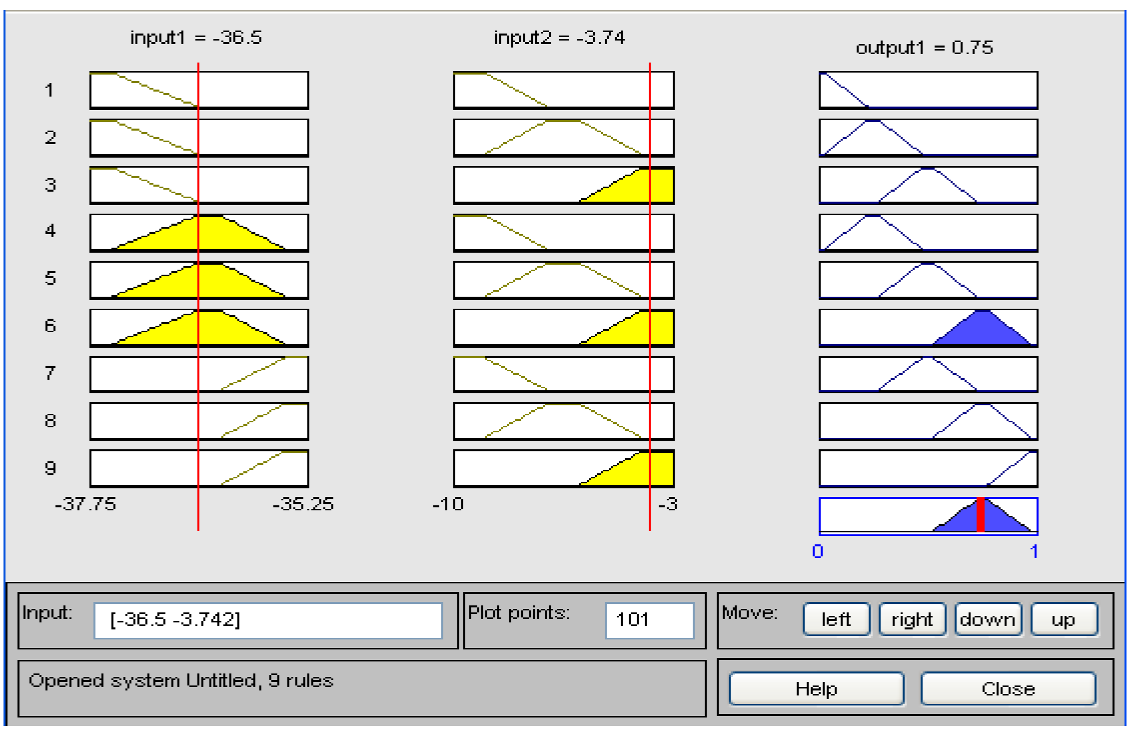


Figure10.5 example of defuzzification

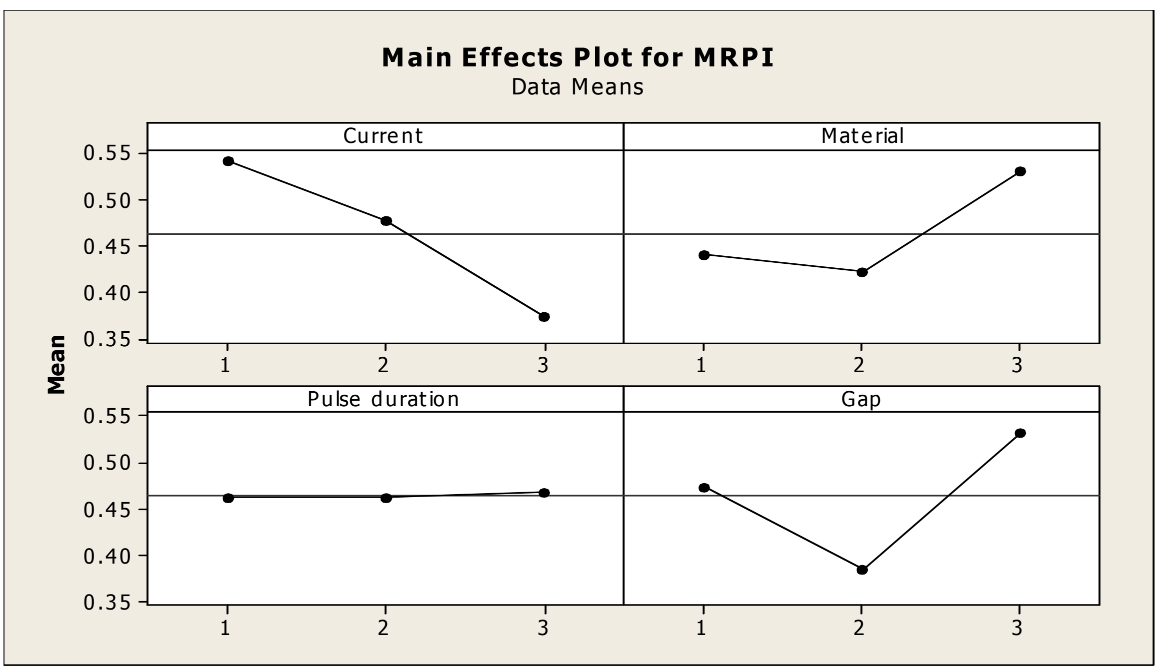
From this we will obtain following MRPI

S.no	MRPI
1	0.513
2	0.353
3	0.500
4	0.403
5	0.356
6	0.333
7	0.593
8	0.425
9	0.293
10	0.160
11	0.493
12	0.437
13	0.343
14	0.672
15	0.743
16	0.500
17	0.588
18	0.646

Table 6.1 MRPI table

6.11 EXPERIMENTAL RESULTS FOR MRPI

By using minitab software we generate following main effect plot for MRPI



Graph 6.8 Main effect plot for MRPI

From above graph we conclude that value of current is decreasing also again EN353 shows good characteristic on MRPI .But pulse duration make very little effect. From above we can say that optimum value of MRPI is A1B3C3D3 because as much higher the value of MRPI smaller variation of performance characteristic around target value.

6.12 ANOVA for MRPI

Anova is use to determine which process parameter is significantly effect the process

PARAMETER	SS	DOF	VARIANCE	F TEST	F CRITICAL	C%
CURRENT	0.017	2	0.0085	0.249	4.26	3.408
MATERIAL	0.0412	2	0.0206	0.60	4.26	8.25
PULSE DURATION	0.0001	2	0.00005	0.0014	4.26	0.02
GAP	0.0651	2	0.003255	0.09	4.26	13.05
ERROR	0.3754	11	0.03412			75.2
TOTAL	0.4988	19				100
E POOL		19				

Table 6.2 ANOVA for MRPI

Again our anova table is not supporting any process parameter.

6.13 CONFIRMATION TEST

The mean of the multi response performance index is summarized and called multi response performance table.

PARAMETER	LEVEL 1	LEVEL 2	LEVEL 3	Max-min
CURRENT	**0.5055**	**0.4546**	**0.4316**	**0.0739**
MATERIAL	**0.4398**	**0.4211**	**0.4475**	**0.01787**
PULSE DURATION	**0.4618**	**0.4616**	**0.4683**	**0.0067**
GAP	**0.4638**	**0.3858**	**0.5321**	**0.1463**

Table 6.3 mean of multi response performance index

Mean of MRPI = 0.4636

The optimum value can be obtained by following equation

$$\eta_{opt} = \eta_m + \sum_{i=1}^{o} (\overline{n_i} - \eta_m)$$

Where $\boldsymbol{\eta_m}$ is mean value of MRPI and $\overline{\boldsymbol{\eta}}_{\mathbf{i}}$ is mean of factor at optimal level

Optimum value of MRPI =

$$\mathbf{0.4636 + (0.5055 - 0.4636) + (0.4475 - 0.4636) + (0.4683 - 0.4636) + (0.532 - 0.4636)}$$

= **1.4897**

CHAPTER-7

RESULTS AND CONCLUSION

7.1 SUMMARY

Objective of this study is to find out optimal condition of EDM for batch production. For thisEN24, EN353,EN19 are considered which are easily and cheaply available in market mechanical properties are given in appendix B .Machining process is carried out EDM machine of model number T 3822 which is available in non traditional lab of mechanical department of Thapar University . I considered MRR and HARDNESS as two most important outputs. Dielectric fluid is kerosene which is readily available in market and also highly machining characteristic. As per literature review current, material, pulse duration and gap were considered important parameter. In order to perform minimum experiment Taguchi method has been employed .For this L18 orthogonal array is considered .Experiment results and various response graph for MRR and HARDNESS were obtained and there optimum value were also considered. In chapter 6 mathematical modeling were done .For this I consider **regression analysis** and **fuzzy logic.** Mathematical equation both for hardness and MRR were obtained by regression analysis where as fuzzy logic is use to understand simultaneously effect of MRR and HARDNESS on EDM.

7.2 RESULTS

- Parameters are not making any significant on determining optimum parameter. EN353 is shown very good characteristic. So EDM controls can be set as per EN 353
- Although parameters are not significant but we able to improve MRR and HARDNESS.
- Mathematical modeling of second order for MRR was showing good result where as per residual analysis first order equation is suitable for hardness
- With the help of fuzzy logic able to get one optimum value both for MRR and hardness but still parameter are not significant

- With help of fuzzy logic we observed from main effect plot that pulse duration is vey linear .But again EN353 is good material for machining.

7.3 CONCLUSION

Form this study it is concluded that how to set optimum condition in industry especially in batch production .EN353 is showing good characteristic. But from ANOVA we can say parameters are not making any significant effect .This is because we must take large number of observation either by considering L27 0r L32 orthogonal array. EN353 showing good characteristic in terms of hardness and MRR. Mathematical equation especially for MRR of second order is of R-sq of 94% which is acceptable. Form this study it is also clear that every time second order equation is not suitable as in the case of hardness where after residual analysis it is clear that first order equation is also acceptable. Application of fuzzy logic was really helpful to determine one optimum value of MRR and HARDNESS. But it was complicated as compare to direct taguchi method.

7.4 LIMITATIONS

- Current value was kept only 4, 5, and 6 ampere but form control its value can vary for 0 to 12 ampere but because of security point of reason its value was kept low.
- Polarity was kept constant that is work piece was as anode and tool as cathode.
- Pulse on time was kept at knob position of 3, 4 and 5 but large range of pulse on time was available.
- Kerosene was only dielectric which was use but there are wide variety of dielectric fluid are available in market.
- Copper tool was used but other tool materials are also available.

7.5 SCOPE OF FUTURE WORK

- Other parameter like flushing etc can be considered and also under presence of some expert we can change polarity.
- Since we are using different materials as one parameter so we must know what other effective dielectric are are available like water etc.

- No interaction is consider so we can consider interaction by applying L27 or L32 this will improve optimum condition as compare to L18 considered in this work.
- Also side clearance and thermal effect on material and work piece can also be considered to study the effect on properties of work piece and tool.
- Other modeling method like genetic algorithm, artificial neural network can also apply.
- Like in this work I considered En series materials but we can perform work on composite and welded materials

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Appendix A

Technical data of EDM

1. Electrical data	
Type	M
Supply volts	415 V,3ϕ,50hz
Mains voltage tolerance	$\pm$10 %
Connected Load (KVA)	3
Power Factor	Approx. 0.8
2. Working parameters	
Machine current maximum (A)	12
Open gap output voltage (V)	135$\pm$5%
Rotary switch Current Range	3 ranges of 4 Amp. each
Rotary knob current adjust	Fine current adjustment from 0-4 Amperes in each current range
Pulse Duration	2 μ s to 650 μ s
Height	1000 mm
Width	550 mm
Depth	690 mm
Weight	135 kg

Appendix B

Properties of EN24, EN19, EN353

COMPOSITION (%)	EN24	EN19	EN353
Carbon	0.35-0.45	0.35-0.45	1.20 max
Silicon	0.10-0.35	0.10-0.35	1.35 max
Magnese	0.45-0.70	0.50-0.80	0.50-1
Sulphur	0.05 max	0.05 max	0.05max
Phosphorus	0.05 max	0.05 max	0.05 max
Chromium	0.90-1.40	0.90-1.50	0.75-1.25
Nickel	-	1.3-1.8	1-1.5
Molybdenum	0.20-0.40	0.20-0.35	0.08-0.15

Appendix C

Properties of Kerosene

Boiling point	150℃
Melting point	20℃
Relative density (water)	1:0.8
Solubility in water	Insoluble
Relative vapour density (air)	1:4.5
Flash point	37-65℃
Auto ignition temperature	220℃
Explosive limits , volume % in air	0.7-5