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# "Mathematical Modeling and Optimization of Process Parameters for En31 Material in EDM by Response Surface Methodology"

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**Abstract -** *Electrical Discharge Machining (EDM) is one of the most accurate manufacturing processes available for creating complex or simple shapes and geometries within parts and assemblies. EDM works by eroding material in the path of electrical discharges that form an arc between an electrode tool and the work piece. EDM manufacturing is quite affordable and a very desirable manufacturing process when low counts or high accuracy is required. The EDM system consists of a shaped tool or wire electrode, and the work piece. The work piece is connected to a power supply. To create a potential difference between the work piece and tool, the work piece is immersed in a dielectric (electrically non-conducting) fluid which is circulated to flush away debris.*

*In this dissertation work optimization problem for En31 material has been solved to satisfy requirements of productivity in EDM operation. Experiments on die sinking EDM have been conducted using Response surface design using various process control parameters like discharge current (Ip), voltage (V) and pulse on time (Ton) which are varied in three different levels. Material Removal Rate (MRR), Tool wear rate (TWR) and surface roughness (SR) have been measured for each experimental run. Problem has been formulated in maximization of MRR (in order to increase productivity) and minimization of tool wear and surface roughness (in order to increase quality).*

*The optimum values have been determined with the help of D-optimal plot and ANOVA table is used to find the significance of input parameters. Commercial grade EDM oil has been taken as dielectric fluid. MINITAB software has been used for mathematical modeling of MRR for different materials.*

***Key Words*: *Discharge Current (Ip)1, Voltage (V)2, Pulse On Time (Ton)3,Material Removal Rate (MRR)4, Tool Wear Rate (TWR)5 And Surface Roughness (SR)6 etc*.**

## 1. INTRODUCTION

Electric discharge machining is a thermo-electric non-traditional machining process. Material is removed from the work piece through localized melting and vaporization of material. Electric sparks are generated between two electrodes when the electrodes are held at a small distance from each other in a dielectric medium and a high potential difference is applied across them. Localized regions of high temperatures are formed due to the sparks occurring between the two electrode surfaces. Work piece material in this localized zone melts and vaporizes. Most of the molten and vaporized material is carried away from the inter-electrode gap by the dielectric flow in the form of debris particles. To prevent excessive heating, electric power is supplied in the form of short pulses. Spark occurs wherever the gap between the tool and the work piece surface is smallest. After material is removed due to a spark, this gap increases and the location of the next spark shifts to a different point on the work piece surface. In this way several sparks occur at various locations over the entire surface of the work piece corresponding to the work piece-tool gap. Because of the material removal due to sparks, after some time a uniform gap distance is formed throughout the gap between the tool and the work piece. If the tool is held stationary, machining would stop at this stage. However if the tool is fed continuously towards the work piece then the process is repeated and more material is removed. The tool is fed until the required depth of cut is achieved. Finally, a cavity corresponding to replica of the tool shape is formed on the work piece.

### 1.1 Principle of EDM

The tool and the work piece form the two conductive electrodes in the electric circuit. Pulsed power is supplied to the electrodes from a separate power supply unit. The appropriate feed motion of the tool towards the work piece is generally provided for maintaining a constant gap distance between the tool and the work piece during machining. This is performed by either a servo motor control or stepper motor control of the tool holder. As material gets removed from the work piece, the tool is moved downward towards the work piece to maintain a constant inter-electrode gap. The tool and the work piece are plunged in a dielectric tank and flushing arrangements are made for the proper flow of dielectric in the inter-electrode gap.

Typically in oil die-sinking EDM pulsed DC power supply is used where the tool is connected to the negative terminal and the work piece is connected to the positive terminal.

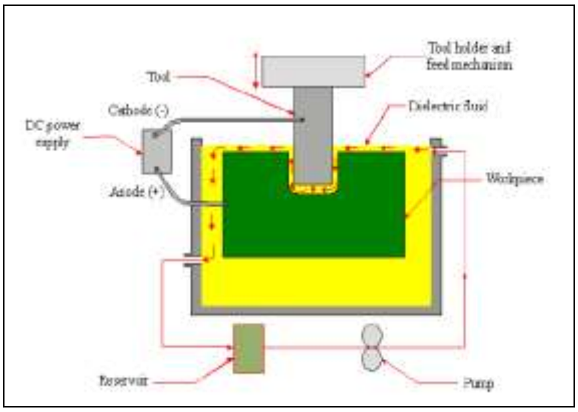


**Fig -1**: Principle of EDM

### 1.2 Mechanism of Material Removal in Electrical Discharge Machining

A perfect theory for EDM cannot be constructed since each machining condition has its own particular aspects and involves numerous phenomenon, i.e. heat conduction and radiation, phase changes, electrical forces, bubble formation and collapse, rapid solidification. In addition, theories of how sparks eroded the work piece and electrode have never been completely supported by the experimental evidence since it is very difficult to observe the process scientifically. Thus most of the published studies are mostly concerned with simplified models of different events of EDM. Generally the physics of the sparks can be investigated in the three phases. 1 Breakdown (Ignition) Phase, 2 Discharge Phase, 3 Erosion (Crater Formation) Phase/ Interval Phase

### 1.3 Process Parameters of EDM

1 Spark On-Time (Pulse On Time or Ton)
2 Spark Off-Time (Pause Time or Toff)
3 Spark Gap (or Gap)
4 Discharge Current (Current Ip)
5 Duty Cycle (τ)
6 Voltage (V)
7 Polarity

### 1.4 Dielectric Fluid

In EDM, as has been discussed earlier, material removal mainly occurs due to thermal evaporation and melting. As thermal processing is required to be carried out in absence of oxygen so that the process can be controlled and oxidation avoided. Oxidation often leads to poor surface conductivity (electrical) of the work piece hindering further machining. Hence, dielectric fluid should provide an oxygen free machining environment. Further it should have enough strong dielectric resistance so that it does not breakdown electrically too easily but at the same time ionize when electrons collide with its molecule. Moreover, during sparking it should be thermally resistant as well. The dielectrics generally used are Transformer or silicon oil, EDM oil, Kerosene oil (Paraffin oil),De-ionized water.etc

### 1.5 Flushing Method

Flushing is the most important function in any electrical discharge machining operation. Flushing is the process of introducing clean filtered dielectric fluid into the spark gap. There are a number of flushing methods used to remove the metal particles efficiently. Flushing can be achieved by one of the following methods: 1) Injection flushing 2) Suction flushing 3) Side flushing 4) Flushing by dielectric pumping.

### 1.6 Tool Material

Tool material should be such that it would not undergo much tool wear when it is impinged by positive ions. Thus the localized temperature rise has to be less by tailoring or properly choosing its properties or even when temperature increases, there would be less melting. Further, the tool should be easily workable as intricate shaped geometric features are machined in EDM.

## 2. OBJECTIVE OF WORK

This work considered the process parameters like discharge current, voltage, spark on time as they have major influence on MRR, TWR and SR and to obtain the common optimum values of process parameters for three responses. work is done on material En31. The machining is done by using copper tool. RSM method is used for design of experiments and optimization of process parameters. The results obtained are analyzed and the models are produced by using MINITAB software.

The objective of this work is to enhance the material removal rate with high surface quality and minimum tool wear rate.

### 2. 1 Selection of Process Parameters

The input parameters which significantly affect on MRR.

1) Discharge current (Ip)

2) Spark on time or Pulse duration (Ton)

3) Voltage (V).

The various levels of the selected parameters are listed in the Table

| Machining parameter | Symbol | Unit | Levels with coding | |
|---|---|---|---|---|
| | | | Low level[ -1] | High level [+1] |
| Discharge current | Ip | A | 4 | 20 |
| Spark on time | Ton | µs | 10 | 40 |
| Voltage | V | volt | 10 | 30 |

**Table no 1:** Levels of process parameters

## 2.2 Design Of Experiment

Design of Experiments (DOE) refers to planning, designing and analyzing an experiment so that valid and objective conclusions can be drawn effectively and efficiently. In performing a designed experiment, changes are made to the input variables and the corresponding changes in the output variables are observed. The input variables are called resources and the output variables are called response.

1. Input variables:

- Discharge current (Ip)
- Spark on time (Ton)
- Voltage (V)

2. Response Variables:

- Material removal rate(MRR)
- Surface Roughness (Ra)
- Tool wear rate (TWR)

## 2.3 Response Surface Methodology

Response surface methodology (RSM) is a collection of mathematical and statistical techniques that are useful for modeling and analysis of problems in which output or response influenced by several variables and the goal is to find the correlation between the response and the variables. It can be used for optimizing the response. It is an empirical modelization technique devoted to the evaluation of relations existing between a group of controlled experimental factors and the observed results of one or more selected criteria.

The first step of RSM is to define the limits of the experimental domain to be explored. These limits are made as wide as possible to obtain a clear response from the model. The Discharge current (Ip), pulse duration (Ton) and voltage (V) are the machining variable, selected for investigation.
In the next step, the planning to accomplish the experiments by means of response surface methodology (RSM) using a Central Composite Design (CCD) with three variables.

CCD offers the advantage that certain level adjustments are allowed and can be used in two-step chronological response surface methods.

## 2.4 Tool Electrode and Work Piece Selection

A cylindrical shaped pure copper of diameter 10 mm is used for machining of EN31 material. EN31 is a popular grade of through-hardening alloy steel. EN31 is used in components such as gears, shafts, studs and bolts.

| Element | Composition weight (%) |
|---|---|
| C | 0.36-0.44 |
| SI | 0.10-0.35 |
| MN | 0.45-0.70 |
| S | 0.040 max |
| P | 0.035 max |
| Cr | 1.00-1.40 |
| Mo | 0.20-0.35 |
| Ni | 1.30-1.70 |

**Table no 2:** Composition of EN31 material

## 2.5 Calculation for material removal rate and Tool wear rate

**1. Mechanism of MRR :** The material removal rate (MRR) is expressed as the ratio of the difference of weight of the work piece before and after machining to the machining time and density of the material.

$$MRR = \frac{Wjb - Wja}{t \times \rho}$$

**2 Mechanism of TWR :** Electrode Wear is an important factor because if affects dimensional accuracy and the shape produced. Electrode wear is related to the melting point of the electrode material.

TWR = (Wbm - Wam)/t

Where,

Wbm = Weight of electrode before machining.

Wam = Weight of electrode after machining.

t = Machining period

## 2.6 Experimental results

The density of the material is 0.0072 gm/mm3. And machining time in each run is 5 min.

| Run | Ip | Ton | V | MRR | TWR | SR |
|---|---|---|---|---|---|---|
| 1 | 12 | 25 | 20 | 14.2 | 0.014 | 1.3 |
| 2 | 4 | 10 | 10 | 6.8 | 0.010 | 1.01 |
| 3 | 12 | 25 | 20 | 14.3 | 0.015 | 1.31 |
| 4 | 12 | 10 | 20 | 12.3 | 0.013 | 1.25 |
| 5 | 20 | 10 | 10 | 16.30 | 0.018 | 1.7 |
| 6 | 4 | 10 | 30 | 7.5 | 0.012 | 1.2 |
| 7 | 20 | 40 | 10 | 18.42 | 0.02 | 1.9 |
| 8 | 20 | 40 | 30 | 22.86 | 0.032 | 2.3 |
| 9 | 12 | 25 | 20 | 14.2 | 0.014 | 1.3 |
| 10 | 20 | 10 | 30 | 19.53 | 0.021 | 2.0 |
| 11 | 12 | 25 | 20 | 14.1 | 0.013 | 1.32 |
| 12 | 12 | 25 | 20 | 14.2 | 0.014 | 1.3 |
| 13 | 4 | 40 | 10 | 7.3 | 0.011 | 1.1 |
| 14 | 12 | 40 | 20 | 12.3 | 0.013 | 1.25 |
| 15 | 12 | 25 | 20 | 14.2 | 0.014 | 1.3 |
| 16 | 12 | 25 | 30 | 11.8 | 0.013 | 1.3 |
| 17 | 20 | 25 | 20 | 21.33 | 0.025 | 2.2 |
| 18 | 4 | 25 | 20 | 8.5 | 0.011 | 1.12 |
| 19 | 12 | 25 | 10 | 12.4 | 0.012 | 1.2 |
| 20 | 4 | 40 | 30 | 10.4 | 0.011 | 1.13 |

MRR increases with increase in spark on time. As the spark duration increases, the heat developed increases and maximum material is melted. So, MRR increases. MRR also increases with increase in voltage. As the voltage increases, the amount of current discharge increases and finally MRR increases.

TWR increases with increase in spark on time. As the spark duration increases, the heat developed increases. So, TWR increases. TWR also increases with increase in voltage.

SR also increases with increase in spark on time. As the spark duration increases, the heat developed increases. So, SR increases. As discharge current increases SR increases. SR also increases with increase in voltage.

## 3. CONCLUSIONS

Discharge current is the most influencing factor than voltage and Pulse duration time.

MRR increases with the increase in discharge current (Ip) and voltage (V).

The obtained optimum values for the selected parameters are: Ip=7.3A, Ton =21.28µs, V= 10 volt

While machining the material EN31, the industrialist can directly use the optimum values so that the material removal rate will be maximum and tool wear rate and surface roughness will be minimum.

This will save the time required for machining, improve surface roughness, avoid excess tool wear, save the electrical power consumption, reduce labor cost, etc.

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