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Optimization of wire EDM parameters of HOT DIE STEEL-13 by Taguchi method

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ABSTRACT: The demands of high surface finish and machining of complex shape geometries, conventional machining process are now being replaced by non-conventional machining processes. Wire EDM is one of the non-conventional machining processes. MRR and Surface roughness are of crucial importance in the field of machining processes. This paper summarizes Taguchi optimization technique to optimize the cutting parameters in Wire EDM for Hot Die Steel- 13. The aim of optimization is to attain the maximum MRR and minimum surface roughness. In this present study Hot Die Steel 13 is used as a work piece, brass wire of 0.25mm diameter used as a tool and distilled water is used as dielectric fluid. The experiment is conduct to Wire EDM set up of RATNAPARKHI ELECTRONICA INDIA PVT LIMITED with L9 orthogonal array has been used. The input parameters as pulse on time, pulse off time and feed rate selected for optimization. Dielectric fluid pressure, wire speed, wire tension and resistance taken as fixed parameters. The optimal value is obtained for surface roughness and MRR by using Taguchi optimization technique, optimized value is obtained separately. Additionally, the analysis of variance (ANOVA) is also useful to identify the most important factor.

1. OVERVIEW OF WIRE EDM

1.1 Introduction of Wire EDM:

Electrical Discharge Machining is commonly known as EDM is a non - traditional machining process used to remove material through a number of repetitive electrical discharges of short duration and high current density between the work piece and the tool. WEDM is an important and cost-effective method of machining extremely tough and brittle as well as electrically conductive materials. In EDM, since there is no physical contact between the work piece and the electrode tool, hence there are no mechanical forces existing between them. Any type of conductive material can be machined by using WEDM according of the hardness or toughness of the material [10, 11 and 12].

In Wire EDM is cut with a special metal wire electrode that is programmed by NC to travel along a programmed path. A Wire EDM generates spark discharges between a wire electrode and a work piece with de ionized water as the dielectric medium and erodes the work piece to production of complexive two- and three dimensional shapes according to a numerically controlled (NC) programmed path.

The Wire EDM uses electrode as a very thin wire 0.02 to 0.3 mm in diameter, an electrode and a work piece mounted on machine tool with electrical discharge machine like a band saw is moving either the work piece or wire. Erosion to the metal by using the phenomenon of spark discharge that is the very similar to the conventional EDM. The prominent feature of a moving wire is that a complicated shape cutout can be easily machined without using a forming electrode

.Wire cut EDM machine basically combination of a machine proper composed of a work piece contour movement control unit (NC unit), work piece mounting table and wire driven section using for accurately moving the wire at constant tension; a machining power supply which is applies electrical energy to the wire electrode and a system which is supplies a dielectric fluid with constant specific resistance [12, 13 and 14].

1.2 Principle of Wire EDM:

WEDM is based on removing material with a series of electrical discharges applied between the electrodes as a tool and work piece (the wire and the work piece). The only requirement of discharging in that both the tool and the work piece must be electrically conductive material. During the cutting process, dielectric fluid is injected into the gap between the electrode and work piece. On other hand, the wire is moving continuously at the constant speed. In order to generate a discharge, In WEDM machine power supply system applies a voltage between work piece and wire enduring the injection delay time. The ignition time is know as the time period between the application of the voltage and the ignition. In Wire EDM processes, four type of gap condition namely open, spark, arc, and short exist [17]

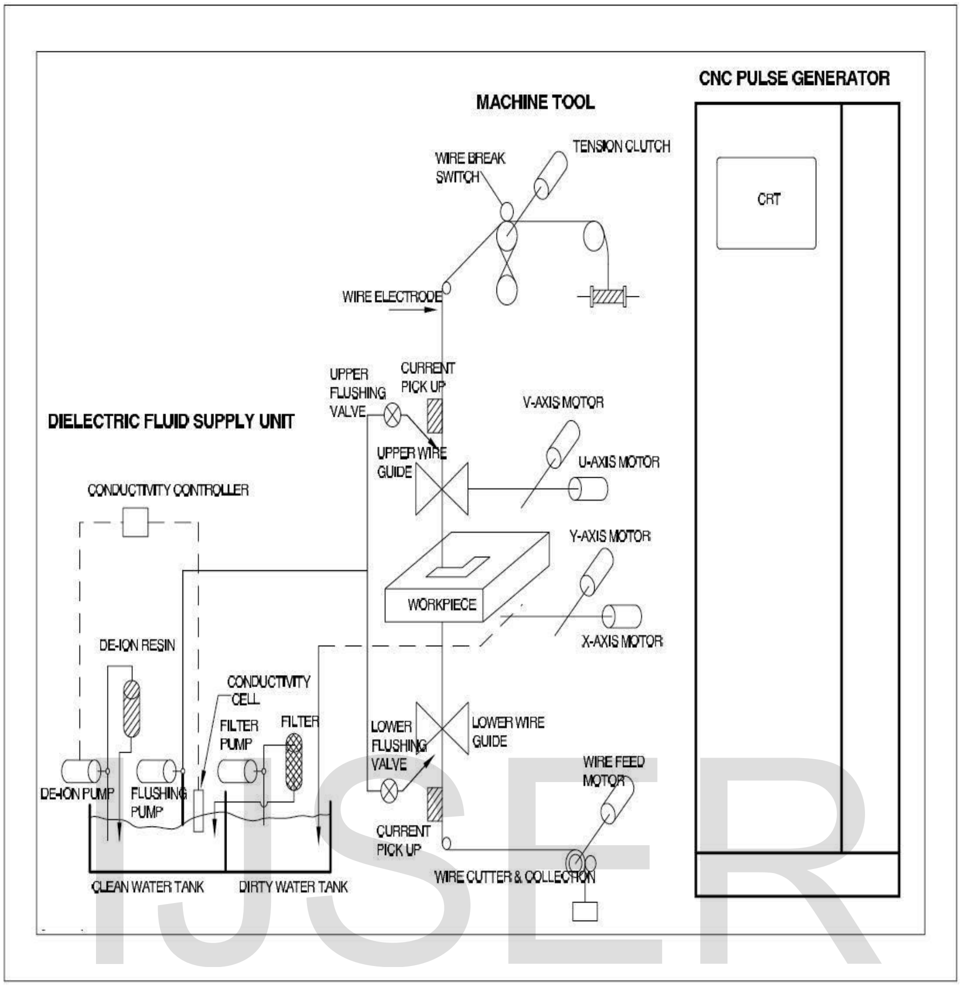

Fig 1.1 Block diagram of Wire EDM [18]

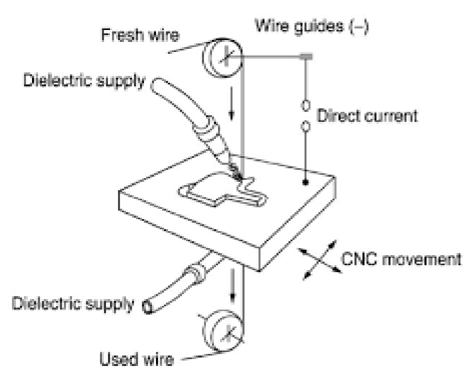

Fig 1.2 Basic principle of WEDM

The sparks or effective Discharge required by some delay time before the discharge current

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reaches its nominal value. The arc however require negligible or zero delay time and occur at the lower breakdown voltage due to partially deionize dielectric. When the distance between the electrode and work piece is far enough, then an open voltage pulse occurs with no current. A short circuit pulse are generate due to physical contact between the wire electrode and work piece. The debris particle may form a bridge between the work piece and wire electrode and create a short circuit. However, a short circuit have prevented by flushing the generated debris with high pressure de-ionized water. Sparks are as the desired gap condition in WEDM but arcs should be invalidate, as it injury the surface finish and dimensional accuracy of the specimen [20].

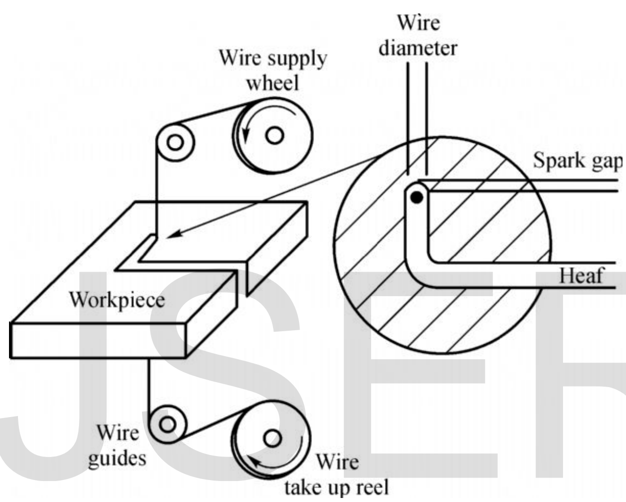

Fig 1.3 Detail of Wire EDM cutting gap [20]

The electrical power supply is used to generate extremely high frequency pulses between the wire tool and work piece which is immersed in a liquid dielectric medium fluid. Due to the presence of the dielectric medium fluid no current flow into the through channel as well as the voltage is increased. At the same time, during generation of more ions, the insulating properties of the dielectric fluid decreases through a narrow channel. The electric field is the strongest at the point where the distance between the two surfaces is less. Thereafter, a flow of current establishes, because the voltage to decrease. A discharge channel is being to form between the electrode and work piece. The voltage dropping continuously with the increasing in current and builds up heat rapidly. At end of the voltage 'ON' cycle, the current and voltage stabilizes. The develop heat and pressure at region of the channel and reaches to maximum value of melting temperature and some of the anode, cathode, and dielectric material vaporize. As the temperature and pressure rapidly decreases at the discharge channel, it collapses and allow expelled the molten material from the surface of the work piece as well as tool wire. Fresh dielectric material flushes the debris away from the channel and quenches the surfaces. Un-expelled molten material resolidifie to the surfaces and form a recast layer [21]. It completes one cycle electric spark and process is ready for the next cycle electric spark. Other than melting, spelling and chemical reaction has been observed in machining different materials mainly ceramics composite material and those lead to impact on cutting speed and surfaces characteristics of the finished job. Spelling process is material removal mechanism by which same call volume of material. This effect is often related to the generation of large micro-crakes make the separation of the volume much easier during successive discharge. The oxidation-evaporation is an additional mechanism for metal removal which is contributes to higher cutting speed in Wire cut EDM process.

1.3 The Sub System of Wire Cut EDM

Wire EDM operation is a very complexive process. Many research works related to machining to the different materials (hard of soft material, i.e., tool steel, different alloys, ceramics and composites) by using WEDM process have been reported till that. The various parameters influencing the process are [22,23,24]

1.3.1 Wire Electrode

Wires electrode used in this machine as a cutting tool. The wire is usually made by brass, molybdenum, copper, or tungsten; zinc or brass coated and multi-coated wires are also used in Wire cut EDM process. Pure copper or brass is extensively used as an electrode material. It is used when fine finish work piece is need. It exhibits a very small wear ratio. The properties required for the wire electrode are:

(a) Electrical properties,
(b) Geometrical properties,
(c) Physical properties and
(d) Mechanical properties.

Fig 1.4 Wire Electrode

Electrical discharge performance is desired for steady and elevated energy discharge need for high-speed cutting. The electrical properties are acted by its electrical resistance. Energy losses are minimized due to using two current contacts and select of high-conductivity electrode materials, such as copper, brass, aluminum and its alloys, with optimized technique settings. A conductivity property determines how readily the energy is transferred to the actual point of cutting from power feed. Due to improving the surface area of the wire electrode will allow faster cutting. Ultra-fine surface of wires (less than 30 mm diameter) are used in micro WEDM, where small pulse energies are largest. The coated layer structure is erased by the thermo physical properties of the electrodes tool, which is associated with its thermal conductivity, melting and evaporation temperature. Coating the wire electrode to initiates cooling of the wire electrode core and yields a good cutting performance [25, 26]. The imperative mechanical properties as tensile strength, elongation and straightness are in wire electrode. High tensile strength signify the ability of the wire electrode to endure tension during machining work. Elongation describes how much the wire gives during cutting before breaks. Straightness properties are important for successful auto threading. Soft wires are used for cut to taper shape and high tensile wires are used for cut to high precision cutting. Non wire-related factors, such as mechanical machine concept, using of improved impulse generator and the dielectric fluid flushing techniques, also play more important role for enhancing machinability of the WEDM process. The wires diameter is typically about 0.3mm for rough cutting and 0.20mm for finish cuts. The wire should have sufficient tensile strength and fracture toughness according to wire material. As well as high electrical conductivity and capacity help to flush away the debris produced during cutting. The wire is generally used only once, as it is relatively inexpensive [27].

1.3.2 Power supply:

The power supply is a most important section of a Wire EDM system. The primary function of this component is producing the unidirectional spark discharge between the tool and work piece. The machining gap maintain by servo system for defined voltage setting. In general resistance or capacitance and diodes are used in the charging/discharging function of circuit and also control the pulse. Larger capacitance generates sharper wave form of charge current in actual machining, results larger peak current generate and therefore deeper crater form. But it has certain limitation to control the discharge energy. The energy of the discharge pulse depends on products of discharge voltage, peak current and the pulse duration where as voltage remains constant during the discharging. Therefore, higher peak current and longer pulse duration of discharge current reasons in larger crater make in each spark due to more discharge pulse energy. The machining process shows the higher material removal rate (MRR) and poor surface roughness due to bigger size of crater [27, 28, and 29].

1.3.3 Dielectric Liquid

Dielectric fluid is a nonconductive liquid that flushing between the work piece and electrode and act as an electrical insulator which is used to needed space and voltage reaches until. At that point dielectric fluid ionizes, then becoming an electrical conductor and because the current or spark flow to the work piece [31, 32 and 33].

The WEDM setup consists of a power supply whose lead is connected to the work piece immersed in a tank having dielectric fluid with coil. The tank is connected to a pump, oil reservoir, and a filter system. The pump produce pressure for flushing the dielectric fluid at work area and moving the oil while the filter system removes or do not proper working and traps the debris in the oil. The oil reservoir restores the surplus oil and use a container for draining the oil between the operations.

The main functions of the dielectric fluid are:

1. To flush the eroded particles from the work piece during machining, from the discharge gap
2. Remove the particles from the oil to pass through a filter system.
3. To establish insulation in the gap between the electrode and the work piece.
4. To cool the heated of discharging machining.

Most commonly used fluids are petroleum based hydrocarbon mineral oils and de-ionized water. The oils should be a high density and a high viscosity properties. These oils have the proper effective on concentrating the discharge channel and discharge energy but they have a difficulty to flushing the discharge products. De ionized water generally has the advantage that faster metal removal rates can be performed. However the surface finish of the work piece is generally poor than oil that which can be achieved when using oil [35].

1.4 Advantages of Wire EDM Process

1. Very small work pieces can be machined where conventional cutting tools may damage the part from excess by cutting tool pressure [36].
2. Delicate sections and weak materials can be machined by this machining process without any distortion because there is no direct contact between tool and work piece.
3. No other electrode fabrication required.
4. No cutting forces requried.
5. Unmanned machining.
6. Die cost reduced by 30-70%.
7. To cut extremely hard material to very close tolerances.
8. Intricate shapes can be cut with ease by this machining process.
9. Very small kerfs width machining easily.
10. A good surface finish can be obtained.

1.5 Disadvantages of Wire EDM Process [37].

1. The slow rate of material removal from work piece.
2. The additional time and cost required for creating electrodes for ram/sinker EDM.

3. Reproducing sharp corners on the work piece is difficult due to electrode wear.
4. Specific power consumption is very high.
5. "Overcut" is formed.
6. Excessive tool wear occurs during machining.
7. Electrically non-conductive materials can be machined only with specific set-up of the process.
8. Higher capital cost required.
9. Electrolysis can occur in some materials.
10. Not applicable to very large work pieces

1.6 Applications of Wire EDM Process [38].

1. Ideal for stamping die components since kerfs is so narrow, it is often possible to fabricate punch and die in a same cut.

2. Tools and parts with complex outline shapes, such as lathe form tools, extrusion dies, flat templates and almost any intricate shape.

3. It has been extensively used for machining of exotic materials used in aero-space industries, refractory metals, and hard carbide and hardens able steel.

4. Prototype production.

5. Coinage dies making.

2. EXPERIMENTATION

In this chapter I will discuss about the experimental work formulated previous to execution of work. It conduct of an L-9 orthogonal array using Taguchi design, selection of work piece, entire set-up, tool design, specimen and calculation of Material Removal Rate and Surface roughness.

2.1 Machine tool

The experiment is work out on a wire-cut EDM machine (RATNAPARKHI ELECTRONICA INDIA PVT LIMITED) [46]. The machine tool has following technical specifications

Table 2.1 Technical specification for Wire cut EDM

MACHINE TOOL	EZEECUT PLUS
Max. work piece size	360×600 mm
Max. z height	400 mm
Max. work piece wt.	300 kg
Mini table traverse (X,Y)	320,400 mm
Auxiliary table traverse(u,v)	25,25 mm
Machine tool size (L*W*H)	1500*1250*1700
Max. taper cutting angle	± 3º/100mm
Machine tool weight	1400 kg
Max dry run speed	25 mm/min
Best surface finish	1-1.5µm
Wire diameter	0.2 to 0.25 mm (brass) 0.12 to0.25 mm (molybdenum)

Fig 2.1 Pictorial view of Wire cut EDM setup

2.2 Work piece material

The H-13 hot die steel plate of 150mm x 110mm x 17mm size has been used as a work piece material for the experiments. H-13 is special hot-worked chromium tool-steel with mechanical

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properties as good hardness and toughness. It is used for extreme load position such as hot-work forging, extrusion etc. It has used in practical applications such as manufacturing of punching tools, mandrels, mechanical press forging die, plastic mould and die-casting dies, aircraft landing gears, helicopter rotor blades and shafts. The working life and dimensional accuracy of Hot die steel (H-13) and tools can be improved with suitable heat treatment. The H-13 die steel plate plane which is heated to a temperature of 10250 ºc with half an hour soak time followed by quenching in a 5000C hot salt bath. It is then tempered in three cycles with maximum temperature of 5500C and 2 hours of soak time to obtain a final hardness of 55 HRC.

2.2.1Chemical Composition

The following table shows the chemical composition of H-13.

Table 2.2 chemical composition of work piece

Elements	**Content (%)**
Carbon	0.32 - 0.4
Chromium	4.75 - 5.5
Manganese	0.2 - 0.5
Molybdenum	1.1 - 1.75
Phosphorus	0.03
Max Silicon	0.8 - 1.2
Sulphur	0.03

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2.3 Preparation of specimens

The H-13 hot die steel plate of 150mm x 110mm x 17mm size is mounted on **EZEECUT PLUS CNC Wire cut EDM** machine tool for machining work and produced specimen of 4.91mm × 4.91mm × 17mm size are cut.

Fig 2.3 Work piece mounted on machine tool

Fig 2.4 CRT Display of wire cut EDM

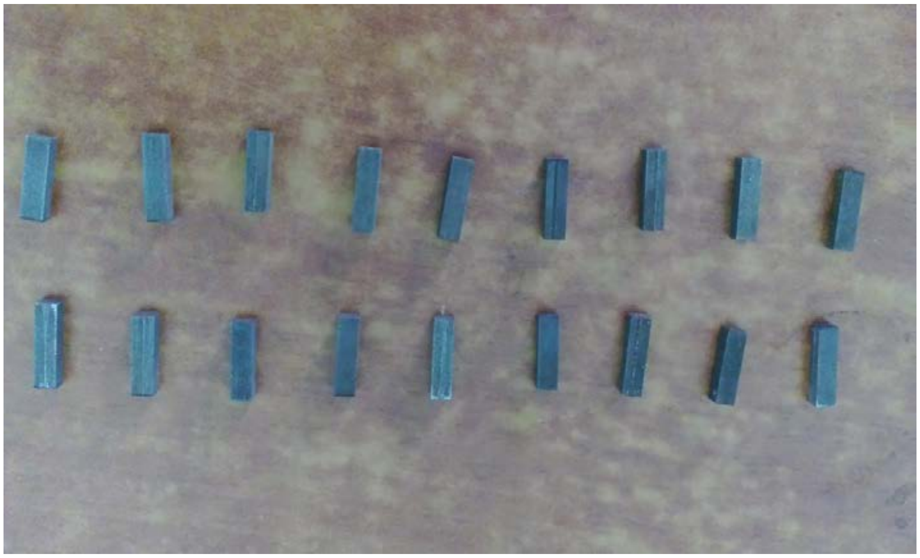

Fig 2.5 Specimens

2.4 Mechanism and evaluation of MRR and Surface roughness

We discuss related to measurement of performance parameters e.g. Metal Removal Rate.

2.4.1 Metal removal rate

MRR is the rate at which the material is removed from the work piece. Electric spark is produced between the tool and the work piece during the machining process. Each spark produces a narrow crater and thus erosion of material is caused. The MRR is defined as the ratio of the difference in weight of the work piece before and after machining it and the product of density of the material and the machining time.

$$MRR = \frac{W_I - W_F}{T \times \rho}$$

Where,

W_I = initial weight before machining

W_F = final weight after machining

T = machining time = 15 min

Density (ρ) = 7.80 g/cm^3

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2.4.2 Surface roughness

Roughness is often a good predictor of the performance of a mechanical object, since irregularities in the surface may be form nucleation locality for cracks or corrosion. Roughness is a measure as texture of a surface. It is quantified through the vertical deviations of a real surface from its ideal form. If these deviations found large, then say surface is rough; if small, the surface is say smooth. Roughness is typically manner considered to be the high frequency as well as short wavelength component of a measured surface.

The parameter mostly used for surface roughness as Ra. It measures average roughness comparing with the peaks as well as valleys to the mean line, and then averaging them all over the entire cut-off length. Cut-off length is the length that the stylus is draggling across the surface; a longer cut-off length will give a more average value, and a shorter cut-off length may be give a less accurate result over a shorter stretch of surface.

Fig 2.6 Surface roughness measurement

3. EXPERIMENTAL RESULT AND DISCUSSION

3.1 Introduction

In this chapter discussed the application of the Taguchi experiment design method. The experiment was selected and the experiment is go to investigate the variation of process parameter on the output response e.g. Surface roughness and MRR. The experimental results are discussed consequently in the following sections [48, 49]

3.2 Taguchi's Philosophy: Taguchi's complete system of quality engineering is one of the greatest engineering achievements of the 20th century. His methods focus on the effective application of engineering strategies instead of advanced statistical techniques. It includes through both upstream and shop-floor quality engineering. Upstream methods well use in small-scale experiments to reduce variability and remain cost-effective, and robust designs for large-scale production as well as market place. Shop-floor designed that it is immune to uncontrollable environmental variables. Taguchi's philosophy is founded on the following three very simple and basic concepts Quality should be designed into the product and not inspected it. To the best quality achieved by minimizing the deviations from the target. The product or process should be so designed by immune to uncontrollable environmental variables. The quality cost should be measured as a function of deviation from the standard and the losses should be measured system-wide. Taguchi suggest an "off-line" strategy for improvement of quality as an alternative to an attempt to inspect quality to the product on the production line. He observes that poor quality cannot be improved by the process of inspection, screening and salvaging. No amount of inspection can put quality reverse into the product. Taguchi recommend a three-stage process: system design, parameter design and tolerance design. In the present work Taguchi's parameter design approach is used to study the variation of process parameters on the various responses of the Wire EDM process [39].

3.3 Experimental Design Strategy

Taguchi recommends orthogonal array (OA) for lying out of experiments. To design the experiment is to select the most suitable orthogonal array and to assign the controlling parameters of the Wire EDM. The use of linear graphs and triangular tables are suggested by Taguchi which makes the assignment of parameters simple. In the Taguchi method, the results of the experiments are analyzed to achieve one or more of the following objectives [39]

1. To establish the best or the optimum condition for a product or Wire EDM process
2. To estimate the contribution of individual parameters of the Wire EDM

The present experimental work the three process parameters each has three levels have been decided. It is desirable to have three minimum levels of process parameters to reflect the true behavior of output response parameter of study. The process parameters are renamed as factors and they are given in the adjacent column. The levels of the individual process parameters value built-in.

Table 3.1 Level value in put factors

Sr **No**	**Factors**	**Levels**		
		1	**2**	**3**
1	T_{on}	40	50	60
2	T_{off}	6	7	8
3	Feed	50	60	70

3.4 Signals to Noise Ratio

The Wire EDM experiments is conduct to the study of effect of process parameters on the output response characteristics with the process parameters .The experimental results for MRR and Surface roughness are obtain. Table 5.2 L9 experiment is conduct using Taguchi experimental design methodology and each experiment is simply repeated three times for obtaining S/N values. In the study of all the designs, plots and analysis have been carried out using Minitab statistical software 17.

Here in experiment larger material removal rate and lower amount of surface roughness show the high productivity in Wire EDM. As a result, larger is the better for material removal and smaller is the better for surface roughness are applied to calculate the S/N ratio rate by using the given equations (1) and (2).

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- **Larger the Better:**

$$(S/N)HB= -10Log\ (MSDHB) \ldots\ldots (1)$$

$$\text{Where: } MSDHB = 1/n \sum_{i=1}^{n} \frac{1}{MRR^2}$$

- **Smaller the Better:**

$$(S/N)L= -10Log\ (MSDLB) \ldots\ldots (2)$$

$$\text{Where: } MSDLB = MSDLB = 1/n\ \sum_{i=1}^{n} yRa^2$$

Here $\mathbf{Y_{MRR}}$, and $\mathbf{Y_{Ra}}$ represents response for metal removal rate and surface finish respectively and **n** is denotes the number of experiments.

3.5 Taguchi Design

Taguchi Orthogonal Array Design

L9 (3^3)

Factors: 3
Runs: 9
Columns of L9 (3^4) Array
1 2 3

Table 3.2 Rotatable design matrix for three factors

Ton	T off	Feed
1	1	1
1	2	2
1	3	3
2	1	2
2	2	3
2	3	1
3	1	3
3	2	1
3	3	2

The results are obtained along with that is found out the influential parameters that affect each of the MRR, Surface Roughness. Taguchi L9 standard orthogonal array is chosen for the experiment is conducting.

Table 3.3 Taguchi L9 standard orthogonal Array

Exp	FACTORS			RESPONSES	
Sr No	T on	T off	Feed	MRR	S R
1	40	6	50	0.020469	2.512
2	40	7	60	0.022746	2.365
3	40	8	70	0.037868	1.420
4	50	6	60	0.031845	1.835
5	50	7	70	0.018992	2.812
6	50	8	50	0.042767	1.204
7	60	6	70	0.035865	1.486
8	60	7	50	0.033566	1.687
9	60	8	60	0.038890	1.267

3.6 ANALYSIS OF METAL REMOVAL RATE

With the intention of see the effect of process parameters on the MRR response, experiments were conducted using L9 OA (Table 5.3). S/N data is obtained by using experimental data with MATLAB 17. The experimental data as well as S/N data is given in Tables 5.4. The values of MRR for each parameter with levels 1, 2 and 3 for raw data and S/N data are plotted in Figures 5.1 and 5.2 respectively.

Table 3.4 Experimental result and S/N Ratio for MRR

MRR	S/N Ratio
0.020469	-33.7781
0.022746	-32.8619
0.037868	-28.4346
0.031845	-29.9392
0.018992	-34.4286
0.042767	-27.3778
0.035865	-28.9066
0.033566	-29.4820
0.038890	-28.2032

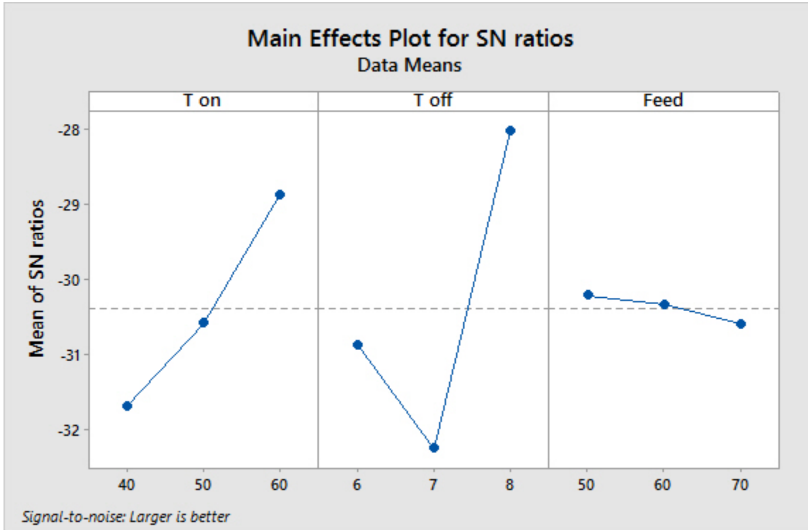

Fig 3.1 Effect of process parameter in MRR (S/N Data)

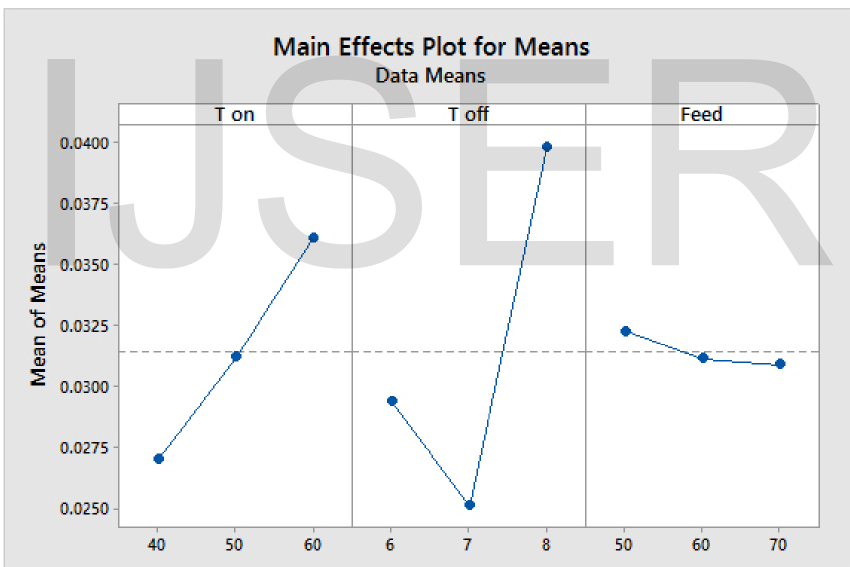

Fig 3.2 Effect of process parameter in MRR (Raw Data)

Table 3.5 Response table for MRR (S/N Data)

Level	T on	T off	Feed
1	-31.69	-30.87	-30.21
2	-30.58	-32.26	-30.33
3	-28.86	-32.26	-30.59
Delta	2.83	4.25	0.38
Rank	2	1	3

3.6 Response Table for MRR (Raw Data)

Level	T on	T off	Feed
1	0.02703	0.02939	0.03227
2	0.03120	0.02510	0.03116
3	0.03611	0.03984	0.03091
Delta	0.00908	0.01474	0.00136
Rank	2	1	3

The response tables (Tables 5.5and 5.6) show the value of each response characteristic (S/N data, means) for each level of each factor. The tables include ranks based rank 1 to the highest delta value, rank 2 to the second highest, and rank 3 to the lowest. The ranks indicate the relative importance of each factor to the response. The ranks and the delta values show that pulse off time have the greatest effect on MRR and is followed by pulse off time and followed by feed. As MRR is the „higher the better‟ type quality characteristic.

It can be seen from (Figure 5.2) that optimal parameter for surface roughness that the 3rd level of pulse on time (A_3), 3rd level of pulse off time (B_3) and 1st level of feed (C_1). The S/N data analysis (Figure 5.1) also suggests the same levels of the variables (A_3, B_3 and C_1) as the best levels for maximum MRR in WEDM process

3.6.1 ANOVA Analysis for MRR

Table 3.7 Analysis of Variance for MRR

Source	DF	Adj SS	Adj MS	F-Value	P-Value
T on	2	0.000197	0.000098	18.43	0.050
T off	2	0.000057	0.000028	5.32	0.048
Feed	2	0.000014	0.000007	1.35	0.426
Error	2	0.000011	0.000005		
Total	8	0.000278			

DF - degrees of freedom, SS - sum of squares, MS - mean squares(Variance), F-ratio of variance of a source to variance of error, $P < 0.05$ - determines significance of a factor at 95% confidence level

Model Summary

S =0.0023098 R-sq =96.17 R-sq(adj)=84.67% R-sq(pred)=22.39%

3.6.2 Regression analysis for MRR

Regression Analysis is a statistical method for estimating the relationship between the variables. Regression is a simple technique using for investigating functional relationship between output and input parameters. Regression analysis estimates the conditional expectation of the output parameters when input variables are fixed. A mathematical model is generated that using regression analysis for MRR by using the experimental data. The generated mathematical model is representing the entire process that has been done in this work. Regression analysis was done by the software MINITAB 17. The generated regression equation is given below

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- **Regression model equation of MRR response**

Table 3.8 Regression table for MRR

Predictor	Coef	SE Coef	T-Value	P-Value	VIF
Constant	-0.0237	0.0338	-0.70	0.514	
T on	0.000454	0.000322	1.41	0.217	1.00
T off	0.00522	0.00322	1.62	0.165	1.00
Feed	-0.000068	0.000322	-0.21	0.841	1.00

Regression Equation for MRR = -0.0237 + 0.000454 T on + 0.00522 T off - 0.000068 Feed

3.6.3 Confirmation experiment for MRR

The confirmation experiment is the final step of the experiment. Table 5.12 show the comparison between the predicted value and the experimental value for the selected combinations of the machining parameters.

Table 3.9 Confirmation Test Result and error of MRR

Test No	MRR	Model of equation	Error (%)
1	0.020469	0.02238	-9.34
2	0.022746	0.02692	-18.35
3	0.037868	0.03146	16.92
4	0.031845	0.02624	17.60
5	0.028992	0.03078	-6.16
6	0.042767	0.03736	12.64
7	0.035865	0.02998	16.40
8	0.033566	0.03668	-9.27
9	0.038890	0.04122	-5.99

Hence, the experimental result confirms that optimization of the machining parameters using Taguchi method design for enhancing the machining performance. However, the error in MRR can be further expected to decrease if the number of measurements is increased.

3.7 ANALYSIS OF SURFACE ROUGHNESS

In order to see the effect of process parameters on the surface roughness, experiments were conducted using L9 OA (Table 5.3). The S/N data is obtained by using experimental data with MATLAB 17. The experimental data as well as S/N data is given in table given in Tables 5.4. The values of surface roughness for each parameter with levels 1, 2 and 3 for S/N data and raw data are plotted in Figures 5.3 and 5.4 respectively.

Table 3.10 Experimental values of surface roughness and its S/N ratio.

surface roughness	S/N Ratio
2.512	-8.00039
2.365	-7.47662
1.420	-3.04577
1.835	-5.27272
2.812	-8.98031
1.204	-1.61253
1.486	-3.44038
1.687	-4.54230
1.267	-2.05553

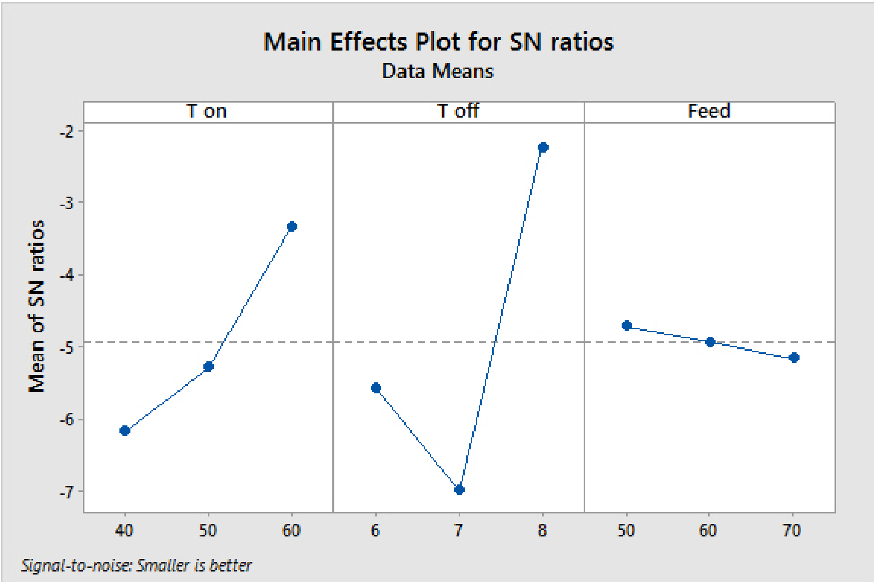

Fig 3.3 Effect of process parameter in surface roughness (S/N Data)

Fig 3.4 Effect of process parameter in surface roughness (Raw Data)

Table 3.11 Response table for surface roughness (S/N Data)

Level	T on	T off	Feed
1	-6.174	-5.571	-4.718
2	-5.289	-7.000	-4.935
3	-3.346	-2.238	-5.155
Delta	2.828	4.762	0.437
Rank	2	1	3

Table 3.12 Responses table for surface roughness (Raw Data)

Level	T on	T off	Feed
1	2.099	1.944	1.801
2	1.950	2.288	1.822
3	1.480	1.297	1.906
Delta	0.619	0.991	0.105
Rank	2	1	3

Figures 5.3 and 5.4 shows that the surface roughness increases with the increase of pulse on time, decreases with increase in pulse off time, and wire feed .The discharge energy increases with the pulse on time and pulse off time larger discharge energy produces a larger crater, causing a larger surface roughness value on the work piece. As the pulse off time decreases, the number of discharges increases which causes poor surface accuracy.

In order to study the significance of the process variables towards surface roughness, analysis of variance (ANOVA) was performed. It was found that pulse on time and pulse off time are significant process parameters for surface roughness. ANOVA of the S/N data and for surface roughness are given in (Tables 5.13). From these tables, it is clear that pulse on time, pulse off time are significant.

The response tables (Tables 5.11 and 5.12) show the value of each response characteristic (S/N data, means) for each level of each factor. The tables include ranks based rank 1 to the highest delta value, rank 2 to the second highest, and rank 3to the lowest. The ranks indicate the relative importance of each factor to the response. The ranks and the delta values show that pulse off time have the greatest effect on surface roughness and is followed by pulse on time and followed by feed. As surface roughness is the „smaller the better‟ type quality characteristic.

It can be seen from (Figure 5.3) that optimal parameter for surface roughness that the first level of pulse on time (A_1), 2^{nd} level of pulse off time (B_2) and 3^{rd} level of feed (C_3). The S/N data analysis (Figure 5.3) also suggests the same levels of the variables (A_1, B_2 and C_3) as the best levels for maximum MRR in WEDM process.

3.7.1 ANOVA Analysis for surface roughness

Table 3.13 Analysis of Variance for surface roughness

Source	DF	Adj SS	Adj MS	F-Value	P-Value
T on	2	0.62648	0.313238	1.11	0.247
T off	2	1.51923	0.759614	2.69	0.027
Feed	2	0.01848	0.009240	0.03	0.751
Error	2	0.56570	0.0282848		
Total	8	2.72988			
DF - degrees of freedom, SS - sum of squares, MS - mean squares(Variance), F-ratio of variance of a source to variance of error, P < 0.05 - determines significance of a factor at 95% confidence level					

S =0.531835 R-sq =79.28% R-sq(adj) =17.11% R-sq(pred) =11%

3.7.2 Regression analysis for surface roughness

Regression Analysis is a statistical for estimating the relationship between the variables. Regression method is a simple technique for investigating functional relationship between output and input parameters. Regression analysis estimates the conditional expectation of the output parameters when input variables are fixed. A mathematical model is generated by using regression analysis for surface roughness to using the experimental results. The generated mathematical model represents the entire that has been done in this work. Regression analysis was done in the software Minitab 17. The obtained regression equation is given below

- **Regression model equation of surface roughness response**

Table 3.14 Regression table for surface roughness

Predictor	Coef	SE Coef	T-Value	P-Value	VIF
Constant	5.34	2.36	2.26	0.073	
T on	-0.0310	0.0224	-1.38	0.226	1.00
T off	-0.324	0.224	-1.44	0.209	1.00
Feed	0.0052	0.0224	0.23	0.824	1.00

Regression Equation for surface roughness = 5.34 - 0.0310 T on - 0.324 T off + 0.0052 Feed.

3.7.3 Confirmation experiment for surface roughness

The confirmation test is the final step of my experiment process. Table 5.12 show the comparison between the predicted value with the experimental value for the selected combinations of the machining parameters.

Table 3.15 Confirmation result and error of surface roughness

Test No	surface roughness	Model of equation	Error (%)
1	2.512	2.416	3.82
2	2.365	2.144	9.34
3	1.420	1.872	-31.83
4	1.835	2.158	-17.60
5	2.812	1.886	32.93
6	1.204	1.458	-21.09
7	1.486	1.90	-27.86
8	1.687	1.472	12.74
9	1.267	1.20	5.28

Hence, the experimental result confirms the optimization of the machining parameters using Taguchi method for enhancing the machining performance. However, the error surface roughness can be further expected to reduce if the number of measurements is increased.

4. CONCULISION AND FUTURE SCOPE

In this work, it is intended to study the maximizations of MRR and minimization of surface roughness of Hot Die Steel 13 with WEDM process. Both responses are important in industrial application. The conduct of experiment depend on input parameters as P_{ON} , P_{OFF} and feed has been selected . Experiment conduct based on L9 orthogonal array by Taguchi design method using MINITAB 17.

Based on Taguchi optimization method the optimum input parameter setting obtain for maximum MRR are T_{ON} = 60, P_{OFF} =8 and feed = 50 and similarly optimized condition to get minimum surface roughness T_{ON} =40, T_{OFF} = 7 and feed = 70.

ANOVA analysis show that in case of MRR, T_{ON} and T_{OFF} have significant factor as (p=0.50) and (p=0.048) on Hot Die Steel – 13 and in case of surface roughness, T_{OFF} has significant factor as (0.027).

Confirmation experiment has been performed and found a good agreement between predicted and experimental value.

Future scope

The mathematical model can be developed different work piece and electrode materials for WEDM processes.

Responses like roundness, circularity, cylindericity, machining cost etc .are to be considered in further research

The standard optimization procedure can be developed and the optimal results are to be validated.

Evaluation of overcut produces the work piece material for WEDM.

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