Fabrication of Micro Channels Using Wire EDM For Optimum Process Parameter Using MADAM-TOPSIS Approach

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DECLARATION

I hereby certify that the work which is being presented in this thesis entitled **"FABRICATION OF MICRO CHANNELS USING WIRE EDM FOR OPTIMUM PROCESS PARAMETER USING MADAM-TOPSIS APPROACH"** in partial fulfillment of award of **Mater's Degree in Production & Industrial Engineering** submitted in Mechanical Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of **Dr. V.P. Agrawal ,Visiting Professor Mechanical Engineering Department,Thapar University,Patiala.**

The matter embodied in this report has not been submitted in part or full to any other university or institute for award of any degree.

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ABSTRACT

Wire Electric Discharge (WEDM) Machining is using for fabrication of micro channels. Wire EDM is time consuming, stochastic and highly complex process. That's why optimum input parameters are required which count on user's technology and experience because of their large diverse and abundant range. In Wire EDM high precision cutting operations are challenging because of more than one responses are taken into account as Material Removal Rate (MRR), Surface Roughness (Ra) and Wire wear ratio (WRR). Aluminum (6061) Work Piece is used for micro channels fabrication. Micro channels of 1mm depth, 0.5mm width are fabricated on Al (6061) work piece of 30mm×30mm for fabrication process parameters taken which are varied in different range as Pulse On Time Ton (105-125 µsec), Servo Voltage (30-90V) and Wire Feed Rate (6-8 mm/min).Material Removal Rate (MRR), Surface Roughness (Ra) and Wire Wear Ratio (WRR) are estimated for micro channels performance. These process parameters and response parameters are co related with the help of Response Surface Methodology (RSM).In Response surface methodology using MINITAB 17.0 software experiment is designed for experimental runs. Using Response Surface Methodology using MINITAB gives 20 experimental runs for different values combination of process parameters of Pulse on Time (Ton), Servo Voltage and Wire Feed Rate .Using Wire EDM Micro channels are fabricated based upon these designed experimental runs. Response parameters are measured corresponding to these 20 experimental runs. Surface Roughness (Ra) is measured with the help of Mitutoyo SJ 400 profilometer.Three Mathematical Equations are produced between process parameters and response parameters which helps to explain the variations in responses with the variations in input or process parameters using MINITAB software. After that we engender the surface plots and contour plots to see the effect of combination of two process parameters on response parameter. Then Main Effects Plots and Residual plots are plotted with MINITAB to examine the individual process parameter effect on responses. It has been concluded that Pulse On Time is most dominant factor in Material Removal Rate (MRR).And Servo Voltage effects the surface roughness (Ra).After the Experimentation and Mathematical Modeling next step is optimization, selection, evaluation and ranking for optimum parameter setting of process having Higher

Material Removal Rate (MRR), Lower Surface Roughness and Wire Wear Ratio is done with MADM (Multiple Attribute Decision Making) Approach. Identification of Pertinent Attributes and Ranking is done with help of TOPSIS (Technique for order preferences by similarity to ideal solution).Optimum process parameters setting is obtained for Maximum Material Removal Rate (MRR), Minimum Surface Roughness (Ra) and Wire Wear Ratio (WRR) explained with illustrative example.

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LIST OF ABBREVIATIONS & SYMBOLS

WEDM	Wire Electric Discharge Machining
EDM	Electric Discharge Machining
Ton	Pulse On Time
Ip	Peak Current
WF	Wire Feed Rate
Ra	Arithmatic Average (Surface Roughness)
MRR	Material Removal Rate
WRR	Wire Wear Ratio
ANOVA	Analysis Of Variance
Al	Aluminium
RSM	Response Surface Methodology
MADM	Multiple Attribute Decision Making
TOPSIS	Technique For Order Preferences By Similarity to Ideal Solution

CHAPTER-1

Introduction

1.1 General

Lots of researches is being carried out in fabrication of micro channels using non traditional machining Like Laser Machining, Focused Ion Machining , Wire Electric Discharge Machining etc.Wire Edm is best option for extremely difficult hard materials and complicated geometry materials which are very difficult to machine. Using Wire EDM machine is used for fabrication of micro channels of Al (6061).These Micro channels are used in various applications like Micro-Electro-Mechanical System (MEMS), Electronic cooling system, Biomedical Engineering; Miniaturization and Biochemistry etc.Microchannel performance depends upon parameters of machining selected during fabrication. In This Proposed work we use 3 process parameters of Wire EDM which are varied in a particular range to get optimum response parameters. These parameters are Pulse On Time (Ton), Servo Voltage (v) and Wire Feed Rate (WF) are varied range of Pulse On Time (115 to 125 µ sec), Servo Voltage (30 to 90 V) and Wire Feed Rate (6 to 8 m/min).Micro channels are then evaluated by three response parameters Surface Roughness (Ra), Material Removal Rate (MRR) and Wire Wear Rate (WRR). Mathematical Modeling Response Surface Methodology (RSM) is used to establish the relation between process parameters and response parameters to find out how process parameters effects response parameters. Mathematical Modeling gives the equation between process parameters and response parameters using Minitab 17.0.Variations in the response parameters due process parameters variations are shown in the form of contour plots and surface plots.Mitutoyo (SJ-400) roughness tester is used to measure the surface roughness (Ra) value of each work piece.

1.2 Introduction to Micro-Channels :-Flow passage having 10-200µm hydraulic dia.

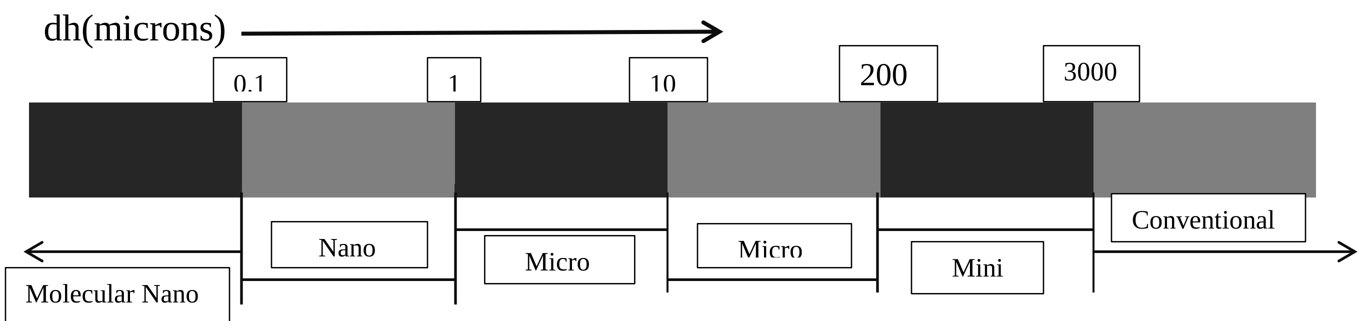


Fig 1.1 Shows the classification of Channels

Fig 1.1 shows the channels classification based on hydraulic diameter given by Kandlikar & Grande (2003). Micro channels are used for micro devices cooling system e.g. in micro devices, high heat flux cooling applications, lab in chip etc. These are strong candidates for heat dissipation from heat devices like integrated circuits due to its high area to volume ratio. There are liquid coolants utilized for heat sinks for higher heat transfer coefficient as compared to gaseous coolants. This cooling system consists of micro channels array fabricated on material bounded to heat source and coolant is continuously flowing through these channels which helps to takes heat away and cools the heating source. Micro channels cooling system used where high heat dissipation is required and area to be cooled is very small as shown in fig.2,e.g.VLSI,ULSI chips, microprocessors in electronics, where no. of components are large fabricated on small chip. These types of Components have high power density and to ensure reliability and quality performance of components their continuous cooling is necessary. Sometimes these channels are etched on backside of I.C chip to reduce thermal resistance of system.

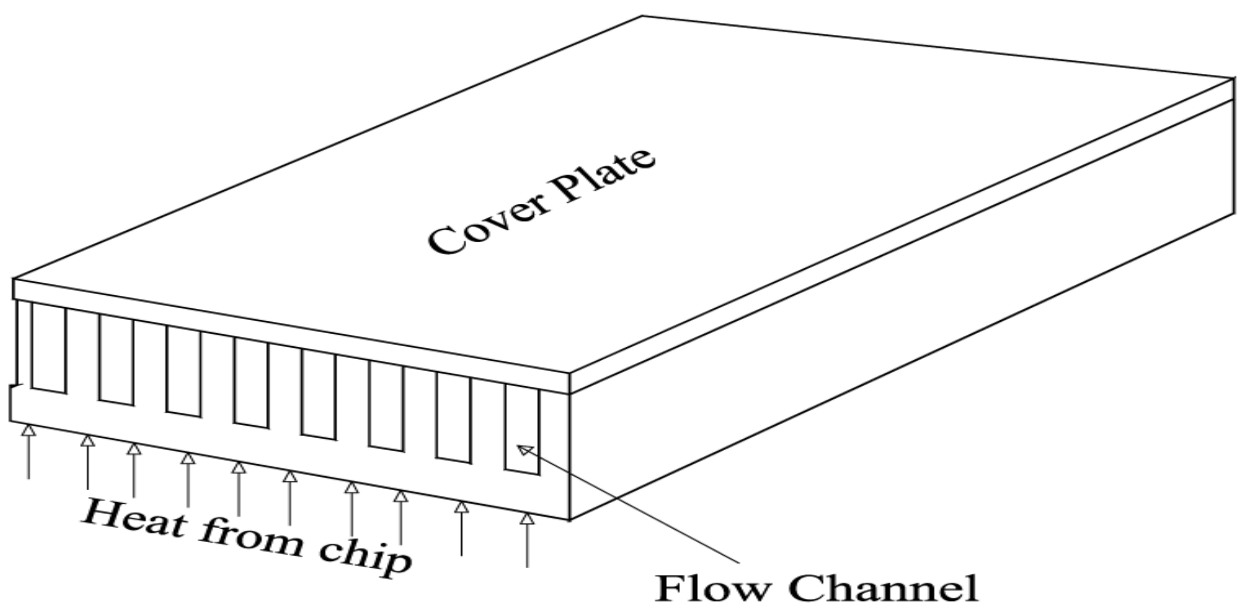


Fig1.2 Shows microchannel used in chips(Pradeep et al.1991)

There are two different ways of heat removal is either single phase liquid flow or phase change of coolant flow with boiling called two phase flow. Micro channels heat sink has unique characteristics which rise to conditions that are totally different from those of traditional channels. Heat sinks performance is totally dependent on surface roughness through which heat is gets convected.if surface roughness is not considered during fabrication of micro channels average thermal resistance and heat transfer coefficient is mostly affected. During Commercial applications Wire Cut EDM is used for fabrication of heat sinks.

Basic Principal of heat transfer in micro channel is heat transfer by convection.Equation Of heat transfer convection is shown as follow.

$$\boldsymbol{q = h}\mathbf{A}(\boldsymbol{T_s - T_f}) \tag{1.1}$$

Where,

A is Suraface Area

h is heat transfer coefficient

s & f subscripts are used for surface and fluid respectively

q is heat transfer by convection

1.2.1 Need Of Micro Channels

With the modernization of technology there is increasing demand of compacting, miniaturization, lightening semiconductor and integration technologies. More powerful and smaller IC's can be manufacture by latest semi-conductor fabrication technologies.Sigificant heat dissipation demands can be met in computer processor industry because of rise in processor speeds and rise in manufacturing smaller processes. Power Density can be increased to great extent by using large no's of transistors on micro processor for this improved cooling system than conventional cooling system like heat pipes, cooling fans, air cooling and immersed coolings.For higher Performance and life proper method of heat flux dissipation is required because increased temperature produces thermal stresses and damaging chips. And affects its reliability.

1. In High Speed Missiles of range supersonic or more cooling of tip of missile is most important .Micro channel cooling system is used for cooling there.
2. For gas turbines having higher speed and higher operating temperature due to leading edges causes excessive local heating which results in thermal fatigue and thermal stress in blade material.
3. Fusion Reactor some components require continuous cooling of an order of 104 W/cm^2 (Boyd et.al 1985).

Cooling system plays an important role in electronic component cooling, because overall reliability of assembly mechanisms in connections and interfaces is reduced as well as lifetime by accelerating failure mechanism in material is also decreased with the rise in temperature of electronic components. The Evident Trend of integrated circuits development is that heat dissipation quantities are increased and sizes are reduced. Methods of thermal engineering is applied to cooling of electronics components consists of primitive ,passive structures to advanced structures for the purpose of meeting rapidly rising heat densities of electronic components.

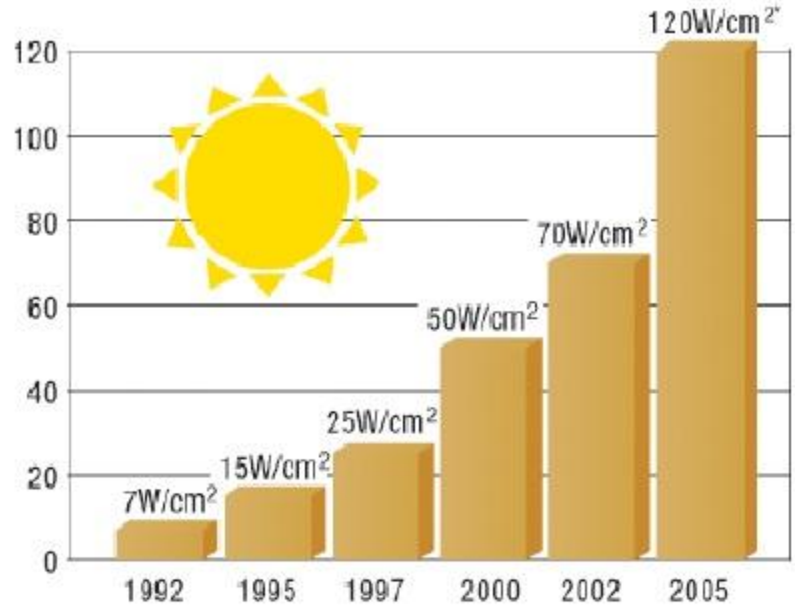


Fig 1.3 Trends of increasing power densities(Seri lee et.al 1995)

For these kind of problems having heat flux beyond 100W/cm^2 air cooling can be applied to such components.but in heat dissipation rate as of 1000 W/cm^2heat exchanger are extending to micro-scale, liquid cooling.Therefore to fulfill the cooling purposes in such scenario micro channel cooling systems are much important.

1.2.2 Fabrication Of Micro-Channels

Micro-channels can be generally fabricated by two different techniques given by **Kandlikar &Grande[1]**

1.Miniaturized Traditional Technique
2.Modern Technique

Traditional Technique, consists of conventional machining which are miniaturized to use them in micro regime e.g. Micro EDM, Stereo lithographic fabrication, electroforming, molding, ultrasonic and water jet machining, electroforming are key processes of this type.

Modern Technique mainly contains Focused Ion Beam, Laser Machining, Isotropic and anisotropic wet chemical etching is some examples of fabrication based on silicon. LIGA

(Lithographie, Galvanoforming, Abforming means Lithography, Electroplating & Molding) is fabrication process which is based on lost wax molding technique mainly it is a high aspect ratio. Which is used for micro-structures fabrication of high aspect ratio with compromising to their surface finish and quality.Hybird fabrication e.g. wafer bonding in which different etched shaped wafers are bonded together to form micro-channels.

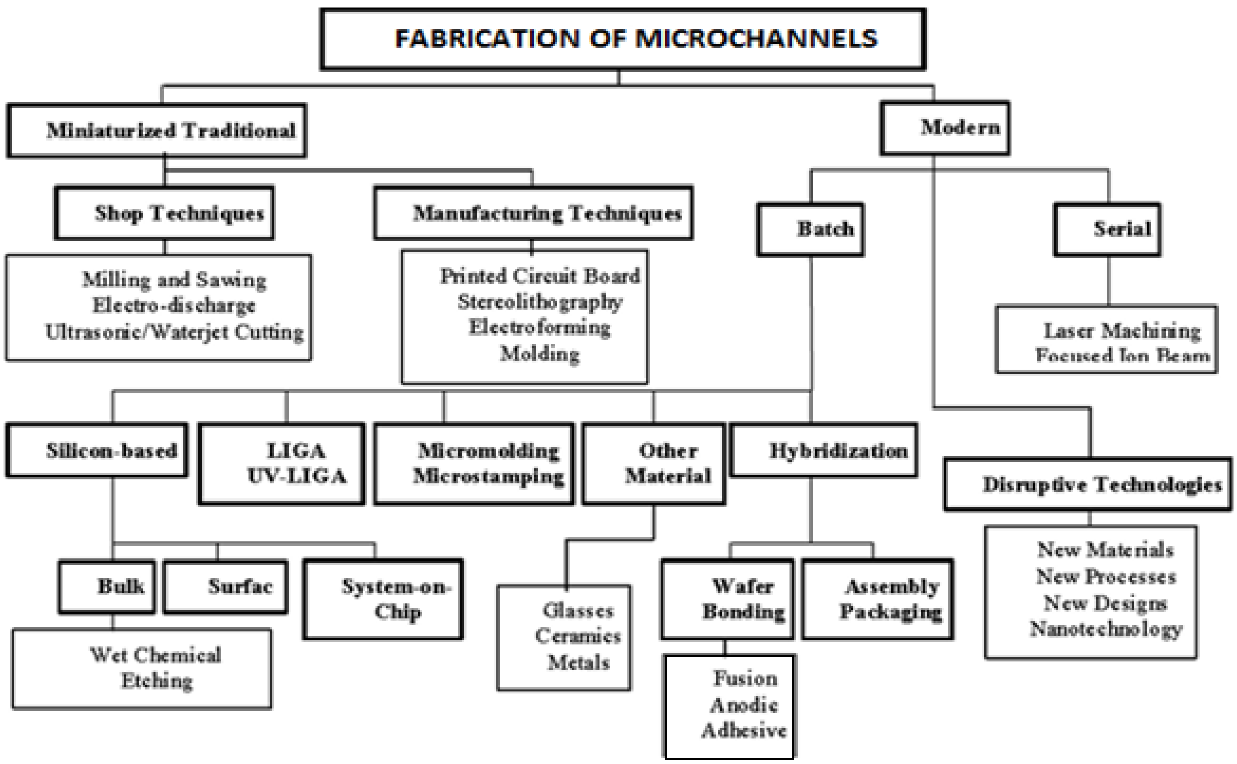


Fig 1.4 Diffrent Fabrication Techniques(Yaung et al.1992)

1.2.3 Advantages of Micro-Channels- Some of the advantages of using Micro-Channels for as given below.

- Micro Devices Cooling containing high heat fluxes.
- Compact Design
- Ability to handle less space with heat fluxes
- Economic in Space and Material

1.2.4 Disadvantages of Micro-Channels

- Complexity and Fabrication Constraints - Fabrication at micro scales is such a challenging and design complexity is also a major consideration factor.
- Hydraulic Diameter and Pressure Drop - While Fabrication main parameter is hydraulic diameter. And Pressure drop is inversely proportional to square of hydraulic diameter. That's why high pressure drop is seen in a usage of micro-channels.
- Scale Formed in very short interval of time - As we know dimensions are in micro scale when channel surface is formed at relatively thinner scale its performance is getting affected and thus become significant shorter period of time.

1.3 Wire Electric Discharge Machining (WEDM)

Wire EDM is a non traditional machining used for highly complexes and extremely difficult material (hard materials) to machine by traditional machining processes. Wire EDM is a thermo-electric machining in which work piece material is eroded with a series of discrete sparks generated between wire electrode (tool) and work piece which are separated by dielectric fluid of thin layer. And continuously forced dielectric is flushed out the eroded particle from machining zone. Wire movement is controlled for the fabrication of three dimensional shape and work piece accuracy.

Wire EDM is a process in which electric energy is transformed into thermal energy. Due to this conductive ceramics, alloy steels and many aerospace parts are machined irrespective of toughness and hardness. In wire edm, wire is feed through the work piece as it unwinds from spool. High Frequency pulses of electricity are delivered from power supply to the work piece and wire. Deionized water of localized stream is flooded in wire and work piece gap. Spark discharges eroded the work piece material ahead of transporting wire. When power source delivered the pulses of electricity, the dielectric fluid insulating properties are momentarily brooked down. This allows jumping the shortest distance by small sparks between wire and work piece at spark point. Around the spark and molten pools a gas bubbles are formed. This gas bubbles are collapses as pulse of electricity and spark disappears. Molten metal ejected from wire and work piece as a result of on rush of cool dielectric leaves the small craters. Thousands of time this action is repeated each second during machining. Removed material from work piece is of opposite of wire.

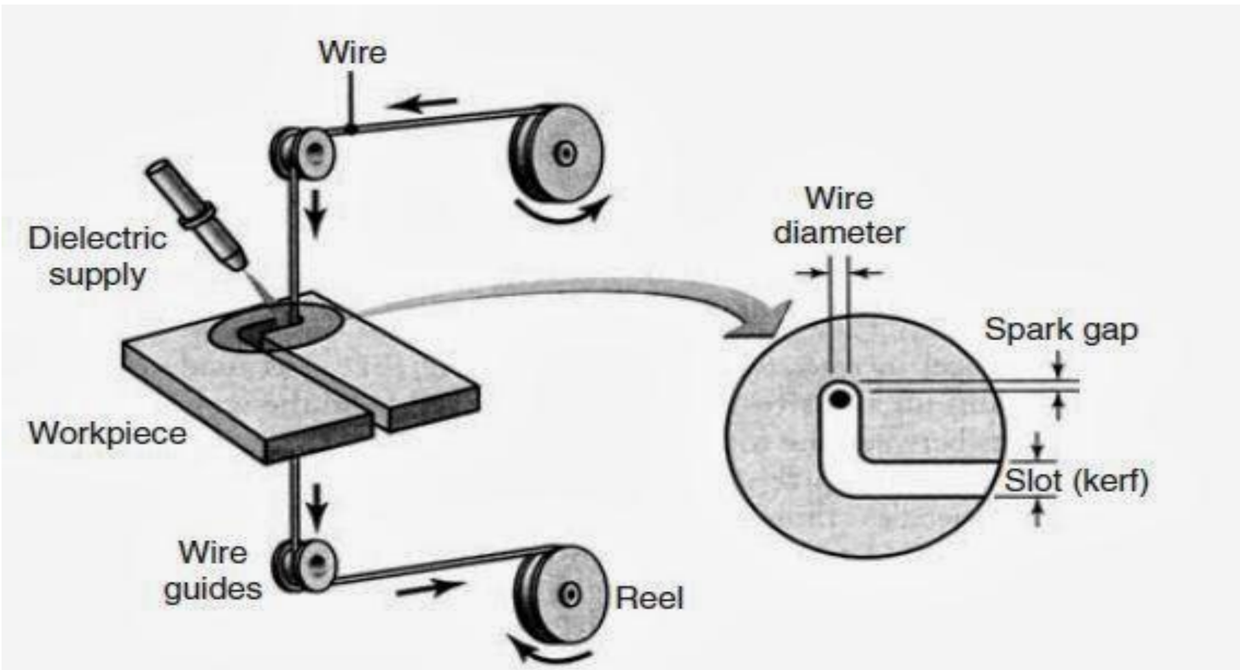


Fig1.5 Schematic Diagram of Wire EDM Process (http://gktk.blogspot.in/2013/12/wire-electric-discharge-machining.html)

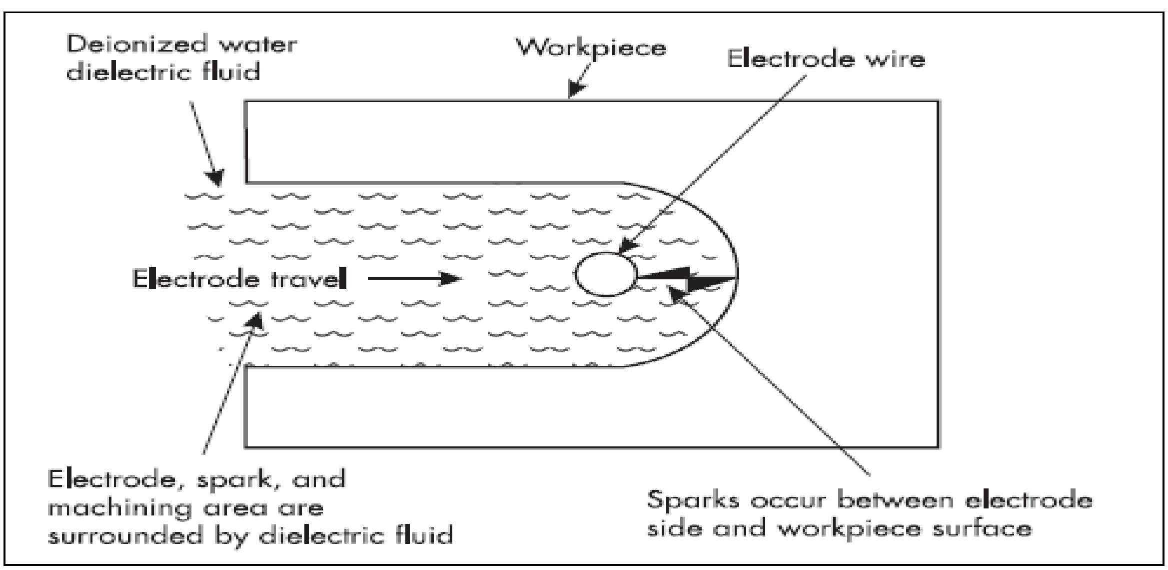


Fig1.6 Sparking in Wire EDM(R.konda et.al 1999)

1.3.1 Features of Wire EDM

- Tool (Wire Electrode) Wear negligible
- High Machined surface quality
- Dimensional and Geometrical tolerances are tight
- Tolerances between die and punch is high and die life is extended.
- No any skills are required for machining
- Irrespective of hardness and strength any conductive material is machined
- Straight holes can be formed with close tolerance

1.3.2 Wire EDM Subsystems:- Wire EDM mainly consists of four subsystems given as follow

1. Wire Drive System
2. Power Supply System
3. Positioning System
4. Dielectric System

These Subsystems are discussed briefly as.

1. Wire Drive System: - Wire Drive System delivers unused wire with constant tension from wire spool to work piece. Vibration mask, taper and machining streaks are major problems which need to be avoided. Wire passes through the several rollers as it is supplied from spool. Many tensioning rollers are also there through which a wire has to be passed before being collected at spool. Wire once used is discarded. Wire is material used usually is copper, molybdenum and brass. Wire Diameter is ranges from 0.02-0.30 mm.Wire angle for taper cutting operation is used by a CNC offset wire guide.
2. Power Supply System: - In conventional machining EDM, Voltage level is high as well as current level current required. Electrode gets melted locally and welding takes place of work piece and electrode as result of high currents. And stray arcing can also be take place. Moreover in micro machining uncontrolled discharge cannot be allowed. Hats

Why different power supply is necessary for wire EDM and we used Pulsed DC power supply. In this system AC is converted into pulsed DC for discharge sparks. By a solid state rectifier input power is transformed into pulsed DC supply. Using small percentage of DC power supply a square-wave signal is generated via digital multi-vibrator oscillator. Time precision of set valves is maintained by this oscillator and is used to start power transistors. To control the flow of remaining DC power these transistors acts as high speed switches. So Material Removal is done by sparks which is generated from power supply. Voltage between work piece and wire is senses by EDM power supply.Voltage, pulse duration, frquency, current; polarity etc. is also controlled by EDM power. Cut Off is used to avoid short circuit.

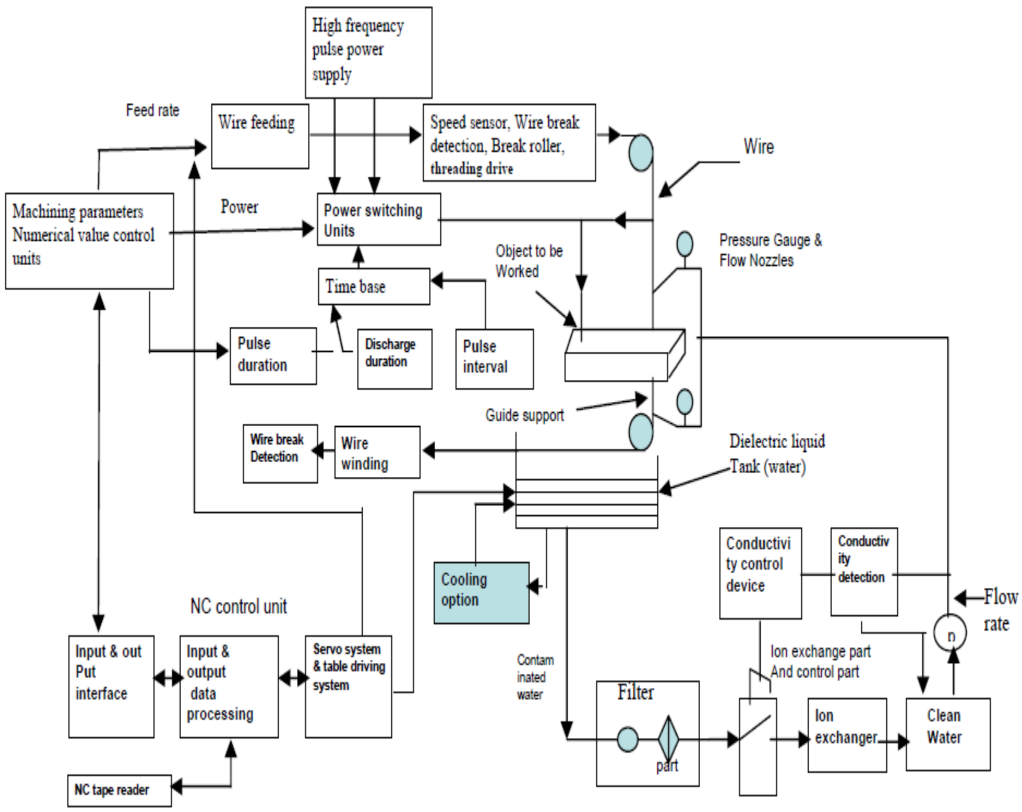


Fig1.7 Schematic Diagram of Wire EDM (http://www.mechanicaldesignforum.com/content.php?61-Electro-discharge machining&s=0c750f47df01b8e7ab30ec8728edee55)

3. Positioning System:-Two axis CNC table is used in this.Contant Gap between work piece and wire is ensured by Positioning System. As the wire touches workpiece, short circuit can be takes place.This condition is sensed by postioning system of WEDM and re-established programmed path taken as a back up for proper cutting gap conditions.
4. Dielectric System:-High Dielectric Strength and quick recoveries after breakdown is the most basic characteristics that a dielectric must attain. It also should have the quenching and flushing ability. Type of Dielectric used and method of flushing affects majorly machining material removal and wear rate. Water and hydrocarbons are most commonly used dielectric fluids. For Wire EDM high precision sinking and de-ionization water is usually used because of its carbon free characteristics and viscosty.Solid and gaseous Debris are removed during machining by flushing the dielectric fluid through spark gap in order to maintain temperature always below the flash point. To create hydraulic pumping as a control feature on many machines to facilitate chip electode.To assist flushing and machining conditions improvement orbiting of tool work piece has to be done .

Dielectric Fluids are performed on three functions as given below:-

- As it carries the eroded material from machining medium. So it acts as flushing medium.
- Between both the wire and work piece it acts as insulator.
- It also acts as a coolant because it carries away heat produced during machining from WEDM process.

Flushing is most critical and important from the above mentioned functions. Stagnation of dielectric and build up of residue particles in gap because of poor flushing. Low material removal rate and short circuiting is result of stagnation.

Deionized water is a dielectric fluid acts as flushing in WEDM.These are four reasons due to which water is used as dielectric fluid in Wire EDM machining.

- Low Viscosity
- Higher cooling rate
- No fire hazard

- Higher material removal rate

As work piece is not submerged in dielectric fluid in Wire EDM.It uses local delivery. Via Hose Dielectric is delivered to cut interface. Sometimes stream of water is delivered co axially with wire. To reduce operating cost water is reused. Water is purified through filters to use it again and again. For purification filters papers are used. In some cases to avoid rust formation special additives are used.

CHAPTER-2

Litreture Review

2.1 Literature Categorization:

Literature can be categorized into two different categories

1. Literature review about Wire EDM process
2. MADM-TOPSIS Approach (System Approach)

2.1.1 Literature Review about Wire EDM

Laio et al. (2003) traditional pulse generating circuit of low power generation was modified ignition as well as machining to achieve good surface finish. Significant parameters identified that affects the surface roughness were current limiting resistance, machining voltage, capacitance and type of pulse generating circuit with the help of ANOVA,Taguchi quality design and F-test.In addition for discharge spark dielectric of low conductivity was used. Fine surface roughness Ra= 0.22µm was obtained with assistance of appropriate values of parameters choose which were directly effects the surface roughness. But short circuiting occurred results in wire deflection and vibrations which results in limited improvement finishing process.

Tosun et al. (2003) explored the machining process parameters effects and optimization on Material Removal Rate and Kerf (cutting width) in Wire EDM operations. Experiments was conducted under varying process parameters Open circuit,votage,wire speed, pulse duration and dielectric flushing pressure.Taguchi Experimental design method used for machining parameters settings. Analysis of variance (ANOVA) used for defining level of significance of process parameters on MRR and Cutting Kerf. Signal-To-Noise ratio analysis used to obtain optimum machining parameters combination. Regression analysis mathematically modeled the variation of MRR and cutting kerf with process parameters. Aim of experimentation is to get the optimum selection of process parameters for maximum MRR with minimum cutting kerf with the use of mathematical models established.

Kandlikar et al. (2004) reviewed compact single phase heat transfer enhancement technique for conventional channels. Flow transition ,break up of boundary layer,vibration,swirl flow, electric fields,secondry flow, entrance region are dominant techniques. Micro channels and minichannels are evaluated with single phase flows. Single phase heat exchanger enhancement in mini channel and micro channel applicability of single phase cooling will extended such as microprocessor cooling, flow boiling is considered.

Murali et al. (2004) discussed about the biocompatible micro devices fabrication mainly done by silicon micro machining techniques.Prepration and use of masks in Lithography and Etching techniques are costly and time consuming. In bio research high complex mechanisms, simulation and modeling is quite difficult and inevitable experimental study. Micro EDM for biocompatible micro devices fabrication can be considered. 25μm small size micro channels were realized. Ultrasonic vibration of work piece also improves the process. For biological devices fabrication Micro EDM can be used and surface finish achieved of Rz is 3.4μm and Ra is 0.4μm.For Biological studies like Implant abutment.

Ramakrishnan et al. (2005) conducted experiment on Wire EDM used Taguchi's robust design of multi response optimization.Taguchi L16 orthogonal array was planned for experimentation. Wire Tension, Pulse on Time (Ton), Wire feed rate, Delay time and ignition current intensity was parameters under which experimentation performed. Material Removal rate (MRR), Surface Roughness (Ra) and Wire Wear Ratio (WRR) were three response parameters considered. Performance characteristics deviates from actual value were measured by multi response S/N (MRSN) ratio. Machining parameters importance levels were identified by ANOVA in accordance with multiple performance characteristics considered. Confirmation was carried out to identify proposed method effectiveness. Improvement was dignified.

Rawool et al. (2005) directed a three dimensional numerical simulation of flow through micro channels serpentine in form of restriction placed with channels walls with designed roughness. Numerical simulations used was CFD-ACE.Friction factor is determined with the effect of

Reynolds number, surface height (surface roughness) and geometry .As there is increase in restriction height non linear fashion increase is found in friction factor. For tringular and reactangular restrictions friction factor is more and decreasing in as geometry is changed to trapezoidal. It was detected that restriction geometry i.e. aspect ratio plays a major role in fiction factor prediction for roughness pitch. Therefore in micro channels design most important design parameter is roughness pitch.

Lin et al. (2006) examined study of SKH 57 High Speed Steel machining using Wire EDM. L18 orthogonal array built on taguchi method. ANOVA and F-test determined signal-to-noise ratio accompanied observed values. Six process parameters were observed and three response parameters such as Material Removal Rate (MRR), Surface Roughness (Ra) and Wire Wear Ratio (WRR).

Young et al. (2009) proposed a set of new roughness parameters for surface roughness reporting as related to fluid flow. Ra is arithmetic average roughness is often used in micro fluidics applications but Ra alone was insufficient for surface roughness evaluation .Ra is not able to assess the surface topology features result of different materials .So new surface roughness parameter was introduced ε_{FP} is the distance between peak value of surface profile and floor mean line of surface profile.ε_{FP} Gives more indicative of surface roughness height.ε_{FP} Would provide a more accurate parameter that affects the surface roughness of fluid flow.

Pradhan et al. (2009) conducted experiment investigation for the machining process having Pulse Duration, applied voltage, discharge current and pulse off time are four process controllable input parameters investigated by response surface methodology (RSM).Central composite design (CCD) second order polynomial models for surface roughness was used to estimate model co-efficient of process controllable input parameters which were assumed to influence the surface roughness in electric discharge machining (EDM) process. Work piece material used was AISI D2 tool steel with copper electrode. Using RSM responses were modeled for experimental data.ANOVA at 5% level of significance used for significant co-efficient. It was shown that Surface roughness had significant effect of pulse duration, pulse off time and discharge current.

Mohammad et al. (2009) compared the Micro end milling and micro electric milling for micro fluidic channels fabriction on polymers and metals.Micro-channels fabricated of dimensions 100-800 µm with aspect ratio of 1-2. Surface roughness measured were 100-200 nm for metals and 80-120 nm for polymers.Micro end milling formed large amount of burrs an metallic surface where as Micro ED milling produced high high aspect ratio micro channels without burr formation.Micro channels of 120µm width and 8-9 aspect ratio gave 40-50nm value of surface roughness.For high aspect ratio machiningof 8-9 micro electric discharge milling is used where as for low aspect ratio of 1-3 micro end milling preffered for used.

Mahendran et al. (2010) reviewed Micro EDM machining used to produce micro parts in a scale of 50µm - 100µm Micro metal holes can be made by Micro EDM with an advantage of non contact thermal process. In a small gap between work piece and electrode and at same time unwanted material is removed from parent metal through vaporization and melting process. So process of tool wear rate and MRR are most important response parameters in Micro-EDM process. Based on previous and recent research done on Micro-EDM,different types of EDM processes, types of generators, dielectric fluid and response parameters like material removaµl rate(MRR),Tool wear rate (TWR).Micro actuators could be fabricated using these developments.

Abdul kareem et al. (2011) analysed Wire EDM effect on topography of stainless steel.The effect of gap voltage and pulse cuurent on surface topography of wet and dry WEDM of stainless steel were investigated.It was seen that surface topography of work piece increases with the two process parameters and work piece becomes worst.

Shandliya et al. (2012) Conducted expeiment for Wire EDM process parameters optimization of metal matrix composites(MMC's).Optimization was done by Response Surface Methodology (RSM) and Genetic Algorithms (GA).Four process parameters of Wire EDM Pulse on Time (Ton),Pulse off Time (Toff),Servo Voltage and wire feed rate (WF) were varied to record their effect on SiCp/6061 Al MMC quality cut using surface roughness as response parameters.Response Surface Methodology develop a realtionship between machining parameters and surface roughness.Genetic Algorithms was used to optimize the process parameters.

Sivakiran et al. (2012) discussed the influence was studied of various machining parameters such as pulse on time (Ton),Pulse off time (Toff),current and bed speed on material removal rate (MRR).Linear Regression was used to create relationship between MRR and process parameters to achieve max Material Removal Rate (MRR).Taguchi L16(4*4) orthogonal array(OA) design occurred on EN-31 tool steel.It was observed that for Pulse on Time (Ton) - 24μ sec, Pulse off time (Toff) - 6μ sec and bed speed of 35μ sec MRR was maximum.

Phipon et al. (2012) conducted experiment on work piece of material (TI-6Al-4V).Single and multi objective optimization of micro EDM process using Genetic algorithms were taken.Response Surface Methodology (RSM) was used to co relate the response and process parameters.Minimum Tool wear rate and minimum overcut while other independent control parameters considered were pulse on time,peak current and flushing pressure.

Harpreet et al. (2012) investigated EDM used for material which could not machined by the conventional machining process.Material Removal Rate calculated using different tool materials were compared.Work piece material was AISID3 and copper tool material used and electrode of brass with pulse on and pulse off parameters .Electrolyte used was kerosene oil.And calculated that material removal rate increases with increase in pulse on time .Material removal rate increased with the pulse on time for copper electrode and decrease with pulse off time for brass wire.

Malik et al. *(*2012) used tungsten carbide. Three factors have been taken for optimization i.e. Metal removal rate (MMR), Electrode wear rate (EWR), and Surface roughness (Ra) used Zinc-coated brass wire. To resolve the multiple performance characteristics problems, the Taguchi method was coupled with grey relational analysis. The analysis of the Taguchi method disclosed that, in general the peak current significantly affects the EWR and Ra, while, the pulse duration mainly affects the MRR.

Rajya lakshmi et al. (2013) used Inconel 825. Taguchi orthogonal array design of experiment and grey relational analysis were combined. The main objective of this study was to obtain improved material removal rate, surface roughness, and spark gap. Grey relational theory was adopted to determine the best process parameters that optimize the response measures. The experiment has been done by using Taguchi's orthogonal array L36. The experimental results confirmed that the proposed method in this study effectively improves the machining performance of WEDM process.

Garg et al. (2013) used mild steel as a work material. The various geometrical parameters affect the performance of micro-channels. . In this study, Taguchi Arrays were used to analyse the effect of various geometrical parameters & response parameters on micro channel performance. Channel width, height of channel, width of fin(all in mm) were process parameters with three levels. Results shown that channel width, height and substrate thickness at the base were the prime factors of concern.

Rajneesh et al. (2013) studied the optimization of Wire EDM for various process parameters at optimal values.Genetic algorithms was used for optimization as it was cost effective method.Unlike other optimization techniques genetic algorithm is more robust and have high performance in mltimodal optimization problems.That's why Genetic algorithm was used for optimization process.Desired response parameters were minimum surface roughness and maximum material removal rate (MRR).Where as process parameters were flushing rate,wire tension,pulse off time and pulse on time.RSM estaiblished the relation between process parameter and response parameters and mathematical models was generated between them.Genetic Algorithm (GA) gave us maximum MRR value as 11.8746 which were 0.6661 lesser im megnitude than measured value .Minimum Surface Roughness predicted using GA was 4.40.

Kanakuppi et al. (2013) investigated the behaviour of zinc-aluminium alloy was checked which was reinforced with silicon carbide particles after machining with Wire EDM.Tool Damage was noticed in conventional machining for machining of metal matrix composites.To reduce this tool damage conventional machining was replaced with the electrical discharge machining.To achieve higher surface finish ZA43 which was reinforced by SiCp with Wire EDM.process parameters were varied as Applied current (2,4,6 amp), Pulse on Time (4,6,16 µ sec) and Pulse off Time (5,7,9µ sec) while other parameters such as Wire tension,dielectric flushing pressure and wire tension) were constant.It was observed that MRR decreased and surface roughness increased when reinforced percentage in composite was increased.

Daniel et al. (2013) discussed about current research trends in Wire EDM with process parameters and response parameters. These process parameters were servo voltage, peak current, pulse on time (Ton), pulse off time (Toff),dielectric flow,wire tension,wire feed rate.Response parameters are material removal rate (MRR),surface roughness (Ra),sparking gap (kerf width),wire wear rate,surface integrity factors,wire lag (LAG).Different Modelling and optimization methods were discussed their application,advantages and disadvantages.Some recommendations about the trends for future were also discussed.

Neeraj et al. (2013) conducted experiment to optimize the parameter settings of Wire EDM.for increased productivity and manufacturing efficency contineous improvement of Wire EDM must have to be there.Manufacturing advancement in WEDM had directly contributed for increased cutting speed and dimentional accuracy.Brass Wire was used as electrode.Analysis of variance was used for process parameter settings design.It was concluded that by decreasing both pulse duration and discharge current surface roughness can be improved.Better surface roughness can be achieved with short pulse duration combined with high peak value.Machined surface roughness was improved with reverse polarity.Work piece hardness and streangth are no longer governed factors for work piece. Wire Wear ratio was increased with increasing pulse duration and open circuit voltage.

Anish et al. (2013) stated the wire rapture frequency in Wire EDM and surface integrity of wire. These input parameters was Pulse off time (Toff),Pulse on Time (Ton), peak current, wire tension, servo voltage and wire feed rate. To develop the empirical model optimum range of process parameters were selected. Machining was done on pure titanium work piece. For economical machining of pure titanium by Wire EDM was most effective eighth one factor at a time strategy. Wire breakage significantly effects the material removal rate (MRR).It was concluded that wire breakage frequency was reduced for parametric setting of pulse on Time (Ton) = 112-120 µsec, Pulse off time (Toff) = 44-56 µsec, peak current (Ip) = 120-200 A, Wire feed rate = 4-10 m/min, Wire tension = 4-10 grams and wire feed rate (WF) = 4-10 m/min.

Parveen et al. (2013) summerised the results obtained from machining for MRR with varying parameter settings,as pulse on time was main effecting parameter for material removal rate (MRR).Material Removal Rate increased as pulse on time (Ton) increased.As the pulse duration and discharge current decreased surface flatness could be improved.Ultimately short pulse duration alongwith high peak current decreases results in better surface roughness which could not be obtained by long pulses. Proper Pulse energy with reversed polarity machining improved the machined surface roughness than with normal polarity.Pulse On Time (Ton) and pulse off time (Toff) impact than other parameters for wire breakage was much higher.Wire tension and Pulse on time increased the wire wear ratio.

Shah et al. (2013) In this work, the study has been made to enhance the process parameters during machining of Inconnel-600 by Wire-EDM (WEDM) using response surface methodology (RSM). Four input process parameters of WEDM namely Peak Current (IP), Pulse-On time (TON), Pulse-Off time (TOFF) and Wire Feed rate (WF)) were chosen as variables to study the process performance in terms of Material Removal Rate (MRR). In the present work, the parametric optimization method using Taguchi’s robust design was proposed for wire-cut electric discharge machining of Inconel-600.

Amitesh et al. (2014) conducted experiment on Wire EDM (Nimonic 80A) process for the investigation on material removal rate, surface integrity and wire wear ratio. Design and plan of experiment methodology was done by Taguchi's design of experiment. Effect of process parameters and two factors integrations had statically substantial the effect on response parameters. Microstructures and effects of machined specimens was calculated with SEM (scanning electron machining).Thicker recast layer was formed with higher pulse on time (Ton).Wire deposition was lower at machined surface with the lower pulse on time and high pulse-off value (Toff).Wire wear ratio statically significantly effected from all the input parameters .Ton_Toff and Ton_IP were two factors interactions contributed most in WWR variations.

Pratik A et al. (2014) reviewed the optimization of Wire EDM for different input parameters.Response Surface methodology was conducted for experimental design to achieve maximum material removal rate(MRR).Wire tension,peak current and pulse on time was investigated.Work piece Material used was AISI D2 cold work steel beneficial in mold and die formation. Response surface Methodology used for experiment design in which second order fitting model obtained from central composite design method.Process parameter effects on material removal rate (MRR) was determined from analysis of variance (ANOVA).Regression analysis done to obtain second order mathematical model considering process parameters for MRR and their substantial relations.Optimization was done with desirablility approach and performed experiment conformation.

2.1.2 Literature review of MADM-TOPSIS Approach

Bhangle et al. (2004) generated and maintain robot manipulators reliable and exhausive database estaiblished on different pertinent atrributes.To standardise the selection procedure for robot this database was very helpful for particular operations of a firm.Tool selection of robot most suited for a operations according to user needs using this will save the user time.Using elemination search which was based on few precarious selection attributes large number of candidate robots were converged to managable shortlist of possible suitable robots.Shortlisting of different attributes was done by specification method and graphical method and selection procedure taken for ranking of alternatives.Ranking of candidate rabots was purely dependent on the +ve benchmark with respect to best possible robot for a particular uses.Selection of robot would became quite easy using this ranking method.It helped the designer and manufacturer for improvement of their products to meet the users need.

Garg et al. (2006) explianed methodology for selction,evaluation and ranking of an optimum power plant.Multiple attribute decision making(MADM) approach was used which consisted elimination search and technique for order preference by similarity to ideal solution (TOPSIS). 190 pertinent attributes were found for comprehensive coding and classification of thermal power plant suggested which was appropriate for development of large database of current plants. Elimination search used to converge the large no. of power plants to manageable shortlist plants.Ranking of alternatives done with TOPSIS in shortlist.This approach was explianed in details with the help of illustrative example.

Agrawal et al. (2007) described methodology for coding,evaluation,ranking and optimum selection of subsystems for composite products to its manufacturers. This would build virtual design, reliable database, develpoment,customization,cutting edge technology and full fills the challanging situations in composite industry.Electronic coding scheme consisted 77 attributes and evaluation approach which were useful for designer for all design phases and optimum sub systems selection which helped for market requirments.TOPSIS technique of MADM approach used for assortment of composite subsystems product development for a required applications.MADM appraoch consists of two graphical methods were used for comparison and evaluation.Illustrative example explained this 3 stage methology.

Tanvir and Agrawal (2014) proposed technique for nanamaterial selection with Multiple Attribute Decision Making Approach (MADM) with the help of Technique for order preference by similarity to ideal solution. Normalized attributes nanomaterial attributes invalidated the effect of different units and values of their in a range of 0-1. For different applications significance different nanomaterials were selected by relative impotance matrix.Using Eigen formulation weight vectors can be derived.Euclidean distance of alternatives with best and worst solutions of nanomaterials were referred to develpoment of suitablility index for ranking were reffered as positive and negative benchmarks.Decision was taken on the basis of opportunity,weakness,streangth and threat analysis.Step by Step procedure was explianed with the illustrative example.

Tanvir and Agrawal (2014) explained the Technique for order preference by similarity to ideal solution (TOPSIS) for ranking and evaluation of nano actuators elements with the help of multiple attribute decision making(MADM) approach. Normalized attributes nanactuators attributes invalidated the effect of different units and values of their in a range of 0-1. For different applications significance different nanoactuators were selected by relative impotance matrix.Using Eigen formulation weight vectors can be derived.Euclidean distance of alternatives with best and worst solutions of nanoactuators were referred to develpoment of suitablility index for ranking were reffered as positive and negative benchmarks.Decision was taken on the basis of opportunity,weakness,streangth and threat analysis.Step by Step procedure was explianed with the illustrative example.

2.2 Literature Summary

From The research papers for Wire EDM ,it has been seen that different alterations are executed for Maximum Material Removal Rate (MRR), Minimum Surface Roughness (Ra) and Wire Wear Ratio (WRR) on Wire EDM and they found useful.Some studied are

- Traditional Pulse Generating Circuit of low power generation was modified.
- Various process parameters are varied with the different range values.
- Different Range of Work Piece materials are used for machining.
- Design of Experiments are done with different Mathematical Modelling Techniques.
- Various Optimization Processes followed for optimum selection of process parameters.

2.3 Gaps in Research

Some Gaps are found during research papers study some of them are discussed below.

- Performance characteristics effected by process parameters are discussed but effects of parameters on performance are not compared with each other for example how much diffrence is seen in response parameters with the effect of variations in process parameters.
- Performance characteristics obtained by keeping the other process parameters constant have been already discussed but change in no. of variable or process parameters effect to achieve optimum response has not discussed.
- MADAM-TOPSIS approach has not applied for Wire EDM process parameter optimization.
- No Work is done for Comparison,Selection,Evaluation and Ranking based on attributes for Wire EDM.

CHAPTER-3

Experimentation And Mathematical Modeling

3.1 Problem Formulation

From literature review it is concluded that for micro-scale machining Wire EDM is best machining process. Wire EDM gives high precision and micro level slots with high accuracy. Micro-scale machining easily done with the help of Wire EDM because it uses 0.25 mm thick wire as electrode. Wire EDM is a non contact machining between work piece and wire as in non traditional process. So there are no forces which are acting on work piece. Due to this there will be no any deformation of work piece during process and dimensional accuracy would be ultimately better with this process.

For heat transfer in integrated circuits and other electronic devices micro channels are used. Efficiency of micro channels can be measured by heat dissipation concern. Surface roughness of micro channels and heat transfer co-efficient of micro channels material are two most important parameters upon which heat transfer depends. Micro channel will dissipate maximum heat if its surface roughness is minimum or extract maximum heat from micro channel. Moreover with the minimum surface roughness pressure drop inside the micro channel will also be minimum. Hence heat transfer performance will be enhanced.

Micro Channels can be Fabricated by two different techniques are given below:-

- Traditional or Miniaturized Technique - (Streo lithography,milling, ultrasonic machining,sawing etc)
- Modern Technique - (Laser machining,LIGA,Wet chemical,plasma etching)

Both fabrication techniques have some advantages and disadvantages. Micro channels can be fabricated with the above discussed techniques but these techniques have high manufacturing costs and availability is lesser so that's why these techniques are not preferred. Wire EDM machining is easily available, comparatively lesser manufacturing cost and less complexity are main reasons for using this. Wire EDM is non traditional machining and tremendous surface finish can be achieved in Wire EDM. That's why micro channel heat sinks are fabricated with this machining processes as per its name suggests micro channels are device having micro scale dimensions. Very fine slots (dimensions in microns) and higher surface finish are the main performance parameters of micro channels which can be easily achieved by Wire EDM fabrication technique.

Aluminum (6061) material is used for micro channel heat sink.Aluminium is an alloy of Magnesium and silicon as a major alloying element. In micro channels heat transfer co-efficient which is mainly depends upon material used for fabrication also affects the heat transfer in micro channels. Mainly micro channels are fabricated with copper because it has high heat transfer co efficient so lots of work is done on copper in micro channels fabrication field.Aluminium is used as micro channels material because of its high surface finish. So to check the performance so aluminum (al) of heat sink, aluminum is used as work material. From literature review it has been concluded that Wire-EDM parameters such as Pulse On Time (T_{on}), Servo Voltage (V) and Wire Feed Rate(WF) has a significant effect on surface roughness(Ra) and material removal rate (MRR).That's why these parameters are selected with different range for machining.

3.2 Experimentation

3.2.1 Work Piece Material

First of all, Aluminum (6061) is used as a work piece material for micro channel fabrication with Wire EDM machining process. Aluminum (6061) contains magnesium and silicon as major alloying elements. Aluminum alloy 6061 is 6000 series aluminum alloy used most extensively. These are high strength capabilities alloys obtained with versatile heat treatments.

Key Properties of Aluminium Alloy (6061)

- Good Surface Finish
- Good Toughness
- High heat dissipation
- High to Medium Strenght

- Widely Available

Table 3.1 Typical Composition of Aluminium alloy (6061)

Component	Amount(Wt.%)
Aluminium	Balance
Magnesium	0.8 - 1.2
Silicon	0.4 - 0.8
Iron	Max 0.7
Copper	0.15 - 0.40
Zinc	Max 0.25
Chromium	0.0 - 0.35
Others	0.05

3.2.2 Experimental Setup

Experimental optimization of Wire-EDM parameter settings to fabricate micro channels is discussed in this chapter. For fabrication of micro channels various machines and tools were used to get optimum results and observations at required points.

Substrate Preparation: - Aluminum (6061) Bar of length 600 mm and thickness 5 mm is cut into square piece of 30mm×30mm with the help of power hacksaw. And Five channels are fabricated on it whose length is 30 mm, thickness 0.5mm and height of 1mm.The drawing of micro channels fabricated in this work is formed in Creo(Pro School Edition) as shown in figure below.

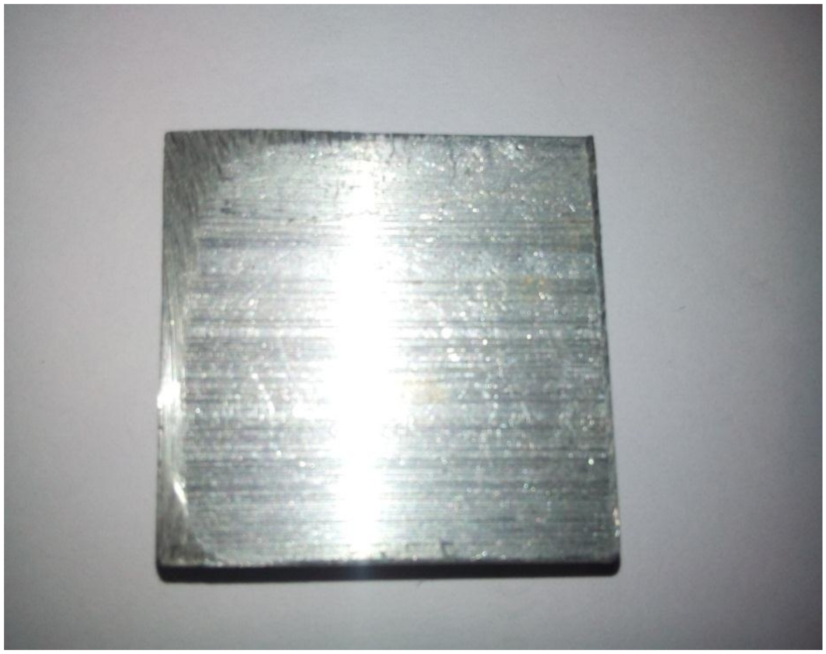


Fig 3.1 Shows the substrate prepared

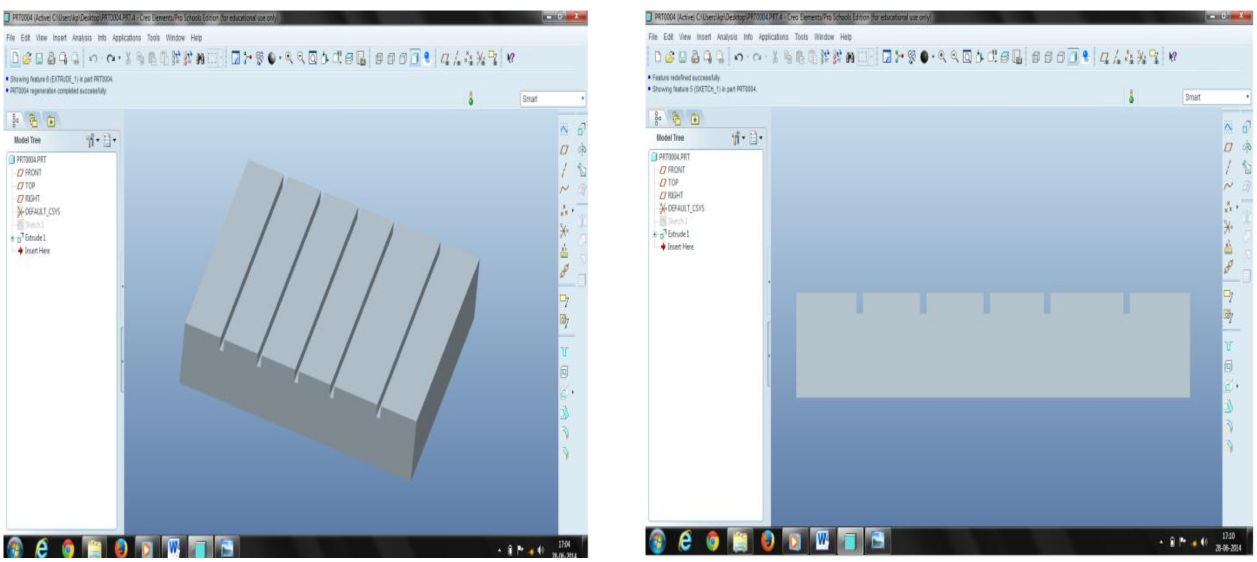


Fig 3.2 Shows the Isometric and Front View of micro channels drawing.

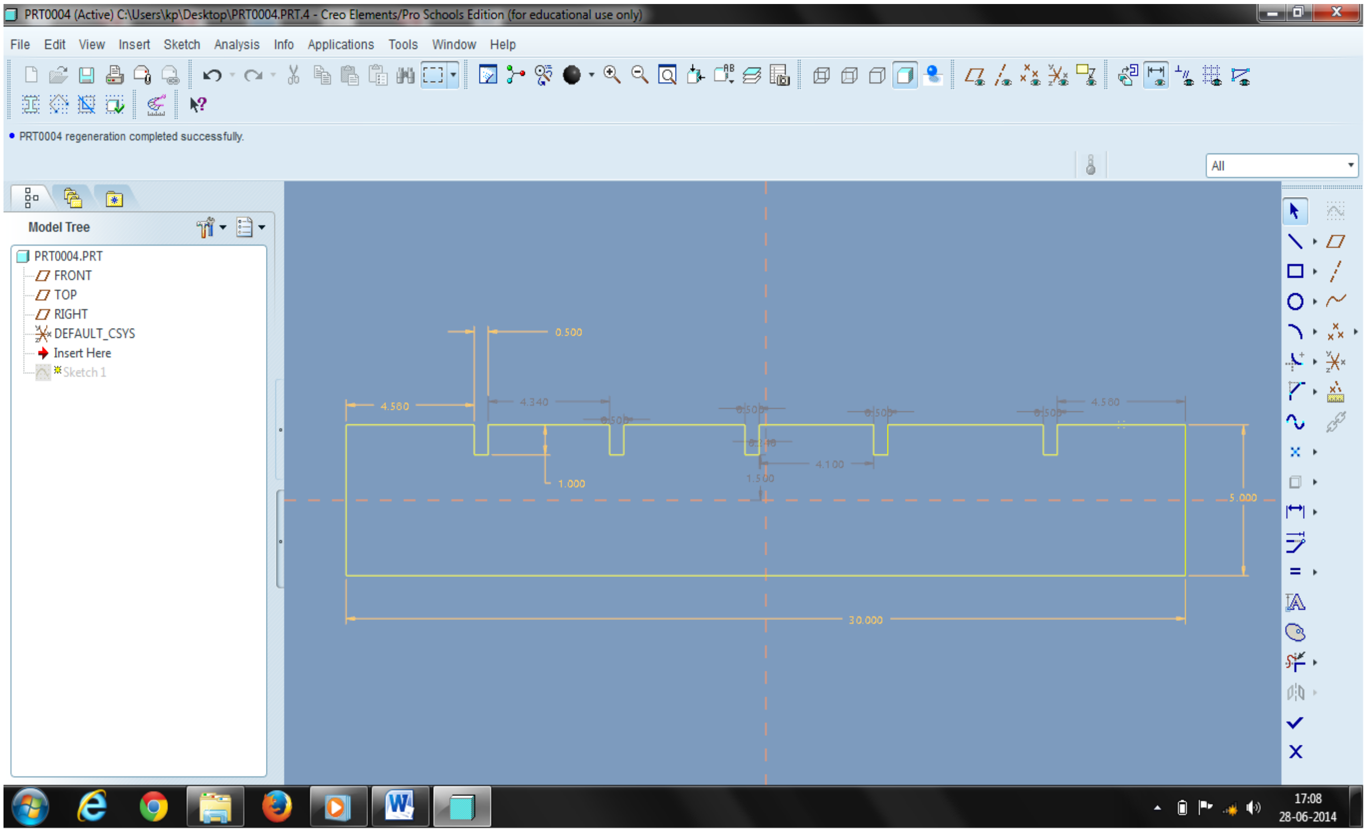


Fig 3.3 Shows the Dimensions of Micro Channels

When the specimen is ready using Wire EDM (Electronica ELPULS 40A DLX) micro-channels are formed as shown in figures.

Specimen Weighing :- After specimen prepration,Weighining of specimens was measured using weighing machine (Wensar) Electronic balance HPB1000H.Weighing of all specimen was for calculating Material Removal Rate (MRR).Weighing of machined specimen is again taken. The Electronic balance weighing machine is shown in figure below.

Fig 3.4 Electronic balance weighining Machine

Wire EDM Machine:- Experimental runs are taken on Wire EDM Electronica ELPULS 40A DLX.Brass wire is used in expeimental runs Of wire diameter 0.25mm.

(i) (ii)

Fig 3.5 (i) (ii) Wire EDM machine Electronica ELPULS 40A DLX.

Specifications of Machine - Electronica Wire EDM machine having Peak Current (I_p) variation from 40 to 230 Ampere.Wire Tension values range is upto 10 kg/cm^2.Dielectric has only two settings i.e. 0 or 1.Pulse On Time(Ton) has variation from 100 to 129 µsec.Pulse off Time (Toff)

0-63 μsec.Spark voltage has 0-99 volts variations. Other technical specifications are shown below.

Table 3.2 Description of Wire EDM

Max Table Size	370×600 mm
Max. Work Piece	200 mm
Max. Work Piece Weight	300 kg
Max taper cutting angle	± 5°/100 mm
Main Table Transverse	250,300 mm
Max wire spool capacity	6 kg
Wire Diameter	0.25mm(standard)0.2mm optional
Display	Colour LCD
Min input command	0.001mm
Min Resolution for x,y,u,v	0.001mm
Interpolation Function	Linear Circular
Simultaneous controlled axes	X,Y,u,v
Data Input/Output	USB 2.0 Keyboard RS232C isolated serial interface
Input Power Supply	3Phase, AC 415,50 Hz
Connected Load	3KVA
Dielectric Fluid	Water
Tank Capacity	140Ltrs

Surface Roughness Measurement:- Surface Roughness is major performance parameter in this experimental work. Surface Roughness is measured with the help of Mitutoyo SJ 400 profilometer.This instrument gives different roughness notations like Ra, Rq, Rz, Ry etc. But in our case we only uses Ra value for results and calculations.Mitutoyo SJ 400 is shown as below in figure.

Fig 3.6 Surface Roughness Tester Mitutoyo SJ 400

Profilometer has stylus which touches the specimen to check roughness. Average value of roughness on specimen is given by profilometer.Stylus of profilometer is inserted I channel width and gives the value of roughness.

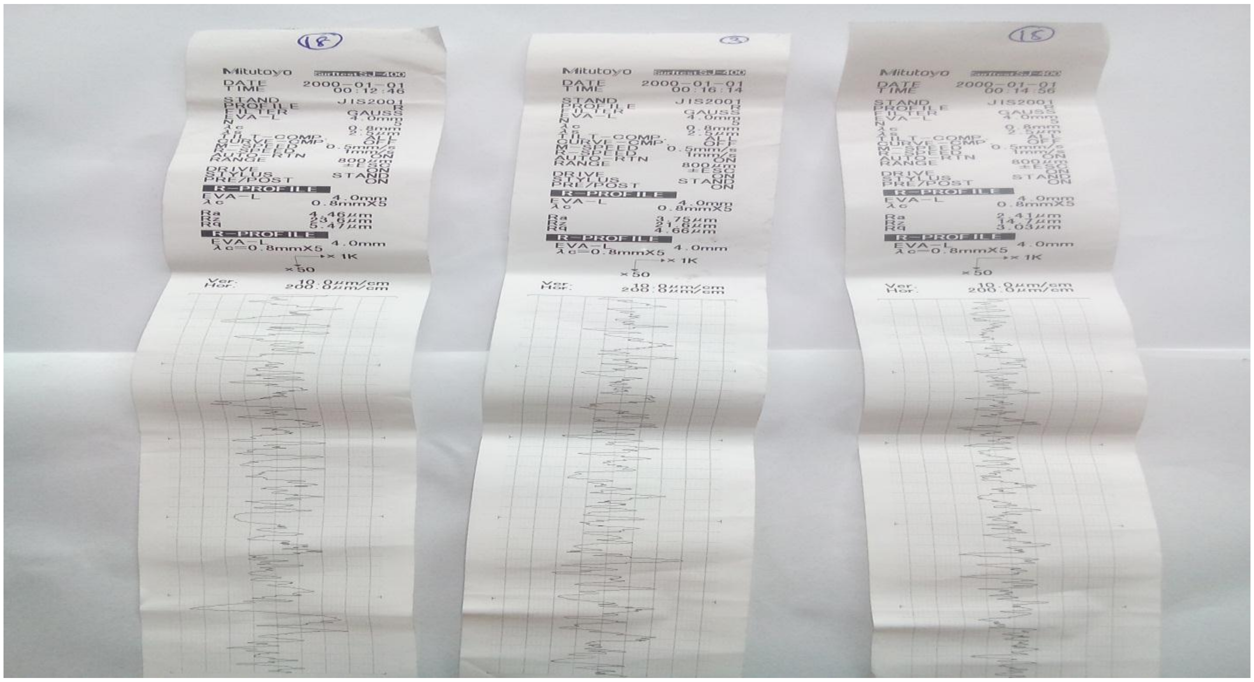


Fig 3.7 Surface Roughness graphs given by Mitutoyo SJ 400

3.3 Design of Experiment

For optimum parameter selection for Wire EDM design of experiment is done with Response Surface Methodology (RSM). Which is implemented by MINITAB 17.0 to construct an experiment design.Mathematical modelling is also done with Response Surface Methodology. Introduction to this method has been discussed below.

3.3.1 Response Surface Methodology:- Collection of statistical and mathematical techniques for empirical model is known as Response Surface Methodology. The main objective of this technique is to optimize a response or output variables which influenced with the effect of input or independent parameters. Series of tests known as runs in which variations or changes are been made in input or independent parameters in order to calculate the changes occurred in output or response parameters.e.g. A response variable influenced by two different input variable having different levels. And response is shown as:-

$$y=f(x_1, x_2) + e \qquad (3.1)$$

Where "e" is referred to error found in response if E(y) = $f(x_{1,}x_2) = \mu$ is expected response then μ= $f(x_{1,}x_2)$ represents the surface is known as Response Surface.

The form if relationship between independent and response variables are mostly unknown. Thus RSM is started with finding out the approximate functional relationship established between set of independent variables and y.In some region of independent variables usually low order polynomial is employed. The approximate function is first order model given below if response is well modeled by linear function of input variables

$$y = \beta_0 + \beta_1 x_1 + \beta_1 x_1 + \beta_2 x_2 \ldots\ldots\ldots\ldots\ldots + \beta_k x_k + e \qquad (3.2)$$

Polynomial of higher degree would be used if there is curvature in system.

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \ldots\ldots\ldots\ldots\ldots\ldots + e \qquad (3.3)$$

Mathematical equation formation almost all the problems are solved by this equations formation. Least Square method is used for estimate of parameters in approximating polynomial.

Response Surface Methodology used for surface plots these plots are used for evaluation of response variables with the effects of input parameters. Variation of input parameters on response variables are very precisely shown by these plots. The surface plot represents the relationship between independent parameter ($x_{1.}x_2$) and response y is shown as given below.

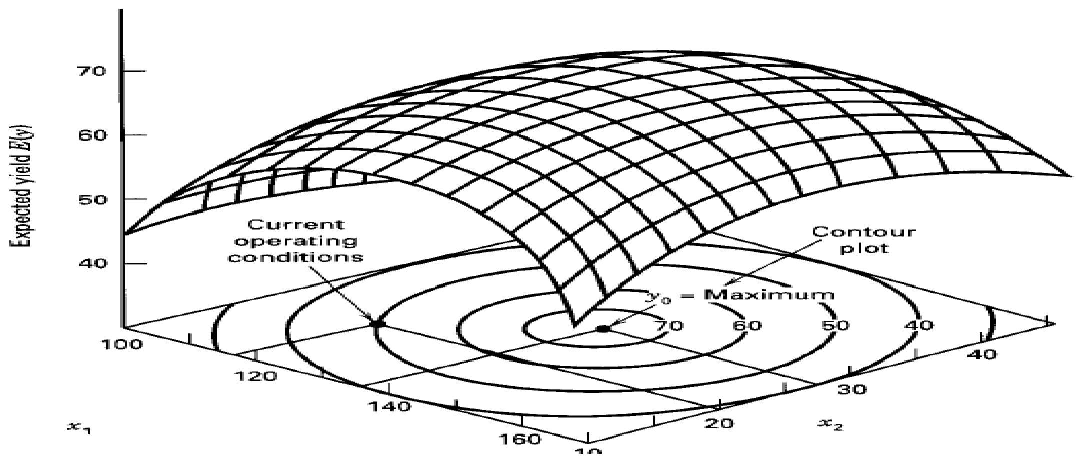


Fig 3.8 Shows the Surface plot generated by RSM.

3.4 Experimentation

First step in experimental work is to prepare specimens from Aluminum (6061) Bar of thickness 5 mm and 600 mm length and cut into 20 specimens of dimensions 30mm×30mm using power hacksaw. Design of experiment for these 20 different specimens is done by Response Surface Methodology. MINITAB 17.0 implements the Response Surface Methodology. In experimentation using MINITAB three input (Independent) parameters are varied in a specific range in accordance to experiment designed by RSM .Five different levels of Pulse on Time (Ton),Servo Voltage(V) and Wire Feed Rate(WF) are fabricate micro-channels. Three response parameters are considered in experimentation i.e. Material Removal Rate(MRR),Surface Roughness(Ra) and Wire Wear Rate(WRR) which will evaluate the performance of Wire EDM machining as independent or input parameters are varied in different levels.

As discussed earlier, RSM designs the experiment with the help of MINITAB software. For Three Input or Independent Parameters (Pulse on Time (Ton), Servo Voltage (V) and Wire Feed Rate (WF) 20 experiment runs would be there designed by MINITAB. Central Composite

Design (CCD) type of design would be used. The worksheet is shown as.

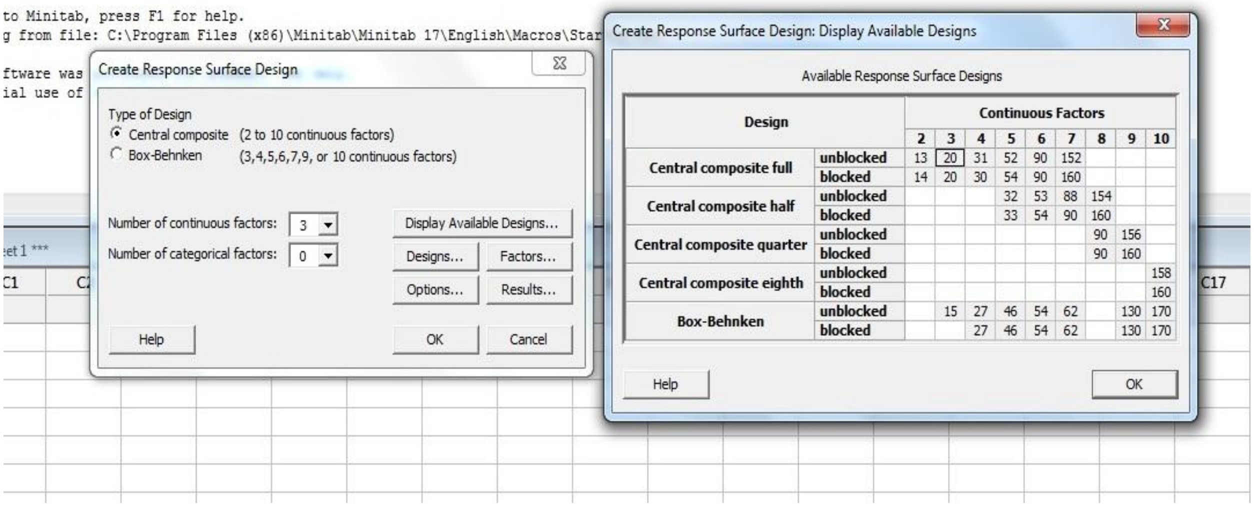


Fig 3.9 Shows the Design of Experiment By RSM using MINITAB.

Five Different levels of Three independent parameters varied in experiment are listed below in table.

Table 3.3 Independent Parameters with levels

Input Parmeters	-α	-1	0	+1	+α	Units
Pulse On Time (Ton)	98.18207	105	115	125	131.8179	µ sec
Servo Voltage(V)	9.5462	30	60	90	110.4538	Volts
Wire Feed Rate(WF)	5.3182	6	7	8	8.6817	mm/min

Parameters mentioned in Table.4 are varied to obtain a best Material Removal Rate(MRR),Surface Roughness (Ra) and Wire Wear Rate (WRR) results.But during experimental work some parameters are kept constant for desired process and response parameter relation.These constant parameters are discussed as below.

Table 3.4 Constant Parameters during machining

Sr.No.	Constant Parameters	Constant Values
I.	Pulse Off Time (Toff)	40 µ sec
II.	Peak Current (I_p)	200 Ampere
III.	Sero Feed(SF)	2100 units
IV.	Wire Tension	7 Machine Units
V.	Dielectric Pressure	1 Machine Units

These Parameters are kept constant while machining. These parameters having units as per according to Wire EDM machine catalogue (Electronica EL PULS 40A DLX) for this experimental work. Every reading is taken by keeping above parameters constant.

3.4.1 Material Removal Rate (MRR) - Material Removal Rate is the transformation of material between electrode and work piece. This transformation can be in terms of solid, liquid or gaseous state. Mathematically it can be defined as it is the ratio of difference of weight work piece before machining is done on it and after machining to the density of Material (work piece).It can be written as

$$MRR = \frac{(W_b - W_a)}{\rho \times t} \tag{3.4}$$

Where W_b = Weight before machining

W_a = Weight after machining

ρ = Density of material

t = Time taken for machining or fabrication .Time is taken in minutes.

3.4.2 Surface Roughness (Ra) - The other response parameter considered is surface roughness (Ra) in experimentation. Micro channel performance is mainly depends upon the surface roughness.Surface roughness of micro channel is greatly affects pressure drop and pumping power .That's why surface roughness is main performance parameter of heat transfer in micro channels. Surface roughness is measured with the help of Mitutoyo SJ 400 profilometer as discussed earlier.

Surface Roughness (Ra) is arithmetic average of data points collected roughness and is area above and below the mean line is shown sum of absolute values of that areas. A Line parallel to general surface direction and divides the surface in a manner that sum of area found above the line is equals to sum the area found below the line and this line is known as Mean Line.

3.4.3 Wire Wear Ratio (WRR) - The wire wear ratio is calculated by ratio of wire wear loss to intial weight of wire .

$$\text{WRR} = \frac{IWW - FWW}{IWW} \tag{3.5}$$

Where IWW - Intial weight of wire

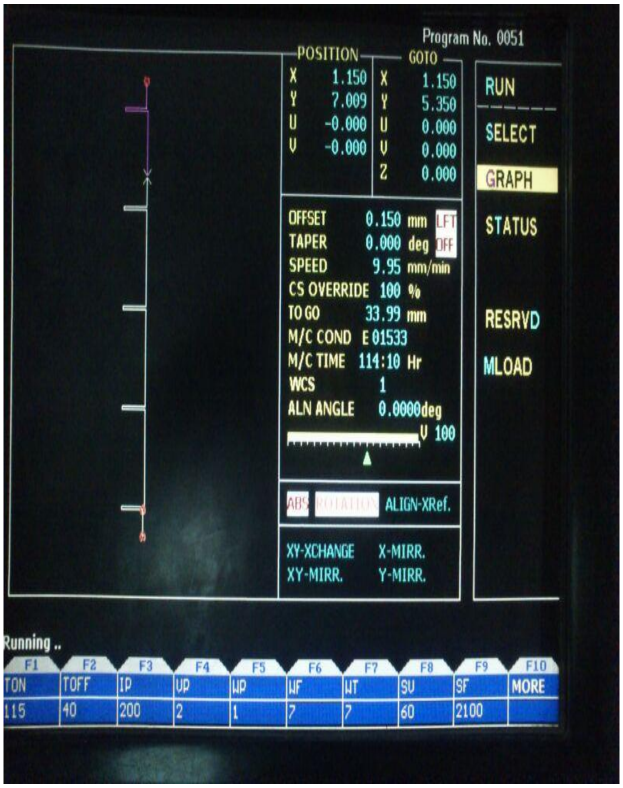
FWW - Final weight of wire

Using Minitab 17.0 we have three Process parameters Pulse on time(Ton),Servo Voltage (V) and Wire Feed Rate(WF) and Minitab gives us 20 different runs of experiments at diffrant values of these process parameters as shown in Table below.

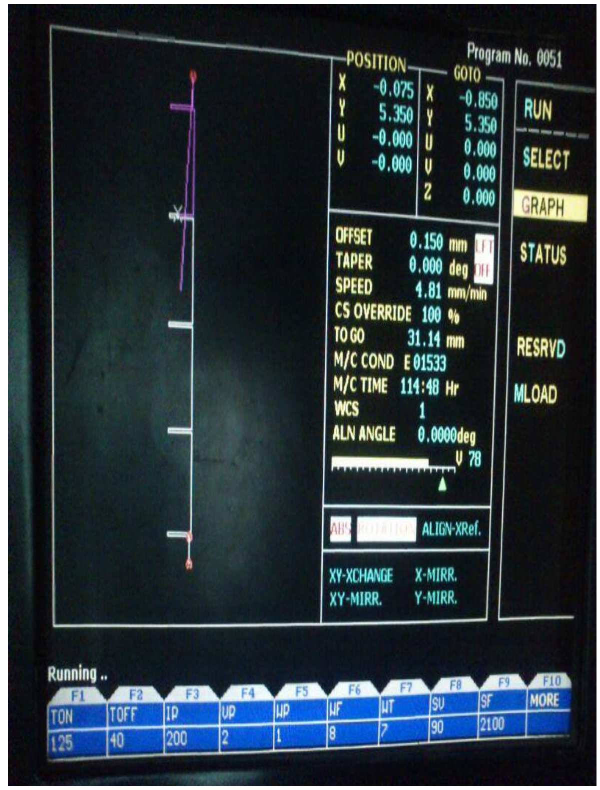
Table 3.5 Experimental runs with different parameters combinations

Sr. No.	Pulse on Time (Ton)	Servo Voltage (V)	Wire Feed Rate(WF)
1.	115	60	7
2.	115	60	7
3.	125	30	6
4.	115	9.5462	7
5.	115	110.4538	7
6.	115	60	5.31
7.	131.8179	60	7
8.	125	90	8
9.	115	60	8.681
10.	115	60	7
11.	115	60	7
12.	105	30	6
13.	105	30	8
14.	115	60	7
15.	105	90	8
16.	125	90	6
17.	98.1820	60	7
18.	125	30	8
19.	105	90	6
20.	115	60	7

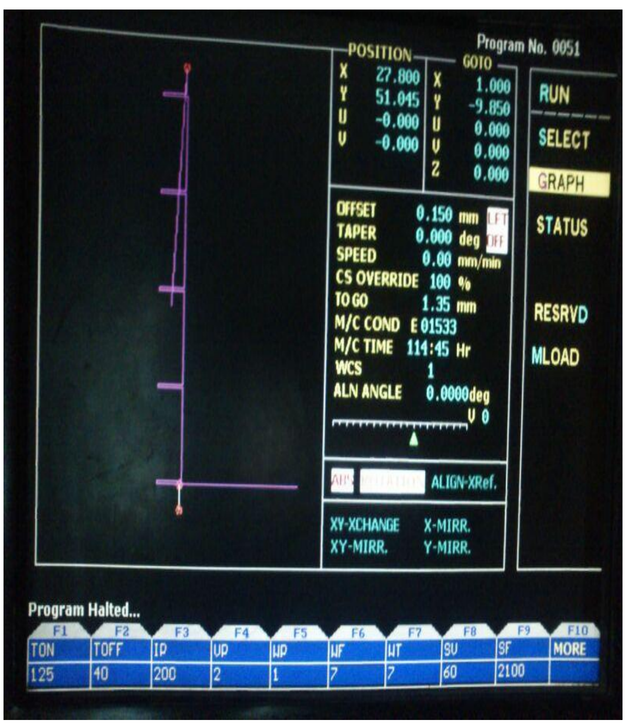
After Design of experiment machining is done with Wire EDM machine in according with these 20 different parameter settings and for each run we record the time for machining at that parameter setting using stop watch. And we get the 20 micro channels with these 20 parameter settings.



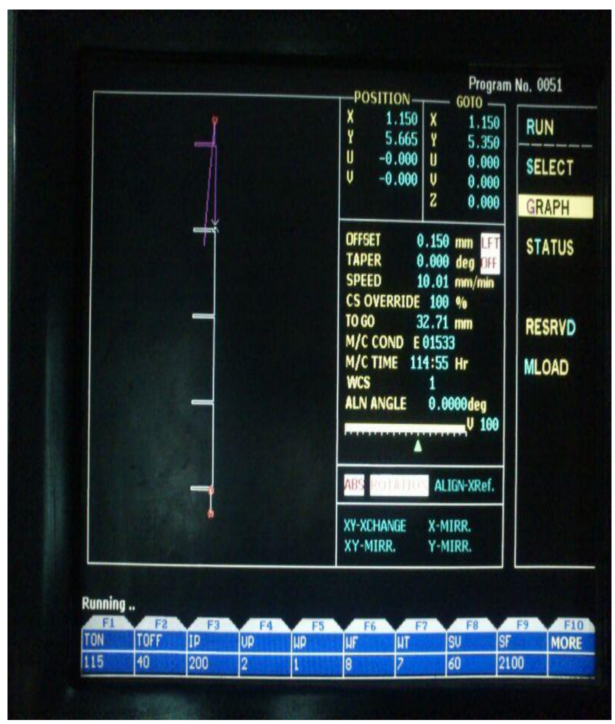
(i)



(ii)



(iii)



(iv)

Fig 3.10 (i-iv) Shows the Wire EDM machine display screen for different parameter settings

(i) (ii)

Fig 3.11 (i) (ii) Shows the front and top view of micro channels made on specimen using Wire EDM

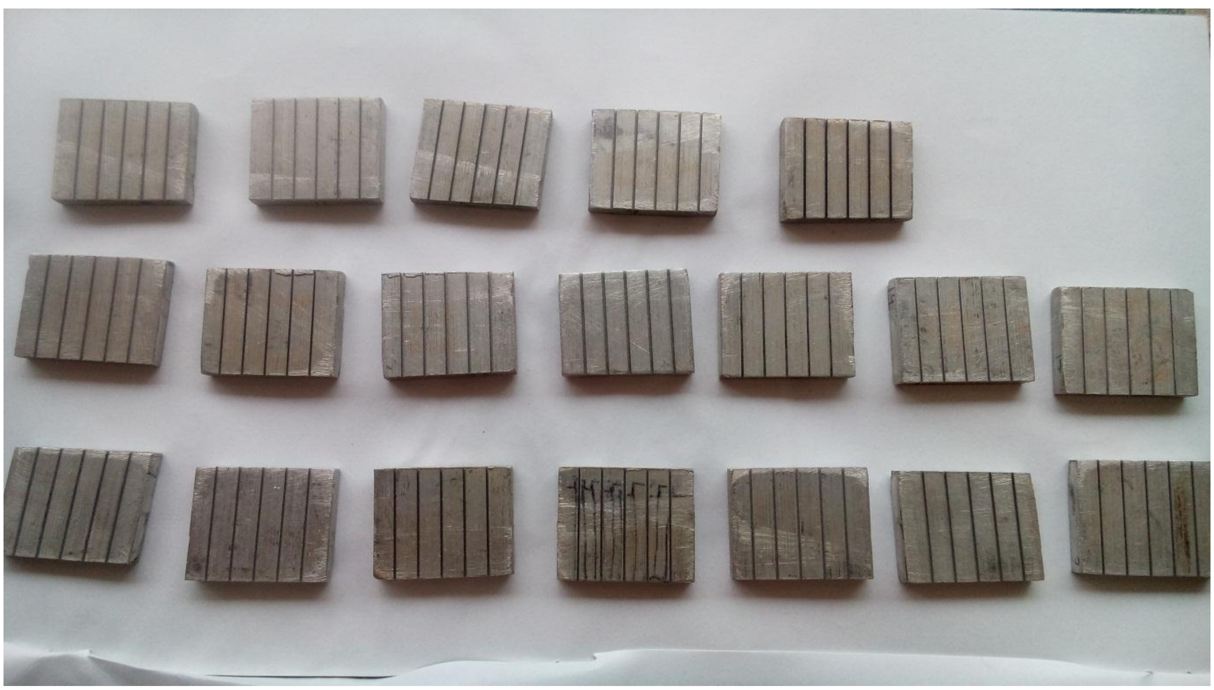


Fig 3.12 Shows 20 specimens on which micro channels are formed with different 20 parameter settings using Wire EDM.

According to table No. 3.5 experimental runs are performed on Wire EDM machine and Time taken for each run is noted to calculate the material removal rate as discussed in formula mentioned above. After machining operation responses Material Removal Rate, Surface Roughness and Wire Wear Ratio is calculated for each run. These values are tabulated in following Table 3.6

Table 3.6 Response values after machining.

Sr. No.	Surface Roughness (Ra)	Material Removal Rate (MRR)	Wire Wear Ratio (WRR)
1.	4.09	4.81	0.05
2.	4.07	3.97	0.07
3.	3.75	3.33	0.065
4.	4.26	5.04	0.047
5.	3.23	2.59	0.08
6.	3.97	4.55	0.075
7.	4.07	4.01	0.055
8.	4.14	3.03	0.077
9.	3.69	5.08	0.035
10.	4.07	4.44	0.055
11.	4.01	4.5	0.062
12.	2.56	2.80	0.097
13.	2.66	1.90	0.062
14.	4.09	4.83	0.057
15.	2.41	1.30	0.092
16.	3.92	3.30	0.069
17.	2.75	2.39	0.085
18.	4.46	2.65	0.081
19.	2.14	2.01	0.09
20.	4.08	3.65	0.052

3.5 Mathematical Modeling

After getting the responses using experimentation on Wire EDM. Now Relationship between process parameters (Ton, Servo voltage, Wire feed rate) and response parameter (MRR, Ra and WRR) has to be estaiblished.Response Surface Methodology is used to create a mathematical relation between the input or process parameters and response parameters. This would helps in finding out the process behavior. This relationship gives us if there are any variations in input or process parameters how response parameters are affected from these variations. Hence mathematical equation is generated between process parameters and response parameters. This equation gives us the variations in responses ith affect of process parameters variations.

Using Response Surface Methodology (RSM) in MINITAB three mathematical equations are generated to predict the Wire EDM process behavior during fabrication of micro channels in 20 different parameter settings. Three Equations of Material Removal Rate, Surface Roughness and Wire Wear Rate are generated individually as shown below.

Surface Roughness (Ra)

$$-47.0 + 0.723(T_{on}) + 0.0042(V) + 1.64(WF) - 0.00313(T_{on} \times T_{on}) - 0.000217(V \times V) - 0.165(WF \times WF) + 0.000217(T_{on} \times V) + 0.0070(T_{ON} \times WF) - 0.00133(V \times WF) \quad (3.5)$$

Material Removal Rate (MRR)

$$-88.6 + 1.568(T_{on}) - 0.049(V) + 0.063(WF) - 0.00703\ (T_{on} \times T_{on}) - 0.000540(V \times V) - 0.132\ (WF \times WF) + 0.00073\ (T_{on} \times V) + 0.0083\ (T_{on} \times WF) + 0.0025\ (V \times WF) \quad (3.6)$$

Wire Wear Ratio (WRR)

$$1.890 - 0.2292\ (T_{on}) - 0.00028(V) - 0.1288(WF) + 0.000077\ (T_{on} \times T_{on}) + 0.00006(V \times V) + 0.00243\ (WF \times WF) - 0.00010\ (T_{on} \times V) + 0.000712\ (T_{on} \times WF) + 0.000121\ (V \times WF) \quad (3.7)$$

Where T_{on} - Pulse on Time

V - Servo Voltage

WF - Wire Feed Rate

These are the equations generated for responses with help of Response Surface Methodology (RSM) in MINITAB software. Significance of these mathematical equations is to show the behavior of machining process in Wire EDM.These equations are further used to choose optimum parameter setting among these 20 parameter settings in MADM optimization technique.

Table 3.7 ANOVA table for Surface Roughness(Ra)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	9	8.19426	0.91047	1.59	0.004
Linear	3	6.09505	2.03168	1.54	0.061
Ton	1	5.56774	5.56774	0.52	0.043
V	1	0.47697	0.47697	3.65	0.029
WF	1	0.5033	0.5033	0.02	0.56
Square	3	0.67114	0.67114	4.64	0.083
Ton*Ton	1	1.41517	1.41517	6.78	0.080
V*V	1	0.54758	0.54758	3.78	0.131
WF*WF	1	0.39175	0.39175	2.71	0.296
Intraction	3	0.02860	0.02860	0.20	0.896
Ton*V	1	0.03380	0.03380	0.23	0.29
Ton*WF	1	0.03920	0.03920	0.27	0.621
V*WF	1	0.01280	0.01280	0.09	0.30
Error	10	1.44732	0.14473	……	……
Lack of Fit	5	1.44284	0.28851	5.24	0.056
Pure Error	5	0.00448	0.00090		
Total	19	9.64158			

Table 3.8 ANOVA table for Material Removal Rate (MRR)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	9	15.8981	1.76645	1.94	0.159
Line	3	5.7669	1.92230	2.11	0.163
Ton	1	3.6131	3.61311	3.96	0.075
V	1	1.9499	1.94991	2.14	0.175
WF	1	0.2039	0.20388	6.22	0.123
Square	3	9.6533	3.21776	3.53	0.000
Ton×Ton	1	7.1262	7.12618	7.81	0.019
V×V	1	3.4006	3.4005	3.73	0.082
WF×WF	1	6.2519	0.25190	0.28	0.611
Intraction	3	0.4779	0.15930	0.17	0.000
Ton×V	1	0.3785	0.3785	0.41	0.365
Ton×WF	1	0.0544	0.0544	0.06	0.158
V×WF	1	0.0450	0.04500	0.05	0.0036
Error	10	9.1255	0.91255	…..	…..
Lack of Fit	5	8.0202	1.60404	7.26	0.024
Pure Error	5	1.1053	0.22107		
Total	19	25.0236			

Table 3.9 ANOVA table for Wire Wear Ratio (WRR)

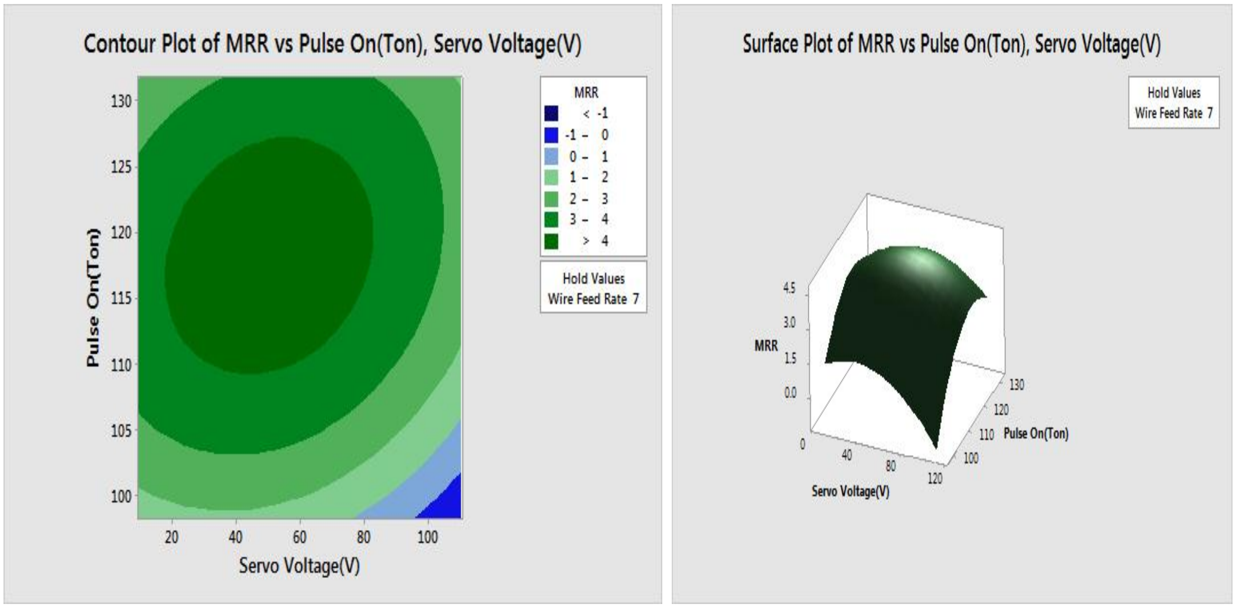
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	9	0.0003380	0.000376	1.97	0.153
Line	3	0.001601	0.000534	2.80	0.095

Ton	1	0.000724	0.000724	3.80	0.166
V	1	0.000451	0.00451	2.37	0.0155
WF	1	0.000426	0.000426	2.23	0.080
Square	3	0.001201	0.0004000	2.10	0.164
Ton×Ton	1	0.00862	0.000862	4.52	0.054
V×V	1	0.00426	0.00426	2.23	0.0166
WF×WF	1	0.000085	0.000085	0.45	0.519
Inraction	3	0.00577	0.000192	1.01	0.429
Ton×V	1	0.000066	0.000066	0.35	0.134
Ton×WF	1	0.000407	0.000407	2.13	0.0175
V×WF	1	0.000105	0.000105	0.55	0.475
Error	10	0.001907	0.000191	……	……
Lack of Fit	5	0.001638	0.000328	6.08	0.035
Pure Error	5	0.000269	0.000054		
Total	19	0.005284			

From Above discussed ANOVA tables it was detected that for 95% level of confidence ($p<0.05$), Response parameters are significantly effected by process parameters i.e. Pulse on Time (Ton), Servo Voltage (V) and Wire Wear Ratio (WRR). From tables it is found that Ton has significant effect on MRR as well as surface Roughness. Where as Servo Voltage significantly effects surface roughness and Wire Wear Ratio (WRR) considerably affected by wire feed rate.

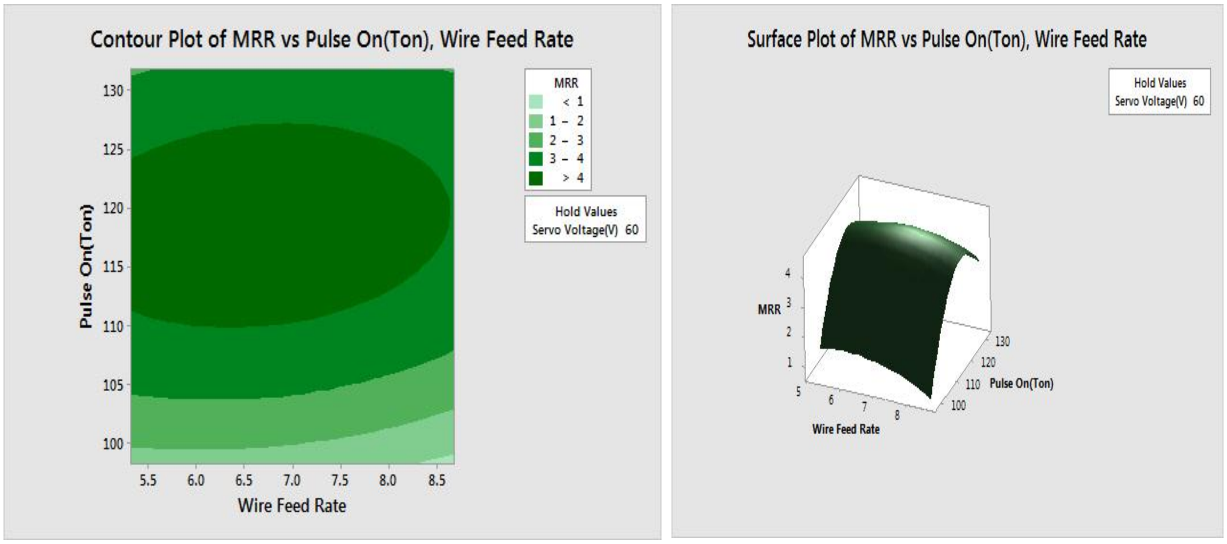
3.5.1 Contour And Surface Plots

Using Response Surface Methodology in MINITAB software contour and Surface plots are taken. These plots signify the variation in response parameters with effect of process or input parameters. Optimum or best response variables can be obtained with evaluation of best combination of input parameters. These optimum values of response parameters can be create from surface plots and contour plots. Contour plots are the representations how process parameters {Pulse on Time (Ton), Servo Voltage and Wire Feed Rate (WF)} are relates with the response parameters Material Removal Rate (MRR), Surface Roughness (Ra) and Wire Wear Ratio (WRR).These are shown as below.



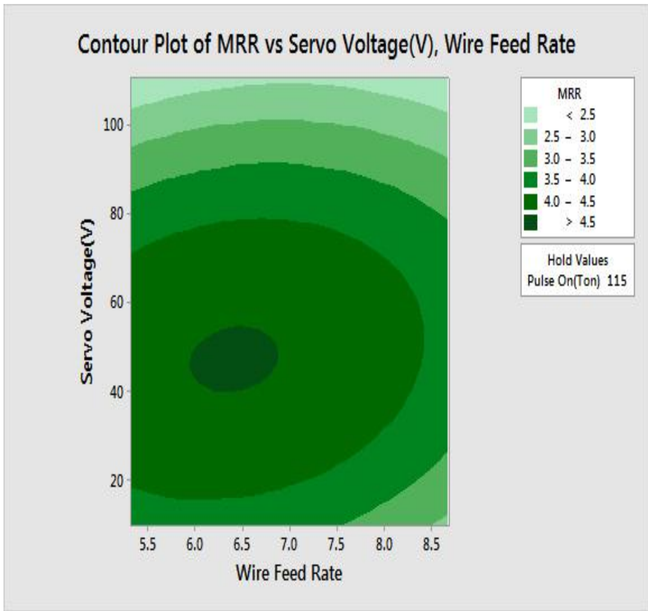
(i) (ii)

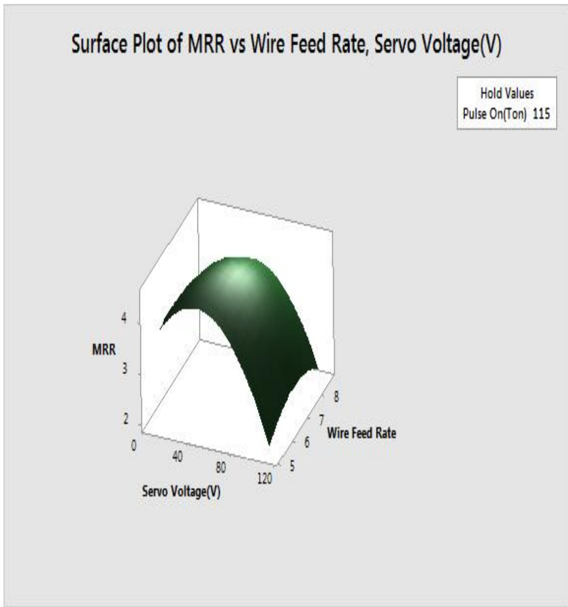
Fig 3.13 (i) (ii) Shows the contour and surface plots of MRR vs Pulse on (Ton) ,Servo Voltage(V)



(i) (ii)

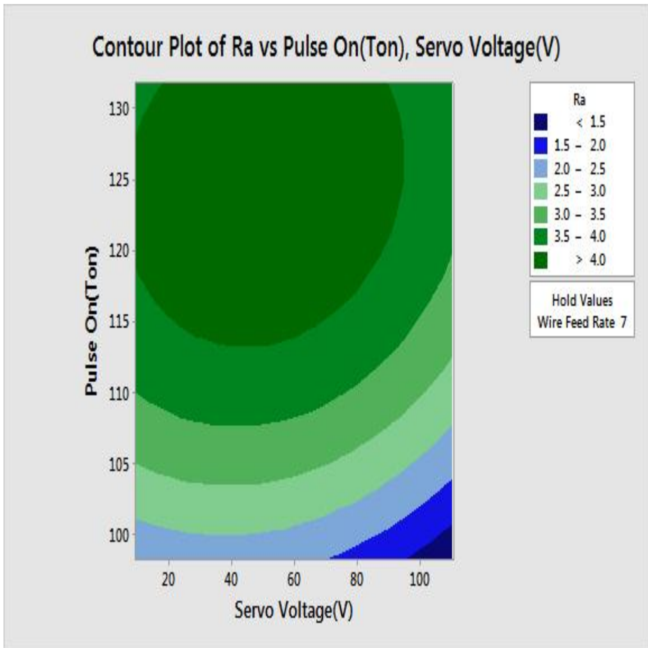
Fig 3.14 (i) (ii) Illustrates the contour and surface plots of MRR vs Pulse On (Ton),Wire Feed Rate

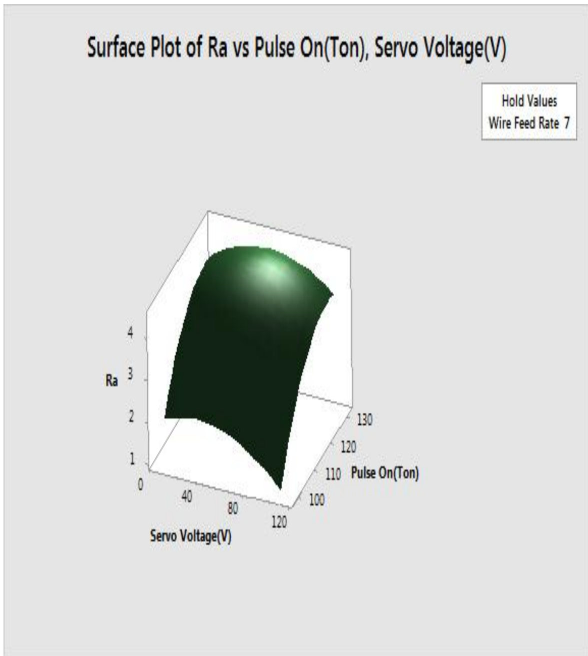




(i) (ii)

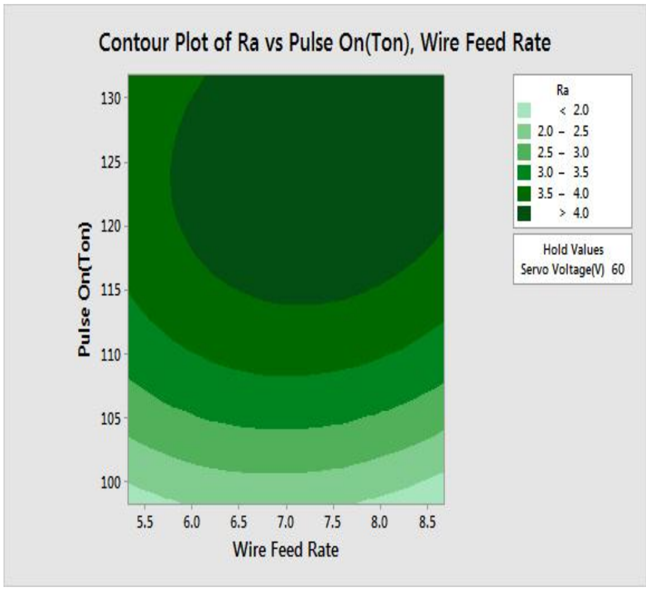
Fig 3.15 (i) (ii) Shows the contour and surface plots of MRR vs Wire feed rate, Servo Voltage(V)



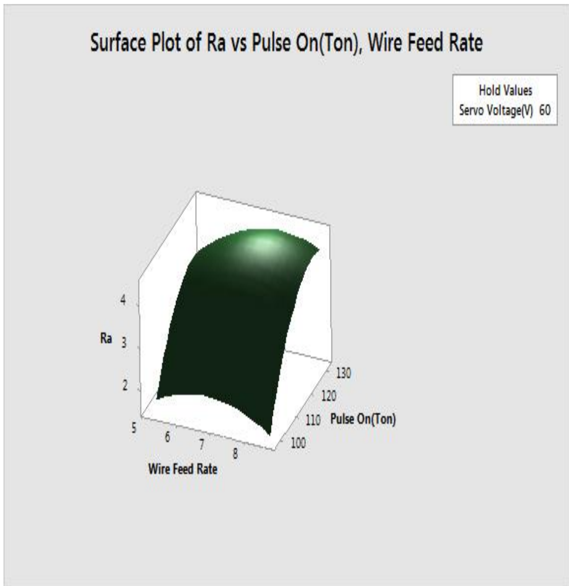


(i) (ii)

Fig 3.16 (i) (ii) Shows the contour and surface plots of Ra vs Pulse on (Ton),Servo Voltage(V)

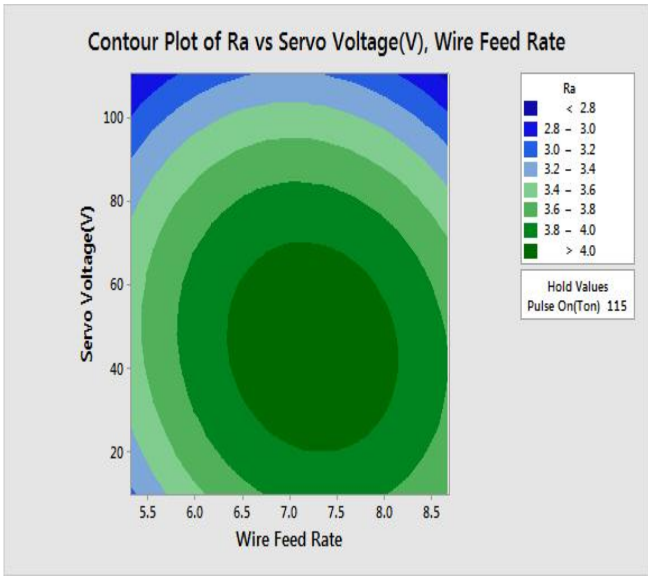


(i)

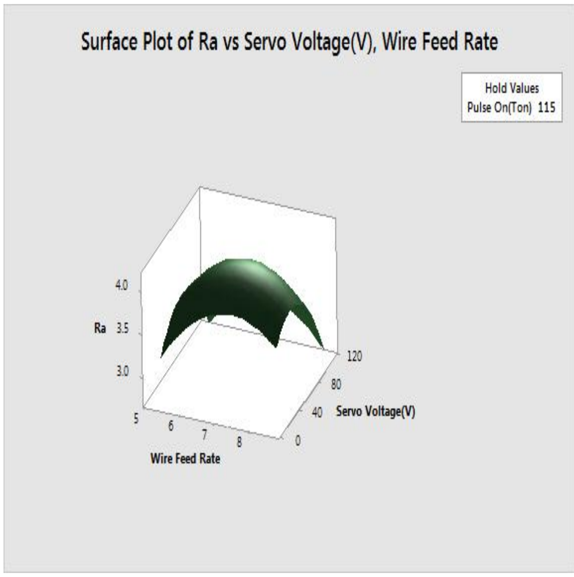


(ii)

Fig 3.17 (i) (ii) Illustrates the contour and surface plots of Ra vs Pulse on (Ton),Wire feed rate

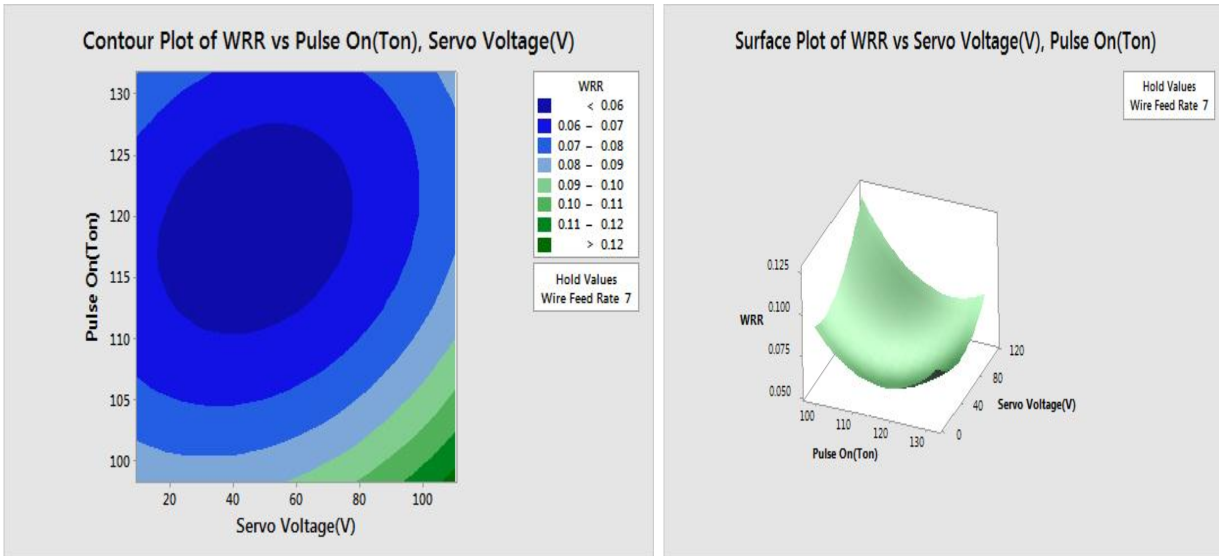


(i)



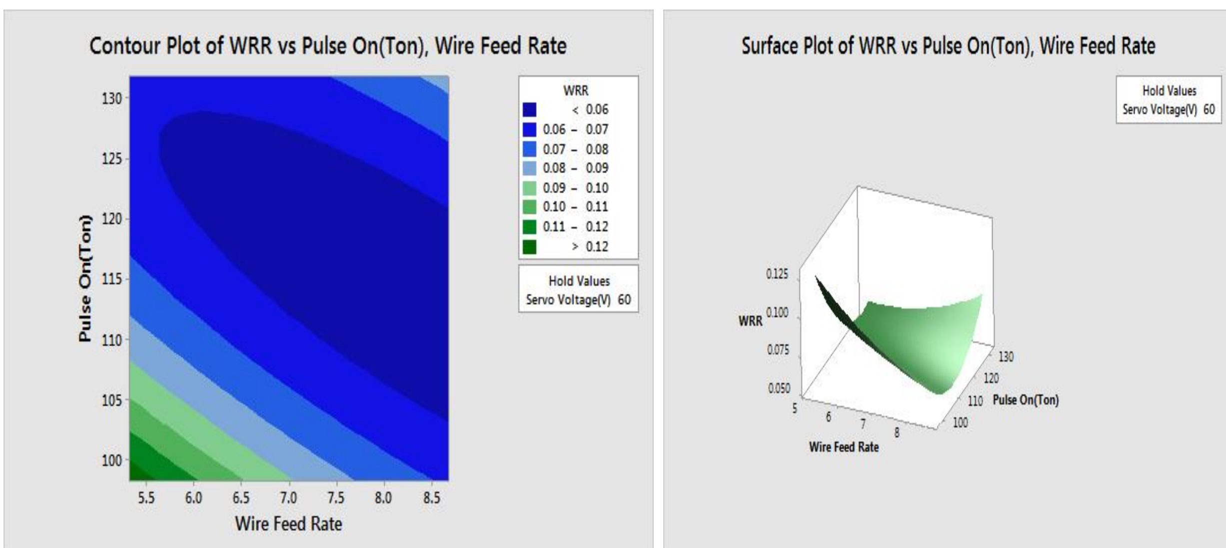
(ii)

Fig 3.18 (i) (ii) Demonstrates the contour and surface plots of Ra vs Servo voltage(V),Wire feed rate



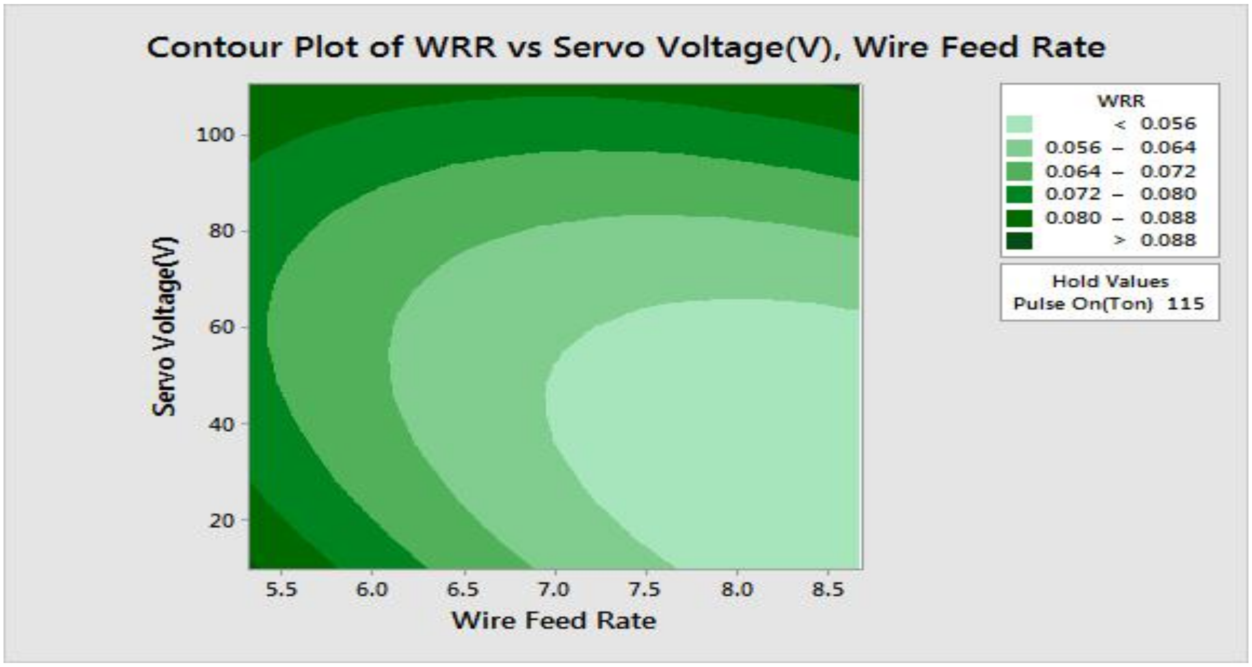
(i) (ii)

Fig 3.19 (i) (ii) Shows the contour and surface plots of WRR vs Pulse on (Ton),Servo Voltage(V)

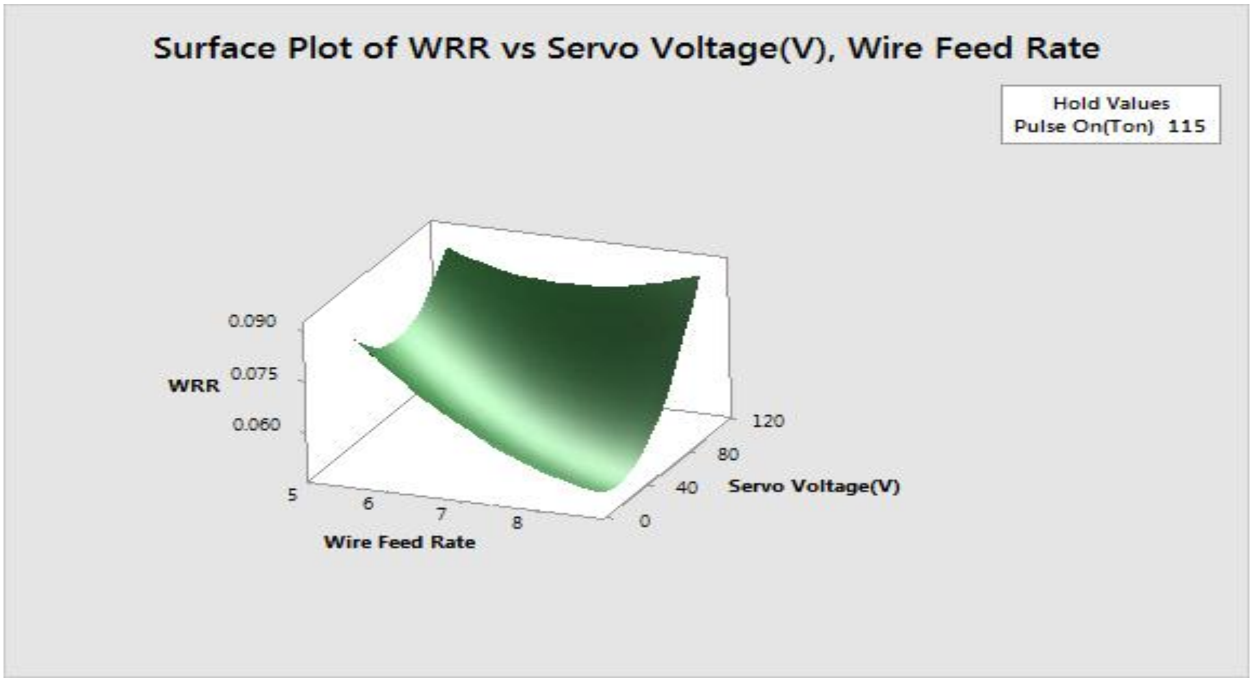


(i) (ii)

Fig 3.20 (i) (ii) Shows the contour and surface plots of WRR vs Pulse on (Ton),Wire feed rate



(i)



(ii)

Fig 3.21 (i) (ii) Shows the contour and surface plots of WRR vs Servo Voltage(V) and Wire feed rate

From above discussed plots it is illustrated that from contour and surface plot for MRR as when servo voltage is maximum and pulse on time is 115µ sec MRR is maximum. So it is concluded that MRR is maximum as Pulse on Time (Ton) is increasing and servo voltage (V) is maximum And In second contour and surface plot MRR is maximum when both wire feed rate and pulse on time (Ton) is maximum. So MRR is increasing as Pulse on Time (Ton) is increasing.

Similarly for Surface Roughness it is clear from contour and surface plots Surface roughness is minimum when servo voltage (V) is maximum. Surface Roughness increases as pulse on time (Ton) is increasing and vice versa. For Wire Wear Ratio (WRR) it is increases as servo voltage and pulse on time (Ton) is increases WRR is increased and Wire feed rate decreases the Wire wear ratio as wire feed rate is decreases.

3.5.2 Main Effect Plots For MRR , Ra and WRR.

Main effect plots are also generated with Response Surface Methodology (RSM) in MINITAB. These Plots gives the variations in response parameter with the effect of individual process or input parameter. When mean response changes along the level of factors main effect can be seen at that situation.

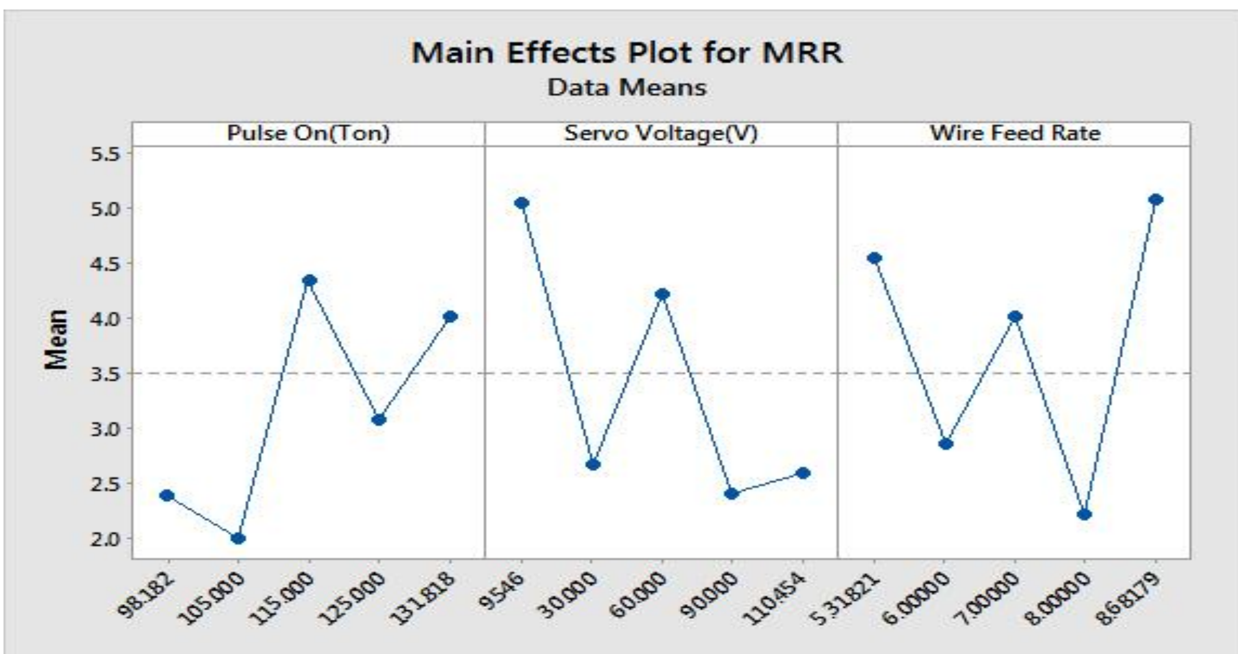


Fig 3.22 Main effect plot for MRR

From Main effect plot it is clear that MRR slightly decreases as pulse on time(Ton) changes from 98.182µ sec (-α) to 105µ sec(-1),then MRR increases in between 105µsec (-1) to 115µ sec(0) and further decreases from 115µ sec (0) to 125µ sec (+1).Transformation of Pulse on time (Ton) from 125µ sec (+1) to 131.818µ sec (+α).With the increase in pulse on time (Ton) MRR increases and then decreases with the increase in pulse on time (Ton). Similarly for Servo Voltage and Wire feed rate MRR is first decreases with increasing servo voltage and wire feed rate and then increases as servo voltage and wire feed rate is increases.

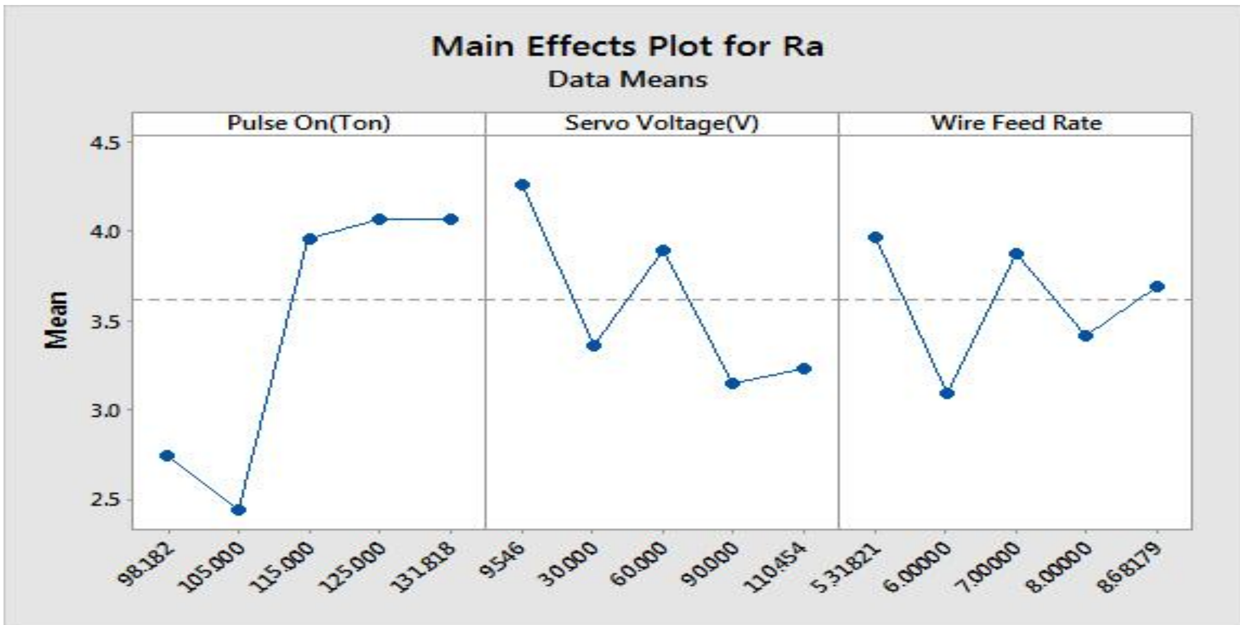


Fig 3.23 Main effect plot surface roughness (Ra)

As seen in Main effect plot surface roughness (Ra) is slightly decreases as pulse on time (Ton) is changes from 98.182µ sec (-α) to 105µ sec (-1) and Surface roughness is continuously increasing as pulse on time (Ton) increases from 105µ sec (-1) to 115µ sec (0) and then further increases to 125 µ sec (+1)And to 131.818 µ sec (+α) surface roughness is continuously increases. Similarly variation of Surface roughness with servo voltage and wire feed rate can also seen from main effect plot.

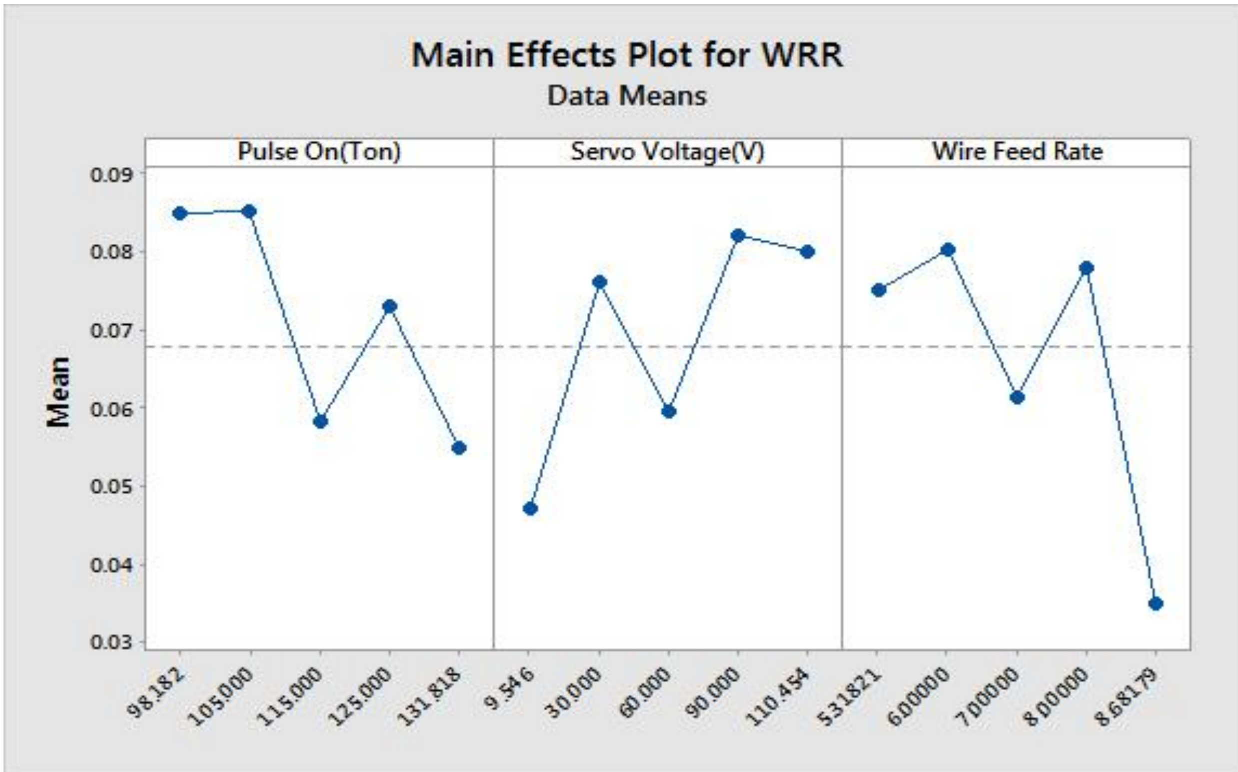


Fig 3.24 Main effect plot of Wire Wear Ratio

As Shown in main effect plot for Wire Wear Ratio as servo voltage is increased from 9.546V (-α) to 30V (-1) WRR increased and then decreased as it is further increased from 30V (-1) to 60V (0) and after this WRR as servo voltage is changes from 60V (0) to 90V (+1) and remains constant as transformation of servo voltage from 90V (+1) to 110.454(+α).Like wise the effect of pulse on time(Ton) and wire feed rate on Wire Wear Rate (WRR) can be observed.

3.5.3 Residual Plots for MRR, Surface Roughness (Ra) and Wire Wear Ratio

Response Surface Methodology (RSM) using MINITAB 17.0 plotted residual plots for responses Material Removal Rate (MRR), Surface Roughness (Ra) and Wire Wear Ratio (WRR).Main significance of residual plot is to check whether the data is normally distributed or not, other variables are influencing the response or not, whether the variance is constant, outliers exist or non linear relationship exists or not. These plots for the MRR, surface roughness and wire wear ratio are given as below.

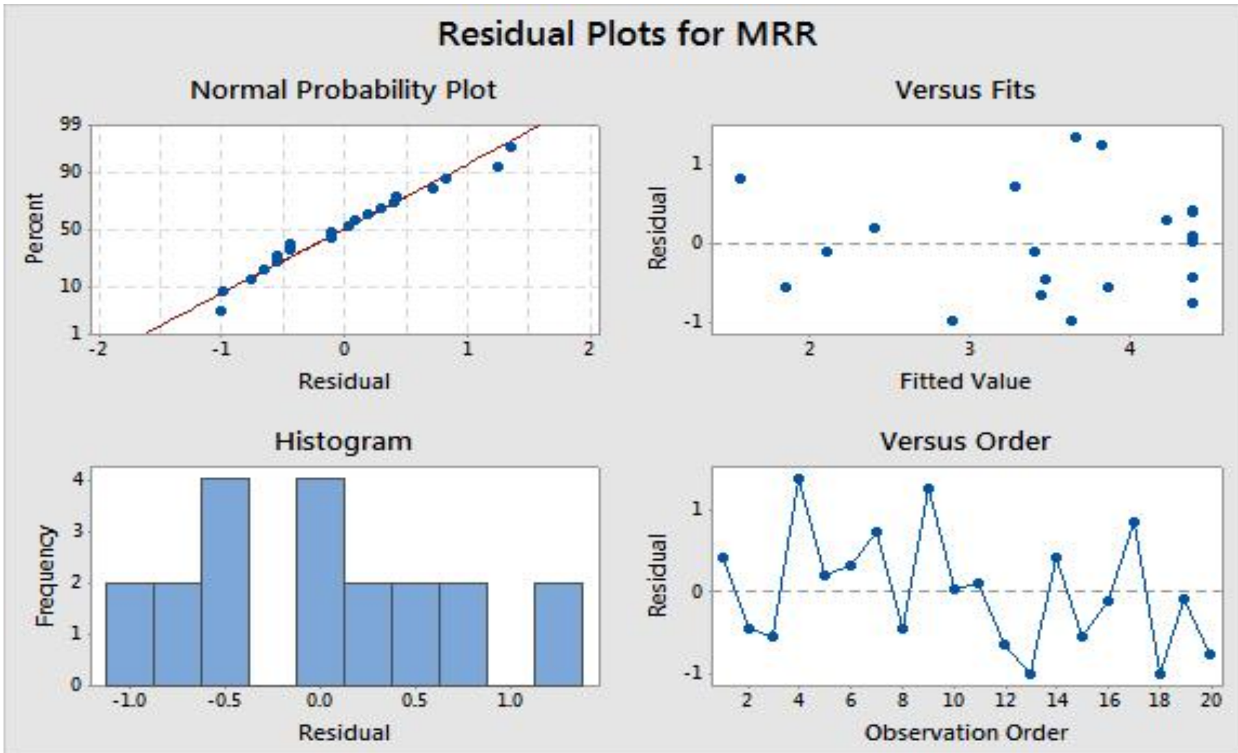


Fig 3.25 Residual plot for material removal rate(MRR)

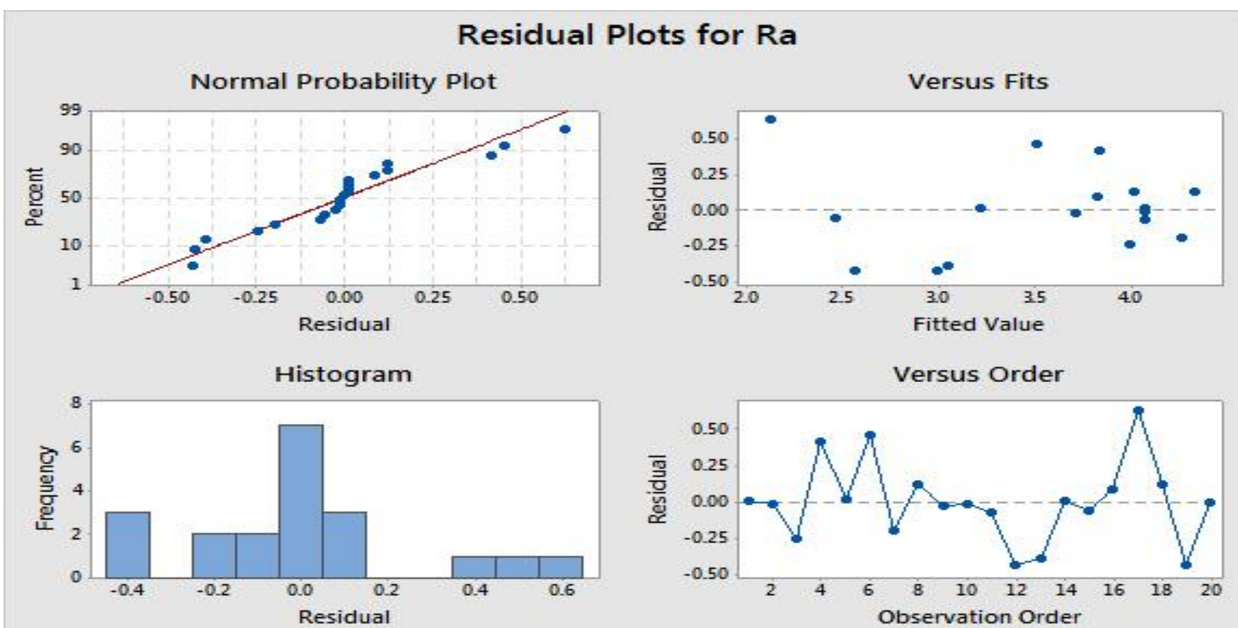


Fig 3.26 Residual plot for Surface roughness (Ra)

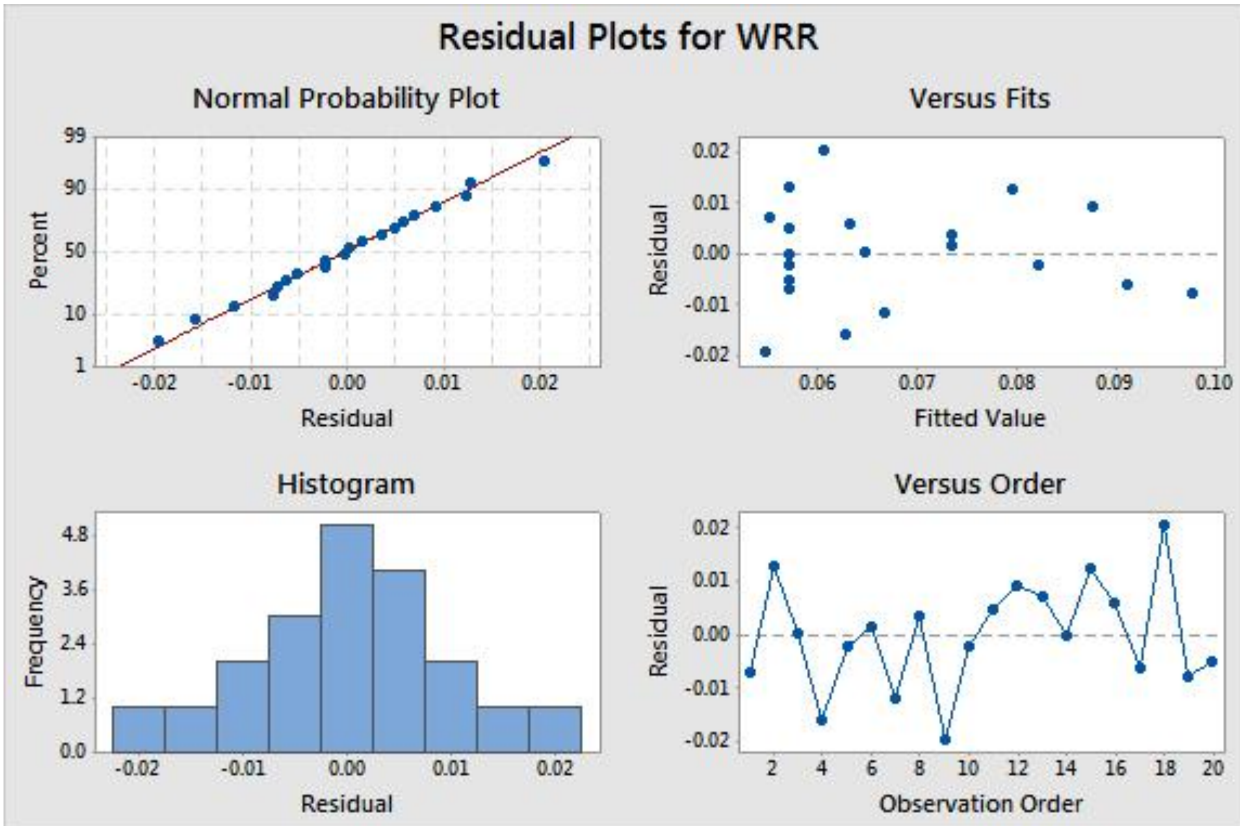


Fig 3.27 Residual Plot for Wire Wear Ratio(WRR)

By creating these plots, genuineness of regression equation is tested. It is seen that straight normal probability plot is followed by the residuals in residual plots and histograms approximate symmetric nature identifies that residuals are normally distributed. There is no error due to data collection order and time because residuals exhibit no clear pattern. This is signifies in residual versus fits plot that variances are not equal.

CHAPTER-4

Coding, Selection, Evaluation And Ranking of Optimum Parameter Settings For Wire EDM Using MADM-TOPSIS Approach

In this chapter we will discuss MADM (Multiple Attribute Decision Making) approach used to find out various pertinent attributes which are required for optimum selection, evaluation and coding of different parameter setting(Pulse On Ton,Servo Voltage V and Wire Feed Rate) for high Material Removal Rate (MRR),Low Surface Roughness (Ra) and Wire Wear Rate(WRR) in Wire Electric Discharge Machining(WEDM).MADM approach helps allot for selection of most useful parameter setting among all the parameter settings. This approach also give us the relative importance of particular parameter setting over the others which identified us which parameter setting can be used for given application like wise in our case we rank the 20 parameter settings to get High Material Removal Rate (MRR), Low Surface roughness (Ra) and Wire Wear Rate (WRR).The Most important application of MADM is to form exhaustive and relative database system based on the process. This data base gives us the standardize procedure for selection of parameter settings in Wire EDM for particular application. These attributes can classified into two terms Quantitative (fuzzy) and Qualitative (deterministic) in nature. Then these attributes are coded on basis of coding scheme named as N-Digit. These Coded attributes now can be used for any particular application as per user requirement and manufacturer applications e.g. different parameter settings are used to form micro channel on wire edm these parameter settings are of Pulse on Time (Ton),Servo Voltage(V) and Wire Feed Rate(WRR) for Higher MRR ,Lower Surface Roughness(Ra) and Wire Wear Rate(WRR).Then Mathematical procedure TOPSIS(Technique For Order Preferences by Similarity To Ideal Solution) is followed for ranking of these 20 parameter settings.MADM Problem generated are solved by TOPSIS .Exhaustive database formed in MADM is converted into mathematical and graphical form using Decision Matrix, Normalized Matrix, Relative Importance Matrix, Positive and Negative Benchmarked followed by Coefficient of Similarity. This parameter setting will help the Wire-EDM user to save Time and Money to obtain High MRR,Low Surface Roughness(Ra) and Wire

Wear Rate(WRR).The Coding and selection of pertinent attributes, Mathematical approach and Graphical approach is Illustrated with an example.

4.1 Steps Followed in MADM Approach:

Step 1: Identification and categorization of attributes under different parameters affecting the system.

Step 2: Different classification of attributes can be identified by cause and effect diagram which plays major role to optimize the system.

Step 3: Coding of Quantitative and Qualitative attributes is done on the basis of N-Digit coding scheme.

Step 4: TOPSIS procedure is used for elimination search and evaluation. And final results are used.

Step 5: Mathematical TOPSIS Procedure, Line Graph representation and Spider diagram representation are used for Ranking Of parameter settings.

Step 6: Methodology can be explained by using an illustrative example having 20 different parameters settings having parameters Pulse on Time (Ton), Servo Voltage (V) and Wire Feed Rate (WF) in Wire EDM for High MRR, Low surface Roughness (Ra) and Wire Wear Rate (WRR).

4.2 Identification of Wire EDM attributes

In Wire EDM machining sub systems can be classified as General parameters, Process Parameters, Response Parameters Work Piece Parameters and Tools Parameters etc. These sub systems are correlated with others**.** Identification of attributes is dependent upon their performance and process parameters and these parameters show the whole process of machining and identify the whole system. These attributes are given by fish bone diagram shown below.

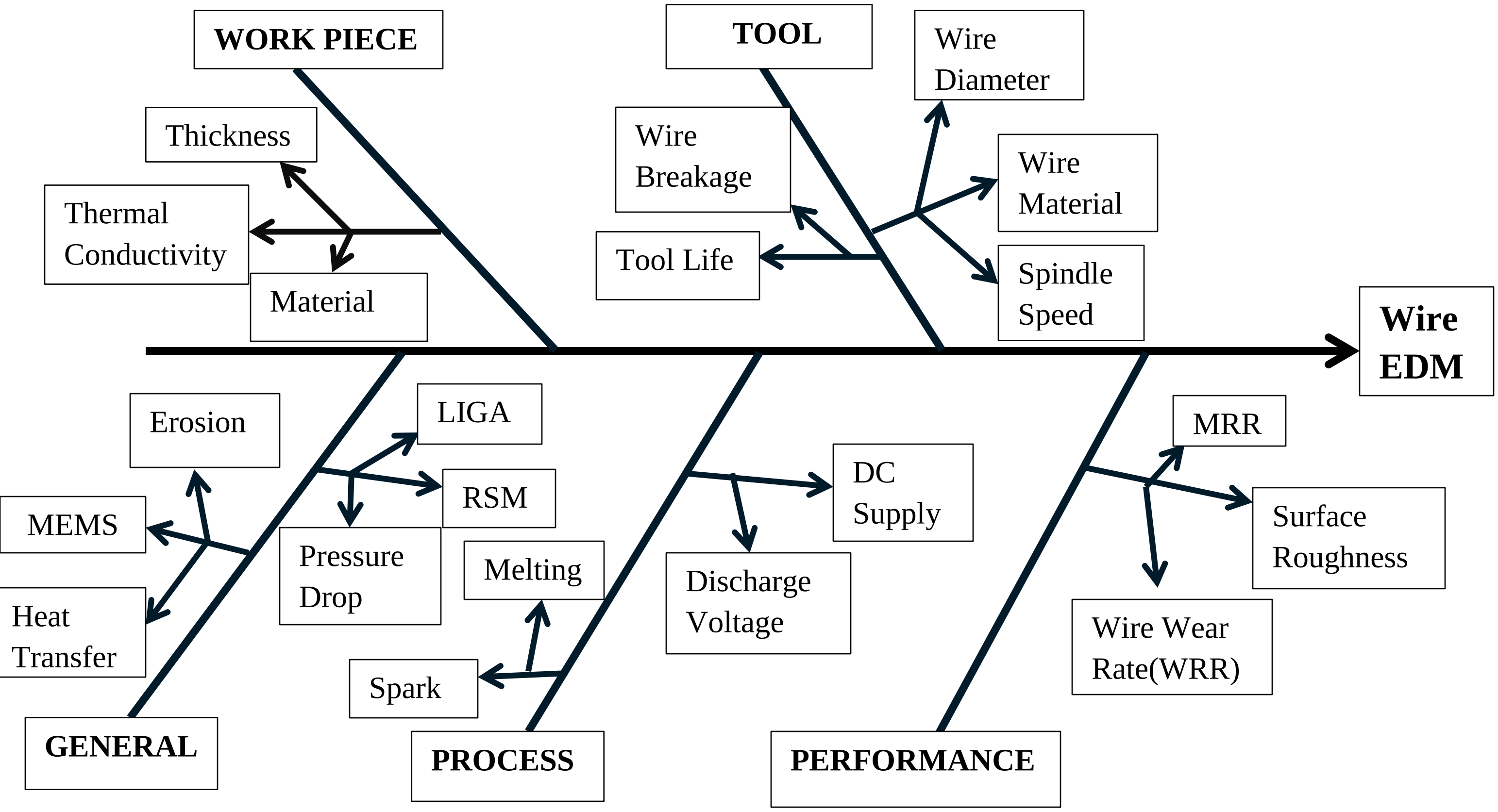


Fig.4.1 Cause and Effect Diagram For Wire EDM

The characteristic equations of system i.e relation of process parameters and response parameters discussed earlier in mathematical modeling chapter which gives the direct relation how process parameters pulse on time(Ton),servo voltage(V) and Wire feed rate(WF) effects Material removal rate (MRR),surface roughness (Ra) and wire wear rate (WRR).These major attributes are further divided into sub system and sub sub system so that attributes can be divided and information about attributes are identified in very detailed manner. Therefore optimum selection of parameter setting in wire edm effects the whole system's performance and selection of optimum parameter settings only dependent on attributes. The attributes are selected basically with the help of process conditions,performance,user experience, experts suggestions and relative importance of parameters in a broad area of wire edm.Fish Bone Diagram Used to identify different attributes of wire edm parameter setting based on requirement and user attention as shown in fig 4.1.Here ,105 attributes of wire edm re identified. Wire edm attributes are found out based on its broad area as General, Process, Performance, Work Piece and Tool based attributes given as below.

- General Attributes.
- Process Based Attributes
- Performance Based Attributes
- Work Piece Based Attributes
- Tool Based Attributes

Table 4.1 List of broad categories attributes of parameters of Wire EDM

General Attributes	
1.Removal Mechanism	2.Micro Channels
3.MEMS	4.Hydraulic Diameter
5.Heat Transfer	6.Water Jet Machining
7.Lithography	8.Streo Lithography
9.LIGA	10.Micro Device Cooling
11.Thermal Resistance	12.R.S.M
13.Electronic Cooling	14.Rapid Prototyping
15.Scaning Electron Machining	16.Profilometer
17.Taguchi Method	18.Wire EDM
19.Impulse Generator	20.Work Piece Geometry
21.Presure Drop	22.Bio Medical Engineering
23.ion Beam Machining	24.Laser Machining
Process Based	
25.Spark	26.Melting
27.vapourization	28.Shock Waves
29.Capacitance	30.Tool Wear

31.Tool Electrode	32.Non Conventional Machining
33.Dielectric Fluids	34.DC supply
35.Discharge Voltage	36.Minimum machanible Size
37.Pulse Generator	38.Pulse Wave form
39.Polarity	40.Eletrode Gap
41.Dieletric Flushing	42.Orthogonal Array
43.Grey Relation Analysis	44.WEDM Machine
45.Electronica WEDM	46.Mitutoyo SJ400
47.Dimensions Of work piece	
Performance Based	
48.MRR	49.Surface Finish
50.Wire Wear Rate	51.Flushing Pressure
52.Pulse On time (Ton)	53.Pulse Off Time (Toff)
54.Wire feed rate	55.Voltage
56.Sevo Voltage	57.Peak Current
58.Table feed Rate	59.Wire tension
60.Dielectric Medium	61.Gap Voltage
62.Air Mist Pressure	63.Spark Generator
64.Tool gap	65.Duty Factor
66.Tool Life	67.Wire Breakage
68.Pulse Duration	69.Pulse Interval
70. Non linear vibration	71.Thermal stress
72.Micro structures	73.Surface profile
74.Fractures	75.Micro cracks
76.Tolrances	77.Cutting Tempreture
Work Piece Based	
78. Material	79.Roughness

80.Conductive	81.Toughness
82. Chemical Composition	83.Machining Quality
84.Hardness of work piece	85.Thermal conductivity
86.Al(6061)	87.Material thickness
88.Si Propertion	89.Experimental conditions
90.Lateral Gap	91.Composites
92.Brittle Material	93. Ceramic matrix composites
Tool Based	
94.Tool Material	95.Static Force
96.Tool Vibration Frequency	97.Depth Of Cut
98.Cutting Force	99.Tool Life
100.Spindle Speed	101.Toughness of tool
102.Speed Ratio	103.Penetation Depth
104.Wire Diameter	105.Wire Breakage

4.2.1 Quantification and Identification of Attributes

The Wire EDM machine can expressed in detailed manners with identified attributes e.g. Pulse on time (Ton) 105-125μ-sec, Servo voltage(V) 30-90V, Wire feed rate(WF) 6-8mm/min etc. These attributes can be expressed in mathematical values as 0,1,2,3 …….n. But all the attributes are not quantitative e.g. Surface Roughness, Accuracy etc. These can't be identified as numeric value so these can be expressed as alphabetically like A,B,C,D……..etc. These attributes scales the wire edm machine in scale of 1-5 with these attributes. Some attributes doesn’t have any mathematical information so quantification of these attributes can done on the basis of simulation, analysis and modeling.

Usefulness To User

The identification of attributes will helps the users to get to know about how process parameters Pulse on Time (Ton),Servo Voltage(V),Wire Feed Rate(WF) etc effects the Response parameters

Material removal rate(MRR),Surface Roughness(Ra) and Wire Feed Rate(WRR).User can use a particular set of parameter setting for particular response or application in machining.

Usefulness To Maintenance Personnel

Maintaince of Machine gets very easy using MADM TOPSIS approach. User using the database formed in approach to know about the break down rate. And user forms the maintaince schedule according these break down rate to reduce break downs, save the time and money.With the Data base user can know the working conditions of machine so that proper cooling or lubrication can provide to work piece.

Usefulness To Designer

Designer can use the Fish Bone Diagram to know about the interrelation of process and response parameters. How the individual parameter affects the performance of machining. Designer can observe the whole working and processing condition before designing the parameter setting for given application.

After identification next step is coding of these attributes based on the information collected about the attributes. This coding can be numeric value or alphabetical. As in identification we have two kind of attributes quantative(deterministic) and qualitative(fuzzy) .Quantitative attributes can be donated with numeric values and alphabets but the quantification of certain attributes are not possible because of absence of information about that attribute from user and manufacturer. For effective, efficient and reliable use of pertinent attributes for identification,comparison,coding,evaluation,optimization and ranking parameter settings of wire edm coding scheme is established . 0-5 scale is given to the attributes for coding.

Table 4.2 N-Digit Coding Scheme

Catagories	**Code**
Very Highly Obeserved	5
Highly Observed	4
Average Observed	3
Less Observed	2
Very Less Observed	1
Absent	0

4.2.2 Coding of attributes:

First Column of table represents the serial no. corresponds to 105 attributes, Second column identifies the name of attribute, third column shows information available regarding that attribute and fourth column defines code in the form of alphanumeric form.

Table 4.3 Coding scheme of attributes

S/No.	Attributes	Information	Code
1.	Removal Mechanism	Erosion	E
2.	Micro channels		5
3.	MEMS		4
4.	Hydralic Diameter	Dh	5
5.	Heat Transfer		0
6.	Water jet Maching		0
7.	Lithography		0
8.	Streo Lithography		0
9.	LIGA		0
10.	Micro Devices Cooling		0
11.	Thermal Resistance		0
12.	RSM	Modelling	M

13.	Electronic Cooling		2
14.	Rapid prototyping		0
15.	Scaning Electron Microscopy		0
16.	Profilometer	Tip Dia 0.3mm	3
17.	Taguchi Method		0
18.	Wire EDM		5
19.	Impulse generator		0
20.	Workpiece Geometry	Reactangular	R
21.	Pressure Drop	Low	L
22.	Bio Medical Engineering		0
23	Ion beam machining		0
24.	Laser machining		0
25.	Spark		5
26.	Melting		0
27.	Vapourization		2
28.	Shock Waves		0
29.	Capacitance		0
30.	Tool Wear		0
31.	Tool Electrode(Wire)	Brass	B
32.	Non Conventional machining		0
33.	Dieltric Fluids	Distilled Water	D
34.	DC supply	Pulsed	P
35.	Discharge Voltage		3
36.	Minimum machineable size		0
37.	Pulse generator		0
38.	Pulse wave Form		0
39.	Polarity		0
40.	Electrode Gap		0
41.	Dielectric Flushing		0

42.	Orthogonal Array		0
43.	Grey Realtion Analysis		0
44.	WEDM machine		3
45.	Electronica Machine		4
46.	Mitutoyo SJ400		2
47.	Dimensions of Work Piece	30*30mm	5
48.	MRR	High	H
49.	Surface Finish	Low	L
50.	Wire wear Rate	Low	L
51.	Flushing Pressure	2100Pa	2
52.	Pulse On time	105-125µ-sec	5
53.	Pulse off time	40µ-sec	3
54.	Wire feed Rate	6-9 mm/min	5
55.	Voltage		0
56.	Servo Voltage	30-90 V	5
57.	Peak Current	200A	1
58.	Table Feed Rate		2
59.	Wire Tension	7 N	1
60.	Diectric Medium		0
61.	Gap Voltage		0
62.	Air mist Pressure		0
63.	Spark generator		0
64.	Tool Gap		0
65.	Duty Factor		0
66.	Tool Life	High	H
67.	Wire Breakage		0
68.	Pulse Duration		0
69.	Pulse Interval		0
70.	Non Linear vibration		0

71.	Thermal stress		0
72.	Micro Structure		0
73.	Surface profile	Rectangular	R
74.	Work Piece Material		0
75.	Roughness	2-5micrometer	5
76.	Conductive		2
77.	Toughness		0
78.	Chemical composition		3
79.	Machining Quality		0
80.	Hardness Of work Piece		0
81.	Fracture		0
82.	Micro Cracks		0
83.	Thermal Conductivity		0
84.	Al(6061)		4
85.	Material thickness	5mm	4
86.	Si Proportion		2
87.	Experimental Conditions		5
88.	Lateral gap		0
89.	Composites		0
90.	Brittle material		0
91.	Ceramic Matrix Composites		0
92.	Tolerance		0
93.	Cutting Tempreture		0
94.	Tool material	Diffused Brass	D
95.	Static Force		0
96.	Tool Vibration frequency		0
97.	Depth of Cut		5
98.	Cutting Forces		0
99.	Tool Life		3

100.	Spindle Speed		0
101.	Penetration Depth		0
102.	Toughness of Tool		0
103.	Speed ratio		0
104.	Wire Diameter	0.3mm	5
105.	Wire Breakage	Low	4

Coding Of 105 attributes shows that information about the attributes is significantly differ provided by manufacturer to user and more elaboration is much needed. We have seen from the table that most of information about the attribute is coded as 0 which means that information about that attribute is not available. But information about all attributes should have to be given so that data base should be more exhaustive.

Table 4.4 Characterization of 105 attributes of Wire EDM.

General	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Process	25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47
Performance	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 76 77
Work Piece Based	78 79 80 81 82 83 84 85 87 88 89 90 91 92 93
Tool Based	94 95 96 97 98 99 100 101 102 103 104 105

Table 4.5 Coding scheme of attributes

General	E 5 4 5 0 0 0 0 0 0 0 M 2 0 0 3 0 5 R L 0 0 0 0
Process	0 5 0 2 0 0 0 B 0 D P 3 0 0 0 0 0 0 0 0 3 4 2 5
Performance	H L L 2 5 3 5 0 5 1 2 1 0 0 0 0 0 0 H 0 0 0 0 0 0 R 0 5 2 0
Work Piece Based	3 0 0 0 0 0 4 4 2 5 0 0 0 0 0 0
Tool Based	D 0 0 5 0 3 0 0 0 0 5 4

4.3- The 3 Stage Optimum Selection Procedure

4.3.1 Stage-1 Elimination Search

From the database formed of attributes all of the attributes would not be important during selection procedure of optimum parameter setting of wire edm. There will very limited attributes which would have direct influence on parameter settings and response parameters. So these limited parametrs are selected as pertinent attributes and the threshold values assigned to these attributes are based on the information collected about these attributes from group of experts and manufacturer/user.So this selecion procedure have prime focus on these pertinent attributes among all the attributes.On the basis of threshold values of pertinent attributes parameter settings are short listed. This would be achieved by scaning of exhaustive database for pertinent attributes.To facilitates this procedure all the parameter settings are identfied by identification system.

4.3.2 Stage-2 Evaluation Procedure

Decision Matrix(D)

The satisfying solutions of mini database are generated i.e alternatives having satisfying level of applications. Main observation is now to finding out the optimum or best among these acceptable satisfying solutions. So selection procedure needs to rank in order of merit of these solutions.

Next Step is to convert all the information obtained in database about these satisfying solutions into a matrix form. So the identification of satisfying solution of corresponding pertinent attributes and represented it in a matrix form is termed as Decision Matrix (D). Rows of This matrix show the different Parameter Settings of Pulse On time (Ton), Servo Voltage (V), Wire Feed Rate (WF) and Columns of matrix represents pertinent attributes or characterization alternatives. Therefore we got a dij element of decision matrix Which shows value of jth attribute in the row for the ith parameter setting. Thus if 'm' is parameter setting for wire edm and 'n' is pertinent attribute then the decision matrix would be m×n matrix.

$$D = \left[d_{ij}\right]_{m\times n} \tag{4.1}$$

i=1,2,3………m j =1,2,3………n

'dij' Decision Matrix Elements

'm' represents the no. of attributes based alternatives of parameter settings in row.

'n' represents the no. of attributes selected for characterization of pertinent attributes.

Normalized Specification

The next step is to construct Normalized Matrix from Decision Matrix D.Main function of Normalized matrix is to bring all pertinent attributes in same rane of 0 or 1 and provides dimensionless megnitude data.The Normalized matrix have the megnitude of different parameter settings of wire edm in range of 0 or 1.

N can be calculated as

$$N = \left[\frac{d_{ij}}{\left(\sum_{i=1}^{m} d_{ij}^{\,2}\right)^{\frac{1}{2}}} \right]_{m\times n} \qquad (4.2)$$

Where dij is an element of Decision Matrix,D.

Relative Importance Matrix

While considering pertinent attributes for optimum parameter setting for wire edm with high MRR, Low Surface Roughness (Ra) and Wire Wear Rate (WRR) for this we have to identify the relative importance of each and every pertinent attribute with respect to application and need. For every process the working design constraints would be there with different level of importance of each pertinent attribute over the other pertinent attibutes.The allotment of relative importance of each pertinent attribute over the others would be given by specialists and experts from various fields based on different standards. In our case as shown in fish bone diagram three performance parameters are given Material Removal Rate(MRR),Surface Roughness(Ra) and Wire Wear Rate(WRR).Based upon Micro channel Performance the main performance parameter is Surface Roughness in microfluidic flow and after performance the main parameter considered for micro channel fabrication is cost. Cost of micro channel fabrication is mainly depends upon the Material Removal Rate of machine and then on the Wire consumed in machining. So Relative importance allots to pertinent attributes would be purely based upon the performance of Micro channels in microfuids. Higher the effect of pertinent attribute on performance of micro channel more importance would be given to that attribute.Relative importance assigned to the pertinent attributes as 1.Surface Roughness, 2 Material Removal Rate(MRR), 3 Wire Wear Rate(WRR).Which means 1 For the most important, 2 For second important,3 For Least Important.

In mathematical form Relative Importance Matrix(A)

i = j = 1 Represents Surface Roughness

i = j = 2 Represents Material Removal Rate

i = j = 3 Represents Wire Wear Rate

a_{ij} represents relative importance of 'i' over 'j' therefore

$a_{1,1}$ = 1/1, $a_{1,2}$ = 1/2, $a_{1,3}$ = 1/3

$a_{2,1}$ = 2/1, $a_{2,2}$ = 2/2, $a_{2,3}$ = 2/3

$a_{3,1}$ = 3/1, $a_{3,2}$ = 3/2, $a_{3,3}$ = 3/3

These Relative Importance Values of pertinent attributes may vary from user to user with different needs.

This Relative Importance Matrix(A) is further modified into Relative Weighted Matrix which gives the relative weights of all pertinent attribute and having unity commulative sum of weights.

Eigen vector method used to calculate weight vector **w** from problem associated of eigen value with the matrix Relative Importance Matrix A,i.e

$$Ax = \lambda x \tag{4.3}$$

λ is Eigen Value of A and x.

For λi There are 'n' Eigen Values of n×nA matrix where i = 1,2…….n, and corresponds to λi

For xi There are 'n' Eigen Vectors where i = 1,2………n,

So w is now calculate in following manners;

1. x_{max} Eigen vector would be corresponds to largest eigen value λ_{max}, so that elements of x_{max} are either positive or negative.

2. Sum of x_{max} elements can be find out as

$$\alpha = \sum_{i=0}^{n} (x)\text{max} \tag{4.4}$$

3. Weight Vector w as

$$\text{w} = (\text{xmax})/\alpha \text{ such that } \sum_{i=1}^{n} w_{\text{i}} = 1 \tag{4.5}$$

Weighted Normalized Specification

Normalized specification have to be applied with weights obtained from relative importance matrix since all the attributes have different importance for the selection of optimum parameter setting of wire edm for high MRR and low Surface Roughness (Ra) and Wire Wear Rate

(WRR).Weighted Normalized Matrix(V) consists of normalized specification and relative weights. So with this we can get the comparable values of attributes as.

$$Q = [q_{ij}]_{m\times n}\ ,\ \mathrm{n} = [n_{ij}]_{m\times n}\ ,\ \mathrm{w} = [w_{ij}]_{1\times n} \quad (4.6)$$

$$[q_{ij}]_{m\times n} = [n_{ij}]_{m\times n} \times [w_{ij}]_{1\times n} \quad (4.7)$$

Where Q is weighted normalized specification

Where n is normalized specification

Where w is relative weights

4.3.3 Ranking And Selection Procedure

The ranking of parameter setting can be done mathematically using TOPSIS method or Graphically (Line Graph and Spider Diagram Method).

TOPSIS Method

Next Step is to obtain Negative and Positive benchmark parameter settings which are obtained from the weighted normalized matrix where these benchmarked parameter settings are hypothetical parameter settings. The Main Concept of TOPSIS the selected options(optimum) must have the minimum distance from +ve benchmark parameter setting (best possible parameter setting) and maximum distance from -ve benchmark parameter setting (worst possible parameter setting).Results ensures that top ranked is closest to +ve benchmark parameter setting and farthest from -ve parameter setting.

Therfore the sepration measures from +ve and -ve benchmark parameter setting can be calculated by S^{+} and S^{-}.

Positive Benchmark Solutions S^{+}

$$S^{*} = \{q_1{}^{+}, q_2{}^{+}, q_3{}^{+}, \dots, q_n{}^{+}\} = \{(max\, q_{ij} |\ j\ L), (min\, q_{ij} |\ j\ S)\} \quad (4.8)$$

Negative Benchmark Solutions S^{-}

$$S^{-} = \{q_1{}^{-}, q_2{}^{-}, q_3{}^{-}, \dots, q_n{}^{-}\} = \{(min\, q_{ij} |\ j\ L), (max\, q_{ij} |\ j\ S)\} \quad (4.9)$$

Where 'L' is used for Positive benchmark solutions which are larger best for optimum parameter settings.

Where 'S' is used for Negative benchmark solutions which are smaller the best for optimum parameter setting.

Separation From +ve benchmark can be measure

$$S_i^{\ *} = \left[\sum_{i=1}^{n}(q_{ij} - q_j^{\ +})^2\right]^{\frac{1}{2}} \tag{4.10}$$

Separation From -ve benchmark can be measure

$$S_i^{\ -} = \left[\sum_{i=1}^{n}(q_{ij} - q_j^{\ -})^2\right]^{\frac{1}{2}} \tag{4.11}$$

Next Step to find out the relative closeness to ideal or optimum solution with reference of Positive benchmark solution is Termed as Goodness Index (C_i^*)

$$C_i^* = \frac{S_i^-}{(S_i^* + S_i^-)} \tag{4.12}$$

$$0 \le C_i^* \le 1$$

Ranking and selection is purely based upon the C_i^*,parameter setting having higher the value C_i^* higher would be its rank. Parameter setting are placed in the increasing order of C_i^*.There fore parameter setting having largest C_i^* value would be preferred.

4.4 Illustrative Example

Multiple Attribute Decision Making (MADM) approach is used to solve the problem for optimum selection, evaluation and ranking of parameter setting of Wire EDM having Higher Material Removal Rate, Lower Surface Roughness (Ra) and Wire Wear Rate (WRR).MADM methodology is used first time for selection of optimum parameter settings among 20 parameters settings having different values of Pulse On Time (Ton), Servo Voltage (V) and Wire Feed Rate (WF) for each parameter setting. As Surface Roughness (Ra) and Wire Wear Rate (WRR) are type of attributes whose magnitude is lower preferable so reciprocal of Surface Roughness (Ra) is taken. So the optimum selection and ranking of parameter is taken as follow.

Step-1.Decision Matrix (D) Formation:-

As Per the Database Generated in quantification part,we can find out the manageable no.s of parameter settings and pertinent attributes from "elimination Search" as shown in Table No. 6.In Decision matrix in Rows we have 20 different parameter settings of Pulse On Time (Ton), Servo Voltage (V) and Wire Feed Rate (WF) and in Columns we have first columns shows the Surface Roughness (Ra) values for different parameter settings ,second column shows the Material Removal Rate (MRR) for different parameter settings and Thrid Column shows the Wire Wear Rate (WRR) for different parameter settings.

Table No 4.6 Data for Different Parameter Settings of Wire Edm

Experimental Parameter Settings	Ra	MRR	WRR
1. Ton-115 ,V-60 ,WF-7	4.09	4.81	0.05
2. Ton-115 ,V-60 ,WF-7	4.07	3.97	0.07
3. Ton-125 ,V-30 ,WF-6	3.75	3.33	0.065
4. Ton-115 ,V-30 ,WF-7	4.26	5.04	0.047
5. Ton-115 ,V-90 ,WF-7	3.23	2.59	0.08
6. Ton-115 ,V-60 ,WF-6	3.97	4.55	0.075
7. Ton-125 ,V-60 ,WF-7	4.07	4.01	0.055
8. Ton-125 ,V-90 ,WF-8	4.14	3.03	0.077
9. Ton-115 ,V-60 ,WF-8	2.69	5.08	0.035
10.Ton-115 ,V-60 ,WF-7	4.07	4.44	0.055

11.Ton-115 ,V-60 ,WF-7	4.01	4.5	0.062
12.Ton-105 ,V-30 ,WF-6	2.56	2.80	0.097
13.Ton-105 ,V-30 ,WF-8	2.66	1.90	0.062
14.Ton-115 ,V-60 ,WF-7	4.09	4.83	0.057
15.Ton-105 ,V-90 ,WF-8	2.41	1.30	0.092
16.Ton-125 ,V-90 ,WF-6	3.92	3.30	0.069
17.Ton-105 ,V-60 ,WF-7	2.75	2.39	0.085
18.Ton-125 ,V-30 ,WF-8	4.46	2.65	0.081
19.Ton-105 ,V-90 ,WF-6	2.14	2.01	0.09
20.Ton-115 ,V-60 ,WF-7	4.08	3.65	0.052

$$D = \begin{bmatrix} 0.244 & 4.81 & 20 \\ 0.245 & 3.97 & 14.28 \\ 0.266 & 3.33 & 15.38 \\ 0.234 & 5.04 & 21.27 \\ 0.309 & 2.59 & 12.5 \\ 0.251 & 4.55 & 13.53 \\ 0.249 & 4.01 & 18.18 \\ 0.241 & 3.03 & 12.98 \\ 0.271 & 5.08 & 28.57 \\ 0.251 & 4.44 & 18.18 \\ 0.250 & 4.5 & 16.12 \\ 0.390 & 2.80 & 10.30 \\ 0.375 & 1.90 & 16.12 \\ 0.240 & 4.80 & 17.54 \\ 0.414 & 1.30 & 10.86 \\ 0.255 & 3.30 & 14.49 \\ 0.3630 & 2.39 & 11.76 \\ 0.224 & 2.65 & 12.34 \\ 0.467 & 2.01 & 11.11 \\ 0.246 & 3.65 & 19.23 \end{bmatrix} \tag{4.13}$$

Step-2. Construction Of Normalized Matrix(N)

Normalized Matrix (N) is used to bring all pertinent attributes magnitude into a particular range of 0 to 1. Normalized Matrix can be calculated using

$$N = \left[\frac{d_{ij}}{\left(\sum_{i=1}^{m} {d_{ij}}^2\right)^{\frac{1}{2}}}\right]_{m\times n}$$

Where "d_{ij}" is Decision Mtrix elements

i = 1,2,3………m

j = 1,2,3……….n

$$
N = \begin{bmatrix}
0.1834 & 0.2920 & 0.2741 \\
0.1842 & 0.2410 & 0.1957 \\
0.1999 & 0.2022 & 0.2108 \\
0.1759 & 0.3060 & 0.2915 \\
0.2323 & 0.1572 & 0.1713 \\
0.1887 & 0.2762 & 0.1854 \\
0.1872 & 0.2435 & 0.2492 \\
0.1812 & 0.1840 & 0.1779 \\
0.2037 & 0.3084 & 0.3916 \\
0.1887 & 0.2696 & 0.2492 \\
0.1879 & 0.2732 & 0.2209 \\
0.2932 & 0.1700 & 0.1412 \\
0.2819 & 0.1154 & 0.2209 \\
0.1804 & 0.2932 & 0.2404 \\
0.3112 & 0.0789 & 0.1488 \\
0.1917 & 0.2004 & 0.1986 \\
0.2729 & 0.1451 & 0.1612 \\
0.1684 & 0.1609 & 0.1691 \\
0.3510 & 0.1220 & 0.1523 \\
0.1849 & 0.2216 & 0.2636
\end{bmatrix} \tag{4.14}
$$

Step-3. Construction Of Relative Importance Matrix (A)

In every process while working under certain conditions each attribute have different level of importance over the other attributes.These relative importance levels of pertinent attribute in relative to other attributes are decided by experts and specialists of different fields using different standards.For example in this case we have three pertinent attributes Surface Roughness (Ra), Material Removal Rate (MRR) and Wire Wear Rate (WRR).Importance of any attribute is depends upon its relative impotance value higher the value higher will be its impotance over the other attributes. So based on the performance parameters we assigns the realtive importance as 1 Surface Roughness (Ra) 2 Material Removal Rate ,3 Wire Wear Rate (WRR). Where 1 stands for most important,2 for second important and 3 for least important.

i = j = 1 represents Surface Roughness

i = j = 2 represents Material Removal Rate

i = j =3 represents Wire Wear Rate

$$A = \begin{bmatrix} a_{1,1} = 1/1 & a_{1,2} = 1/2 & a_{1,3} = 1/3 \\ a_{2,1} = 2/1 & a_{2,2} = 2/2 & a_{2,3} = 2/3 \\ a_{3,1} = 3/1 & a_{3,2} = 3/2 & a_{3,3} = 3/3 \end{bmatrix} \quad (4.15)$$

$$A = \begin{bmatrix} 1.00 & 0.50 & 0.30 \\ 2.00 & 1.00 & 0.60 \\ 3.00 & 1.50 & 1.00 \end{bmatrix} \quad (4.16)$$

Step-4. Finding out the Maximum Eigen Value of relative importance matrix (A):

Weight Vector Can be calculated using the eigen value formulated

$$(A - \lambda_{max} I)W^T = 0$$

Where 'I' is identity Matrix and W^T is weight vector

$$\begin{bmatrix} 1-\lambda & 0.50 & 0.30 \\ 2 & 1-\lambda & 0.60 \\ 3 & 1.50 & 1-\lambda \end{bmatrix} \quad (4.17)$$

(A-λI)=0

Eigen value(λ) =[2.9318,-0.0000,0.0682]

λmax= 2.9318

Step-4.Calculating Weights for each attribute using eigen vector associated with maximum Eigen value.

$$(A - \lambda_{max} I)W^T = 0$$

$$(A-\lambda_{max} I)W^T = \begin{bmatrix} -2 & 0.50 & 0.30 \\ 2 & -2 & 0.60 \\ 3 & 1.50 & -2 \end{bmatrix} \begin{bmatrix} W_1 \\ W_2 \\ W_3 \end{bmatrix} = 0 \quad (4.18)$$

Relative weight vector(W) - W_1 = 0.1638

W_2 = 0.3275

W_3 = 0.5087

Step-5. Calculating Weighted Normalized Matrix (Q)

Now Relative Importance of attributes and their normalized values are incorporated to form a single parameter for optimum parameter setting.

$$[q_{ij}]_{m\times n} = [n_{ij}]_{m\times n} \times [w_{ij}]_{1\times n} \quad (4.19)$$

$$Q = \begin{bmatrix} 0.1834 & 0.2920 & 0.2741 \\ 0.1842 & 0.2410 & 0.1957 \\ 0.1999 & 0.2022 & 0.2108 \\ 0.1759 & 0.3060 & 0.2915 \\ 0.2323 & 0.1572 & 0.1713 \\ 0.1887 & 0.2762 & 0.1854 \\ 0.1872 & 0.2435 & 0.2492 \\ 0.1812 & 0.1840 & 0.1779 \\ 0.2037 & 0.3084 & 0.3916 \\ 0.1887 & 0.2696 & 0.2492 \\ 0.1879 & 0.2732 & 0.2209 \\ 0.2932 & 0.1700 & 0.1412 \\ 0.2819 & 0.1154 & 0.2209 \\ 0.1804 & 0.2932 & 0.2404 \\ 0.3112 & 0.0789 & 0.1488 \\ 0.1917 & 0.2004 & 0.1986 \\ 0.2729 & 0.1451 & 0.1612 \\ 0.1684 & 0.1609 & 0.1691 \\ 0.3510 & 0.1220 & 0.1523 \\ 0.1849 & 0.2216 & 0.2636 \end{bmatrix} \times \begin{bmatrix} 0.1638 \\ 0.3275 \\ 0.5087 \end{bmatrix} \quad (4.20)$$

$$Q = \begin{bmatrix} 0.0300 & 0.0957 & 0.1394 \\ 0.0302 & 0.0790 & 0.0996 \\ 0.0327 & 0.0662 & 0.1072 \\ 0.0288 & 0.1002 & 0.1483 \\ 0.0380 & 0.0515 & 0.0872 \\ 0.0309 & 0.0905 & 0.0943 \\ 0.0307 & 0.0797 & 0.1298 \\ 0.0297 & 0.0603 & 0.0905 \\ 0.0334 & 0.1010 & 0.1992 \\ 0.0309 & 0.0883 & 0.1268 \\ 0.0308 & 0.0895 & 0.1124 \\ 0.0480 & 0.0557 & 0.0718 \\ 0.0462 & 0.0378 & 0.1124 \\ 0.0295 & 0.0961 & 0.1223 \\ 0.0510 & 0.0259 & 0.0757 \\ 0.0314 & 0.0656 & 0.1010 \\ 0.0447 & 0.0475 & 0.0820 \\ 0.0276 & 0.0527 & 0.0860 \\ 0.0575 & 0.0400 & 0.0775 \\ 0.0303 & 0.0726 & 0.1341 \end{bmatrix} \quad (4.21)$$

4.4.1 Topsis Method For Ranking-

Positive (+ve) benchmark and Negative (-ve) benchmark parameter settings of weighted normalized matrix can be calculated by taking largest and smallest values from all the columns with respect to all the pertinent attributes .

Positive Ideal Solution(S^+)

$$S^+ = \{q_1^+, q_2^+, q_3^+ \dots\dots\dots.. q_n^+\} = \{(max\ q_{ij}|jL), (min\ q_{ij}|jS)\}$$

$$S^+ = (0.0575, 0.1010, 0.1992) \quad (4.22)$$

Negative Ideal Solution(S^-)

$$S^- = \{q_1^-, q_2^-, q_3^- \dots\dots\dots.. q_n^-\} = \{(minq_{ij}|jL), (maxq_{ij}|jS)\}$$

$$S^- = (0.0272 , 0.0259, 0.0718) \quad (4.23)$$

Next Step is to calculate sepration value from positive benchmark parameter setting (S^*). Using formula given below.

$$S_i^* = \left[\sum_{i=1}^{n}(q_{ij} - q_j{}^+)^2\right]^{\frac{1}{2}}$$

S^*_1=0.0660, S^*_{11}=0.0915

S^*_2= 0.1056 S^*_{12}=0.1355

S^*_3= 0.1014 S^*_{13}=0.1080

S^*_4= 0.0584 S^*_{14}=0.0820

S^*_5= 0.1240 S^*_{15}=0.1447

S^*_6=0.1087 S^*_{16}=0.1076

S^*_7=0.0801 S^*_{17}=0.1295

S^*_8= 0.1194 S^*_{18}=0.1266

S^*_9= 0.0241 S^*_{19}=0.1362

S^*_{10}=0.0782 S^*_{20}=0.0761

Sepration from negative benchmark parameter setting (S^-).Negative Sepration Can be calculated as.

$$S_i^- = \left[\sum_{i=1}^{n}(q_{ij} - q_j{}^-)^2\right]^{\frac{1}{2}}$$

Negative Separation Measures(S^-) =

S^-_1 = 0.0972 S^-_{11} = 0.0755

S^-_2 = 0.0600 S^-_{12} = 0.0362

$S^-_3 = 0.0540$ $S^-_{13} = 0.462$

$S^-_4 = 0.1067$ $S^-_{14} = 0.0865$

$S^-_5 = 0.0317$ $S^-_{15} = 0.0237$

$S^-_6 = 0.0685$ $S^-_{16} = 0.0495$

$S^-_7 = 0.0770$ $S^-_{17} = 0.0294$

$S^-_8 = 0.0392$ $S^-_{18} = 0.0304$

$S^-_9 = 0.1480$ $S^-_{19} = 0.0336$

$S^-_{10} = 0.0832$ $S^-_{20} = 0.0779$

C^* is Relative closeness to positive ideal solution of feasible solutions is obtained as;

$$C_i^* = \frac{S_i^-}{(S_i^* + S_i^-)}$$

Relative Closeness To Ideal Solution (C*)=

$C^*_1=0.5957$ $C^*_{11}= 0.4521$

$C^*_2=0.3621$ $C^*_{12}=0.2106$

$C^*_3=0.3473$ $C^*_{13}=0.2996$

$C^*_4=0.6461$ $C^*_{14}=0.5134$

$C^*_5=0.2034$ $C^*_{15}=0.1408$

$C^*_6=0.3867$ $C^*_{16}=0.3151$

$C^*_7=0.4901$ $C^*_{17}=0.1852$

$C^*_8=0.2472$ $C^*_{18}=0.1935$

$C^*_9=0.8598$ $C^*_{19}=0.1977$

C^*_{10}=0.5156 C^*_{20}=0.5059

Ranking and selection is purely based upon the C_i^*,parameter setting having higher the value C_i^* higher would be its rank. Parameter setting are placed in the increasing order of C_i^*.There fore parameter setting having largest C_i^* value would be preferred.

Table 4.7 Ranking Of Parameter Settings

Sr.No.	Experiment Order	Parameter Settings	C^*_i value	Ranking
1.	9.	Ton-115 , V-60 , WF-8	0.8595	1st
2.	4.	Ton-115 , V-30 , WF-7	0.6461	2nd
3.	1.	Ton-115 , V-60 , WF-7	0.5957	3rd
4.	10.	Ton-115 , V-60 , WF-7	0.5156	4th
5.	14.	Ton-115 , V-60 , WF-7	0.5134	5th
6.	20.	Ton-115 , V-60 , WF-7	0.5059	6th
7.	7.	Ton-125 , V-60 , WF-7	0.4901	7th
8.	11.	Ton-115 , V-60 , WF-7	0.4521	8th
9.	6.	Ton-115 , V-60 , WF-6	0.3867	9th
10.	2.	Ton-115 , V-60 , WF-7	0.3621	10th
11.	3.	Ton-125 , V-30 , WF-6	0.3473	11th
12.	16.	Ton-125 , V-90 , WF-6	0.3151	12th
13.	13.	Ton-105 , V-30 , WF-8	0.2996	13th
14.	8.	Ton-125 , V-90 , WF-8	0.2472	14th
15.	12.	Ton-105 , V-30 , WF-6	0.2106	15th
16.	5.	Ton-115 , V-90 , WF-7	0.2034	16th
17.	19.	Ton-105 , V-90 , WF-6	0.1977	17th
18.	18.	Ton-125 , V-30 , WF-8	0.1935	18th
19.	17.	Ton-105 , V-60 , WF-7	0.1852	19th
20.	15.	Ton-105 , V-90 , WF-8	0.1408	20th

4.5 Discussion About Process

Evaluation, Ranking and Optimum Selection of parameter settings for Higher Material Removal Rate (MRR), Lower Surface roughness and wire wear ratio has been done using MADM TOPSIS approach. As we use process parameters Pulse on Time (Ton), Servo voltage and Wire Wear Ratio (WRR) so to choose best parameter setting for required response parameters is very difficult task. But Ranking of parameter settings using MADM TOPSIS selection of optimum parameter setting for required response parameters becomes very easy. As in case 20 different parameters settings having process parameters (Ton, V and WF) for required response parameters (MRR, Ra and WRR) is study. Decision matrix is formed having response parameters (MRR, Ra and WRR) values taken for these 20 parameters. After the process contains different steps as Normalization, Relative importance weight matrix, Normalized weight matrix and TOPSIS gives the ranking of these 20 process parameters settings contains response parameters values.

CHAPTER-5

Conclusion And Future Scope

5.1 Conclusion

In present study using Wire EDM micro channels are fabricated and optimization of process parameters of Wire EDM to get ideal results for anticipated responses.Variations of three process parameters {Pulse on Time (Ton),Servo Voltage (V) and Wire Feed Rate} in a specific range to get best results.Work piece used was Aluminium (6061). Design of Experiment has been done by Response Surface Methodology in MINITAB 17.0 software. MADM-TOPSIS approach is used for the parameter settings optimization in this study. Some implications came out in study are discussed as:-

- First of all Mathematical Modelling has been done by Response Surface Methodology in MINITAB 17.0 and three mathematical equations are created which relates process and response parameters.Wire EDM behaviour can be evaluated by these three mathematical equations.
- Analysis of Variance (ANOVA) presented in this study.These consists of Three tables one for material removal rate (MRR) second table is for surface roughness and third equation is used for Wire Wear Ratio (WRR).Desired responses (MRR,Ra and WRR) data tables indicates the insignificance and significance of various parameters (Ton,SV and WF) are found susbtantial.This result is calculated from ANOVA tables at 95% confidence level.It can be seen from tables that Ton is most significant for MRR and Servo voltage is dominant in case of Ra.
- Contour plots and surface plots are formed in MINITAB 17.0 software using response surface methodology(RSM).It represents the 3-D graphical relation of input and response parameters.These plots gives the change in desired responses with the variations of input parameters in a specific range.MRR is maximum when Ton is increasing and servo voltage is maximum. As the Ton is increasing time for energy transfer from wire electrode to work piece increases.Thats why Material removal rate (MRR) is increases concurrently and MRR is minimized as Ton value is decreased.

- Main effects are also generated with MINITAB 17.0 using Response Surface Methodology with different levels of process parameters. It can be observed that these plots how response are varied as changes the process parameters at different levels.MRR,Ra and WRR values are obtained with different levels of process parameters.
- For the three response parameters MRR, Ra and WRR residual plots are plotted.Authencity of Regression equation is checked using graphs.In study residual follows approximate symmetric nature of histograms and stright line in normal probability plot which specifies that residuals are normally distributed.
- Wire EDM process parameter settings optimization is done by MADM-TOPSIS approach using MATLAB software.MADM-TOPSIS approach used for evaluation,ranking and optimum selection of process parameters in Wire EDM.
- MADM-TOPSIS gives us the ranking of 20 process parameters setting for desired response parameters of high MRR, Low surface roughness (Ra) and wire wear ratio (WRR) by giving a C^* values of these parameters setting.Higher the value given to the parameter setting higher would be its rank.
- The best values of response parameters we got from this ranking procedure,Material Removal Rate (MRR) 5.0898 mm^3/min, Surface Roughness (Ra) 2.69 μm and Wire Wear Ratio (WRR) 0.035 g/m with the corresponding process parameter setting of Pulse on Time (Ton) 115 μ sec, Servo Voltage (V) 60 volts and Wire Feed Rate (WF) 8 mm/min.
- It is optimum solution of experiment done on Wire Electric Discharge Machining (WEDM).

5.2 Future Scope

New Ideas are developed during current work.These can be describes as future work.

- Selection Procedure can become easy by using electronic database with the provision of storage and retrial of process attributes.
- Change in Response parameters with the geometry change in micro channels like fabrication of circular,triangular,reactangular or square micro channels for high heat transfer and lower pressure drop.

- Fabrication will be done with other process parameters(Pulse off Time (Toff),Peak Current,Voltage) for same response parameters.

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