

Optimization of WEDM parameters using Taguchi method for higher material removal rate on EN31 steel

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ABSTRACT

With the increasing demands of high surface finish and machining of complex shape geometries, conventional machining processes are now being replaced by non-traditional machining processes. Wire EDM is one of the non-traditional machining processes which is based on Electrical Discharge Machining Process, which is also called electro-erosion machining process. When the gap voltage is sufficiently large (i.e. reaches the breakdown voltage of dielectric fluid), high power spark is produced, which increase the temperature about 10,000 degrees Celsius. By this way the metal is removed from the work piece. The selection of optimum machining parameters in WEDM is an important increasing productivity. As Material Removal Rate (MRR) is most important response in WEDM; various investigations have been carried out by several researchers for improving the MRR . In this paper, the Taguchi method has been extensively adopted in manufacturing to improve processes with single performance characteristic to achieve higher Material Removal Rate.

Keywords – WEDM, Taguchi, Anova, S/N, MRR

I. INTRODUCTION

WireEDM removes material; but wire EDM removes material with electricity by means of spark erosion. Therefore, material must be electrically conductive. Rapid DC electrical pulses are generated between the wire electrode and the work piece. Between the wire and the work piece is a shield of deionized water, called the dielectric. Pure water is an insulator, but tap water usually contains minerals that cause the water to be too conductive for wire EDM. To control the water conductivity, the water goes through a resin tank to remove much of its conductive elements—this is called deionized water. As the machine cuts, the conductivity of the water tends to rise, and a pump automatically forces the water through a resin tank when the conductivity of the water is too high.

When sufficient voltage is applied, the fluid ionizes. Then a controlled spark precisely erodes a small section of the workpiece, causing it to melt and vaporize. These electrical pulses are repeated thousands of times per second. The pressurized cooling fluid, the dielectric, cools the vaporized metal and forces the resolidified eroded particles from the gap. The dielectric fluid goes through a filter which removes the suspended solids. Resin removes dissolved particles; filters remove suspended particles. To maintain machine and part accuracy, the dielectric fluid flows through a chiller to keep the liquid at a constant temperature. A DC or AC servo system maintains a gap from .002 to .003" (.051 to .076 mm) between the wire electrode and the workpiece. The servo mechanism prevents the

wire electrode from shorting out against the workpiece and advances the machine as it cuts the desired shape. Because the wire never touches the workpiece, wire EDM is a stress-free cutting operation. The wire electrode is usually a spool of brass, or brass and zinc wire from .001 to .014" (.025 to .357 mm) thick. Sometimes molybdenum or tungsten wire is used. New wire is constantly fed into the gap; these accounts for the extreme accuracy and repeatability of wire EDM.

1.1. Pictured Step by Step EDM Process:

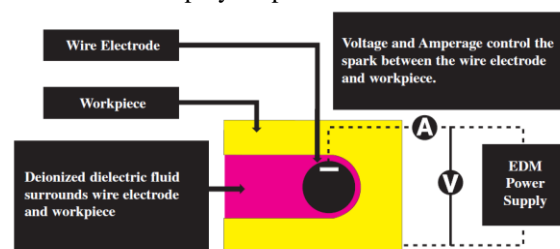


Fig 1 Power Supply Generates Volts and Amps

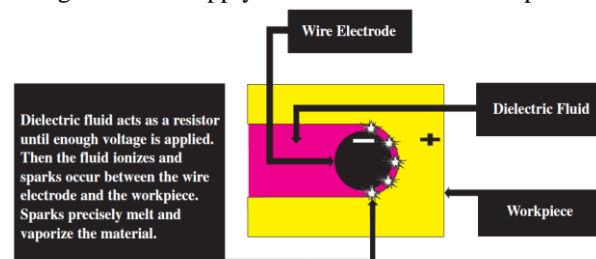


Fig 2. During On Time Controlled Spark Erodes Material

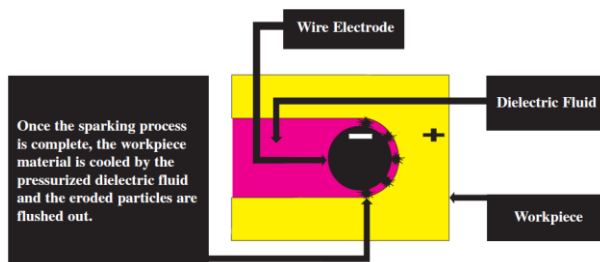


Fig 3 Off Time Allows Fluid to Remove Eroded Particles

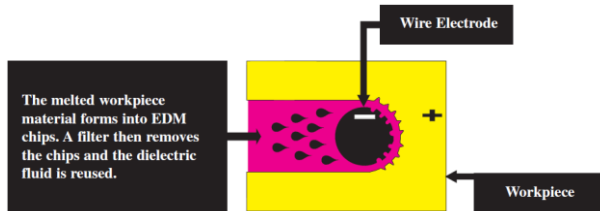


Fig 4 Filter Removes Chips While the Cycle is Repeated

1.2. Mechanism of Material Removal in WEDM Process:

The mechanism of metal removal in wire electrical discharge machining mainly involves the removal of material due to melting and vaporization caused by the electric spark discharge generated by a pulsating direct current power supply between the electrodes. In WEDM, negative electrode is a continuously moving wire and the positive electrode is the work piece. The sparks will generate between two closely spaced electrodes under the influence of dielectric liquid. Water is used as dielectric in WEDM, because of its low viscosity and rapid cooling rate. No conclusive theory has been established for the complex machining process. However, empirical evidence suggests that the applied voltage creates an ionized channel between the nearest points of the work piece and the wire electrodes in the initial stage.

In the next stage the actual discharge takes place with heavy flow of current and the resistance of the ionized channel gradually decreases. The high intensity of current continues to further ionize the channel and a powerful magnetic field is generated. This magnetic field compresses the ionized channel and results in localized heating.

Even with sparks of very short duration, the temperature of electrodes can locally rise to very high value which is more than the melting point of the work material due to transformation of the kinetic energy of electrons into heat. The high energy density erodes a part of material from both the wire and work piece by locally melting and vaporizing and thus it is the dominant thermal erosion process.

1.3 WEDM parameters:

The effect of some important input parameters on material removal rate (MRR), surface roughness and accuracy is discussed below.

1.3.1 Gap Voltage (V):

Gap voltage, also called open circuit voltage specifies the supply voltage to be placed on the gap. Greater the gap voltage, greater will be the electric discharge. If the gap voltage increases, the peak current will also increase.

1.3.2. Pulse-on Time (Ton):

Machining takes place only during the pulse-on time. When the wire electrode is at negative potential, material removal from the anode (work piece) takes place by bombardment of high energy electrons ejected from the wire surface. At the same time positive ions move towards the cathode. When pulses with small on times are used, material removal by electron bombardment is predominant due to the higher response rate of the less massive electrons. However, when longer pulses are used, energy sharing by the positive ions is predominant and the material removal rate decreases. When the electrode polarities are reversed, longer pulses are found to produce higher MRR.

1.3.3. Pulse-off Time (Toff):

A non-zero pulse off time is a necessary requirement for WEDM operation. Discharge between the electrodes leads to ionization of the spark gap. Before another spark can take place, the medium must de-ionize and regain its dielectric strength. This takes some finite time and power must be switched off during this time. Too low values of pulse-off time may lead to short-circuits and arcing. A large value on the other hand increases the overall machining time since no machining can take place during the off-time.

1.3.4 Wire Feed (WF):

Wire feed is the rate at which the wire-electrode travels along the wire guide path and is fed continuously for sparking. The wire feed range available on the present WEDM Machine is 1–15 m/min in steps of 1m/min. It is always desirable to set the wire feed to maximum. This will result in less wire breakage, better machining stability and slightly more cutting speed.

1.3.5 Peak Current:

Peak current is the amount of power used in discharge machining and is measured in unit of amperage. The current increases until it reaches a preset value during each pulse on time, which is known as peak current, is shown in figure 2. Peak current is governed by surface area of cut. Higher peak current is applied during roughing operation and details with large surface area.

1.3.6 Wire Tension:

If the wire tension is high enough the wire stays straight otherwise wire drags behind. Within considerable range, an increase in wire tension significantly increases the cutting speed and accuracy. The higher tension decreases the wire vibration amplitude and hence decreases the cut width so that the speed is higher for the same discharge energy. However, if the applied tension exceeds the tensile strength of the wire, it leads to wire breakage.

1.3.7 Dielectric flow rate:

Dielectric flow rate is the rate at which the dielectric fluid is circulated. Flushing is important for efficient machining. Flushing pressure is produced from both the top and bottom nozzle.

II. MATERIALS AND METHODOLOGY

2.1 EN 31:

EN31 is a quality high carbon alloy steel which offers a high degree of hardness with compressive strength and abrasion resistance.

Applications: Typical applications for EN31 steel include taps, gauges, swaging dies, ejector pins, ball and roller bearings. It is a good quality steel for wear resisting machine parts and for press tools which do not merit a more complex quality.

2.2 Composition of EN 31:

- Carbon 0.90-1.20%
- Chromium 1.00-1.60%
- Sulphur 0.050% max
- Silicon 0.10-0.35%
- Silicon 0.10-0.35%
- Manganese 0.30-0.75%
- Phosphorous 0.050% max



Fig5: EN31size (30×20×12) mm

2.3 Experiment:

The experimental studies were performed on a ECO CUT WEDM machine. Zinc coated brass wire with 0.25 mm diameter (900 N/mm² tensile strength) was used in the experiments. The parameters, selected for different settings of pulse on time, pulse off time, gap voltage and wire feed were used in the experiments (Table 1). The photographic view of the machine and machining zone has been shown in Fig.6 (a) and (b) respectively. The other details of the experimentation have been shown in Table 2.

Table1 (machining settings used in the experiment)

| Parameter | Unit | Level1 | Level2 | Level3 |
|----------------|--------|--------|--------|--------|
| Gap voltage | v | 40 | 45 | 50 |
| Wire feed | mm/min | 2 | 4 | 6 |
| Pulse on time | µs | 4 | 6 | 8 |
| Pulse off time | µs | 4 | 6 | 8 |

Table2 (fixed parameters)

| | |
|----------------------------------|--|
| Wire | Zinc coated brass wire of diameter 0.25mm. |
| Shape and size of work piece | Rectangular piece of 50×30×12 mm |
| Dielectric fluid | Deionised water |
| Conductivity of dielectric fluid | 20mho |



Fig 6(a)

Fig 6(b)

2.4Design of Experiment Based On Taguchi Method
 To evaluate the effects of cutting parameters of Wire EDM process in terms of cutting performance characteristics such as Surface Roughness a Taguchi method used here to model the Wire EDM process. In this study, Taguchi method, a powerful tool for parameter design of performance characteristics, for the purpose of designing and improving the product quality. In the Taguchi method, process parameters which influence the products are separated into two main groups: control factors and noise factors. The control factors are used to select the best conditions for stability in design or manufacturing process, whereas the noise factors denote all factors that cause variation. In Taguchi a loss function is used to calculate the deviation between the experimental value and the desired value. This loss function is known as signal to noise ratio(s/n ratio). There are several s/n ratios are available such as lower is better, nominal is best, higher is better. In WEDM higher MRR and lower surface roughness are the indication of better performance. Therefore 'higher is better' for MRR and 'lower is better' for surface roughness is used.

The loss function L for machining performance results Yi of n number repeated are

$$L_{HB} = \frac{1}{n} \sum_{i=1}^n \frac{1}{y_i^2}$$

$$L_{LB} = \frac{1}{n} \sum_{i=1}^n y_i^2$$

The S/N ratio N_{ij} for the ith performance characteristics in the jth experiment can be expressed as:

$$N_{ij} = -10 \log (L_{ij})$$

2.5 Calculation of MRR:

$$MRR = [(2 * \text{Spark Gap}) + (\text{Wire Diameter})] * \text{Job Thickness} * \text{Speed Of Machine}$$

Data Used:

- Spark Gap=50μm=0.05mm
- Wire Diameter=0.25mm
- Job Thickness=12mm
- Speed Of The Machine Varies In Each Experiment.

Table3: Calculation of material removal rate

| JOB | INDIVIDUAL | | | | | | Final MRR |
|-----|---------------|------|------|------|------|------|-----------|
| 1 | MACHINE SPEED | 0.8 | 0.9 | 1 | 1.1 | 1.2 | 4.284 |
| | MRR | 3.36 | 3.78 | 4.2 | 4.62 | 5.04 | |
| 2 | MACHINE SPEED | 1 | 1.1 | - | - | - | 4.42 |
| | MRR | 4.2 | 4.62 | - | - | - | |
| 3 | MACHINE SPEED | 0.9 | 1 | - | - | - | 4.001 |
| | MRR | 3.78 | 4.2 | - | - | - | |
| 4 | MACHINE SPEED | 0.8 | 0.9 | - | - | - | 3.582 |
| | MRR | 3.36 | 3.78 | - | - | - | |
| 5 | MACHINE SPEED | 1.1 | 1.2 | - | - | - | 4.839 |
| | MRR | 4.62 | 5.04 | - | - | - | |
| 6 | MACHINESPEED | 0.7 | 0.8 | 0.9 | - | - | 3.395 |
| | MRR | 2.94 | 3.36 | 3.78 | - | - | |
| 7 | MACHINE SPEED | 0.9 | 1 | 1.1 | 1.2 | 1.3 | 4.696 |
| | MRR | 3.78 | 4.2 | 4.62 | 5.04 | 5.46 | |
| 8 | MACHINE SPEED | 0.8 | 0.9 | 1 | - | - | 3.811 |
| | MRR | 3.36 | 3.78 | 4.2 | - | - | |
| 9 | MACHINE SPEED | 0.9 | 1 | 1.1 | - | - | 4.228 |
| | MRR | 3.78 | 4.2 | 4.62 | - | - | |

Table 4: S/N Ratios for MRR

| Job | Gap Voltage | Wire Feed | Pulse on Time | Pulse off Time | MRR | S/N Ratio |
|-----|-------------|-----------|---------------|----------------|-------|-----------|
| 1 | 40 | 2 | 4 | 4 | 4.284 | 12.636989 |
| 2 | 40 | 4 | 6 | 6 | 4.42 | 12.908445 |
| 3 | 40 | 6 | 8 | 8 | 4.001 | 12.043371 |
| 4 | 45 | 2 | 6 | 8 | 3.582 | 11.082512 |
| 5 | 45 | 4 | 8 | 4 | 4.839 | 13.695112 |
| 6 | 45 | 6 | 4 | 6 | 3.395 | 10.616796 |
| 7 | 50 | 2 | 8 | 6 | 4.696 | 13.434562 |
| 8 | 50 | 4 | 4 | 8 | 3.811 | 11.620779 |
| 9 | 50 | 6 | 6 | 4 | 4.228 | 12.5227 |

III. RESULTS AND DISCUSSION

The experimental results are collected for MRR and 9 experiments were conducted using Taguchi (L9) experimental design methodology and there is one replicates for each experiment to obtain S/N values. In the present study all the designs, plots and analysis have been carried out using Minitab statistical software. Higher amount of MRR show the high productivity of Wire EDM. Therefore, high the better is applied to calculate the S/N ratio of MRR.

3.1 ANALYSIS OF MRR:

The purpose of the analysis of MRR is to determine the factors and their interactions that have strong effects on the machining performance.

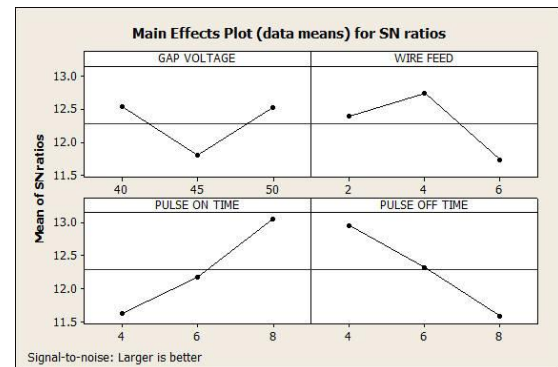


Fig 7 Factors affecting S/N ratio for MRR

Table 5 Factors affecting the S/N ratio

| LEVEL | VOLTAGE | WIRE FEED | PULSE ON TIME | PULSE OFF TIME |
|-------|---------|-----------|---------------|----------------|
| 1 | 12.53 | 12.38 | 11.62 | 12.95 |
| 2 | 11.80 | 12.74 | 12.17 | 12.32 |
| 3 | 12.53 | 11.73 | 13.06 | 11.58 |
| Delta | 0.73 | 1.01 | 1.43 | 1.37 |
| Rank | 4 | 3 | 1 | 2 |

Table 6 Optimized Values For MRR

| PARAMETER | RANK | LEVEL | VALUE |
|----------------|------|-------|---------|
| Pulse On Time | 1 | 3 | 8μs |
| Pulse Off Time | 2 | 1 | 4μs |
| Wire Feed | 3 | 2 | 4mm/min |
| Gap Voltage | 4 | 3 | 50V |

The optimal machining performance for MRR was obtained as 8 μs pulse-on time (Level 3), 4 μs pulse-off time (Level 1), 50v gap voltage (Level 3) and 4 mm/min wire feed (Level 2) settings that give the maximum MRR. Fig.7 shows the effect of machining parameters on the MRR. That MRR increases with the increase of pulse on time and decreases with increase in pulse off time, MRR increases up to wire feed value of 4mm/min and then decreases but gap voltage has mixed effect on MRR.

3.2 ANOVA ANALYSIS:

The analysis of variance was used to establish statistically significant machining parameters and percent contribution of these parameters on the MRR and SR. A better feel for the relative effect of the different machining parameters on the MRR and SR was obtained by decomposition of variances,

which is called analysis of variance. The relative importance of the machining parameters with respect to the MRR and SR was investigated to determine more accurately the optimum combinations of the machining parameters by using ANOVA. The results of ANOVA for the machining outputs are presented. Statistically, F-test provides a decision at some confidence level as to whether these estimates are significantly different. Larger F-value indicates that the variation of the process parameter makes a big change on the performance characteristics. F-values of the machining parameters are compared with the appropriate confidence.

Table 7 Anova for MRR

| Process Parameter | DO F | SS | V | F-value | P-value | % contribution |
|--------------------------|------|--------|---------|---------|---------|----------------|
| Gap Voltage | 2 | 0.1818 | 0.09088 | 0.32 | 0.739 | 9.57 |
| Wire Feed | 2 | 0.3588 | 0.1794 | 0.70 | 0.533 | 18.90 |
| Pulse On Time | 2 | 0.7155 | 0.3577 | 1.81 | 0.242 | 37.69 |
| Pulse Off Time | 2 | 0.6426 | 0.3213 | 1.53 | 0.290 | 33.84 |
| Total | | | | | | 100 |
| At least 95% confidence. | | | | | | |

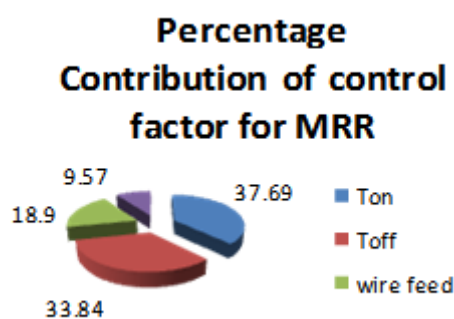


Fig 8 Percentage contribution of control factor for MRR

According to F-test analysis, the significant parameters on the MRR are pulse-on time and pulse off time. The percent contributions of the machining parameters on the MRR are shown. Pulse On Time is found to be the major factor affecting the MRR (37.69%). The percent contribution of pulse-off time, wire feed and gap voltage on the MRR are 33.84%, 18.90% and 9.57% respectively.

3.3 Confirmation Experiment

The confirmation experiment is performed by conducting a test using a specific combination of the factors and levels previously evaluated. The final

step of the Taguchi's parameter design after selecting the optimal parameters is to be predicted any verify the improvement of the performance characteristics with the selected optimal machining parameters.

| | Prediction Value | Experiment Value | %Error |
|-----------------------|------------------|------------------|--------|
| Material Removal Rate | 5.145 | 4.876 | 5.22 |

Table 8 The results of experimental confirmation using optimal machining parameters

From the above observations, it can be interpreted that the obtained MRR has reasonable accuracy for resulting model because an error of 5.22% for MRR is measured.

IV. CONCLUSION

This paper describes the optimization of the WEDM process using parametric design of Taguchi methodology. It was observed that the Taguchi's parameter design is a simple, systematic, reliable, and more efficient tool for optimization of the machining parameters. The effect of various machining parameter such as pulse-on time, pulse off time, gap voltage and wire feed has been studied through machining of EN31 steel. It was identified that the pulse on time has influenced more than the other parameters for MRR considered in this paper. The confirmation experiment has been conducted. Result shows that the errors associated with MRR are only 5.22 %.

The selection of optimum values is essential for the process automation and implementation of a computer integrated manufacturing system. Thus the optimized condition, not only makes the WEDM a more commercially viable process for industrial applications, but also turns a spotlight on WEDM process as a promising field for further advancements.

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