# Experimental Analysis and Modeling of MRR in Electrical Discharge Machining

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**Abstract**

The selection of machining parameters is one of the most important aspects in the electrical discharge machining operation as these conditions has important effect on material removal rate (MRR). In this paper the experiments were conducted on the machining of EN 31 die steel with graphite electrode with electrical discharge machining (EDM). The EDM oil commercial grade has been used as dielectric fluid. The effect of various EDM parameters such as discharge current, Ton and Toff has been investigated to yield the response in terms of MRR. In this work mathematical models have been developed for relating the MRR with machining parameters like discharge current, Ton, and Toff. The optimum value has been determined with the help of main effect plot and ANOVA table.

## 1. Introduction

Electric discharge machining (EDM), sometimes also referred to as spark machining, spark eroding, burning, die sinking or wire erosion, is a manufacturing process whereby a desired shape is obtained using electrical discharges (sparks). In the present day of technological advancement in industries like, automobile, aeronautics, nuclear, mould, tools and die making industries, there is a heavy demand of the advanced materials with high strength, high hardness, temperature resistance and high strength to weight ratio etc. This necessity leads to evolution of advance materials like high strength alloys, ceramics, fiber-reinforced composites etc. In machining of these materials, conventional manufacturing processes are increasingly being replaced by more advanced techniques, which use different form of energy to remove the material because these advance materials are difficult to machine by the conventional machining processes, and it is difficult to attain good surface finish with close tolerance. Electrical discharge machining is a machining method primarily used for hard metals or those that would be very difficult to machine with traditional techniques. EDM typically works with materials that are electrically conductive, although methods for machining insulating ceramics with EDM have also been proposed. EDM can cut intricate contours or cavities in pre-hardened steel without the need for heat treatment to soften and re-harden them. Also, applications of this process to shape polycrystalline diamond tools have been reported. To obtain a specific geometry, the EDM tool is guided along the desired path very close to the work; ideally it should not touch the workpiece, although in reality this may happen due to the performance of the specific motion control in use. In this way, a large number of current discharges (colloquially also called sparks) happen, each contributing to the removal of material from both tool and workpiece, where small craters are formed. The size of the craters is a function of the technological parameters set for the specific job at hand. The presence of these small craters on the tool results in the gradual erosion of the electrode.

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In the present study the optimal condition of MRR has been evaluated with the correlation of machining parameters like discharge current, pulse on time, pulse off time. The objective of this research work is to study MRR and surface roughness with the following design variables:

1. Discharge current
2. Pulse on Time (Ton)
3. Pulse off Time (Toff)

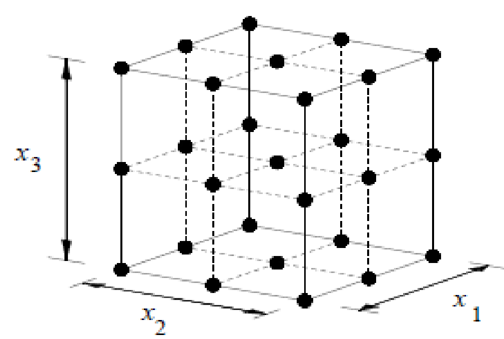


Fig: 1 Full Factorial Design (27 Points)

Montgomery in 1997 given a full factorial approach to construct an approximation model. A *factorial* experiment is an experimental strategy in which design variables are varied together, instead of one at a time. The lower and upper bounds of each of *N* design variables in the optimization problem needs to be defined. The allowable range is then discretized at different levels. If each of the variables is defined at only the lower and upper bounds (two levels), the experimental design is called $2^N$full factorial. Similarly, if the midpoints are included, the design is called $3^N$full factorial and shown in Figure.

Generally, for a large number of variables, the number of experiments grows exponentially ($3^N$for a full factorial) and becomes impractical. A full factorial design typically is used for five or fewer variables.

The experiments were conducted on the machining of EN 31 die steel with graphite electrode with electrical discharge machining (EDM). The EDM oil commercial grade has been used as dielectric fluid. The effect of various EDM parameters such as discharge current, $T_{on}$ and $T_{off}$ has been investigated to yield the response in terms of MRR. In this work mathematical models have been developed for relating the MRR with machining parameters like discharge current, $T_{on}$, and $T_{off}$. The optimum value has been determined with the help of main effect plot and ANOVA table.

## 2. Experimental Setup

The experiments for the have been conducted on Spark erosion machine (SPARKMAN SN-35, Sparkonix) as shown in Fig.1. The machine has maximum current capacity of 35 amps. The experiment was conducted in straight polarity i.e. the tool was connected to the negative terminal whereas workpiece was connected to the positive terminal. In the present study the optimal condition of MRR has been evaluated with the correlation of machining parameters like discharge current, pulse on time, pulse off time. The machining conditions used during experimentation have been shown in table1. Work piece material was cut into rectangular cross section and top and bottom faces of the work piece were ground to make flat and good surface finish prior to experimentation. A photograph of the EDMed work piece is shown in fig 2. The graphite electrode of diameter φ35mm is used with EDM oil as dielectric. Machining depth was kept constant at 1mm for every experimental run and corresponding machining time was measured. After each run the work piece was removed from the machine, dried and weighed before and after machining.

**Fig: 2.** EDM machine SPARKMAN SN-35, Sparkonix

## 3. Results and Discussions

There are large numbers of factors to be considered for MRR calculation in EDM process but in the present work discharge current, pulse on time (Ton), and pulse off time (Toff) have only been taken into account as design factors. The reason why these three factors have been selected as design factors is that they are the most widespread and used amongst EDM researchers.Material removal rate was calculated from the difference of weight of work piece before and after machining process. MRR = ($W_i$ - $W_f$) /T gm/min, Where $W_i$ is the initial weight and $W_f$isthe final weight after machining and T is the total time taken for the machining.

**Fig: 3.** Photograph of EDMed Work Piece

**Table: 1.** Machining Condition used During Experimentation

| **Electrode** | **Work piece** | **Dielectric Fluid** | **Flushing Type** |
|---|---|---|---|
| Graphite, φ35mm<br>Thermal conductivity 80 W/m-k<br>Melting point 4800 $^0$C<br>Electrical resistivity $3.5\times10^{-3}$ ohm-cm<br>Specific heat capacity 7.10 J/g $^0$C | EN 31 die steel<br>Elements Composition (wt. %)<br>C 1.07<br>Si 0.32<br>Mn 0.58<br>P 0.04<br>S 0.03<br>Cr 1.12<br>V -<br>Fe Balance | EDM Oil<br>Specific Gravity 0.757<br>Flash Point 108°C<br>Pour Point 0°C,<br>Viscosity cSt @40°C 3.05<br>Copper Corrosion 1A<br>Di-electric Strength 40 | Submerged |

**Table: 2.** Values of Variables at Different Level

| **Factors** | **LEVELS** | | | |
|---|---|---|---|---|
| | -1 | 0 | +1 | UNIT |
| Control factors | I | II | III | |
| Discharge | 8 | 10 | 12 | Amp |
| Pulse | 4 | 6 | 8 | Micro |
| $T_{OFF}$ | 3 | 5 | 7 | Micro |

## 4. Results and Analysis of MRR

### ANOVA (Analysis of Variance)

The purpose of the statistical analysis of variance (ANOVA) is to investigate which design parameter significantly affects the material removal rate. Based on the ANOVA, the relative importance of the machining parameters with respect to material removal rate is investigated to determine more accurately the optimum combination of the machining parameters.

**Table: 3.** ANOVA: MRR (gm/min) versus Current, Ton, Toff

| Factor | Type | Levels | Values |
|---|---|---|---|
| Current | random | 3 | 8, 10, 12 |
| Ton | Fixed | 3 | 4, 6, 8 |
| Toff | Fixed | 3 | 3, 5, 7 |

**Table: 4.** Analysis of Variance for MRR (gm/min)

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Current | 2 | 0.042855 | 0.021428 | | 0.004 |
| Ton | 2 | 0.028876 | 0.014438 | 4.84 | 0.019 |
| Toff | 2 | 0.002804 | 0.001402 | 0.47 | 0.632 |
| Error | 20 | 0.059619 | 0.002981 | | |
| Total | 26 | 0.134155 | | | |

S = 0.0545981 R-Sq = 55.56% R-Sq(adj) = 42.23%

**Table: 5.** Experimental Results and S/N Ratis of MRR

| Exp No | Peak Current | $T_{ON}$ | $T_{OFF}$ | Initial Wt(gm) | Final Wt(gm) | Time taken(min) | MRR(gm/min) |
|---|---|---|---|---|---|---|---|
| 1 | 8 | 6 | 7 | 565.365 | 554.253 | 184 | 0.0604 |
| 2 | 10 | 6 | 7 | 565.363 | 558.063 | 117 | 0.0624 |
| 3 | 12 | 6 | 7 | 561.131 | 553.632 | 78 | 0.0961 |
| 4 | 8 | 8 | 7 | 599.231 | 591.921 | 146 | 0.05 |
| 5 | 10 | 8 | 7 | 595.912 | 588.531 | 97 | 0.0761 |
| 6 | 12 | 8 | 7 | 530.501 | 522.481 | 76 | 0.1055 |
| 7 | 8 | 4 | 7 | 470.015 | 464.164 | 117 | 0.05 |
| 8 | 10 | 4 | 7 | 465.392 | 458.911 | 92 | 0.0704 |
| 9 | 12 | 4 | 7 | 433.981 | 426.951 | 76 | 0.0925 |
| 10 | 8 | 6 | 5 | 464.162 | 458.081 | 51 | 0.1192 |
| 11 | 10 | 6 | 5 | 458.915 | 452.531 | 34 | 0.1878 |
| 12 | 12 | 6 | 5 | 522.092 | 516.821 | 21 | 0.251 |
| 13 | 8 | 8 | 5 | 570.441 | 563.43 | 70 | 0.1001 |
| 14 | 10 | 8 | 5 | 514.771 | 507.581 | 42 | 0.1712 |
| 15 | 12 | 8 | 5 | 532.352 | 525.221 | 38 | 0.1877 |
| 16 | 8 | 4 | 5 | 533.423 | 527.812 | 105 | 0.0534 |
| 17 | 10 | 4 | 5 | 491.572 | 486.642 | 45 | 0.1096 |
| 18 | 12 | 4 | 5 | 524.014 | 518.073 | 54 | 0.11 |
| 19 | 8 | 6 | 3 | 527.815 | 520.384 | 43 | 0.1728 |
| 20 | 10 | 6 | 3 | 486.642 | 479.513 | 30 | 0.2376 |
| 21 | 12 | 6 | 3 | 442.132 | 435.121 | 23 | 0.3048 |
| 22 | 8 | 8 | 3 | 463.075 | 456.714 | 80 | 0.0795 |
| 23 | 10 | 8 | 3 | 459.915 | 453.065 | 58 | 0.1181 |
| 24 | 12 | 8 | 3 | 435.101 | 427.391 | 30 | 0.257 |
| 25 | 8 | 4 | 3 | 456.712 | 450.292 | 104 | 0.0617 |
| 26 | 10 | 4 | 3 | 453.064 | 446.945 | 47 | 0.1302 |
| 27 | 12 | 4 | 3 | 438.981 | 433.982 | 26 | 0.1922 |

The regression equation is

MRR(gm/min) = 0.0203 Current - 0.0134 Ton + 0.00063 Toff

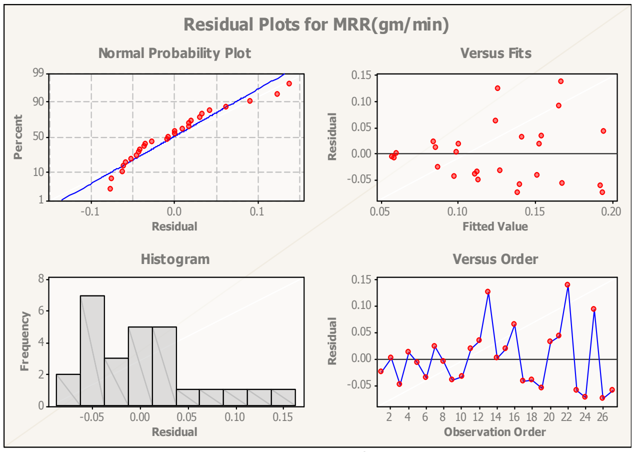


**Fig: 4.** Residual Plots for MRR

## 5. Conclusions

After analyzing the results of the experiment performed on EN31 die steel with graphite electrode material with different discharge current, $T_{on}$ and $T_{off}$, following conclusions are arrived at:

MRR increases with increase in discharge current. The enhancement in MRR may be attributed due to increase in pulse energy as the current increases.At higher levels of current, wear rate of graphite increases and causes some machining problems which further reduces MRR. This may be due to arc produced at high current densities.With increase in Ton for same discharge current the MRR decreases. With increase in Toff for the same current the MRR decreases.With lower Toff the MRR is more as compared to lower Ton.

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