

Thesis On
**MODELING, ANALYSIS, EVALUATION, SELECTION
AND EXPERIMENTAL INVESTIGATION OF EDM PROCESS**

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IN

PRODUCTION AND INDUSTRIAL ENGINEERING

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DECLARATION

I hereby declare that the thesis entitled “**MODELING, ANALYSIS, EVALUATION, SELECTION AND EXPERIMENTAL INVESTIGATION OF EDM PROCESS**”, submitted in partial fulfillment of the requirements for the award of degree of Master of Engineering in Production Engineering submitted in Mechanical Engineering Department of Thapar University, Patiala, during July 2012 to July 2013 is an authentic record of my own work carried out under supervision of Dr. V.P. Agrawal and refers other researcher’s works which are duly listed in reference section. The matter presented in this seminar report has not been submitted for the award of any other degree of this or any other university.

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Abstract

Electrical discharge machining (EDM) is one of the earliest non-traditional machining processes. EDM process is based on thermoelectric energy between the work piece and an electrode. A pulse discharge occurs in a small gap between the work piece and the electrode and removes the unwanted material from the parent metal through melting and vaporizing. The electrode and the work piece must have electrical conductivity in order to generate the spark. There are various types of products which can be produced using EDM such as dies and moulds. Parts of aerospace, automotive industry and surgical components can be finished by EDM. This study presents a methodology for evaluation, ranking and selection of parameters of Electric Discharge Machine by using MADM approach. A three stage selection procedure is used for identification of pertinent attributes and ranking is done with TOPSIS and graphical methods (Line graph and Spider Diagram). Then results of MADM approach are validated by comparing with results of experimental work done with ANOVA. This study also presents methodology for calculating the permanent function and numerical index of EDM system by dividing EDM into four subsystems and interactions between subsystems are represented into matrix form. This study provides a general formula which can be applied to any EDM system.

Keywords

Electric discharge machining

MADM- TOPSIS approach

Graph Theory

Table of Contents

	Page No.
Certificate	ii
Acknowledgement	iii
Abstract	iv
List of figures	ix
List of tables	x
Abbreviations	xi
Chapter 1 : Introduction	1
1.1.Electrical discharge machining	2
1.2.Principal of EDM	3
1.2.1.Phenomenon of material transfer	4
1.3.Process parameters	8
1.3.1.Discharge voltage	8
1.3.2.peak current	8
1.3.3.Pulse On-time and Off-time	9
1.3.4.Polarity	10
1.3.5.Electrode gap	10
1.3.6.Frequency	10
1.4. Dielectric fluids	11
1.5. Flushing	11
1.5.1.Suction flushing	12
1.5.2.Side flushing	12
1.5.3.Flushing by dielectric pumping	12
1.5.4.Injection flushing	12
1.6. Selection of electrode material	12
1.7. Components of EDM	13

1.8. EDM controls	14
1.9. Introduction MADM-TOPSIS approach	20
1.9.1 Methodology of MADM TOPSIS	21
1.10 Introduction to Graph Theoretic Approach	21
1.10.1 Methodology of Graph Theory	22
1.11 Objectives of proposed study	23
Chapter 2 : Literature Review	24
2.1. Categorization of Literature	24
2.1.1. General EDM process	24
2.1.2. According to MADM TOPSIS approach	30
2.1.3 According to Graph Theory	31
2.2. Literature summary	32
2.3. Gaps in Literature	33
Chapter 3 : Attribute based Coding, Evaluation and Optimum Selection of Parameters for EDM System	34
3.1 Introduction of MADM approach	34
3.2 Illustrative Example	40
3.2.1 Identification of EDM attributes	40
3.2.1.1 Cause and Effect Diagram	40
3.2.1.2 Classification of attributes	41
3.2.1.3 Usefulness of attributes	46
3.2.2 Coding Scheme	46
3.2.3 Selection Procedure	54
3.2.4 TOPSIS Method	57
3.2.5 Graphical Technique	58
3.2.5.1 Line Graph	58
3.2.5.2 Spider Diagram	60

3.3 Usefulness of proposed methodology	61
3.4 Discussion	61
3.5 Results	62
Chapter 4: Structural Modelling, Characterization and Integrative Analysis of EDM System	63
4.1 Need for Structural Modeling and Analysis of EDM System	63
4.2 Introduction to Graph Theoretic Approach	64
4.3 Identification of Subsystems of the EDM system and their Interactions	65
4.4 Graph Theoretic Modeling of an EDM System	66
4.5 Matrix Representation for the EDM system Graph	68
4.5.1 EDM system Matrix	68
4.5.2 EDM system Characteristic Matrix	69
4.5.3 EDM system Variable Characteristic Matrix	70
4.5.4 EDM system Variable Permanent Matrix	71
4.6 Development of Permanent Function	72
4.7 Identification and Comparison of EDM System	74
4.8 Generalization of Permanent function	75
4.9 EDM system Analysis	75
4.10 Usefulness of the Methodology	76
4.11 SWOT Analysis	76
4.12 Conclusion	77
Chapter 5 Experimental Set up, Results and Analysis of Results	78
5.1 Introduction	78
5.2 Overall Experimental Design Strategy	78
5.3 Taguchi's Experimental Design and Analysis	79
5.4 Orthogonal Arrays	80
5.5 Analysis of Variance	81

5.6 Experimental Set up	82
5.7 Equipments and Instruments Used	82
5.8 Procedure for Experimentation	83
5.9 Selection of Orthogonal Array & Parameter Assignment	83
5.10 Results for MRR	84
5.11 Analysis of Variance for MRR	85
5.12 Results for TWR	87
5.13 Analysis of Variance for TWR	88
5.14 Results for Surface Roughness (SR)	89
5.15 Analysis of Variance for SR	90
5.16 Pictorial view of work pieces	91
5.17 Conclusion	92
5.18 Comparison with Results of MADM	92
Chapter 6 Conclusion and Future Scope	93
6.1 Conclusion	93
6.2 Future Scope	95
References	96

List of figures

Fig no.	Name of Figure	Page No.
Fig1.1	Basic EDM system	3
Fig1.2	Schematic diagram of working principle of EDM	4
Fig 1.2(a)	First stage of single EDM cycle	5
Fig 1.2(b)	Second stage of single EDM cycle	6
Fig 1.2(c)	Third stage of single EDM cycle	7
Fig 1.2(d)	Final stage of single EDM cycle	8
Fig 1.3	Effects of current on surface	9
Fig 1.4	Concept of pulse on time & pulse off time	9
Fig 1.5	EDM (model T-3822 M)	14
Fig 1.6	Controls of EDM	15
Fig 3.1	Line graph and Spider diagram	39
Fig 3.2	Cause and effect diagram of EDM	40
Fig 3.3	Line graph of EDM Tools	59
Fig 3.4	Spider Graph of EDM tools	60
Fig 4.1	EDM systems & Subsystems	65
Fig 4.2	Schematic representation of EDM	67
Fig 4.3	EDM system Digraph	68
Fig 4.4	Permanent function for EDM	73
Fig 5.1	EDM used for Experimentation	82
Fig 5.2	Plots showing ANOVA for MRR	86
Fig 5.3	Plots for TWR	88
Fig 5.4	Plots for Surface roughness	90
Fig 5.5	D2 Steel Work piece	91
Fig 5.6	D3 Steel Work piece	91
Fig 5.7	H13 Steel Work piece	91

List of Tables

S.no	Name of Table	Page No.
Table1.1	Recommended polarities for different tool-job pairs	10
Table1.2	Performance of several dielectric fluids	11
Table 1.3	Different electrode materials	13
Table 1.4	Ranges of machining Current with respect to switch 8	17
Table 3.1	Process based attributes	41
Table 3.2	Work piece based attributes	42
Table 3.3	Tool & Dielectric based attributes	43
Table 3.4	Analysis based attributes	44
Table 3.5	General attributes	45
Table 3.6	Coding Scheme for attributes	47
Table 3.7	N- digit Coding	47
Table 3.8	Data for Tools	54
Table 3.9	Ranking using TOPSIS Method	58
Table 3.10	Ranking using Line Graph	60
Table 3.11	Ranking using Spider Diagram	61
Table 4.1	SWOT Analysis of EDM	77
Table 5.1	L18 Orthogonal Array used	84
Table 5.2	Results for MRR	85
Table 5.3	ANOVA for MRR	86
Table 5.4	Results for TWR	87
Table 5.5	ANOVA for TWR	88
Table 5.6	Results for SR	89
Table 5.7	ANOVA for SR	90

Abbreviations

EDM	Electric Discharge Machine
MRR	Material Removal Rate
TWR	Tool Wear Rate
SR	Surface Roughness
ANOVA	Analysis Of Variance
OR	Orthogonal Array
MADM	Multi Attribute Decision Making
TOPSIS	Technique for order preference by Similarity to ideal solution.

CHAPTER – 1

INTRODUCTION

Industries like aeronautics, automobiles, nuclear reactors, missiles etc requires materials like high strength temperature resistant alloys which have higher strength, corrosion resistance, toughness and other properties. So it has become essential to develop cutting materials and processes which can safely and conveniently machine such new materials with good productivity, high accuracy. This can be achieved by non conventional methods. These processes do not use cutting tool instead use energy in direct form to remove materials from work pieces. Applications of these processes is determined by work piece properties like electrical and thermal conductivity, melting temperature, electrochemical equivalent etc. [Abbas et al.2007]. These techniques can be classified into 4 categories based on type of energy used, the mechanism of metal removal, the source of energy requirement:

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 . Examples are ultrasonic machining , water jet machining and abrasive jet machining etc .

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 the 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.

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. Examples are electro-chemical machining, electro chemical grinding etc.

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. Examples are chemical machining and photochemical machining.

1.1 ELECTRICAL DISCHARGE MACHINING

Electrical discharge machining (EDM) is a thermal process with a complex metal-removal mechanism, involving the formation of a plasma channel between the tool and work piece. It has proved especially valuable in the machining of super-tough, electrically conductive materials such as the new space-age alloys that are difficult to machine by conventional methods [Kunieda et al.]. 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. This technique has been developed in the late 1940s where the process is based on removing material from a part by means of a series of repeated electrical discharges between tool called the electrode and the work piece in the presence of a dielectric fluid [Abbas et al.2007].

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

- The process can be readily applied to electrically conductive materials. Physical and metallurgical properties of the work material, such as strength, toughness, microstructure, etc., are no barrier to its application.
- During machining, the workpiece is not subjected to mechanical deformation as there is no physical contact between the tool and work. This makes the process more versatile. As a result, slender and fragile jobs can be machined conveniently.
- Although the metal removal in this case is due to thermal effects, yet there is no heating in the bulk of the material.
- Complicated die contours in hard materials can be produced to a high degree of accuracy and surface finish.
- The overall production rate compares well with the conventional processes because it can dispense with operations like grinding, etc.
- The process can be automated easily thereby requiring very little attention from the machine operator.

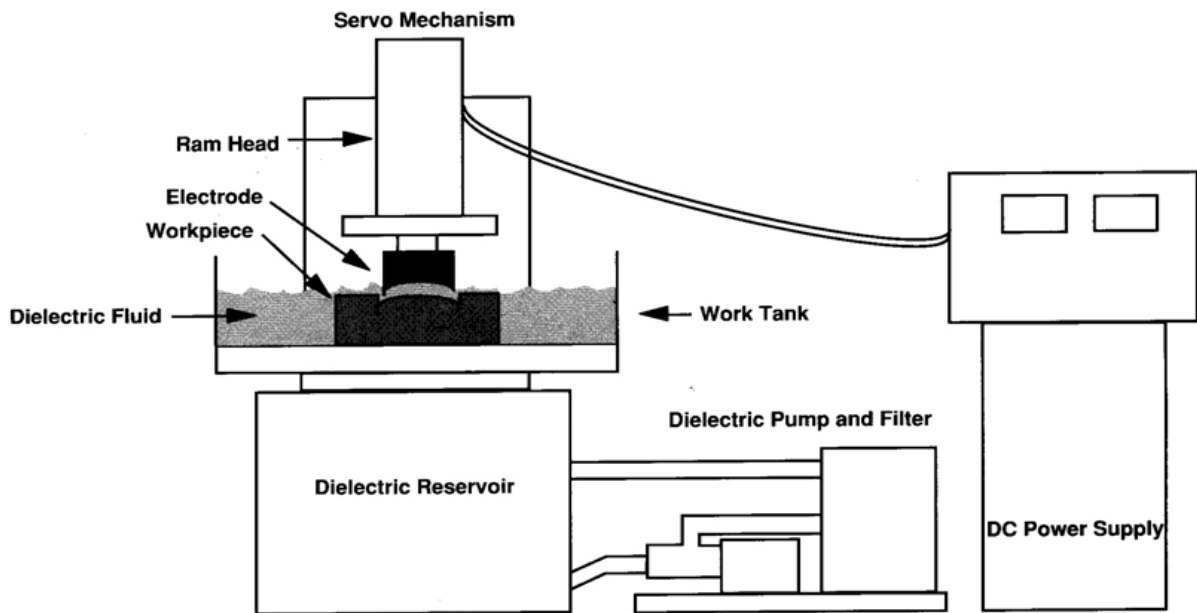


Figure 1.1 Basic EDM System [Kumar, 2008]

1.2 Principle of EDM

Figure 1.1 shows the concept of EDM. Pulsed arc discharges occur in the “gap” filled with an insulating medium, preferably a dielectric liquid like hydrocarbon oil or de-ionized (de-mineralized) water between tool electrode and work piece [Kunieda et al.]. The dielectric medium is used in avoiding electrolysis effects on the electrodes during an EDM process. An offset equal to the gap-size is given to electrode, the liquid should be selected to minimize the gap (10-100 μ m) to obtain precise machining. On the other hand a certain gap width is needed to avoid short circuiting, especially when electrodes that are sensitive to vibration. The ignition of the discharge is initiated by a high voltage, overcoming the dielectric breakdown strength of the small gap. A channel of plasma is formed between the electrodes and develops further with discharge duration. As the metal removal per discharge is very small, discharges should occur at high frequencies (10³ -10⁶ Hz). For every pulse, discharge occurs at a single location where the electrode materials are evaporated and/or ejected in the molten phase. As a result, a small crater is generated both on the tool electrode and work piece surfaces. Removed materials are cooled and resolidified in the dielectric liquid forming several hundreds of spherical debris particles, which are then flushed away from the gap by the dielectric flow.

After the end of the discharge duration, the temperature of the plasma and the electrode surfaces contacting the plasma rapidly drops, resulting in a recombination of ions and electrons and a recovery of the dielectric breakdown strength. The next pulse discharge occurs at a spot distanced sufficiently far from the previous discharge location where the gap is small or contaminated with debris particles which may weaken the dielectric breakdown strength of the liquid. The interval time between pulse discharges must be sufficiently long so that the plasma generated by the previous discharge can be deionized and the dielectric breakdown strength around the previous discharge location can be recovered by the time the next pulse voltage is applied. Otherwise discharges occur at the same location for every pulse, resulting in thermal overheating and a non uniform erosion of the work piece [Kunieda et al.].

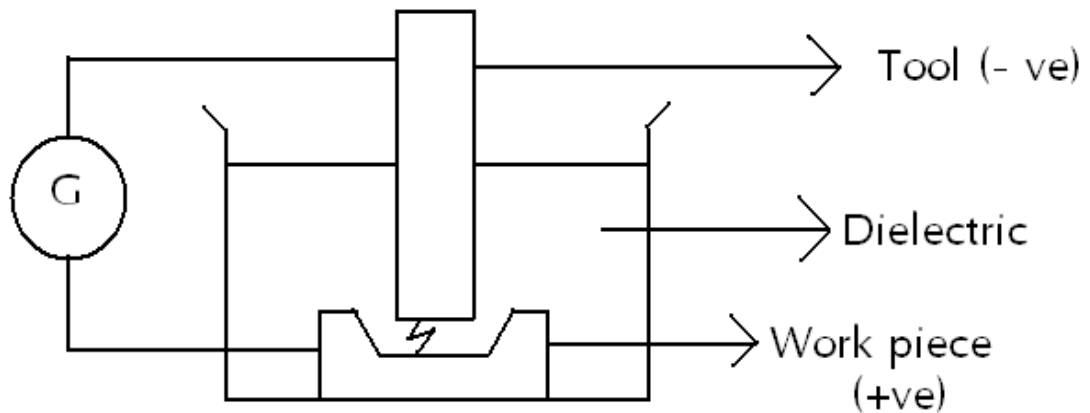


Fig. 1.2 Schematic representation of the working principle of EDM process

1.2.1 Phenomenon of material transfer

The thermoelectric model is mostly used for studying phenomenon of material transfer. The four illustrations given in Fig. 1.2 (a), (b), (c) and (d) show the steps during a single EDM cycle. It also explains how material transfer to the machined workpiece surface may take place from the electrode material or from the dielectric medium or both. The graphs below the illustrations show the relative values of voltage and current at the point depicted.

Stage 1: As the charged electrode is brought near the workpiece, electrical field is strongest at the point where distance between the electrode and workpiece is the least. Even though the dielectric fluid is a good insulator, a large enough electrical potential can cause it to break down into ionic (charged) fragments, allowing an electrical current to pass from electrode to the workpiece. [Kunieda et al.]

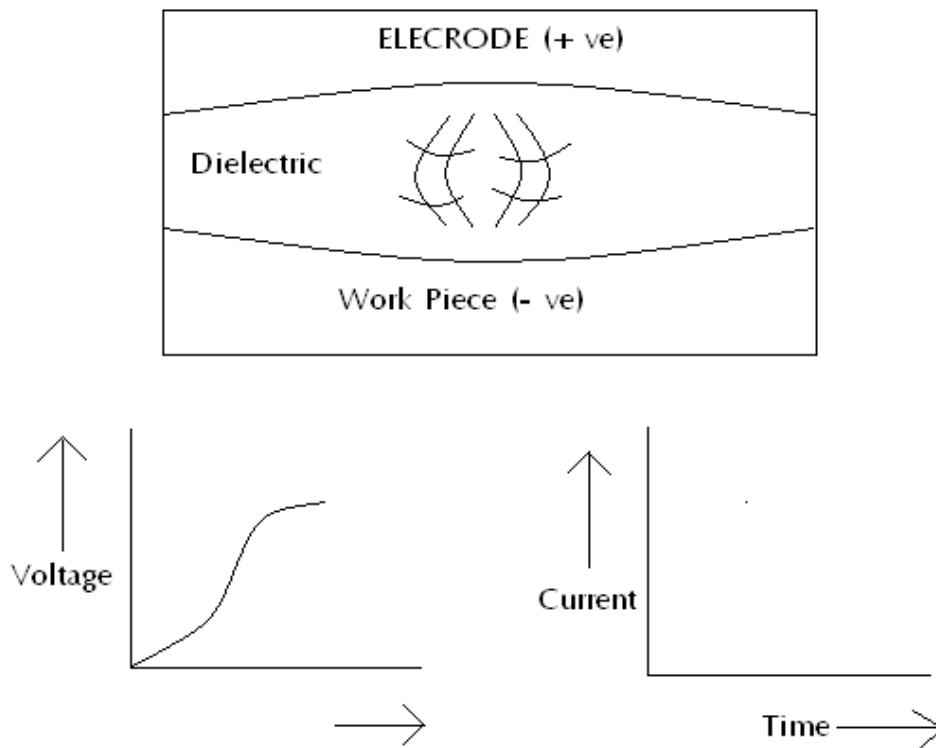


Fig. 1.2 (a) First stage of a single EDM cycle

In Fig. 1.2 (a), voltage is increasing and ionization of the fluid is beginning to happen, but current is still zero. As the voltage reaches its peak, insulating properties of the dielectric fluid begin to decrease along a narrow channel centered in the strongest part of the field. A current is established as the

number of ionic particles increase and the fluid becomes less of an insulator. This stage is depicted in Fig. 1.2 (b).

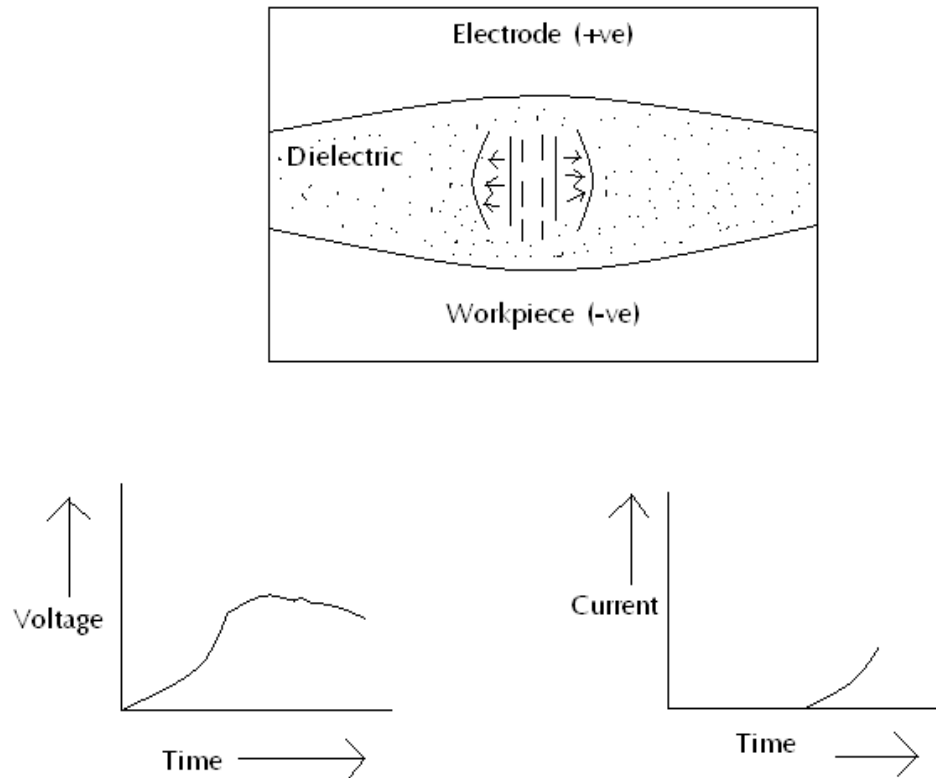


Fig. 1.2 (b) Second stage of a single EDM cycle

Stage 2: Heat builds up rapidly as current increases, and voltage continues to drop. It vaporizes some of the fluid, workpiece and the tool electrode. A discharge channel is formed consisting of superheated plasma made up of vaporized material from the electrode as well as workpiece; and carbon and other elements from the dielectric fluid. This vapour bubble tries to expand outwards, but its expansion is limited by a rush of ions towards the discharge channel. These ions are attracted by the extremely intense electromagnetic field that has built up. Voltage and current stabilizes towards the end of pulse on-time [Fig. 1.2 (c)].

Stage 3: As the off-time starts, heat and pressure within the plasma channel have reached their maximum. The layer of material directly under the discharge column is in the molten state, but is held in place by the pressure of vapor bubble. More material is vaporized from the surfaces of workpiece

and tool electrode. In the super heated plasma, various elements may react with each other or with the carbon to form their carbides.

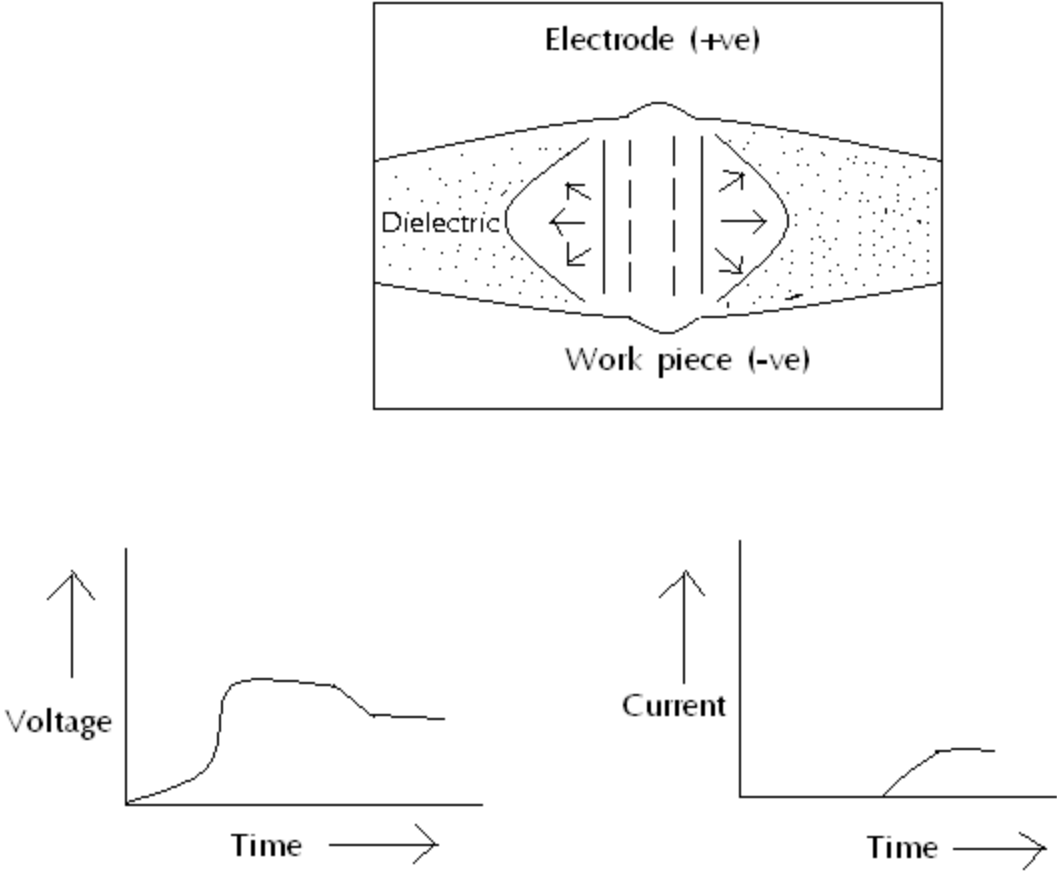


Fig. 1.2 (c) Third stage of a single EDM cycle

Stage 4: As the voltage and current drop to zero, temperature decreases rapidly and the plasma channel collapses, causing the molten material to be taken away by the flowing dielectric [Fig1. 2 (d)]. It is at this stage that some of the elements or their compounds from the plasma channel may get deposited on the workpiece surface under appropriate machining conditions. Fresh dielectric fluid now rushes in, flushing away the debris (particles eroded from the electrodes) and quenching the surface of the workpiece. Without a sufficient pulse off-time, debris may accumulate in the machining area and make the spark unstable. This situation can create a DC arc which may damage the electrode and workpiece surfaces. This complete sequence represents one EDM cycle and the frequency of sparking may be as high as thousands of sparks per second. [Kunieda et al.]

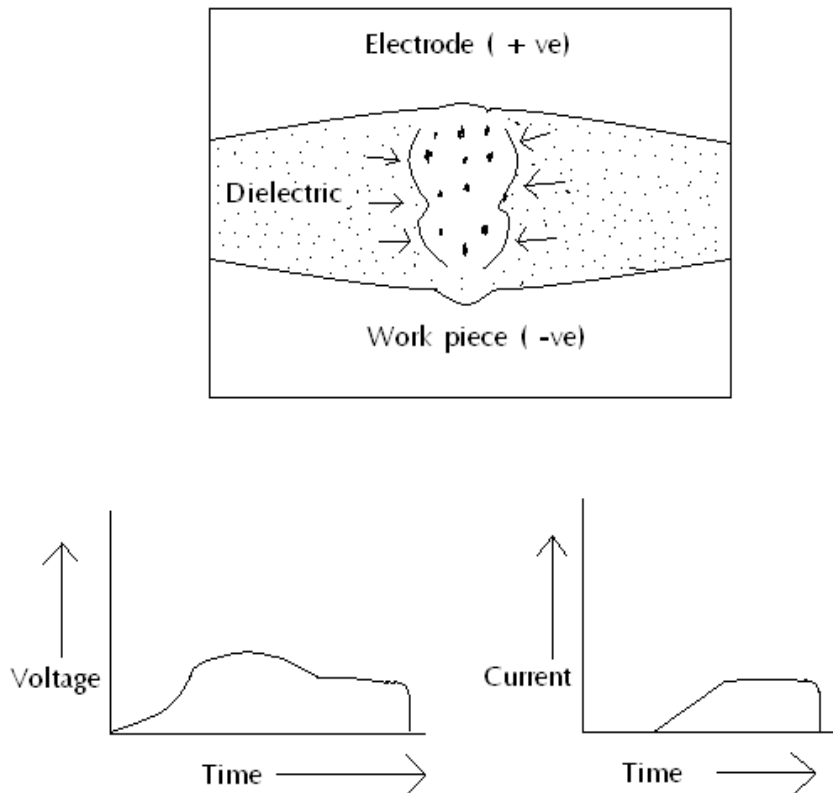


Fig.1.2 (d) Final stage of a single EDM cycle.

1.3 Process Parameters

1.3.1 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. $MRR < TWR$ and surface roughness increases with increasing open circuit voltage because electric field strength increases.[Kunieda et al.]

1.3.2 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. Fig 1.3 shows effect of current on surface.

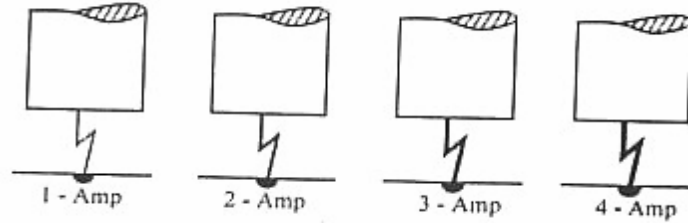


Fig 1.3 Effect of current on surface [Sahai, 2009]

1.3.3 Pulse On-time & Off-time

Each cycle has an on-time and off-time. It is expressed in units of microseconds(μs). 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 rate 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. 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. [Kunieda et al.]

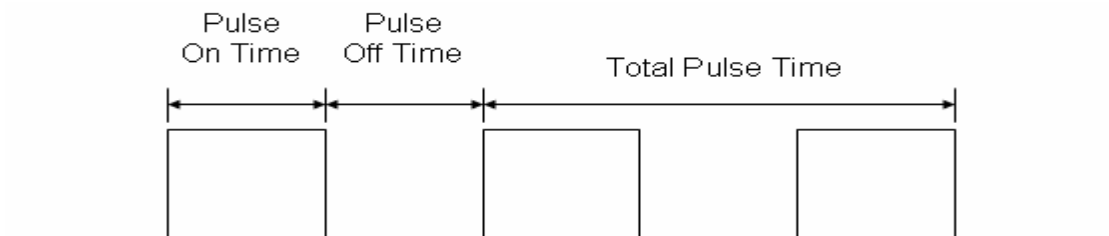


Fig 1.4: Concept of Pulse on Time and Pulse off Time [Sahai, 2009]

1.3.4 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: [Sahai, 2009]

Table 1.1 : Recommended Polarities for different Tool-Job pairs.

Work material	Polarity
Tool Steel	+
Stainless Steel	+
Aluminum	+ -
Titanium	-
Carbides	-
Copper	-

1.3.5 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.

1.3.6 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. Frequency is distinct from the duty cycle, as this is a measure of efficiency.

1.4 Dielectric Fluids

Dielectric fluid used in EDM should be:

1. Dielectric medium should have high dielectric strength i.e. remain electrically non conductive until the required breakdown voltage is reached.
2. Breakdown electrically in shortest possible time once the breakdown voltage has been reached.
3. Rapidly deionize the spark gap after discharge has occurred.
4. It also acts as effective cooling medium.
5. It should have a good degree of fluidity.
6. It should be cheap and easily available.
7. Light hydro carbons oil like kerosene satisfies this condition.

1.5 Flushing

Flushing is defined as correct circulation of dielectric fluid between work piece and tool. For highest machining efficiency flushing is necessary. In beginning dielectric medium should be fresh that is free from eroded particles and residue resulting from dielectric cracking and its insulation strength is high. After successive discharges dielectric gets contaminated, then its insulation strength reduces 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. [Kunieda et al.] Debris are 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

1.5.1 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.

1.5.2 Side Flushing

In this type flow of dielectric is from one side to another. It is used when flushing hole cannot be drilled either in the work piece or the tool this type of flushing is employed.

1.5.3 Flushing by Dielectric pumping

Flushing is obtained by using electrode pulsation movement. When the servo control raise the electrode ,the gap increases. This results in cleaning of dielectric by suction into mix with contaminated fluid and as electrode is lowered the particles are flushed out.

1.5.4 Injection flushing

In Injection 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. The dielectric takes away debris away from cutting area.

1.6 Selection of Electrode Material

Different types of electrodes are available. For e.g. Copper, Copper Tungsten, Brass, Inconel etc. Each one has it's own merits and demerits. Four main factors 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.

Table 1.3. Different electrode material

Material	MRR	TWR	Cost
Copper	High	Low	High
Tungsten	Low	Lowest	High
Brass	High	High	Low
Copper graphite	High	Low	High
Steel	Low	High	Low
Zinc alloys	High	High	Low
Cast Iron	Low	Low	Low

1.7 Components of Electric Discharge Machine

Its main components (Figure 1.5) are given as under:

1. Control Unit
2. Electrode holder
3. Electrode feed mechanism
4. Tank
5. Fixture



Figure 1.5: Electric Discharge Machine (Model T – 3822M)

1.8 EDM Controls

The controls of EDM (Model T- 3822M) are listed below:

1. Rotary Switch (Mains)
2. Indicator Lamps (Three Phase)
3. Rotary Switch (Finish)
4. Rotary Switch (Pump)
5. Rotary Switch (Current Range)
6. Rotary Knob (Current Adjust)
7. Ammeter (Gap Current)
8. Rotary Switch (Base)
9. Rotary Switch (Duration)
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)
17. Rotary Potentiometer (Lifting Time)
18. Indicator Lamp (OV/SP)
19. Push Button Red (OFF)
20. Rotary Switch (AUT/MAN)
21. Push Button (UP/DN)
22. Indicator Lamp (Interlock)
23. Rotary Switch (Ignition)
24. Indicator Lamp (Pump ON)
25. Push Button (AUTOPOS)
26. Indicator Lamp (AUTOPOS)
27. Piezo Ceramic Alarm
28. Toggle Switch
29. Decade Counter

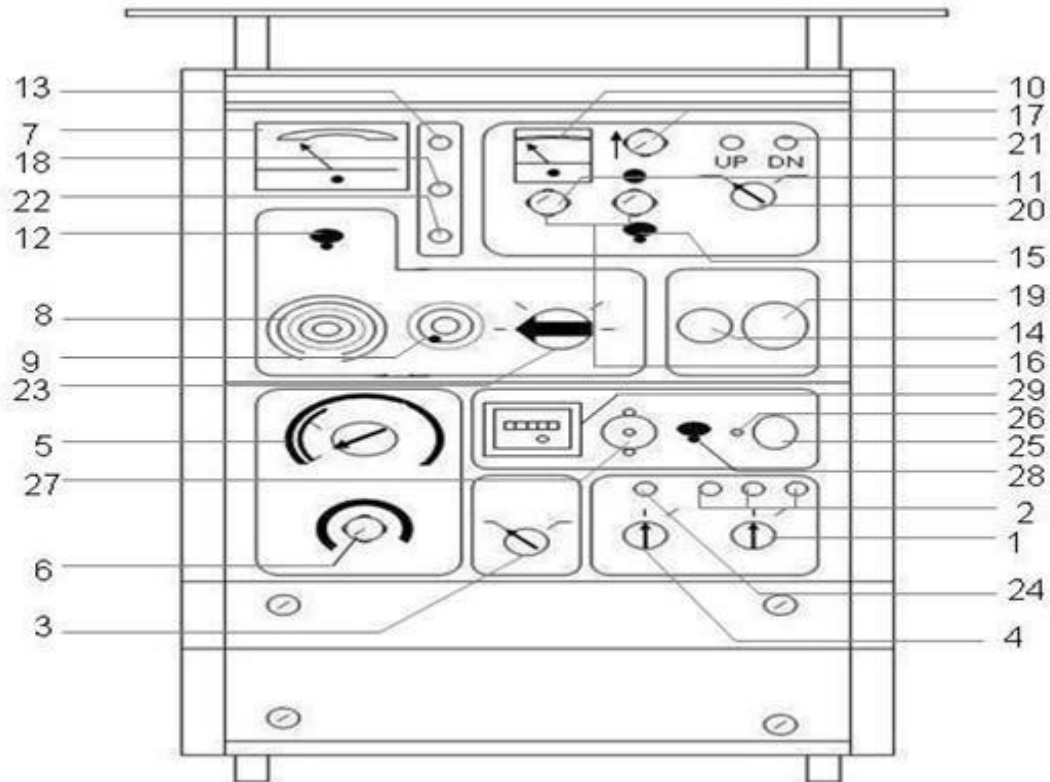


Figure 1.6: Indicating the controls of EDM (Model No. T – 3822M)

Courtesy: Operational Manual for T-3822M EDM by Victory Electromech

Various types of controls of EDM (Model T- 3822M) are explained as under:

Rotary Switch (Mains)

It is used switching mains ON for total power supply (Generator). In position ‘1’ the supply is ON and in position ‘0’ the supply is OFF.

Indicator Lamps (Three Phase)

These indicators shows the presence of all three phases of main supply.

Rotary Switch (Finish)

It has two positions viz. NORMAL and MIRROR. The position MIRROR is selected only for finishing the job. The NORMAL position is to be selected for all other machining, electrode and workpiece material combinations.

Rotary Switch (Pump)

It is used for switching the pump on/off. This switch has two positions ‘0’ and ‘1’. In position ‘1’ the dielectric pump is started. In position ‘0’ the pump is put OFF.

Rotary Switch (Current Range)

This switch has three positions. The positions ‘1’, ‘2’ and ‘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 in fully counterclockwise (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 process. The range provided is 0 to 15 amps. Green band is upto 12 amps and the remaining is red band.

Rotary Switch (Base)

It has 8 positions which are explained as given below:

Positions 8, 7 - Roughing

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

Positions 5, 4, 3, 2 - Finishing

Position 1 - Super-finishing

Rotary Switch (Duration)

This switch has ‘12’ positions. Pulse duration can be changed from minimum (position 1) to maximum (position ‘12’) in ‘12’ positions by switch ‘9’ (Duration) for each position of switch ‘8’ Base.

Table 1.4: Ranges of machining current with respect to switch ‘8’ (Base)
Courtesy: Operational Manual for T-3822M EDM by Victory Electromech

Base Position	Machining Current Range
8	6A to 12A
7	4A to 12A
6	3 A to 10A
5	1 A to 8A
4	0.5 A to 6 A
3	0.5 A to 4A
2	0.1 A to 2A
1	0.1 A to 1A

Thus, one can obtain a full range of pulse duration from a minimum of 2 μ s to a maximum of (520 μ s which largely covers the duration limits used in a pulse generator with a total power of 3 KVA) . Increasing the duration reduces the machining rate with a drastic reduction in the relative electrode tool wear.

Too long pulse duration (duration position '10' to '12') with copper electrode and steel workpiece results in excessive accumulation of carbon in the machining zone with a subsequent instability of the machining process.

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 arcing tendency and ensure stable machining process under these conditions. Normally, Soft Pulse should be switched on (position '1') whenever the average machining current is greater than 2-3 amps. However, in finishing ranges where the machining current is less than 2-3 amps; putting off this switch improves the surface finish and also reduces 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 process.

Toggle Switch (Auto-flushing)

This switch selects auto-flushing (lifting during machining) in position '1'. In position '0' the auto-flushing cycle stops.

Rotary Potentiometer (Sparking Time)

This control adjusts lifting time with Toggle Switch '15' (auto flushing) selecting. 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, the time goes on increasing.

Indicator Lamp (OV/SP)

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

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 down movement of the quill is possible.

Push Button (UP/DN)

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

Indicator Lamp (Interlock)

The LED is ON when level of dielectric is 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 arcing tendency and instability of the machining process. Hence, whenever, the arcing tendency is more or the panel meter GAP (in spite of adjusting the GAP Control) is overshooting frequently, a higher position of switch ignition should be selected.

Indicator Lamp (Pump ON)

This LED is ON when switch (4) above is in position '1' i.e. 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 electrode comes in the vicinity of workpiece (job), it maintains a constant gap at low voltage between the electrode and the

workpiece with weak sparking. The AUTOPOS can be stopped by pressing push button '19' or by operation of preset depth switch on machine head.

Indicator Lamp (AUTOPOS)

This LED glows when AUTOPOS function starts by pressing push button '25' and becomes OFF when the function is stopped.

Piezo Ceramic Alarm (Buzzer)

This is an audio signal which indicates that the electrode has made contact with the workpiece. The function can be selected by a switch '28'. The buzzer sounds only when switch '10' is in MAN mode or when AUTOPOS is ON.

Toggle Switch (Buzzer Select)

This has two positions '0' and '1'. In position '1', the buzzer '27' is selected and in position '0' the buzzer '27' is selected.

Decade Counter (Hour Counter)

This counts the total machining time, i.e. the time counting is effective only during machining process. The counter counts continuously and hence the initial reading has to be recorded while counting machining time taken for any job. The least count is 0.01 hours.

1.9 Introduction MADM-TOPSIS APPROACH

It identifies the various attributes needing to be considered for the optimum evaluation and selection of parameters of EDM. It also provides a coding system for depicting the various attributes. It recognizes the need for, and processes the information about, relative importance of attributes for a given application without which inter-attribute comparison is not possible. It presents the result of the information processing in terms of a merit value, which is used to rank the parameters in the order of their suitability for the given application[Bhangale et al.2004].

The contributions of this work can be summarized as

1. The method is especially suitable for generating database of parameters of EDM and their subsequent retrieval. It provides coding scheme to produce electronic database.
2. This database will be helpful to all sorts of people related to EDM from manufacturer, designers, and users to maintenance personnel. It will be helpful to improve the overall productivity of the organization.

3. Here by identifying attributes of the EDM, the attempt has been made to codify most of the EDM characteristics, which will define the processes precisely and accurately. The coding scheme is used.
4. Evaluation and ranking based on the mathematical and graphical approaches is done.

1.9.1 Methodology of MADM TOPSIS

- (1) Quantification and measurement of the attributes based
 - (a) Usefulness to the manufacturer.
 - (b) Usefulness to the user.
 - (c) Usefulness to the designer.
 - (d) Usefulness to the maintenance personnel.
- (2) Identification of new attributes.
- (3) Coding scheme.
- (4) Illustration of coding.
- (5) The 3-stage selection procedure
 - Elimination search
 - Evaluation procedure (Normalized specifications & weighted normalized specification)
 - Ranking and selection procedure (TOPSIS method & Graphical methods)[Bhangale et al.2004].

1.10 Introduction to Graph Theoretic Approach

To fill the research gap and to show the importance of a structure based EDM system design, a graph theory based EDM system model is proposed. The model can include all the subsystems along with the interactions therein and thus becomes a tool for EDM system analysis. A graph is required for visual analysis of an EDM system, but quantification of these interactions is necessary for design and analysis. Matrix algebra is used for quantifying these interactions. A graph $G = (V, E)$ [1] consists of a set of objects $V = \{v_1, v_2, \dots\}$ called vertices or nodes, and another set $E = \{e_1, e_2, \dots\}$, of which the elements are called edges, such that each edge e_k is identified with a pair of vertices.

Assumptions for developing graph theoretic model

The proposed graph theoretic model for EDM systems is based on some assumptions as listed below:-

- The structure of the system can be compared quantitatively with its performance.

- The interactions as well as the subsystems discussed are assumed for a general EDM system. The subsystems must be identified separately for applying the model to any specific EDM system.
- Variable permanent matrix is capable of storing complete information related to a real life situation of a typical EDM system as all its elements are variables and functions of characterizing attributes representing subsystem and interconnections. These attributes if identified comprehensively, the matrix represents the EDM system completely.
- Permanent function of the variable permanent matrix characterizes uniquely the EDM system from the point view of the structure.
- Performance of the EDM system depends on individual performance of subsystems, sub-systems and their components along with interactions between them.
- Modeling methodology is based on bottom-up approach. Permanent function values of sub-subsystems are used in permanent matrices of subsystems. Permanent function values of subsystems are used to calculate permanent functions of EDM system.
- The experts may assign correct and representative score to the elements of the EDM system at the lowest level in a particular dimension of performance.

1.10.1 Methodology of Graph Theory

The methodology described for complete analysis of system is summarized in step-by-step manner as below:

1. Select the desired system. Study the system and its subsystems and also their interactions.
2. Develop a system graph of the given system with subsystems as vertices and edges for interaction between the vertices.
3. Using the graph in step 2, develop matrix similar to given system variable permanent matrix given in Equation (5).
4. Calculate system permanent function.
5. The numerical index of given system would be obtained by substituting the numerical values of subsystems and their interactions.
6. Different type of systems can be compared on the basis of permanent numerical index thus obtained. Necessary improvements and developments can be done on the basis of this approach.

7. From the different alternatives of given systems, the alternative with highest value of numerical index is the best choice for the given application.

1.11 Objectives of proposed Study

The proposed work has the following objectives and contributions in the field of EDM system:

1. To develop a flexible mathematical model by using systems approach and integration of all the parameters that defines the whole system, and also analyzing the interactions and relationships between different parameters affecting the EDM system.
2. To propose a methodology by which the design and selection of Tools for EDM system can be made comprehensive and easy.
3. This model could be used in modeling and analysis for in depth study of the whole EDM system.
4. Optimization of Tools for EDM system with respect to the performance i.e. MRR, TWR and Surface roughness.
5. Experimental analysis, performance evaluation and comparison of different tools for EDM machine by performing experiments on EDM machine by L18 array taking six levels of current, three levels of pulse on time, on three different work pieces with three tools.
6. Ranking of tools by using MADM approach by using decision matrix which is based on readings taken during experimentation.
7. Validation of results of MADM approach by comparing the results with graphs and data obtained from experiments.

CHAPTER – 2

LITERATURE REVIEW

In this study Literature review is classified into three categories. In first category there is literature review related to research work done in field of EDM. In second category literature review is related to MADM approach and in third category related to graph theory. This chapter also presets literature summary and gaps in literature.

2.1 Categorization of Literature

The literature is reviewed under following three distinctive categories:

1. General literature review about EDM process. (component as well as whole system basis)
2. MADM-TOPSIS Approach
3. Graph Theory Approach

2.1.1 General EDM process

Zhao et al. (2002) conducted the study on PMEDM in rough machining. This paper performed experimental research on machine efficiency and surface roughness of PMEDM in rough machining. The result showed that PMEDM machining can clearly improve machine efficiency and at same time surface roughness by selecting proper discharging parameters.

Bleys et al. (2004) studied that Milling EDM enables machining of complex cavities with simple cylindrical or tubular electrodes. To assure an acceptable machining accuracy, milling EDM requires compensation of the tool electrode wear. Existing wear compensation methods were mostly based on off-line prediction of tool wear. This paper discussed a new wear compensation method, incorporating real-time wear sensing based on discharge pulse evaluation. Tool wear was continuously evaluated during machining, and the actual wear compensation was adapted on the basis of this real-time wear evaluation.

Pham et al. (2004) conducted the study on recent developments and research issues in Micro-EDM. Due to the high precision and good surface quality that it can give, EDM was potentially an important process for the fabrication of micro-tools, micro-components and parts with micro-features. However, a number of issues remained to be solved before micro-EDM can become a reliable process with repeatable results and its full capabilities as a micro-manufacturing technology can be realized. This

paper presented some recent developments in micro-EDM in its various forms (wire, drilling, milling and die-sinking) and discussed the main research issues. The paper focused on the planning of the EDM process and the electrode wear problem. Special attention was paid to factors and procedures influencing the accuracy achievable, including positioning approaches during EDM and electrode grinding.

Han et al. (2004) described the improvement of machining characteristics of micro electrical discharge machining (micro-EDM) using a newly developed transistor type isopulse generator and servo feed control. The *RC* generator was mainly applied in conventional micro-EDM even though the transistor type isopulse generator was generally more effective for obtaining higher removal rate, because the transistor type generator was unable to generate iso-duration discharge current pulses with small pulse duration (several dozen nano-seconds), which was the normal level for micro-EDM. A new transistor type isopulse generator was therefore developed using a current sensor with high frequency response. With the new transistor type isopulse generator developed, the pulse duration can be reduced to about 30 ns, which is equivalent to the pulse duration used in finishing by the conventional *RC* pulse generator for micro-EDM. In order to achieve stable machining and improve machining characteristics, a new servo feed control system for micro-EDM using average ignition delay time to monitor the gap distance was also developed. By integrating the transistor type isopulse generator with this new servo feed control system, we were able to obtain a removal rate of about 24 times higher than that of the conventional *RC* pulse generator with a constant feed rate in both semi finishing and finishing. The effectiveness of the servo feed control proved higher in finishing than in semi finishing, whereas the transistor type isopulse generator was more effective in semi finishing than in finishing.

Kansal et al.(2005) in their study presented work, to optimize the process parameters of powder mixed electrical discharge machining (PMEDM). Response surface methodology was used to plan and analyze the experiments. Pulse on time, duty cycle, peak current and concentration of the silicon powder added into the dielectric fluid of EDM were chosen as variables to study the process performance in terms of material removal rate and surface roughness. Experiments were performed on a newly designed experimental setup developed in the laboratory. The results identified the most important parameters to maximize material removal rate and minimize surface roughness.

Narasimhan et al. (2005) studied about micro electrical discharge machining (micro EDM) and found that tool wear adversely affected the accuracy of a machined feature or a part. Therefore, tool wear compensation techniques were proposed for micro and macro EDM operations. However, some of these techniques required extensive experiments in determining the appropriate tool path (which depends on part feature, material, and machining parameters) for machining a desired surface. This paper reported the development of a theoretical model to develop the tool path for generating a desired work piece surface profile. The application of the model was illustrated for micro and macro EDM by machining flat slots.

Sanchez et al. (2006) concluded that tooling costs, machining time and surface finish in an EDM operation can be improved by using multi-stage planetary EDM strategies. However, the technological tables provided by machine manufacturers do not always adequately fit to the specific user application, especially in the case of gap values. In this work, a methodology for the calculation of gap variation between two consecutive stages that can be applied both in roughing and in finishing regimes was described. The methodology defined required the realization of a number of EDM tests, in which the surface finish of each intermediate stage must be assured. It was shown in the paper that this was optimally done by using the strategy based on the complete removal of R_t . Results also show that gap variation was dependent upon the radius of the first orbit until a limit value was reached. It was observed from the experiments that larger gap variations are related to the use of smaller electrodes and copper electrodes. Finally, it was shown that the steepest decreases in gap variation occur at the regimes at which both discharge current and pulse time decrease.

Valenticic et al. (2006) presented a 'Design Adaptation System for machining in tool making (DASMT)' in order to avoid the knowledge gap between product and tool designers. The focus of the presented paper is on the development of the Design Adaptation System for EDM (DAS-EDM). This system helped the designer to check the viability of individual features to their machinability by EDM process. The system revealed features, which were critical for EDM machining and makes suggestions to the designer to alter the features by keeping the overall functionality of the product.

Tzeng et al. (2007) described the application of the fuzzy logic analysis coupled with Taguchi methods to optimize the precision and accuracy of the high-speed electrical discharge machining (EDM) process. A fuzzy logic system was used to investigate relationships between the machining

precision and accuracy for determining the efficiency of each parameter design of the Taguchi dynamic experiments. From the fuzzy inference process, the optimal process conditions for the high-speed EDM process were easily determined as A1B1C3D1E3F3G1H3. In addition, the analysis of variance (ANOVA) was also employed to identify factor B (pulse time), C (duty cycle), and D (peak value of discharge current) as the most important parameters, which account for about 81.5% of the variance. The factors E (powder concentration) and H (powder size) were found to have relatively weaker impacts on the process design of the high-speed EDM. Furthermore, a confirmation experiment of the optimal process showed that the targeted multiple performance characteristics were significantly improved to achieve more desirable levels.

Abbas et al. (2007) presented a review on current research trends in electrical discharge machining (EDM). Electrical discharge machining (EDM) was one of the earliest non-traditional machining processes. EDM process was found to be based on thermoelectric energy between the work piece and an electrode. A pulse discharge occurs in a small gap between the work piece and the electrode and removed the unwanted material from the parent metal through melting and vaporizing. The electrode and the work piece had electrical conductivity in order to generate the spark. There were various types of products which can be produced using EDM such as dies and moulds. Parts of aerospace, automotive industry and surgical components can be finished by EDM. This paper reviewed the research trends in EDM on ultrasonic vibration, dry EDM machining, EDM with powder additives, EDM in water and modeling technique in predicting EDM performances.

Uhlmann et al. (2008) conducted investigations on reduction of tool electrode wear in micro-EDM using novel electrode materials. In micro-electrical discharge machining discharge energies of less than $W_e = 100$ mJ per single discharge were used. Due to the short pulse durations in micro-EDM the tool electrode was usually charged as cathode to reduce tool electrode wear. Nevertheless, compared to conventional EDM, especially when relaxation generators were used, the relative wear can increase to more than 30%. In order to reduce the electrode wear, novel electrode materials were applied. Experimental investigations aim to decrease the wear of tool electrodes by using boron doped CVD-diamond (B-CVD) and polycrystalline diamond (PCD). Both materials offer high thermal conductivity and a high melting/sublimation point which were general requirements for tool electrode materials. This paper gives an insight into latest research results regarding the process behavior of B-

CVD and PCD in micro-EDM as well as influences of electrode materials on tool electrode wear and surface formation processes.

Bamberg et al. (2009) presented a novel machining technique for micro-EDM that actuates the EDM electrode on an orbital trajectory that was created by a 2-axis flexural micro-EDM head with a range of $\pm 100\ \mu\text{m}$ in both x - and y -directions. The orbital motion with its adjustable radius decouples the size of the hole to be drilled from the size of the electrode, allowing a range of hole sizes to be drilled. The orbital motion of the electrode increases the hole diameter proportional to the orbital radius, thereby creating a larger gap between the work piece and the electrode, which promotes increased flushing. For holes with large depth to diameter ratios, the increased flushing reduces electrode wear, creates a better surface finish, and eliminates the exponential reduction in material removal rates typical for EDM drilling.

Izquierdo et al. (2009) studied that the electrical discharge machining (EDM) process was by far, the most popular amongst then on conventional machining processes. The technology was optimum for accurate machining of in hard materials, as those required in the tooling industry. However, although a large number of EDM machines were sold every year, scientific knowledge of the process was still limited. The complex nature of the process involved simultaneous interaction of thermal, mechanical, chemical and Electrical phenomena, which makes process modeling very difficult. In this paper a new contribution to the simulation and modeling of the EDM process was presented.

Zhou et al. (2009) studied that in order to improve the performance of machines, there was a growing need to develop a highly stable servo control system for EDM. With the perpetual push towards the untended EDM operation, an adaptive control system was continued to be a primary option. In this paper, a new EDM adaptive control system which directly and automatically regulates tool-down-time had been developed. Based on the real-time-estimated parameters of the EDM process model, by using minimum-variance control strategy, the process controller, a self-tuning regulator, was designed to Control the machining process so that the gap states follow the specified gap state.

Sivapirakasam et al. (2011) conducted study on “Multi-attribute decision making for green electrical discharge machining”. This paper was aimed to develop a combination of Taguchi and fuzzy TOPSIS methods to solve multi-response parameter optimization problems in green manufacturing. Electrical

Discharge Machining (EDM), a commonly used non-traditional manufacturing process was considered in this study. A decision making model for the selection of process parameters in order to achieve green EDM was developed. An experimental investigation was carried out based on Taguchi L9 orthogonal array to analyze the sensitivity of green manufacturing attributes to the variations in process parameters such as peak current, pulse duration, dielectric level and flushing pressure. Weighing factors for the output responses were determined using triangular fuzzy numbers and the most desirable factor level combinations were selected based on TOPSIS technique.

Singh et al. (2012) studied that Electrical discharge machining (EDM) had steadily gained importance over the years because of its ability to cut and shape a wide variety of materials and complicated shapes with high accuracy. The effectiveness of the EDM process was evaluated in terms of the material removal rate, relative wear ratio and the surface roughness of the work piece. The input discharge energy during this process was distributed to various components of the process, which further influences the material removal rate and other machining characteristics like surface roughness. The accurate prediction of the fraction of energy effectively transferred to the workpiece will help to reduce the errors of the thermal models. In this study experiments were performed to study the percentage fraction of energy transferred to the workpiece utilizing heat transfer equations, at different EDM parameters. This study also related the optimum parameters with the optimum utilization of input discharge energy and hence helped to improve the technological performance of this process.

Zahiruddin et al.(2012) conducted study on “Comparison of energy and removal efficiencies between micro and macro EDM”. It was found that Micro and macro EDM were similar, but differences in machining conditions result in a differing power density (P_e). This caused differences in the ratio of energy consumed for material removal with regard to energy distributed into the work piece, and the ratio of total removal volume per pulse with respect to the molten area volume, so-called energy efficiency, E_e , and removal efficiency, R_e , respectively. It was found that, the P_e of micro EDM is approximately 30 times greater than that of macro EDM. Consequently, E_e and R_e in micro EDM were significantly greater than those of macro EDM.

2.1.2 According to MADM TOPSIS approach

Bhangale et al. (2004) had solved the robot selection problem which arisen due to increasing complexity, available features, and facilities offered by different robotic products. The objective of their research was to generate and maintain reliable and exhaustive database of robot manipulators based on their different pertinent attributes. That database can be used to standardize the robot selection procedure when the manufacturing firm has decided to use the robot for a particular operation. The methodology presented in this paper can help the robot user to save time by providing him a tool for selecting the robot system most suited for his operational needs. This paper presented a robot selection procedure based on the Multiple Attribute Decision Making (MADM) approach. Here by identifying 83 attributes of the robots, the attempt has been made to codify most of the robot characteristics, which will define the robot precisely and accurately. The coding scheme is illustrated with example of selecting a robot for some pick-n-place operation. It has presented the result of the information processing in terms of a merit value, which was used to rank the robots in the order of their suitability for the given application.

Prabhakaran et al. (2006) described a methodology for evaluation, coding, ranking, and optimum selection of subsystems for composite product used directly by its manufacturers. The 77-attribute electronic coding scheme and the evaluation techniques were presented in this paper and were useful to the designer during all the phases of design process, and manufacturer for the selection of optimum subsystems, which meet global market requirements. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) was a Multiple-Attribute Decision Making (MADM) approach was used for selection of subsystems for a composite product development in order of preference for given application. Two graphical methods of MADM approach for evaluation and comparison are also introduced by the authors. It was recommended in this paper that manufacturer of composite product should develop attribute-based specification in the form of proposed coding scheme. This will directly help industry in carrying out SWOT (Strength– Weakness–Opportunities–Threats) analysis from the point of view of its manufacturing and business strategies.

Garg et al. (2007) presented a computational methodology for a computer-based solution to the problem of evaluation and selection of an optimum power plant. This methodology was named as multiple attribute decision making (MADM) methodology and consists of elimination search and technique for order preference by similarity to ideal solution (TOPSIS) approach. Authors have

suggested a coding scheme based on 190 pertinent attributes for a given thermal power plant for the development of a large database of available plants, and their subsequent retrieval. The “technique for order preference by similarity to ideal solution” (TOPSIS) approach has provided a complete and thorough comparison and ranking of available power plants. Authors have also developed a user friendly computer software for Elimination Search and TOPSIS approach.

Kiran et al. (2011) presented a methodology useful in optimal selection of a Mechatronic system based on the Multi Attribute Decision Making (MADM) approach. Authors contributed in this paper by proposing a coding scheme which was a collection of 88 attributes which characterize a Mechatronic system and was useful in differentiating Mechatronic system alternatives. An illustrative example of selecting a hard disk drive (HDD), a Mechatronic system, for the up-gradation of customer’s office desktops was given to explain the methodology. Authors also identified 3-stage selection procedure, which includes elimination search, TOPSIS based evaluation and ranking, other graphical methods (linear graph and spider diagram), works on the information of the pertinent attributes. This procedure ranks the Mechatronic system alternatives based on the Euclidian distance of alternatives from hypothetically best and hypothetically worst Mechatronic systems.

2.1.3 According to Graph Theory

R.K. Garg et al. (2006) developed a deterministic quantitative model based on graph theoretical approach. In this study a comparison is made between various technical and economical features of wind, hydro and thermal power plants and also used to evaluate and rank the power plants in ascending or descending order in accordance with the value of their suitability index. The methodology present in this paper allows a decision maker to perform general analysis and other various focused analysis regarding his personal preferences.

R.T. D. Prabhakaran et al. (2006) used graph theory and matrix algebra to develop an integrated systems model for the structure of the composite product system in terms of its constituents and interactions between the constituents and the molding processes, curing kinetics etc. In this study a methodology is purposed for developing a composite product considering all attributes responsible for design, production, and process parameters. The composite product is first modeled with the help of graph theory, then by variable adjacency matrix and then by a multinomial known as permanent function. The permanent function has provided an opportunity to carry out structural analysis of the

composite product in terms of strength, weakness, improvement, and optimization by correlating the properties of a composite with its structure.

Varinder Singh and V.P. Agrawal (2008) have presented a methodology for structural analysis of manufacturing system. In this study the identification of elements constituting a manufacturing system and the interactions between them is done and it has been represented by graph-based model. The matrix models and the variable permanent function models have been developed to carry out decomposition, characterization and the total analysis. In this work structural patterns and combination sets of subsystems interacting in various ways have been recognized as capabilities of manufacturing system. The permanent function of the manufacturing system matrix has been proposed as a systematic technique for structural analysis of manufacturing system.

C.P. Kiran et al. (2011) presented a methodology to develop a high quality product. This methodology combines all the design aspects of product together to generate a useful form of solution for the Mechatronic industry. This methodology considered all the x-abilities/design aspects along with interactions without missing any useful information. The methodology consists of graph theory, matrix algebra, and permanent multinomial. Eight x-abilities are indentified i.e. miniaturization, intelligence, integration, environment, quality, reliability, manufacturing, and assembly for concurrent design of a Mechatronic. For visual analysis a color graph is proposed.

2.2 LITERATURE SUMMARY

From the study of research papers on Electro discharge machining, it is seen that for improving MRR, TWR and surface finish, different modifications are implemented on conventional EDM and they are found beneficial. Some are:

1. Experimental research was done to improve surface finish and efficiency by changing parameters.
2. Adapted tool wear compensation was done by using on line prediction of tool wear.
3. Transistor type isopulse generator was integrated with conventional R.C. pulse generator to improve MRR.
4. Response surface methodology was used to plan and analyze the experiments.
5. Theoretical model was developed for developing tool path for generating a desired work piece profile.
6. Multi stage planetary strategies were developed for improving EDM process.

7. Design adaption system (DASMT) was used for making tools.
8. Fuzzy logic analysis coupled with Taguchi method was applied to optimize precision and accuracy.
9. Investigation was done on reduction of tool electrode wear in micro EDM.
10. EDM adaptive control system was developed which automatically regulate tool downtime.
11. Multi attribute decision making was applied on green EDM.
12. A simulation and modeling with new contribution was presented.
13. Research trends were reviewed in Dry EDM, Powder EDM and Ultrasonic Vibration EDM.
14. Planning of EDM process was done to reduce the electrode wear problem.

2.3 Gaps in literature

Some gaps are identified on the basis of which aim for further study has been decided. Some are:

1. It is been identified that insufficient amount of work has been done in the field of applying Graph theory in EDM process.
2. MADM -TOPSIS approach is not applied in case of EDM.
3. The work is not done for Structural Modelling, Characterization and Integrative Analysis of EDM System .
4. No work is done for attribute based Coding, Evaluation and Optimum Selection of Parameters for EDM System

CHAPTER-3

ATTRIBUTE BASED CODING, EVALUATION AND OPTIMUM SELECTION OF PARAMETERES FOR EDM SYSTEM

3.1 Introduction of MADM (Multi Attributes Decision Making) TOPSIS Method

The Multiple Attribute Decision Making (MADM) approach used to evaluate, rank and select system for particular application according to the requirements of the users. There are the following steps in MADM approach used: [Bhangale et al.2004]

Step 1. Identification of system attributes

A system consists of various sub system. All these sub system are interdependent and interrelated to each other. The performance, cost, behavior, etc of product or process depends upon the performance of each sub or sub-sub system. One of the critical factors to evaluate system is the identification of attributes affecting its characteristics performance. [Bhangale et al.2004].

Precise identification of attributes is highly critical in comparing, evaluation and selection of systems. When a user goes to a supplier for purchase of a new system the identification of the critical attributes become highly significant.

Step 2.Characteristics of a system

1. Performance characteristics
2. Physical characteristics
3. Application Characteristics
4. Structural Characteristics
5. Ability Characteristics
6. Stability characteristics

From the above attributes under different characteristic, it is found that the system characteristics are interdependent of each other. Varying one attribute to improve one characteristic of the system affect some other characteristic of the system. Here, many attributes can be found, but the user, designer or manufacturer can add or delete some of the attribute depending upon their requirement. Because it is evident that the importance of an attribute is changing depending upon application, use or industries. Even all the attributes may not be known to user, manufacturer or designer, but they may be important to them, so sensitive/critical attribute should be considered by them. [Bhangale et al.2004]

Step 3.Coding scheme

This method is particularly useful for comparing or ranking finite number of alternatives which are measured by relevant attributes. MADM methods apply to problems where a decision maker is choosing or ranking a finite number of alternatives which are evaluated by two or more relevant attributes. [Bhangale et al.2004].

Most MADM methods, whether compensatory or non compensatory, single purpose or multipurpose allow the decision maker to assign different levels of importance to different attributes.

A common two-part approach for overcoming this difficulty is to:

1. Convert the attributes to weighting problem into one of making pair-wise comparison among them for given application.
2. To specify a computational procedure for converting the paired comparison data into attribute weights.

Each and every attribute can be evaluated either quantitatively (value based) or qualitatively (good, average, poor, etc.).

Step 4.Illustration of coding

For illustrating the methodology large number of attributes are considered, but user, designer or manufacturer can delete or add attributes according to his requirement, because relative importance of attributes are changing as per application or industries.

Here it is found that most of the cells are having value 0 as code in them. The code 0 represents that the information relating to the particular cell is not available to the authors. This information is not

provided by the manufacturer, but the authors think that this information also should be provided to make the data base exhaustive. Moreover, the data base storage, retrieval and the selection procedure will be more precise and accurate. This coding scheme can use for comparing two System up to certain extent. It allows faster comparison in various formats.. [Bhangale et al.2004]

Step 5.The three stage selection procedure:

Stage 1: Elimination search

Though all the attributes have been identified all of them would not be important while selecting the System for particular application. There will be a few attributes which will have direct effect on the selection procedure. This small number of attributes may be set aside as pertinent attributes. The values to these attributes may be assigned by obtaining information from the user/ manufacturer and group of experts. On the basis of these values a smaller shortlisted number of systems are obtained. This is achieved by scanning the database for the various System systems.

Stage 2: Evaluation procedure

A mini-database is thus formed which comprises these satisfying solutions i.e., alternatives which have all attributes satisfying the acceptable levels of aspiration. The problem is now one of finding out the optimum or best out of these satisfying solutions. The selection procedure there for needs to rank this solution in order of merit.

The first step will be to represent all the information which has been obtained about the chosen pertinent attributes for the short listed systems in a matrix form. Such a matrix is called as decision matrix, D. [Bhangale et al.2004].

a)Normalized specifications

The next step is construction of the normalized specification matrix N, from the decision matrix D. Normalization is used to bring the data within particular range or scale, moreover, it provides dimensionless magnitudes. This phenomenon is used to calculate the normalized specification matrix. The normalized specification matrix will have the magnitudes of all the attributes of the system on the common scale of 0 to 1. It is a sort of value, which indicates the standing of that particular attribute magnitude when compared to the whole range of the magnitudes for all candidate System systems. [Bhangale et al.2004].

An element of the normalized matrix N can be calculated as

$$n_{ij} = \frac{d_{ij}}{\sqrt{\sum_{i=1}^m d_{ij}^2}}$$

where d_{ij} is an element of the decision matrix D. [Bhangale et al.2004]

The next step is to obtain information from the user or the group of experts on the relative importance of one attribute with respect to another. This information is sought in terms of a ratio. Information on all such pair-wise comparisons is stored in a matrix called as relative importance matrix, A, which is an $n * n$ matrix.

The Eigen vector method seeks to find weight vector w from the Eigen value problem associated with the matrix, A,

$$\text{i.e., } Ax = \lambda x$$

b)Weighted normalized specification

The weights obtained from the relative importance matrix have to be applied to the normalized specifications since all the attributes have different importance while selecting the system for a particular application. [Bhangale et al.2004]. The matrix which combines the relative weights and normalized specification of the candidates is weighted normalized vector

$$V = \begin{bmatrix} w_1 n_{1,1} & w_2 n_{1,2} & \dots & w_n n_{1,n} \\ w_1 n_{2,1} & \ddots & \dots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ w_1 n_{m,1} & w_2 n_{m,2} & \dots & w_n n_{m,n} \end{bmatrix} = \begin{bmatrix} v_{1,1} & v_{1,2} & \dots & \dots & v_{1,n} \\ v_{2,1} & \ddots & \dots & \dots & \vdots \\ \vdots & \vdots & \ddots & \dots & \vdots \\ \vdots & \vdots & \dots & \ddots & \vdots \\ v_{m,1} & v_{m,2} & \dots & \dots & v_{m,n} \end{bmatrix}$$

Stage 3. Ranking and selection procedure of System

The ranking of the systems can be done either mathematically (TOPSIS method) or graphically (Line graph and Spider diagram method). We need a measure to compare the candidates with benchmark System so that they can be ranked and selected. [Bhangale et al.2004].

a)TOPSIS method

The TOPSIS method is based on the concept that the chosen option (optimum) should have the shortest distance from the +ve benchmark System (best possible System) and be farthest from the -ve benchmark System (worst possible System) [Bhangale et al.2004].

$$V^* = [v_1^*, v_2^*, v_3^*, \dots, v_n^*] = \{(max_j v_{ij} | i \in I). (min_j v_{ij} | i \in J)\}$$

$$V^- = [v_1^-, v_2^-, v_3^-, \dots, v_n^-] = \{(min_j v_{ij} | i \in I). (max_j v_{ij} | i \in J)\}$$

The separation from +ve benchmark is given by

$$S_i^* = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^*)^2}, \text{ for } i = 1, 2, 3 \dots m$$

The separation from -ve benchmark is given by

$$S_i^- = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^-)^2}, \text{ for } i = 1, 2, 3 \dots m$$

Then the relative closeness to the +ve benchmark system C. which is measure able and suitable for the system for the chosen application on the basis of the attributes considered, is calculated. A electroplating with the largest C is preferable.

$$C_i^* = S_i^- / (S_i^* + S_i^-), \quad i = 1, 2, 3, \dots, m \text{ [Bhangale et al.2004]}$$

b) Graphical method

The mathematical representation of specifications normalized and weighted normalized specifications. The ranking of the systems can be done graphically (Line graph and Spider diagram method). [Bhangale et al.2004].

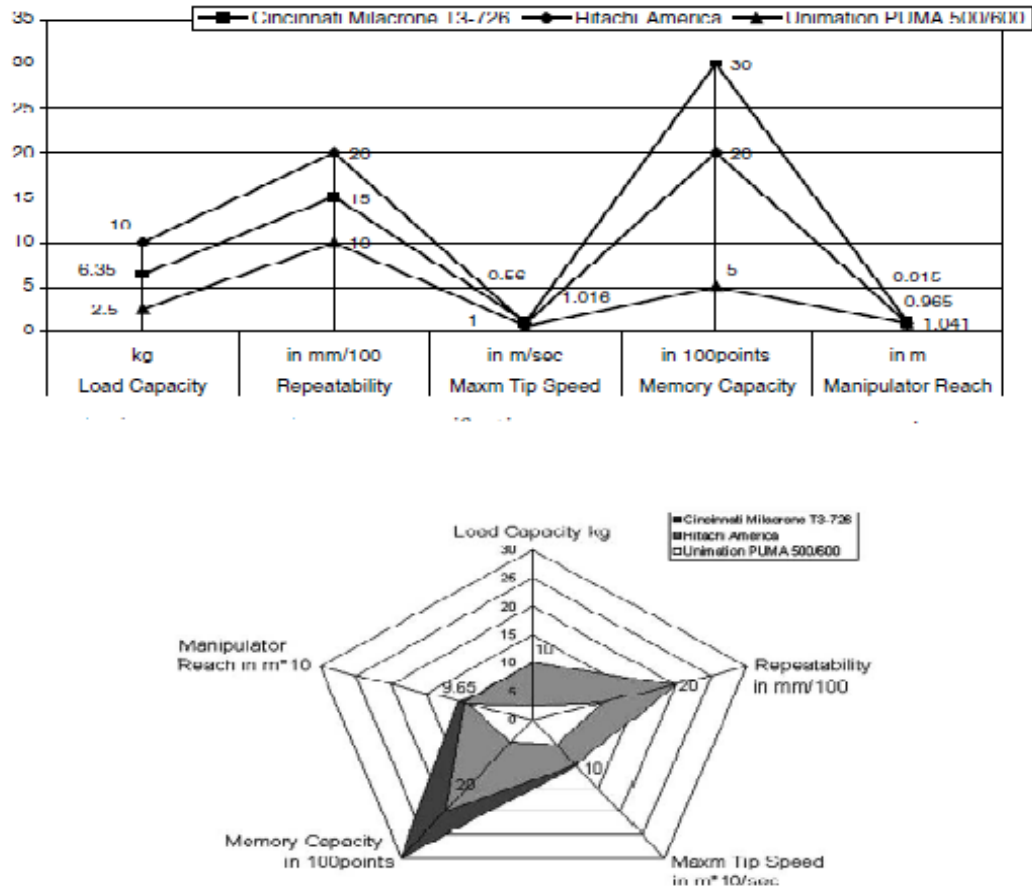


Figure 3.1 Line graph and spider diagram for robot selection[Bhangale et al.2004]

Step 6.Role of user/top management in selection

Sometimes, the ranking done by TOPSIS and graphical methods vary from each other. Also, for both graphical methods the ranking may not be same. The user/top management should find out which method is the best suited for desired application. Thus the selection is done using ranking in order of preference based on the attributes. However, before a final decision is taken, the following factors come into picture: (1) Economic consideration, (2) Availability, (3) Management constraints,

corporate policies, (4) International market policies, which were not previously considered in coding and evaluation. [Bhangale et al.2004].

3.2 Illustrative Example

3.2.1 Identification of system attributes

A EDM system consists of various sub systems. All these sub system are interdependent and interrelated to each other. The performance, cost, behavior, etc of product or process depends upon the performance of each sub or sub-sub system. One of the critical factors to evaluate system is the identification of attributes affecting its characteristics performance. 196 attributes related to EDM system are identified and classified into different categories.

3.2.1.1 Cause and Effect Diagram

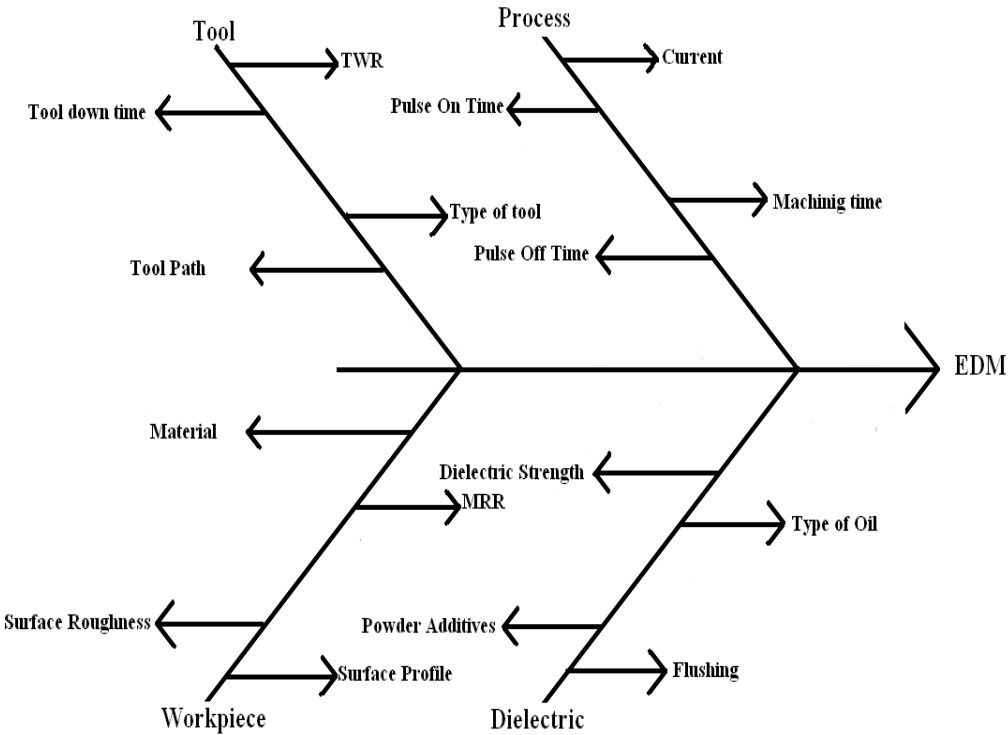


Figure 3.2 Cause and Effect Diagram

3.2.1.2 Classification of attributes

All the EDM attributes are broadly classified into five categories:

1. Process based attributes
2. Work piece based attributes
3. Tool and dielectric medium based attributes.
4. Analysis and modeling based attributes
5. General attributes

Table 3.1 Process Based attributes

1. Pulse time	2. Machine settings
3. Machining time	4. Plasma radius
5. Transitional time	6. Rough cutting
7. Electrical resistance	8. Finish cutting
9. Energy consumption	10. Duty cycle
11. Energy loss	12. Peak value of discharge current
13. Removal efficiency	14. Discharge energies
15. Pulse duration	16. Static pressure
17. Current	18. Pulse interval
19. Electrode polarity	20. Positioning
21. Specified gap state	22. Machining speed
23. Constant angle	24. Heat source
25. Power density	26. Thermal volt equivalent of discharge
27. Energy distribution	28. Bottom gap
29. Flushing	30. Drop voltage
31. Material removal rate	32. Volumetric MRR
33. Tool wear rate	34. Arcing

35. EDM accuracy	36. Nominal capacitance
37. Machining precision	38. Slicing rate
39. Machining efficiency	40. Kerf
41. Cutting parameters	

Work piece based

Table 3.2 Work piece based attributes

1. Surface profile	2. Side wall roughness
3. Grain size	4. Surface roughness
5. Residual stress	6. Micro structure
7. Micro holes	8. Blind holes
9. Orbital cutting	10. Sic percentage
11. Aerosol	12. Mirror
13. Surface	14. Cut
15. Flatness	16. Surface modification
17. Tungsten carbide	18. Ceramics
19. Titanium nitride	20. Silver coating
21. Machining geometry	22. High purity germanium
23. Heat affected zone	24. Cemented carbide
25. Chemical vapour deposited diamond	26. Inconel 601
27. Surface quality	28. White layer dimensions
29. Analysis of craters	30. Crater depth
31. Crater diameter	32. White layer thickness
33. Poly crystalline diamond	34. Heavy metals

Tool and dielectric based

Table 3.3 Tool & Dielectric based attributes

1. Ultrasonic vibration	2. Powder additives
3. Dielectric	4. Tool making
5. Tool wear	6. Tabular electrode
7. Tool wear compensation	8. Gap
9. Planetary movement	10. Tool electrode material
11. Tool path	12. Adapted tool down time
13. Plasma channel diameter	14. Convective coefficient of dielectric
15. Powder concentration	16. Powder size
17. Circumferential speed	18. Synchronous rotation
19. Flow speed	20. Particle contamination
21. Powder metallurgy electrodes	22. Break down
23. Static deflection of wire	24. Dielectric strength
25. Debris deposition	26. Dynamic viscosity
27. Bubbles	28. Debris
29. Electrode jump motion	30. Electrode downtime
31. Bubble expansion	32. Powder mixed dielectric
33. Wire breakage	34. Electrode jump height
35. Electrode jump speed	36. Mixing degree
37. Clamping position	38. Hydrocarbon oils
39. Distilled water	40. Wire tension
41. Electrode rotation speed	

Analysis and modeling based

Table 3.4 Analysis based attributes

1. Empirical modeling	2. Machining simulation
3. Mathematical model	4. Parameter estimation
5. Roughness prediction	6. Thermal model
7. MADM- TOPSIS	8. Process optimization
9. DFM	10. Analysis of variance (ANOVA)
11. Fuzzy logic analysis	12. Modeling
13. Concurrent engineering	14. Design for X-ability
15. Graphs	16. Concurrent design
17. Response surface methodology	18. Mathematical modeling equation
19. Optical cutting conditions	20. Heat source model
21. Semi empirical model	22. Dynamic optimization
23. First order system	24. Parametric programming
25. Optical feedback law	26. Artificial neural network
27. Genetic algorithm	28. Pareto optimal set
29. Risk assessment	30. Occupational hygienic characterization
31. Artificial bee colony	32. Biogeography based optimization
33. Grey relational analysis	34. Regression model
35. Ant colony optimization	36. Industrial survey

General

Table 3.5 General attributes

1. EDM	2. Wire EDM
3. Micro EDM	4. Computer networks
5. Mechatronic system	6. Dry EDM
7. Powder mixed EDM	8. Milling EDM
9. Expert systems	10. Micro machining
11. Green manufacturing	12. Transistor type isopulse generator
13. R.C. pulse generator	14. Servo feed control
15. Macro EDM	16. Multi stage
17. Diamond materials	18. Adaptive control
19. Self turning regulator	20. Minimum variance control
21. Sinking EDM	22. Contour EDM
23. Free form machining	24. 4-axis machining
25. Emission	26. Imission
27. EDG	28. Optics
29. Maglev local actuator	30. Ablation
31. Effective enthalpy of corrosion	32. Thermo physical
33. Hybrid machining process	34. Vibrational behavior
35. Near dry machining	36. Observation
37. Movement	38. Die sink
39. Environment	40. 3D milling
41. EDM polishing	42. Die & mould making

3.2.1.3 Usefulness of Identification of attributes

a) Usefulness to the manufacturer

The quantification and monitoring of the attribute magnitudes help the manufacturer to control them closely so that he fulfils the demand of the user precisely. Moreover, he finds out the market trend by observing the attributes magnitudes. It helps the manufacturer to modify his product to suit the future needs of the user. The EDM manufacturer uses these attributes for the SWOT (Strength–Weakness–Opportunity–Threat) analysis of EDM.

b) Usefulness to the designer

For the designer at conceptual design stage, identification helps to generate various alternative designs, which is developed as modular EDM. Using the modular EDM approach, the optimum EDM according to the market requirements is designed in very little time. He identifies the critical attributes, which directly affects the performance. The designer changes these critical attributes and monitors them to control particular parameters so that the required performance obtained from the EDM. Designer use these attributes for cause and effect analysis, where he find out the effects of manipulating these attributes on the EDM performance.

c) Usefulness to the user

Identification of the attributes helps the user for the data storage and its retrieval. It generates the computerized data, which is used in different formats for different purposes by different people in the organization. It helps the user to select the best possible EDM for the particular application whenever it is required.

3.2.2 Coding Scheme

After the identification of the attributes the next step is to assign codes to the attributes which is either a numerical value or an alphabet. This is done under the coding scheme which is very important as it gives all the detailed information about the attributes. The attributes are qualitative and quantitative in nature. The qualitative attributes are non-deterministic whereas the quantitative attributes are deterministic in nature. In this study the quantitative attributes are given codes on an interval scale of 0-5, where 0 indicates that no information is available about the attribute and 5 indicates the best information and this attribute is used in experimentation.

Table 3.6 Coding Scheme for Attributes

S.no	Condition	Code
1	Attribute having no information	0
2	Attribute which is very less important	1
3	Attribute which is less important	2
4	Attribute which is average important	3
5	Attribute which is highly important	4
6	Attribute which is very highly important	5

The attributes which are indentified are arranged according to N-digit coding scheme. The Table 3.7 shows N-digit coding scheme.

Table 3.7 N- digit coding scheme

Process Based	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41
Work piece based	42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75
Tool & Dielectric based	76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116
Analysis & Modeling based	117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152
General	153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196

S. No	Name of attribute	Information	Code
1.	Pulse time	10,20 and 50 μ s	5
2.	Machining time	10 min	5
3.	Transitional time		0
4.	Electrical resistance		0
5.	Energy consumption		0
6.	Energy loss		0
7.	Removal efficiency		0
8.	Pulse duration	10, 20 and 50 μ s	5
9.	Current	2-7 amperes	5
10.	Electrode polarity	Straight	4
11.	Specified gap state		0
12.	Constant angle		0
13.	Power density		0
14.	Energy distribution		0
15.	Flushing	Manual	4
16.	Material removal rate	Medium	5
17.	Tool wear rate	Low	5
18.	EDM accuracy		0
19.	Machining precision		0
20.	Machining efficiency		0
21.	Cutting parameters	Four parameters	5
22.	Machine settings	Control panel	5
23.	Plasma radius		0
24.	Rough cutting	Rough	5
25.	Finish cutting		0
26.	Duty cycle		0
27.	Peak value of discharge current		0
28.	Discharge energies		0
29.	Static pressure		0

30.	Pulse interval	57 μ s	5
31.	Positioning	Work table	4
32.	Machining speed		0
33.	Heat source		0
34.	Thermal volt equivalent		0
35.	Bottom gap		0
36.	Drop voltage		0
37.	Volumetric MRR		4
38.	Arcing	At high current	3
39.	Nominal capacitance		0
40.	Slicing rate		0
41.	Kerf		0
42.	Surface profile	Flat	4
43.	Side wall roughness		0
44.	Grain size		0
45.	Surface roughness		4
46.	Residual stress		0
47.	Micro structure		0
48.	Micro holes		0
49.	Blind holes		0
50.	Orbital cutting		0
51.	Sic percentage		0
52.	Aerosol		0
53.	Mirror		0
54.	Surface		0
55.	Cut		0
56.	Flatness		0
57.	Surface modification		0
58.	Tungsten carbide		0
59.	Ceramics		0
60.	Titanium nitride		0
61.	Silver coating		0

62.	Machining geometry		0
63.	High purity germanium		0
64.	Heat affected zone		0
65.	Cemented carbide		0
66.	Chemical vapour deposited diamond		0
67.	Inconel 601		0
68.	Surface quality		0
69.	White layer dimensions		0
70.	Analysis of craters		0
71.	Crater depth		4
72.	Crater diameter	10 mm	5
73.	White layer thickness		0
74.	Poly crystalline diamond		0
75.	Heavy metals		0
76.	Ultrasonic vibration		0
77.	Powder additives		0
78.	Dielectric	EDM Oil	4
79.	Tool making		0
80.	Tool wear		4
81.	Tabular electrode		0
82.	Tool wear compensation		0
83.	Gap		3
84.	Planetary movement		0
85.	Tool electrode material	Cu, CuW, Brass	5
86.	Tool path		0
87.	Adapted tool down time		0
88.	Plasma channel diameter		0
89.	Convective coefficient of dielectric		0
90.	Powder concentration		0
91.	Powder size		0
92.	Circumferential speed		0
93.	Synchronous rotation		0

94.	Flow speed		0
95.	Particle contamination		3
96.	Powder metallurgy electrodes		0
97.	Break down		0
98.	Static deflection of wire		0
99.	Dielectric strength		4
100.	Debris deposition		3
101.	Dynamic viscosity		0
102.	Bubbles		3
103.	Debris	Work piece particles	4
104.	Electrode jump motion		0
105.	Electrode downtime		0
106.	Bubble expansion		0
107.	Powder mixed dielectric		0
108.	Wire breakage		0
109.	Electrode jump height		0
110.	Electrode jump speed		0
111.	Mixing degree		0
112.	Clamping position		0
113.	Hydrocarbon oils		0
114.	Distilled water		0
115.	Wire tension		0
116.	Electrode rotation speed		0
117.	Empirical modeling		0
118.	Machining simulation		0
119.	Mathematical model		5
120.	Parameter estimation		0
121.	Roughness prediction		0
122.	Thermal model		0
123.	MADM- TOPSIS		5
124.	Process optimization		0
125.	DFM		0

126.	Analysis of variance (ANOVA)	4
127.	Fuzzy logic analysis	0
128.	Modeling	0
129.	Concurrent engineering	0
130.	Design for X-ability	4
131.	Graphs	5
132.	Concurrent design	0
133.	Response surface methodology	0
134.	Mathematical modeling equation	0
135.	Optical cutting conditions	0
136.	Heat source model	0
137.	Semi empirical model	0
138.	Dynamic optimization	0
139.	First order system	0
140.	Parametric programming	0
141.	Optical feedback law	0
142.	Artificial neural network	0
143.	Genetic algorithm	0
144.	Pareto optimal set	0
145.	Risk assessment	0
146.	Occupational hygienic characterization	0
147.	Particle swarm optimization	0
148.	Sheep flock algorithm	0
149.	Ant colony optimization	0
150.	Artificial bee colony	0
151.	Biogeography based optimization	0
152.	Grey relational analysis	0
153.	Regression model	0
154.	Industrial survey	0
155.	EDM	4
156.	Wire EDM	0
157.	Micro EDM	0

158.	Computer networks	0
159.	Mechatronic system	0
160.	Dry EDM	0
161.	Powder mixed EDM	0
162.	Milling EDM	0
163.	Expert systems	0
164.	Micro machining	0
165.	Green manufacturing	0
166.	Transistor type isopulse generator	0
167.	R.C. pulse generator	3
168.	Servo feed control	3
169.	Macro EDM	0
170.	Multi stage	0
171.	Diamond materials	0
172.	Adaptive control	0
173.	Self turning regulator	0
174.	Minimum variance control	0
175.	Sinking EDM	0
176.	Contour EDM	0
177.	Free form machining	0
178.	4-axis machining	0
179.	Emission	0
180.	Imission	0
181.	EDG	0
182.	Optics	0
183.	Maglev local actuator	0
184.	Ablation	0
185.	Effective enthalpy of corrosion	0
186.	Thermo physical	0
187.	Hybrid machining process	0
188.	Vibrational behavior	0
189.	Near dry machining	0

190.	Observation	0
191.	Movement	0
192.	Die sink	0
193.	Environment	0
194.	3D milling	0
195.	EDM polishing	0
196.	Die & mould making	0

3.2.3 Selection Procedure:

In EDM we can use large number of parameters i.e. we can use different current levels, different pulse on time and pulse off time, different work pieces, different tools etc. But the selection of the best possible parameters for a given application is extremely important. The main emphasis is to select set of parameters which would give us maximum MRR, minimum TWR and desired surface finish. So after consideration and evaluation of all the parameters available we have to select best set of parameters for given application. For example in this study we have to select best tool from given three tools (Cu, CuW and Brass) for D3 workpiece. Results for MRR, TWR and Surface roughness are calculated after conducting experiments on EDM machine (Model T- 3822M) which is available in workshop of Thapar University. The data is taken for the three different tools for the D3 workpiece. In following procedure ranking and selection of tools is done for D3 workpiece.

Table 3.8 Data for all three Tools

S.no	Tool	SR (μm)	MRR (mm^3/min)	TWR (mm^3/min)
1	Copper (Cu)	8.27	5.2630	0.337070
2	Copper Tungsten (CuW)	7.40	3.0263	0.114280
3	Brass	5.10	0.7890	0.352900

Now the procedure for the selection of the tool is as follows:

Step-1: Formation of the decision matrix ‘**D**’, in which the rows of the matrix are candidate tool and the columns are their attribute values.

$$D = \begin{bmatrix} 8.27 & 5.2630 & 0.337070 \\ 7.40 & 3.0263 & 0.114280 \\ 5.10 & 0.7890 & 0.352900 \end{bmatrix}$$

Step 2: In this step the normalized specification matrix is calculated which helps to provide the dimensionless elements of the matrix. It is denoted by N.

$$N = \begin{bmatrix} 0.68 & 0.86 & 0.67 \\ 0.61 & 0.49 & 0.23 \\ 0.42 & 0.13 & 0.70 \end{bmatrix}$$

Step 3: Construction of relative importance matrix from decision matrix. A group of experts and the user will determine the importance of one attribute over the other. Now for selected application we define this as $a_{ij} = w_i/w_j$, where this ratio represents the relative importance of i^{th} attribute with respect to the j^{th} attribute corresponding to the particular. Mostly this will be obtained by team of experts by preparing the questionnaires and send it to other team of experts of same area and prepare a database matrix by calculating the average values and put into the relative importance matrix. The relative importance matrix which is formed from the decision matrix is shown here.

$$A = \begin{bmatrix} 1 & 0.77 & 1.4 \\ 1.28 & 1 & 1.8 \\ 0.71 & 0.55 & 1 \end{bmatrix}$$

Step 4: Now the maximum eigen value of the relative importance matrix R is to be found out.

Therefore $(A - \lambda_{\max} I)$ is equal to

$$\begin{bmatrix} 1-\lambda & 0.77 & 1.4 \\ 1.28 & 1-\lambda & 1.8 \\ 0.71 & 0.55 & 1-\lambda \end{bmatrix}$$

Also, $(A - \lambda_{\max} I) = 0$, On solving the above matrix we have $\lambda_{\max} = 2.9898$ so take $\lambda_{\max} = 3$

Therefore, Now $(A - \lambda_{\max} I) =$

$$\begin{bmatrix} -2 & 0.77 & 1.4 \\ 1.28 & -2 & 1.8 \\ 0.71 & 0.55 & -2 \end{bmatrix}$$

Step 5: In this step the weights for each attribute using the eigen vector associated with the maximum eigen value are calculated. This can be represented by the equation,

$$(A - \lambda_{\max} I) w = 0$$

$$\begin{bmatrix} -2 & 0.77 & 1.4 \\ 1.28 & -2 & 1.8 \\ 0.71 & 0.55 & -2 \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ w_3 \end{bmatrix} = 0$$

Also we know that, $w_1 + w_2 + w_3 = 1$

On solving this above matrix we have,

$$w_1 = 0.35 \quad w_2 = 0.39 \quad w_3 = 0.26$$

Step 6: In this step the weighted normalized specification matrix is calculated. It is denoted by **V**.

$$V = \begin{bmatrix} 0.2108 & 0.3268 & 0.1541 \\ 0.1891 & 0.1862 & 0.0529 \\ 0.1302 & 0.0494 & 0.1610 \end{bmatrix}$$

The weighted normalized matrix involves both the attribute values and their relative importance to each other. So this matrix provides a very good basis for the comparison of the attributes with each other and with the benchmark tool.

3.2.4) TOPSIS method for ranking:

The weighted normalized attributes for the positive and negative benchmark tools are obtained which are as follows:

$$V^+ = (0.2108, 0.3268, 0.1610)$$

$$V^- = (0.1302, 0.0494, 0.0529)$$

Now from the formulas above mentioned in the explanatory part of the TOPSIS method and relative closeness to the ideal solution can be calculated and the values for the same are as follows:

$$S_1^+ = 0.0069$$

$$S_1^- = 0.3060$$

$$C_1^* = 0.9779$$

$$S_2^+ = 0.1786$$

$$S_2^- = 0.1489$$

$$C_2^* = 0.4546$$

$$S_3^+ = 0.2888$$

$$S_3^- = 0.1081$$

$$C_3^* = 0.2723$$

As the C* value of the first tool is the highest therefore it is the best Tool and C* value of third Tool is the lowest so it is the worst tool.

Table 3.9 Ranking using TOPSIS method

S. no	Tool	Value of C*	Rank
1	Copper (Cu)	0.9779	1 st
2	Copper Tungsten (CuW)	0.4546	2 nd
3	Brass	0.2723	3 rd

As shown in above table Copper is the highest ranked tool so it is the best possible tool for the EDM process and Brass is worst tool for EDM machining.

3.2.5) Graphical technique:

After using the TOPSIS procedure for the ranking and selection of the tool. We also can use two graphical techniques i.e. Line graph and Spider graph for the ranking and thus final selection of the tool.

3.2.5.1) Line Graph: A graph is drawn for the weighted normalized matrix between the weighted normalized values and the attributes for different tools as shown in fig. The area under the curve in the line diagram for each system is calculated and is further used to calculate COS^{VL} which is used to compare the systems. The system with the highest value of COS^{VL} is ranked highest and the system with the least value of COS^{VL} is ranked last. The COS^{VL} for the line diagram is calculated by the following formulae:

$$COS^{VL} = AV_i^L / AV_{+B}^L$$

$$AV_i^L (\text{Area}) = (p_{i,1} + 2 (p_{i,2} + \dots + p_{i,j} + \dots + p_{i,n-1}) + p_{i,n}) / 2$$

Where, p_{ij} – The weighted normalized value of j^{th} attribute in i^{th} system

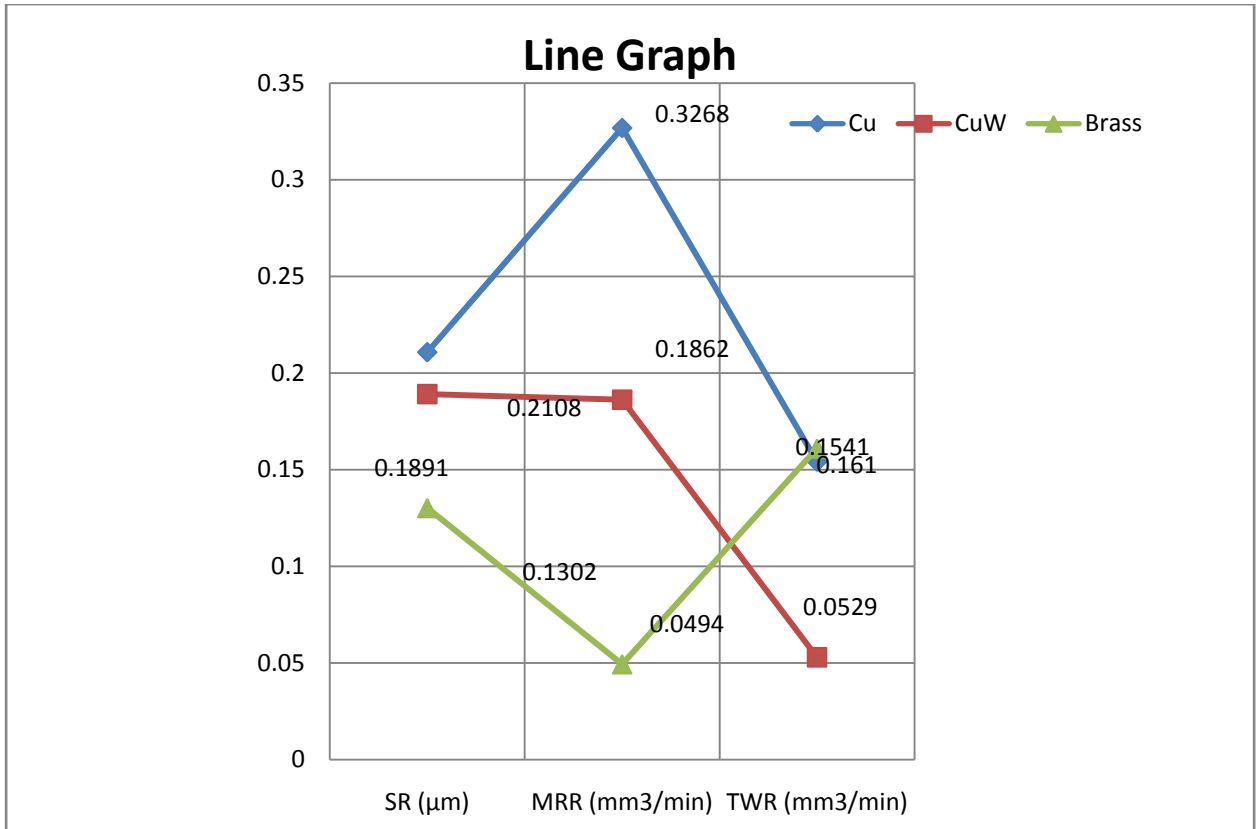


Figure 3.3 Line Graph of different tools

On the basis of the line diagram shown above the COS^{VL} for each tool is calculated and hence ranking of the three different tools is done.

$$AV_1^L = 0.5092$$

$$AV_2^L = 0.3072$$

$$AV_3^L = 0.1950$$

$$AV_{+B}^L = 0.5127$$

$$COS_1 = 0.9932$$

$$COS_2 = 0.5991$$

$$COS_3 = 0.3803$$

Ranking based on line graph:

Table 3.10 Ranking of EDM tools based on the COS in line diagram

S.no	Name of tool	COS ^{VL}	Rank
1.	Cu	0.9932	1 st
2.	CuW	0.5991	2 nd
3.	Brass	0.3803	3 rd

We can see from the table that Cu is the highest ranked tool, CuW is the second ranked and Brass is lowest ranked tool. So we can conclude that Cu is best tool and Brass is the worst tool.

3.2.5.2) Spider graph representation:

The area under the curve for Tools in a spider graph representation is calculated

by the following formulae:

$$\text{Area} = (\sin \theta/2) \sum_{j=1}^n p_{i,j} \times p_{i,j+1} \text{ where } p_{i,n+1} = p_{i,1} \text{ and } \theta = 360/n$$

The spider diagram representation for three tools and their attribute values is shown in figure.

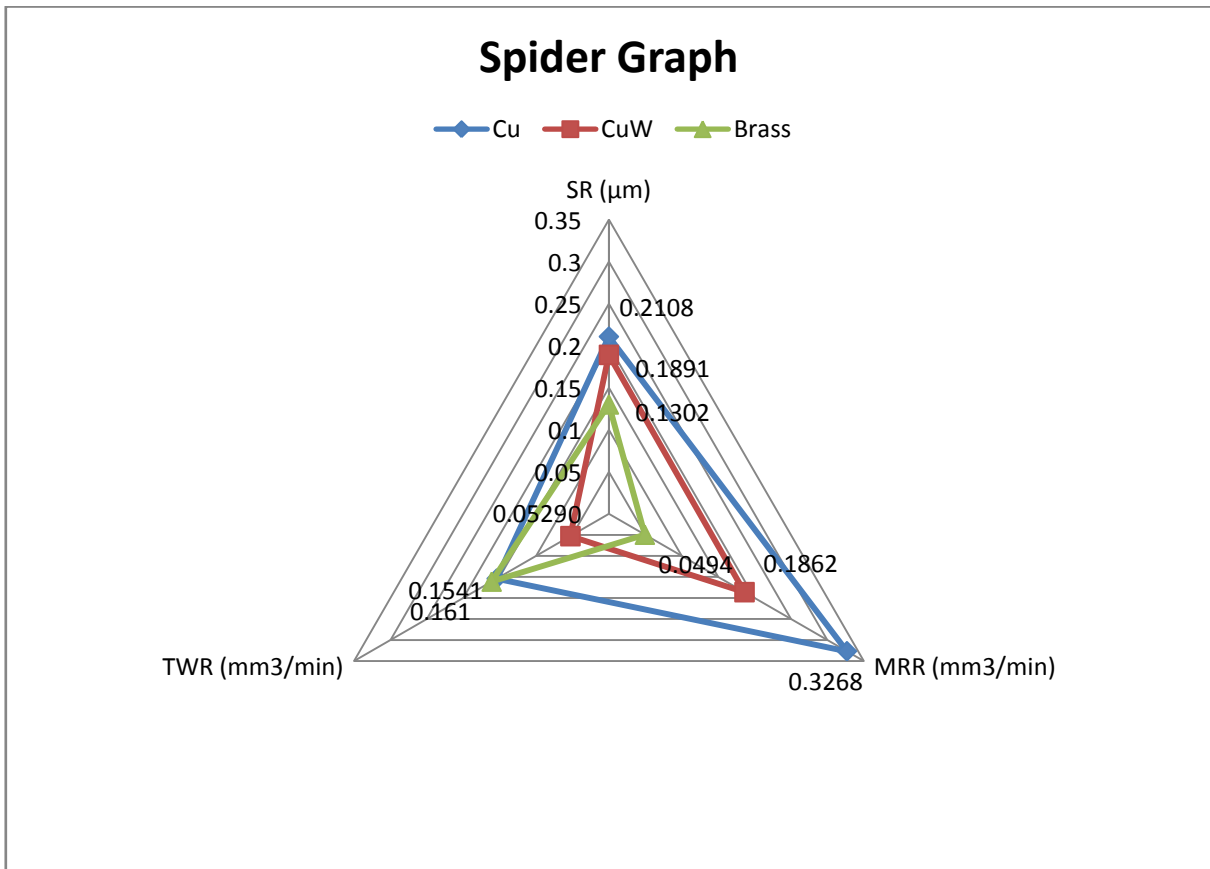


Figure 3.4 Spider graph for EDM tools.

On the basis of the spider diagram shown above the area under the curve for every Tool is calculated and hence ranking of the three different Tools is done.

Ranking based on spider graph:

Tool which has highest area should be ranked first and tool with lowest area should be ranked last.

Table 3.11 Ranking of Tools based on the area under the curve in spider diagram

S. no	Name of Tool	Area under the curve	Rank
1.	Cu	0.1314	1 st
2.	CuW	0.0476	2 nd
3.	Brass	0.0306	3 rd

From above table it is clear that Cu is best tool and Brass is the worst tool.

3.3 Usefulness of the proposed methodology

1. This proposed methodology will help in optimization of parameters of EDM system.
2. There are number of parameters and moreover each parameter has number of levels, so selection of best levels of parameter is difficult task. This methodology will help in solving this problem.
3. This methodology will help in validation of results of ANOVA.
4. This methodology will help in increasing MRR and reducing TWR and SR.
5. It provides methodology for evaluation, selection and ranking of parameters of EDM system.

3.4 Discussion

In this chapter we applied MADM TOPSIS method for evaluation, ranking and selection of Tool for EDM process. As we know that EDM is a advanced machining process which means it is a costlier process so selection of best parameters is very important for economical feasibility of this process. We can use substantial number of parameters for this process like Current level, Pulse on time, pulse off time, type of work pieces and type of tools. So to choose a best set of parameters is a difficult task. To solve this problem we mainly use ANOVA and DOE techniques but these techniques provides us data and graphs from which user has to make decision. But MADM TOPSIS method provide us ranking of different parameters which makes the selection of parameters very easy. As in this study the problem of selection of best tool is solved. Three tools made of copper,

copper tungsten and brass are considered and decision matrix is made from experimental data by taking Surface roughness, Material Removal Rate and Tool wear Rate as Attributes corresponding to these three tools. After applying this method Copper proves to be best tool and brass proves to be worst tool.

3.5 Results

In this chapter MADM TOPSIS method is applied for evaluation, selection and ranking of tools for EDM process. Ranking is done by TOPSIS C^* values, COS^{VL} values of line graphs and area under the spider diagram. Results of these techniques is shown in tables above in this study. In all three methods of ranking Copper (Cu) proves to be best tool , Copper Tungsten (CuW) got 2nd rank and Brass proves to be worst tool. All three techniques i.e. TOPSIS, Line Graph and Spider Diagram gives same results. This results are validated by applying ANOVA to experimental data used for making decision matrix. ANOVA also gives same trends. So results are unanimous and are correct.

CHAPTER-4

STRUCTURAL MODELLING, CHARACTERIZATION AND INTEGRATIVE ANALYSIS OF EDM SYSTEM

4.1 Need for Structural Modeling and Analysis of EDM System

Electrical discharge machining (EDM) is a thermal process with a complex metal-removal mechanism, involving the formation of a plasma channel between the tool and work piece. It has proved especially valuable in the machining of super-tough, electrically conductive materials such as the new space-age alloys that are difficult to machine by conventional methods [Tzeng et al. 2007]. 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. This technique has been developed in the late 1940s where the process is based on removing material from a part by means of a series of repeated electrical discharges between tool called the electrode and the work piece in the presence of a dielectric fluid [Abbas et al.2007]. An EDM system consists of a number of components. These components are having different functionalities and are from different disciplinary backgrounds like mechanical, electrical, electronics etc. or combination of these. In physical systems, interactions exist among these components. The components are connected in certain configurations that allow Electrical energy to be converted into thermal energy and material is removed. A system performance is the combined effect of its constituents and the interactions between these constituents. Each component in the configuration is dedicated to perform certain function of EDM. The behavior of each of the components is controlled by a number of parameters associated to it. Therefore, the integration and compatibility among the components also affects the functionality, quality, performance, etc. of an air conditioning system. Many authors have converged

towards a particular subsystem oriented design. Design of an EDM system considering all these interactions, is a complex job.

From the literature review given in chapter 2, we can say that no one has considered the structural constituents for analyzing EDM system along with their interactions at the conceptual and design stages, and also there is no methodology proposed for an integrated system approach for analyzing EDM systems, i.e., by considering the subsystems as its constituents, and their interactions, interdependence, and connectivity's. There is a need to develop a mathematical model that can help in analysis and synthesis of an EDM system at conceptual stage and also in developing a virtual model. Also in literature review there is good number of applications of system models using graph theory for the structural modeling and analysis of different engineering systems. Thus, for the modeling and analysis of the EDM system, it is quite logical to select the graph theory and matrix algebra.

4.2 Introduction to Graph Theoretic Approach

To fill the research gap and to show the importance of a structure based EDM system design, a graph theory based EDM system model is proposed. The model can include all the subsystems along with the interactions therein and thus becomes a tool for EDM system analysis. A graph is required for visual analysis of an EDM system, but quantification of these interactions is necessary for design and analysis. Matrix algebra is used for quantifying these interactions. A graph $G = (V, E)$ [1] consists of a set of objects $V = \{v_1, v_2, \dots\}$ called vertices or nodes, and another set $E = \{e_1, e_2, \dots\}$, of which the elements are called edges, such that each edge e_k is identified with a pair of vertices.

Assumptions for developing graph theoretic model

The proposed graph theoretic model for EDM systems is based on some assumptions as listed below:-

- The structure of the system can be compared quantitatively with its performance.
- The interactions as well as the subsystems discussed are assumed for a general EDM system. The subsystems must be identified separately for applying the model to any specific EDM system.
- Variable permanent matrix is capable of storing complete information related to a real life situation of a typical EDM system as all its elements are variables and functions of characterizing attributes representing subsystem and interconnections. These attributes if identified comprehensively, the matrix represents the EDM system completely.
- Permanent function of the variable permanent matrix characterizes uniquely the EDM system from the point view of the structure.

- Performance of the EDM system depends on individual performance of subsystems, sub-systems and their components along with interactions between them.
- Modeling methodology is based on bottom-up approach. Permanent function values of sub-subsystems are used in permanent matrices of subsystems. Permanent function values of subsystems are used to calculate permanent functions of EDM system.
- The experts may assign correct and representative score to the elements of the EDM system at the lowest level in a particular dimension of performance.

4.3 Identification of Subsystems of the EDM System and their Interactions

The EDM system consists of large number of components i.e. generator, RC circuits, pump, filter, working tank, work head , controls, indicators, tools, servo controls etc. We can broadly divide EDM into 4 subsystems namely power supply unit, control panel, dielectric unit and machine tool. These subsystems further contains components in them as shown in figure 4.1

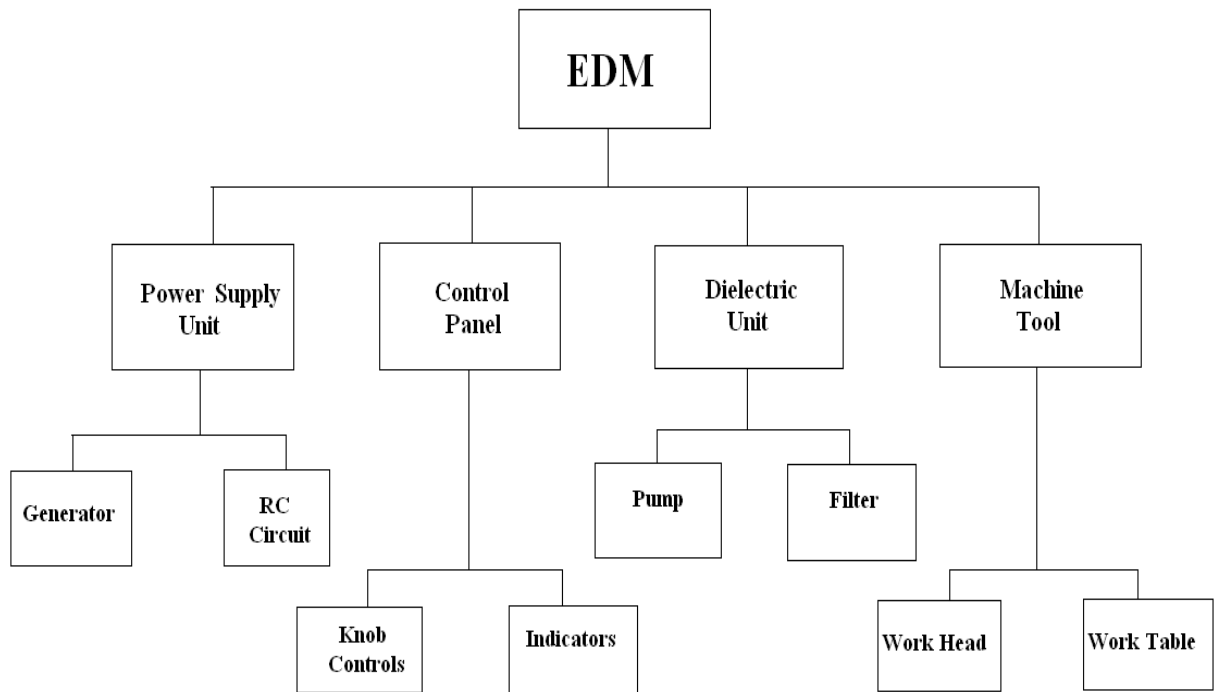


Figure 4.1 EDM system and subsystems

Power supply unit

Power supply unit mainly consists of generator and circuits. Several different electric circuits are available to provide the pulsating dc across the work tool gap. The suitability of circuit depends on the machining conditions and requirements. The commonly used principles for supplying the pulsating dc can be classified into three groups i.e. resistance capacitance relaxation circuit with a constant dc source, Rotary impulse generator and controlled pulse circuit.

Control panel

A control panel acts as a interface between machine and operator. It contains 29 controls each for performing different task. It consists of toggle switches, push buttons, indicator lamps , ammeter and alarms etc.

Dielectric unit

It consists of tank, pressure unit, suction unit and filter unit. Kerosene oil is used commonly as dielectric medium. The tool and workpiece should be submerged in the dielectric. Due to material removal the oil became contaminated. In order to remove dirt from oil a filter unit is used and pump unit is required for circulation of oil between tank and filter.

Machine tool

It consists of work head and co-ordinate table. Work head contains dial gauge, grub screw, spark indicator, micrometer, quill scale, depth stop switch, zero adjustment and electrode connection. It has servo control for moving tool up and down. Co-ordinate table with work tank consists of drain gate, door clamps, hand wheel for 'X' slide, scale Y, machine base, brake slide X and hand wheel for Y slide.

4.4 Graph Theoretic Modeling of an EDM System

The schematic diagram of EDM system as shown in Figure 4.2 is a good representation of different identified components and their interactions which provides the good understanding of the structure of EDM system, but it is not a mathematical entity. To overcome this problem, a graph theory based modeling of an EDM system is proposed. A graph theory based mathematical model is derived for representing the physical structure of EDM system along with interactions.

Four subsystems of EDM system as shown in the Figure 4.2 and interactions among them are represented using a digraph as shown in Figure 4.3. In general graph is represented mathematically by $G = \{V, E\}$; where V represents vertices of the graph and E represents the edges connecting between those vertices. In the EDM system, let the vertices correspond to subsystems (V_i) and the edges (e_{ij})

correspond to interaction of its two sub systems. In Figure 4.3 components of EDM system are represented by the vertices of the graph and the interaction of the subsystems are represented by the edges of the graph. Undirected graph are used where directional property is not significant as shown in Figure 4.3. This means that the influence of i th vertex on j th vertex is equal to the influence of j th vertex on i th vertex. For directed graph i.e. digraph $e_{ij} \neq e_{ji}$. Figure 4.2 shows the schematic representation of EDM and Figure 4.3 shows system digraph of EDM system.

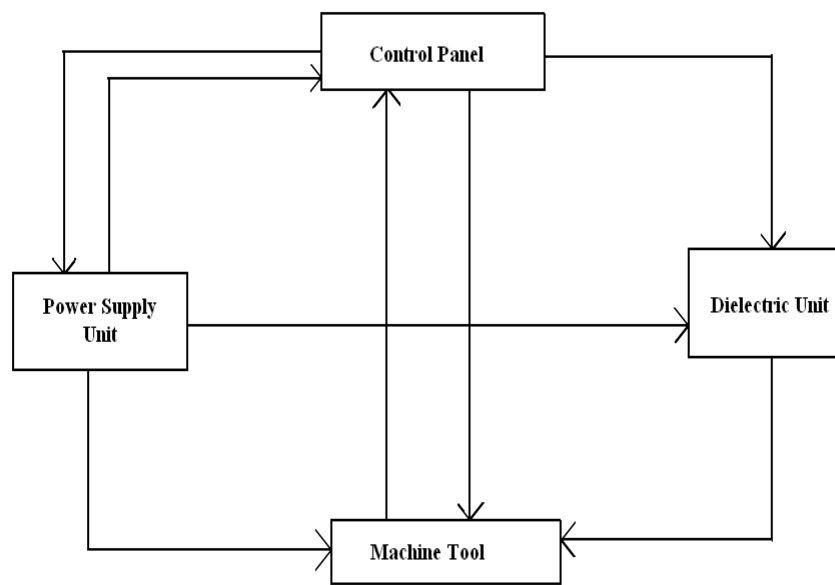


Figure 4.2 Schematic representation of EDM

Let

S₁- Power Supply Unit

S₂- Control Panel

S₃- Dielectric Unit

S₄- Machine Tool

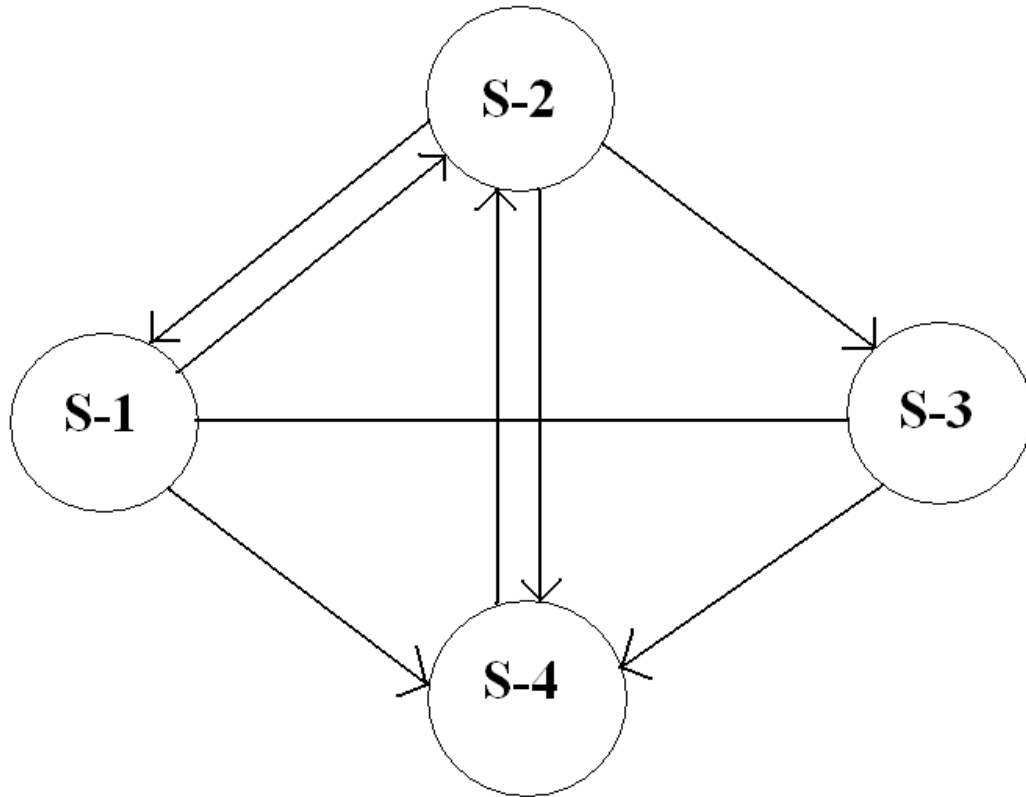


Figure 4.3 EDM System Digraph

4.5 Matrix Representation for the EDM System Graph

To quantify sub systems and interactions in EDM system graph an equal mathematical representation known as Matrix is used. In general the graph is represented by a matrix called adjacency matrix. Since adjacency matrix represents the physical structure of an EDM system, it is termed as EDM System Structure Matrix.

4.5.1 EDM System Matrix (EDMSM)

EDM System matrix is a square matrix, having rows and columns correspond to respective sub system. This matrix is a binary square matrix having (0, 1) as elements. EDM system of N sub

systems is represented by a structure matrix of size $N \times N$. The system structure matrix of the EDM system graph with four nodes will be a

Four order binary (0,1) square matrix, $\mathbf{A}=[e_{ij}]$ such that:

$$e_{ij} = \begin{cases} 1, & \text{if subsystem } i \text{ is connected to subsystem } j. \\ 0, & \text{otherwise} \end{cases}$$

$$\mathbf{A} = \begin{bmatrix} 0 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 \end{bmatrix} \quad (1)$$

4.5.2 EDM System Characteristic Matrix (EDMCM)

To characterize the EDM system, a new matrix \mathbf{B} is defined using the identity matrix \mathbf{I} , a variable \mathbf{S} which represents the EDM system, and the adjacency matrix \mathbf{A} . Based on the standard characteristic equation in mathematics, the EDM characteristic matrix \mathbf{B} for the graph shown is Figure , may be expressed as $\mathbf{B} = [\mathbf{SI} - \mathbf{A}]$.

Where \mathbf{I} = Identity Matrix

\mathbf{S} = variable representing EDM system

$$\mathbf{B} = \begin{bmatrix} \mathbf{S} & -1 & -1 & -1 \\ -1 & \mathbf{S} & -1 & -1 \\ 0 & 0 & \mathbf{S} & -1 \\ 0 & -1 & 0 & \mathbf{S} \end{bmatrix} \quad (2)$$

$$\mathbf{Det}(\mathbf{B}) = \mathbf{S}^4 - 2\mathbf{S}^2 - 2\mathbf{S} - 1$$

In Equation (2), the value of all diagonal elements is same (i.e., all EDM system components are assumed to be identical which is not true in reality). In real situation different sub systems are having

different physical structures and characteristics. Also interaction represented by a binary number 1 in matrix **B** does not provide information like type of interaction and degree of interaction. So, Equation (2) is not the complete representation of EDM system structure. To overcome this problem, another matrix called the EDM system variable characteristic matrix is proposed.

4.5.3 EDM System Variable Characteristic Matrix (EDMVCM)

The EDM system variable characteristic matrix takes into consideration, the effect of different EDM subsystem (i.e. components) and their varying degrees of interactions. The EDM structure graph in Figure is considered for defining this variable characteristic matrix **C** as below in Equation (3). For this purpose, a four order square matrix **E** with off-diagonal elements S_{ij} representing varying levels of interactions between the subsystems is defined. Another matrix **D**, a diagonal matrix with diagonal elements S_i $i=1,2,3,\dots,5$ representing four different subsystems or components is defined. The matrix **C** can be developed from the matrices **E** and **D** as $\mathbf{C} = [\mathbf{D} - \mathbf{E}]$

$$\mathbf{D} = \begin{bmatrix} S_1 & 0 & 0 & 0 \\ 0 & S_2 & 0 & 0 \\ 0 & 0 & S_3 & 0 \\ 0 & 0 & 0 & S_4 \end{bmatrix}$$

$$\mathbf{E} = \begin{bmatrix} 0 & e_{12} & e_{13} & e_{14} \\ e_{21} & 0 & e_{23} & e_{24} \\ 0 & 0 & 0 & e_{34} \\ 0 & e_{42} & 0 & 0 \end{bmatrix}$$

$$C = D - E = \begin{bmatrix} S_1 & -e_{12} & -e_{13} & -e_{14} \\ -e_{21} & S_2 & -e_{23} & -e_{24} \\ 0 & 0 & S_3 & -e_{34} \\ 0 & -e_{42} & 0 & S_4 \end{bmatrix} \quad (3)$$

$$\begin{aligned} \text{Det}(C) = & S_1 S_2 S_3 S_4 - S_1 e_{42} e_{23} e_{34} - S_1 S_3 e_{24} e_{42} \\ & - S_3 S_4 e_{12} e_{21} - e_{21} e_{13} e_{34} e_{42} - S_3 e_{21} e_{14} e_{42} \end{aligned}$$

The above matrix distinctly represents characteristic features of the subsystems and their interactions. Thus, the matrix C in Equation (3) is complete structural representation of the EDM system capturing all the data related to the system including the interactions. This information is useful for analysis, design, and development of new EDM systems at conceptual stage or for optimization purposes. The matrix provides a powerful tool through its determinant, called the variable characteristic EDM system multinomial. This is a characteristic of the system and represents the complete EDM system, considering the effect of components and their interactions.

4.5.4 EDM System Variable Permanent Matrix (EDMVPM)

The determinant of the matrix, C i.e., the variable characteristic EDM system multinomial, includes both positive and negative signs. On substituting numerical values in place of diagonal and off-diagonal elements, some of the information is lost in the determinant. This information loss is due to subtraction of some of the terms in the expression. To avoid information loss during mathematical process, another term EDM system variable permanent matrix is introduced. Let the permanent matrix of four-subsystem system be defined as

$$Q = \begin{bmatrix} S_1 & e_{12} & e_{13} & e_{14} \\ e_{21} & S_2 & e_{23} & e_{24} \\ 0 & 0 & S_3 & e_{34} \\ 0 & e_{42} & 0 & S_4 \end{bmatrix} \quad (4)$$

4.6 Development of Permanent Function for EDM System

To develop a unique and comprehensive model of EDM system, another entity permanent matrix, frequently used in combinatorial mathematics is proposed. The permanent function is obtained from a similar manner as its determinant, but all negative terms obtained after expression for the calculation of the determinant of the matrix are replaced with positive equivalent terms. This computation results in a multinomial (Equation 5) whose every term has a physical significance related to the EDM system. The multinomial representation includes all the information regarding various components as subsystems and interactions among them. The multinomial is derived based on Equation (4), and a numerical index is obtained. When the actual values of each term are substituted in the multinomial, the final values after the algebraic addition gives a numerical index, which can be considered as a score of total EDM system in any performance dimension depending upon the one selected for giving values to the individual structural constituents. This score can prove a powerful tool for comparison, ranking of different EDM systems and optimum selection of EDM system. Thus permanent function is proposed as complete tool for the total structural analysis of the EDM system. The variable permanent function for an EDM system derived from

Equation (4) is as follows:

$$\begin{aligned} \text{Per (Q)} = & S_1S_2S_3S_4 + S_1S_3e_{24}e_{42} + S_3S_4e_{12}e_{21} + S_1e_{42}e_{23}e_{34} \\ & + S_3e_{21}e_{14}e_{42} + e_{21}e_{13}e_{34}e_{42} \end{aligned} \quad (5)$$

Every term of these equations represents a subset of the EDM system. It is possible to write these equations simply by visual inspection of the EDM system of Figure 4.3. To achieve this objective and for the unique representation and interpretation, the permanent function is written in a standard form as $(N + 1)$ groups, where N is the number of subsystems. The permanent function when written in $(N + 1)$ groups present an exhaustive way of analysis of an EDM system at different levels. The multinomial consists of different combinations of EDM system interaction components for example, structural constituents such as subsystem characteristics (S_i 's) and structural interactions (S_{ij} 's). The existence of elements such as S_{2ij} or $S_{ij} S_{ji}$, S_{ij} , S_{jk} , S_{ki} , S_{ij} , S_{jk} , S_{kl} , S_{li} , etc. correspond to the subsystems interacting in the form of a dyad, two subsystem loop, four subsystem loop, etc. respectively. The terms in each group of the multinomial form a separate group, which may be used for characterizing the EDM system uniquely. The permanent function has terms in different groups as follows:

- The first group contains only isolated four components are to be considered together as independent entities.
- The second group is absent, because the system has no term with three subsystems.
- The third group has two terms, first term is a combination of two dyad S_1S_3 and one loop L_{24} and second term is a combination of two dyad S_3S_4 and one loop L_{12} .
- The fourth group has two terms, first term is a combination of one dyad S_1 and one loop L_{234} and second term is a combination of one dyad S_3 and one loop L_{142} .
- The fifth group has only one term which only contains a loop L_{1342} .

So equation 5 can be written in terms of loops as follows:

$$\text{Per (Q)} = S_1S_2S_3S_4 + S_1S_3L_{24} + S_3S_4L_{12} + S_1L_{234} + S_3L_{142} + L_{1342} \quad (6)$$

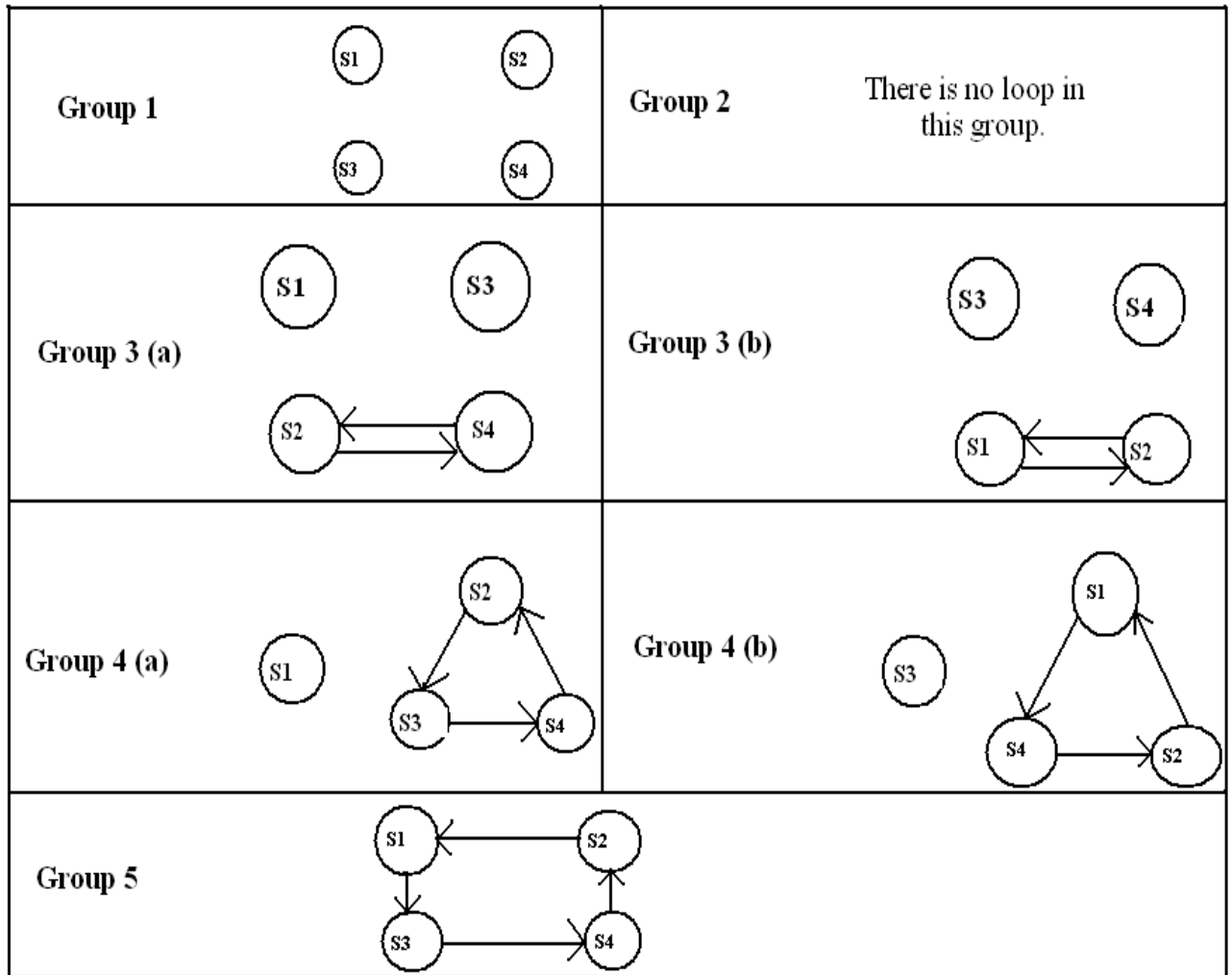


Figure 4.4 Physical representation of permanent function for EDM system

The multinomial defined in Equation (5), gives a unique numerical index which is defined as:
EDM system numerical index = Per (**Q**) (after substituting

numerical values in the matrix **Q**) (7)

Researchers can assign the numerical values to various subsystems as well as the interactions, depending on the type of EDM system and according to parameters of EDM machine i.e. current, tool material and workpiece material etc. For complex subsystems, the numerical values may be assigned by splitting the subsystem into further lower subsystems and their permanent function may be used as the numerical score for the subsystem i.e. separate graph, matrix, or index can be derived for each subsystem using the same procedure. To calculate correct degree of interactions between the subsystems, we may have to consider the views of technical team experts. This numerical index is considered as a composite score of total EDM system depending upon the type of system and interactions between its subsystems. This score can prove a powerful tool for comparison, ranking of different EDM systems and optimum selection of EDM system.

4.7 Identification and Comparison of EDM System

The EDM system permanent function is useful for identification and comparison of EDM system structures. The number of terms in each grouping of the EDM system permanent function for all kind of EDM systems for a given set of components will be same. However, their values will be different. Two EDM systems may be similar from the qualitative aspects, if their system structure graphs are isomorphic. Two such graphs are isomorphic, if they have identical permanent function matrix set representation. This means not only the number of terms in the groupings as well as sub-grouping as same but also their values are also same. Based on this, system structure identification set of EDM systems is represented as

$$[(M_{1T}/M_{2T}/M_{3T}/M_{4T}/M_{51T}/M_{52T}/M_{61T}/M_{62T}/\dots)(N_{1T}/N_{2T}/N_{3T}/N_{4T}/N_{51T}/N_{52T}/N_{61T}+N_{62T}/\dots) \quad (8)$$

Where $M_{i T}$ represents the total number of terms in the i th grouping, M_{ijT} represents the total number of terms of the M th sub grouping in the i th grouping. Similarly, $N_{i T}$ represents the numerical value of the i th grouping and N_{ijT} represents the numerical value of the M th sub grouping in the i th grouping. Numerical values of the S_i 's and S_{ij} 's are substituted in the sub grouping or the grouping to obtain the permanent system numerical index.

4.8 Generalization of the permanent function

For general EDM system with N subsystems, the EDM system characteristic and interdependence matrix, **Q** may be written as in Equation (9) below:

$$Q = \begin{bmatrix} S_1 & S_{12} & \dots & S_{1N} \\ S_{21} & S_2 & \dots & S_{2N} \\ \dots & \dots & \dots & \dots \\ S_{N1} & S_{N2} & \dots & S_N \end{bmatrix} \quad (9)$$

For general N subsystem EDM system with all the subsystems linked together, the total number of terms of the permanent function shall be equal to N! The permanent for the above matrix, i.e., per (Q) is called variable permanent function. The variable permanent function for the above matrix is written in sigma (Σ) form as

$$\begin{aligned} \text{Per (Q)} = & \Pi^N_1 S_i + \Sigma_i \Sigma_j \Sigma_k \Sigma_l \dots \Sigma_N (S_{ij} S_{ji}) S_k S_l \dots S_N \\ & + \Sigma_i \Sigma_j \Sigma_k \Sigma_l \dots \Sigma_N (S_{ij} S_{ik} S_{ki} + S_{ik} S_{kj} S_{ji}) S_l S_m \dots S_N + \\ & \{ \Sigma_i \Sigma_j \Sigma_k \Sigma_l \dots \Sigma_N (S_{ij} S_{ji}) (S_{kl} S_{lk}) S_m S_n \dots S_N + \\ & \Sigma_i \Sigma_j \Sigma_k \Sigma_l \dots \Sigma_N (S_{ij} S_{ik} S_{kl} S_{li} + S_{il} S_{lk} S_{kj} S_{ji}) S_m S_n \dots S_N \} \\ & + \dots \dots \dots \end{aligned} \quad (10)$$

4.9 EDM System Analysis

The methodology described in this chapter for complete analysis of EDM system is summarized in step-by-step manner as below:

1. Select the desired EDM system. Study the system and its subsystems (power supply unit, control panel, machine tool and dielectric unit), and also their interactions.
2. Develop a system graph of the EDM system with subsystems as vertices and edges for interaction between the vertices.
3. Using the graph in step 2, develop matrix similar to EDM system variable permanent matrix given in Equation (5).
4. Calculate system permanent function.
5. The numerical index of an EDM system would be obtained by substituting the numerical values of subsystems and their interactions.
6. Different type of EDM machines can be compared on the basis of permanent numerical index thus obtained. Necessary improvements and developments can be done on the basis of this approach.

7. From the different alternatives of EDM systems, the alternative with highest value of numerical index is the best choice for the given application.

4.10 Usefulness of the Methodology

The proposed approach is useful for product design engineer, researcher, and industries at conceptual stage. This methodology is useful while

1. Taking decision for purchasing EDM machine from different types available for given application.
2. Carrying out cause and effect analysis to find out the reasons of less MRR and more TWR etc.
3. Carrying out SWOT (Strength-Weakness-Opportunity-Threats) analysis on EDM system.
4. Carrying out re-engineering of the product, process etc. for break through improvement.
5. Increasing the product life cycle of the EDM machine.
6. Developing maintenance strategies.
7. The methodology is dynamic in nature as sub-systems/components and interactions, which appear as variables in different models may be changed without any difficulty.

4.11 SWOT Analysis

SWOT analysis is a technique to consider the strengths, weakness, opportunities and threats of any given system. It is very important tool for decision making and analysis of system. In strengths all the positive points of system are noted. In weakness all the drawbacks of system are enlisted. Both these are internal factors of the system. In 3rd cell all the opportunities of the system like scope of system means in which fields it's usage will increase etc. are enlisted and in threats all the competitors are enlisted means which other alternatives can be used in place of given system. Both these are the external factors affecting the system. Factors on left side are the positive factors and factors on the right side are the negative factors.

In this study SWOT analysis of EDM machine is done. In strengths advantages of EDM machine are enlisted like ability to cut hard materials etc. In weakness disadvantages of the EDM machine are enlisted like low MRR etc. The top two cells highlights internal factors of EDM. In opportunities scope of EDM process is enlisted and in threats competitors of EDM are enlisted like high speed milling is giving stiff competition. Bottom two are external factors. By doing SWOT analysis decision making becomes easy. It provides complete overview of EDM. Results from graph theory and MADM of EDM combined with SWOT analysis of EDM are together used for reaching final conclusion.

Table 4.1 SWOT Analysis of EDM

INTERNAL			
P O S I T I V E	Strengths	Weakness	N E G A T I V E
	<ol style="list-style-type: none"> 1. It is a advanced process which is used to cut very hard materials. 2. Machining of complicated shapes is possible. 3. There is no contact between tool and workpiece. 4. It is a thermal process so hard materials like quenched steels, cemented carbide can be machined. 	<ol style="list-style-type: none"> 1. MRR is low as compared to conventional processes. 2. EDM can only used for electrical and thermal conductive materials. 3. There is fire hazards due to use of dielectric mediums. 4. Efficiency is low compared to other processes. 	
	Opportunities	Threats	
	<ol style="list-style-type: none"> 1. EDM of micro parts has paved the way for expanding application fields. 2. Availability of different variants of EDM process make it suitable for large number of applications. 3. Extensive research is going on EDM which makes it process of future. 	<ol style="list-style-type: none"> 1. Mostly used in die & mould making processes. 2. Improvement of high speed milling technology is giving stiff competition to EDM process. 3. Misfits in the concept of Green Manufacturing processes. 	
EXTERNAL			

4.12 Conclusion

The final decision for improvement and analysis of EDM system is taken by considering other factors also. The factors like cost, availability are very important. The techniques like SWOT Analysis and Force Field Analysis are used for assistance in decision making. In this study a SWOT analysis of EDM system is done. It presents strengths, weakness, opportunities and threats of system. Improvement in design of EDM is done by considering present factors which are presented by SWOT Analysis.

CHAPTER – 5

EXPERIMENTAL SET UP, RESULTS & ANALYSIS OF RESULTS

5.1 Introduction

A number of input process parameters can be varied in the EDM process. Each parameter has its own impact on output parameters such as material removal rate, tool wear rate, hardness of the machined surface, surface finish, dimensional accuracy and overall surface integrity.

The input machining parameters of EDM are enlisted below:

- (a) Discharge voltage
- (b) Current
- (c) Type of tool
- (d) Pulse off-time
- (e) Pulse on-time
- (f) Type of workpiece
- (g) Pulse frequency
- (h) Polarity
- (i) Electrode gap
- (j) Type of dielectric flushing

The effect of each of these parameters on EDM process has been discussed in detail in the preceding literature review. From the above listed parameters, four parameters directly affect the phenomenon of surface modification in electrical discharge machining. These four parameters are **peak current, pulse on-time, pulse off-time and polarity**. In this study current, pulse on-time, type of tool and type of work pieces have been investigated. The value of current and pulse on-time parameters can be easily changed from the control panel switches of the EDM machines that are currently being used by the tool and die making industry.

5.2 Overall Experimental Design Strategy

The objective of this experimentation is to calculate MRR, TWR and Surface Roughness by using three tools and three type of work pieces, Six levels of current and three levels of pulse on time by applying L18 orthogonal array. The readings are then analyzed by using Taguchi methods. These readings are also used to prepare decision matrix which is used for ranking of tools by MADM

approach and then results of MADM are compared with results of ANOVA. By comparing validation of results of MADM is done. The design variables can be summarized as follows:

- (a) Three die steel materials; namely D2 high-carbon high chromium die steel, D3 die steel and H13 hot work die steel are used.
- (b) Three electrode materials; namely Copper, Copper-Tungsten and Brass are used.
- (c) Six levels of peak current (2 amp, 3 amp, 4amp, 5amp, 6amp and 7amp) are used.
- (e) Three levels of pulse on-time are used (10 μ s, 20 μ s and 50 μ s)
- (f) The pulse off-time is kept fixed. (57 μ s)

Apart from these variable parameters, some parameters are kept constant on EDM machine which are enlisted below:

1. Open Circuit Voltage is $135 \pm 5\%$ Volts.
2. Straight polarity is used i.e. workpiece is connected to positive and tool is connected to negative.
3. Machining Time of 10 minutes is taken.
4. EDM oil is used as dielectric medium.
5. Electrode Quill Movement is 10 : 4.

In this study Taguchi methods, orthogonal arrays and analysis of variance is used for design of design of experiments and calculation of MRR, TWR and Surface Roughness.

5.3 Taguchi's Experimental Design and Analysis

For deriving clear and accurate conclusions from the experimental observations a properly planned and executed experiment is of utmost importance. Design of experiments is used for accomplishing these tasks. Engineering experiments involves large number of process variables. Technical experience and experiments through prototype hardware models or computer simulations, is needed to come up with conclusion about these variables. This needs very long time span for completing the design process. To overcome this problem computer software's are used for scientifically designing the experiments such that complete information is obtained about the process with relatively fewer experiments and redundant data is eliminated.

The science of statistical experimental design and the associated data analysis technique called Analysis of Variance (ANOVA) is used for this purpose. Various types of matrices are used for planning experiments to study several decision variables simultaneously. Nowadays several innovations such as Full Factorial Design, Fractional Factorial Design and Taguchi method etc. have been introduced to extract maximum possible usage from the concept.

5.4 Orthogonal Arrays

The Taguchi Robust Design method uses a mathematical tool called Orthogonal Arrays (OAs) to study a large number of process variables with a small number of experiments. OAs are “fractional factorial designs” which are symmetrical sub-sets of all combinations of treatments in the corresponding full factorial designs (that is, when all levels of all the factors are taken into consideration one by one). If experiments are conducted by taking one level of each parameter at a time, the number of experiments will run into thousands, making it a very time consuming and expensive process. Another major disadvantage of one-parameter-at-a-time approach is that it fails to consider any possible interaction between the parameters. An interaction is the failure of one parameter to produce the same effect on the response at different levels of another parameter.

As the name Orthogonal Array suggests, the columns of the array are mutually orthogonal. It means that for any pair of columns, all combinations of factor levels occur and they occur an equal number of times. This is called the balancing property and it implies orthogonality. The number of rows of an orthogonal array represents the number of experiments. The number of columns of an array represents the maximum number of factors that can be studied using that array. A number of standard OAs are available and one of these can be selected for a particular experiment by knowing the following details:

- How many factors are to be studied?
- How many treatment levels are possible for each factor?
- What specific 2-factor interactions are to be investigated?
- Would one encounter any particular difficulty during the runs (for example, some factors may not permit frequent treatment changes)?

There exists a large variety of industrial experiments. Each experiment has a different number of factors. Some factors have two levels, some three levels and some even more. Taguchi has tabulated 18 basic orthogonal arrays that are called standard orthogonal arrays. Depending upon the number of factors and their levels, it is generally possible to select one of these for a specific requirement. However, the standard orthogonal arrays can also be modified to suit complicated designs. The first step in selecting the appropriate OA involves the counting of the total degrees of freedom (DOF) present in the study. As per Taguchi’s method, the total DOF of the selected OA must be greater than or equal to the total DOF required for the experiment. Then the levels of various factors to be included in the study are finalized. The next task is the assignment of process parameters and

interactions of interest to the appropriate columns. The use of linear graphs and triangular tables suggested by Taguchi makes the assignment of parameters simple. The array forces all experimenters to design almost identical experiments. The control log for the experiment is then prepared by assigning the levels of each parameter to various rows of the OA. Such designed experiments are called *matrix experiments* and individual experiment constituting one row of the orthogonal array is called *run* or *treatment*. Settings are also referred to as *levels* and parameters as *factors*. Experiments are performed at random by setting the value of each process parameter according to a single row of the orthogonal array. Three repetitions of each setting are desirable. The results of the experiments are analyzed to achieve one or more of the following objectives:

- To estimate the best or the optimum condition for a product or process.
- To estimate the contribution of individual parameters and their significance for a stated level of confidence.
- To estimate the response under the optimum condition.

5.5 Analysis of Variance

Taguchi suggests two different routes to carry out complete analysis of the experimental data. In the first approach, results of a single run or the average of repetitive runs are processed through main effect and ANOVA analysis of the raw data. The second approach, which Taguchi strongly recommends, is to use Signal-to-Noise (S/N) ratios for the same steps of the analysis. The S/N ratio is generally represented by η and is a concurrent quality metric linked to the loss function. By maximizing the S/N ratio, the loss associated with the process can be minimized. The S/N ratio determines the most robust set of operating conditions from variation within the results. It is treated as a response parameter (transform of raw data) of the experiment. For this study, the second approach has been used for analysis of the data. The primary goal of conducting a matrix experiment is to optimize the product or process design – that is, to determine the best or the optimum level for each factor. The optimum level for a factor is the level that gives the highest value of η in the experimental region. Thus, the optimum level for each factor can be obtained but this best setting may not correspond to one of the rows in the matrix experiment. In such cases, the value of η realized for the predicted best setting is better than the best among the rows of the matrix experiment.

Taguchi recommends that a confirmation experiment should be conducted at the best setting and its result should be compared with the theoretical value predicted by the analysis

5.6 Experimental set up

Experiments are conducted on the Electrical Discharge Machine model T- 3822 of Victory Electromech Company available in Machine Tool Lab of Thapar University Patiala. On this machine large number of input parameters can be varied i.e. Discharge voltage, Current, Pulse On Time, Pulse Off Time, electrode gap, Polarity, Type of flushing, Type of tool and type of workpiece. Each of these parameters effect the output parameters i.e. MRR, TWR and Surface Roughness. Current, Pulse On time, Tools and Workpiece are the four parameters which are varied in this study. Some parameters like discharge voltage , pulse off time , electrode gap , polarity and type of dielectric are fixed during experimentation.

A specially designed tank of mild steel is used for storing dielectric medium and to support the workpiece during experimentation.



Figure 5.1 Electric Discharge Machine used for experimentation.

5.7 Equipments and Instruments used

Apart from EDM machine some other equipments and instruments are used for calculating MRR, TWR and Surface Roughness (SR) and for specimen preparation. Following are the instruments used:

- a) Surface Grinder is used for specimen preparation. This machine is available at workshop of Thapar University Patiala. The workpiece which are purchased from market are in bad condition. To make the surface of workpiece smooth and flat surface grinder is used.
- b) A Electronic Weighing Machine is used for measuring initial weight and final weight of both workpiece and tool which are used for calculating MRR and TWR. This machine can weigh up to 500 g.
- c) A Surface roughness tester is used for measuring surface roughness of each cut. A Mutitoy6, model SJ400, Germany is available at Metrology Lab of Thapar University. It uses stylus method of measurement. It has profile resolution of 12 nm and can measure surface roughness up to 100 μ m.

5.8 Procedure for Experimentation

1. Establish objective function.
2. Selection of parameters and Interactions.
3. Selection of number of level of Controllable factors.
4. Calculation of Degree of Freedom needed.
5. Select the appropriate orthogonal Array.
6. Assignment of Factors to columns.
7. Execution of experiments according to trial conditions in the array.
8. Analyze results.
9. Confirmation experiments.

5.9 Selection of Orthogonal Array & Parameter Assignment

In this experiment, there are four parameters three parameters at three levels each and one parameter has 6 levels. Current has six levels so it has degrees of freedom and pulse on time, tools and work pieces has 3 levels each so these have 2 degrees of freedom each, hence total DOF for the experiment is 11. The DOF of an orthogonal array selected for an experiment should be more than the total DOF for that experiment. The difference should also not be very high, otherwise the cost and effort involved in conducting the extra experiments is wasted. Out of the standard orthogonal arrays available in Taguchi design, L18 orthogonal array has 17 degrees of freedom and it can accommodate 11 degrees of freedom, so it has been selected for this work. Amongst the parameters of this design, Current is assigned first column, work pieces are assigned to second column, pulse on time is

assigned to third column and tools are assigned to fourth column. The array has been shown in Table 5.1.

Table 5.1 L18 Orthogonal Array used in experimentation

Trial	Current	Workpiece	Pulse On Time	Tool
1	2	D2	20	Cu
2	2	D3	50	CuW
3	2	H13	10	Brass
4	3	D2	20	CuW
5	3	D3	50	Brass
6	3	H13	10	Cu
7	4	D2	50	Cu
8	4	D3	10	CuW
9	4	H13	20	Brass
10	5	D2	10	Brass
11	5	D3	20	Cu
12	5	H13	50	CuW
13	6	D2	50	Brass
14	6	D3	10	Cu
15	6	H13	20	CuW
16	7	D2	10	CuW
17	7	D3	20	Brass
18	7	H13	50	Cu

5.10 Results for MRR

The effect of above parameters on the MRR is evaluated using ANOVA by MINITAB 16 software. The results of MRR for each of 18 trials is calculated from weight difference of workpiece before and after the experiment for each trial. The formula for MRR is given by:

$$MRR = (W_i - W_f / \rho \times t) \times 1000 \text{ (mm}^3 \text{ / min)}$$

Where W_i = Initial weight of workpiece in gms

W_f = Final weight of workpiece in gms

ρ = Density of workpiece in gms/ mm

t = Time period of trials in minutes

Table 5.2 Results for MRR

Trial	Current	Workpiece	Pulse On	Tool	MRR(mm³/min)
1	2	D2	20	Cu	1.3160
2	2	D3	50	CuW	0.7895
3	2	H13	10	Brass	0.5196
4	3	D2	20	CuW	0.6580
5	3	D3	50	Brass	0.7890
6	3	H13	10	Cu	2.9870
7	4	D2	50	Cu	4.6050
8	4	D3	10	CuW	3.0263
9	4	H13	20	Brass	1.0392
10	5	D2	10	Brass	1.1840
11	5	D3	20	Cu	3.4210
12	5	H13	50	CuW	4.5466
13	6	D2	50	Brass	1.3180
14	6	D3	10	Cu	5.2630
15	6	H13	20	CuW	3.8970
16	7	D2	10	CuW	5.6842
17	7	D3	20	Brass	1.4473
18	7	H13	50	Cu	3.8960

5.11 Analysis of Variance for MRR

The results are analyzed by using ANOVA in MINITAB16 software. The analysis of variance at 99% confidence level is given by F test in table 5.3. The principle of F test is that larger the value of F of parameter more is the significance of parameter on the MRR. ANOVA table shows that tool has the highest value(F= 9.48). It means tool is the most significant factor for MRR and current with F= 3.40 is second most important factor. From table it is clear that workpiece has least effect on MRR.

Table 5.3 ANOVA for MRR

Source	DOF	Adj SS	Adj MS	F	P
Current	5	19.4180	3.8836	3.40	0.084
Workpiece	2	0.5064	0.2532	0.22	0.808
Pulse On	2	4.0090	2.0045	1.75	0.252
Tool	2	21.6942	10.8471	9.48	0.014
Residual error	6	6.8625	1.1437		
Total	17	52.4901			

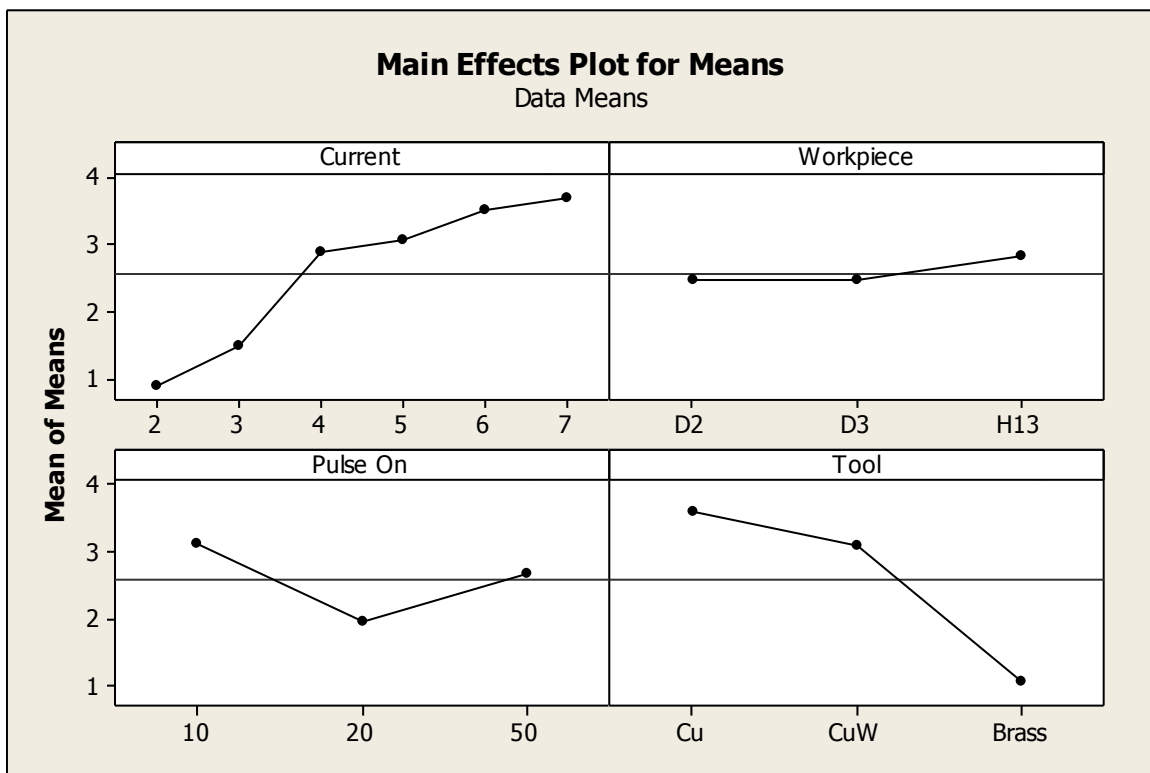


Figure 5.2 Plots showing ANOVA for MRR

The Plots in figure 5.2 shows the effect of selected parameters on the MRR. From the plots it is clear that MRR increase with increase in current level. Workpiece has very less effect on MRR, only H13 material shows little higher MRR. The Pulse on time shows that MRR is higher at 10 μ s and is lower at 20 μ s. the tools shows significant effect on MRR. Copper tool has highest MRR and Brass tool shows very MRR.

5.12 Results for TWR

The effect of selected parameters on the TWR is evaluated using ANOVA by MINITAB 16 software. The results of TWR for each of 18 trials is calculated from weight difference of tool before and after the experiment for each trial. The formula for TWR is given by:

$$\text{TWR} = (W_i - W_f / \rho \times t) \times 1000 \text{ (mm}^3 / \text{min)}$$

Where W_i = Initial weight of Tool in gms

W_f = Final weight of Tool in gms

ρ = Density of Tool in gms/ mm³

t = Time period of trials in minutes

Table 5.4 Results for TWR

Trial	Current	Workpiece	Pulse On	Tool	TWR(mm ³ /min)
1	2	D2	20	Cu	0.056180
2	2	D3	50	CuW	0.057142
3	2	H13	10	Brass	0.117600
4	3	D2	20	CuW	0.057140
5	3	D3	50	Brass	0.352900
6	3	H13	10	Cu	0.112360
7	4	D2	50	Cu	0.112360
8	4	D3	10	CuW	0.114280
9	4	H13	20	Brass	0.705880
10	5	D2	10	Brass	0.941176
11	5	D3	20	Cu	0.112360
12	5	H13	50	CuW	0.114285
13	6	D2	50	Brass	0.705880
14	6	D3	10	Cu	0.337070
15	6	H13	20	CuW	0.114285
16	7	D2	10	CuW	0.228570
17	7	D3	20	Brass	0.823500
18	7	H13	50	Cu	0.112300

5.13 Analysis of Variance for TWR

The results are analyzed by using ANOVA in MINITAB16 software. The analysis of variance at 99% confidence level is given by F test in table 5.5. The principle of F test is that larger the value of F of parameter more is the significance of parameter on the TWR. ANOVA table shows that tool has the highest value(F= 21.76). It means tool is the most significant factor for TWR and current with F= 3.98 is second most important factor. From table it is clear that workpiece and Pulse on time has very less effect on TWR.

Table 5.5 ANOVA for TWR

Source	DOF	Adj SS	Adj MS	F	P
Current	5	347.50	69.50	3.98	0.061
Workpiece	2	25.14	12.57	0.72	0.525
Pulse On	2	33.88	16.94	0.97	0.432
Tool	2	760.42	380.21	21.76	0.002
Residual error	6	104.83	17.47		
Total	17				

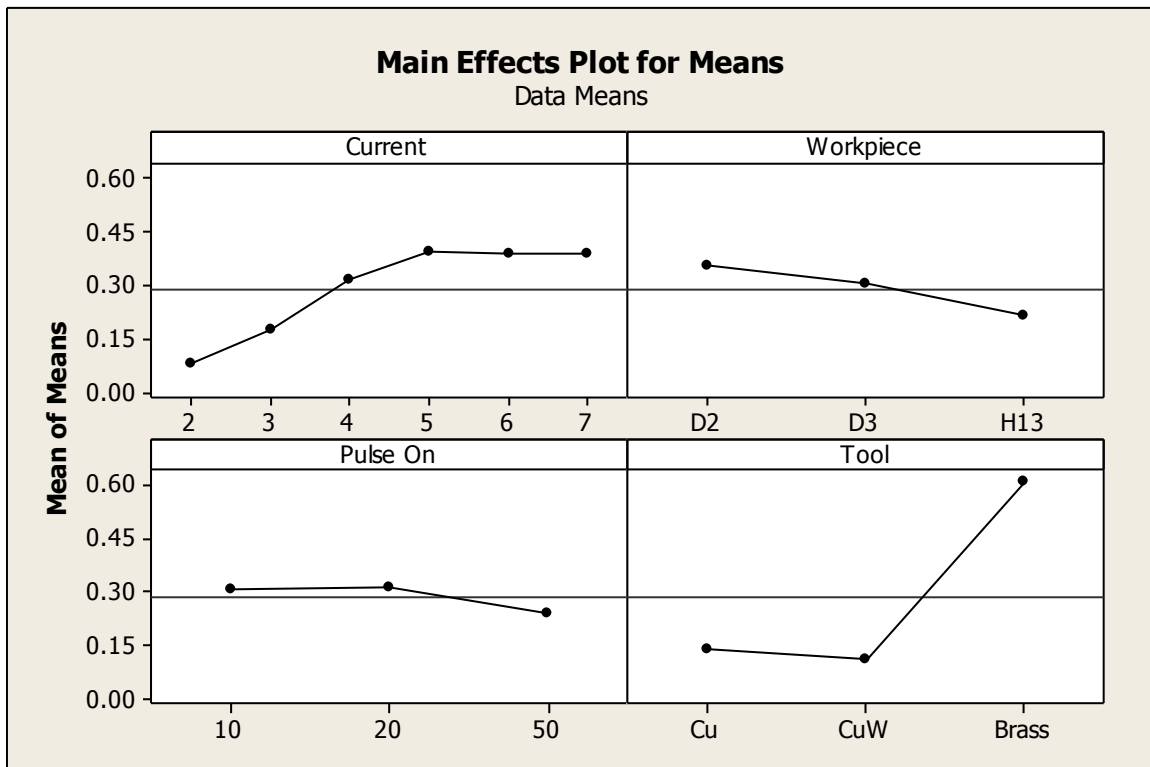


Figure 5.3 Plots for TWR

The plots shows that the most important parameter which effect the TWR is tool. Brass tool shows maximum TWR and Copper Tungsten tool shows very little TWR. Apart from Tool, Current also effect the TWR. The TWR increases with increase in current level. Pulse on time has very little effect on TWR. TWR decreases with increase in Pulse on time. The D2 material shows higher TWR and H13 shows lower TWR.

5.14 Results for Surface Roughness (SR)

In this experiment Surface Roughness of each cut is measured by a Surface Roughness Tester is used for measuring surface roughness of each cut. A Mutitoy6, model SJ400, Germany is available at Metrology Lab of Thapar University. It uses stylus method of measurement. In this experiment surface roughness (Ra) is measured at one position i.e. centre of cut made by each trial. Surface roughness (Ra) for each of 18 trials is shown in table 5.6.

Table 5.6 Results for Surface Roughness (Ra)

Trial	Current	Workpiece	Pulse On	Tool	SR (Ra)
1	2	D2	20	Cu	6.20
2	2	D3	50	CuW	6.10
3	2	H13	10	Brass	5.09
4	3	D2	20	CuW	6.40
5	3	D3	50	Brass	5.10
6	3	H13	10	Cu	6.90
7	4	D2	50	Cu	7.10
8	4	D3	10	CuW	7.40
9	4	H13	20	Brass	6.50
10	5	D2	10	Brass	5.39
11	5	D3	20	Cu	7.98
12	5	H13	50	CuW	7.70
13	6	D2	50	Brass	6.30
14	6	D3	10	Cu	8.27
15	6	H13	20	CuW	8.40
16	7	D2	10	CuW	8.59
17	7	D3	20	Brass	7.10
18	7	H13	50	Cu	9.88

5.15 Analysis of Variance for Surface Roughness (Ra)

The results are analyzed by using ANOVA in MINITAB16 software. The analysis of variance at 99% confidence level is given by F test in table 5.7. The principle of F test is that larger the value of F of parameter more is the significance of parameter on the SR. ANOVA table shows that tool has the highest value(F= 67.90). It means tool is the most significant factor for SR and current with F= 35.62 is second most important factor. From table it is clear that Pulse on time (F= 0.44) has negligible effect on SR.

Table 5.7 ANOVA for SR

Source	DOF	Adj SS	Adj MS	F	P
Current	5	14.8454	2.96908	35.62	0.000
Workpiece	2	1.6884	0.84421	10.13	0.012
Pulse On	2	0.0742	0.03709	0.44	0.660
Tool	2	11.3190	5.65951	67.90	0.000
Residual error	6	0.5001	0.08336		
Total	17				

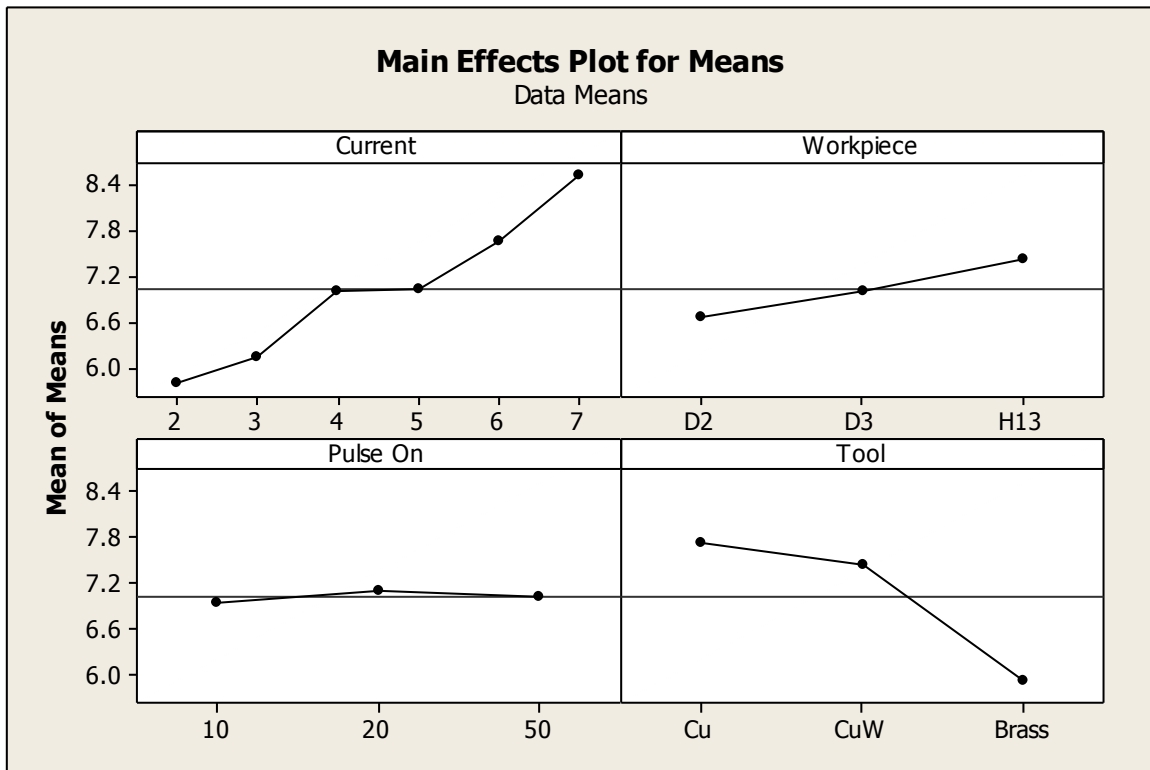


Figure 5.4 Plots for Surface Roughness

The plots shows that with increase in value of current the surface roughness increases. The Brass tool shows the minimum surface roughness and Cu shows highest Surface Roughness. As discussed earlier plots also shows that Pulse On Time has negligible effect on SR. The D2 material has lowest SR and H13 material shows highest SR.

5.16 Pictorial view of Work pieces



Fig 5.5 D2 Steel Work piece



Fig 5.6 D3 Steel Work Piece



Fig 5.7 H13 Steel Work Piece

5.17 Conclusion

In this experimental work four parameters Current, Tool, Workpiece and Pulse On Time are varied. Six levels of current are used, three different tools, three different work pieces and three levels of Pulse on time are used. L18 orthogonal array is used. MRR, TWR and surface roughness are calculated after experiments. After applying ANOVA by using MINITAB16 software F test is applied and plots for MRR, TWR and SR are constructed. In this study the tool comes out factor which has maximum effect on all three outputs. The Cu tool shows highest MRR and SR and Brass shows lowest MRR and SR. CuW tool shows minimum TWR and Brass shows highest TWR. The current comes out to be second most important factor. Value of current is directly proportional to MRR, TWR and SR. It means that with increase in current MRR, TWR and SR increases. The work pieces are mainly significant in Surface roughness. The D2 shows lowest SR and H13 shows highest SR. The on time has small effect on MRR, TWR and SR.

5.17 Comparison with results of MADM

In ideal conditions it is desirable that EDM should have high MRR, low TWR and low SR. So any input parameter which shows these results is considered good. In case of Tools Copper (Cu) shows high MRR and low TWR as compared to other two tools. Brass shows high TWR and low MRR so it is not fit for production. CuW is intermediate tool which show lowest TWR but it's MRR is less than Cu. So overall after experiments Cu proves to be best Tool. Cu also proves to be best Tool by applying MADM. So this experimental work validates the results of MADM approach.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1 Conclusion

In this study the main focus is on modeling, evaluation, optimum selection and analysis of EDM system using system approach. To achieve the objectives of this work two different methodologies are presented. The most important outcome of this work is that for analysis of the system, firstly a system should be divided into subsystems, then analysis presents a better picture of the operation of every system component and the interaction.

In Chapter 3 Multi-Attribute Decision Making (MADM) approach is presented for evaluation, ranking and optimum selection of parameters of EDM machining system from different alternatives. It identifies the various attributes needed to be considered for the optimum evaluation, ranking and selection of parameters of EDM. It also provides a coding scheme for various attributes. In this chapter MADM approach is applied for selection of tools of EDM. The work regarding MADM approach in chapter 3 can be summarized as

1. In this study 196 attributes related to EDM are indentified. Then these attributes are classified into 5 categories. It presents a coding scheme, in which all 196 attributes are given codes in scale of 0 to 5 according to their importance in working of EDM. Majority of the attributes are coded 0 and only pertinent attributes are highly coded.
2. This study presents a 3-stage selection procedure including elimination search, TOPSIS method and graphical methods (line graph and spider diagram) for ranking of parameters and generated hypothetically best and worst solutions.
3. The proposed methodology ensures that the selection of parameter (tool) is nearest to the hypothetical best tool and farthest from the hypothetical worst tool.
4. In this output values MRR, TWR and SR are taken from experimental work done by using 3 tools (Cu, CuW and Brass) and then decision matrix is developed from this data. Then MADM approach is applied to get best and worst tool. The ranking is done with 3 methods (TOPSIS, Line Graph and Spider diagram) and Cu comes out to be best tool and Brass worst tool unanimously in all 3 methods.
5. This study presents a novel methodology which can be applied to other parameters of EDM and moreover it can also be applied to other machining processes.
6. The final choice is to be made by user by considering other factors like cost and availability etc.

7. The results of MADM are validated with results of experimental work as experimental work also shows Cu as best tool Brass as worst tool. This proves the accuracy of MADM approach.

In Chapter 4 Graph Theoretic Approach is presented in order to achieve the objective of developing the systems model for the structural analysis of EDM system. This model integrates the different subsystems of EDM and interactions between them. In this study the work related to Graph Theoretic Approach can be summarized as:

1. This study presents a methodology to build a flexible and comprehensive model of EDM, which shows the subsystems and has the capability to consider the interactions between various subsystems.
2. This work identifies four subsystems (Dielectric unit, Control panel, Machine tool and power supply unit) which parameterize the EDM.
3. This methodology consists of the EDM system structure digraph, the EDM system matrix, and EDM system permanent function. The system digraph is the mathematical representation of the structural characteristics and their interactions, useful for visual modeling and analysis. The EDM system matrix converts graph into mathematical form. This matrix representation is powerful tool for storage and retrieval of EDM systems in computer database and for calculation of permanent function.
4. This study presents the EDM system permanent function which is a mathematical model characterizing the structure of the EDM system and also helps to determine the EDM system numerical index. This numerical index is used for analysis and improvement of EDM.
5. This work presents a framework for developing various quantitative performance indices of EDM in various dimensions of performance i.e. MRR, TWR and SR etc. It provides the measure of the overall performance of the EDM.
6. This study presents a generalized methodology to model a system consisting of N subsystems and their interactions. This study gives a criterion how to compare two EDM systems with the help of permanent function on structure basis.
7. The present work emphasizes the numerical methodology of EDM system that can also optimize the design and the production parameters.

The Chapter 6 presents work related to ***Experimental Set Up, Results and Discussion of Experimental Investigations***. The two main objectives of this work are enlisted below:

- a) The first objective is to provide input data for making decision matrix in MADM approach. The parameters like material removal rate (MRR), tool wear rate (TWR) and surface roughness (SR) which are used in decision matrix are obtained from this experimental work.

- b) The second objective is to do validation of the results obtained from MADM approach by applying analysis of variance (ANOVA).

This chapter presents the methodology for performing experimental work, calculating results and analysis of the results. The work done in this chapter can be summarized as:

1. This experiment is conducted by taking 6 levels of current, 3 levels of pulse on time, 3 types of work piece and three types of tools on EDM Model T3822 available in Machine Tool Lab in Thapar University Patiala. Then L18 orthogonal array is selected for design of experiment.
2. MRR and TWR for each of 18 trials are calculated by formulas and SR is measured by Surface Roughness Tester model Mutitoy6, model SJ400, Germany available at Metrology Lab of Thapar University, Patiala.
3. ANOVA is applied on results of each MRR, TWR and SR. The F-test is applied to find parameters which has maximum effect on outputs. Tool and Current comes out to be main factors affecting outputs.
4. The plots are presented which shows the trends in which input parameters effect output parameters. The plots shows that Cu tools show maximum MRR, low TWR which is required and hence proves to be best tool.
5. In the end validation of results of MADM is done by making comparison between the results of ANOVA and MADM approach. The results of both approaches are similar showing Cu as best tool and Brass as best tool.

6.2 Future Scope

1. The permanent function and numerical index of the EDM system will be given in future work with illustrative examples.
2. The MADM approach can be applied to other parameters of the EDM.
3. The MADM can be applied to other machining processes like ECM, LBM, IBM, EBM, PAM etc..
4. Computer software's like MINITAB can be developed for solving MADM and Graph Theory approach.
5. Both of these system approaches can be applied in other fields also.

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