

**Experimental study of Material Removal Rate for Electrical Discharge Machining**Mehul G. Mehta¹, Dr. Jeetendra A. Vadher²¹S.S.Engineering college, Bhavnagar²S.S.Engineering college, Bhavnagar

Abstract: Electrical discharge machining (EDM) process is one of the most commonly used nonconventional precise material removal processes, based on thermo electric energy between the work piece and an electrode. It is the thermal erosion process in which metal is removed by a series of recurring electrical discharges between a cutting tool acting as an electrode and a conductive work piece, in the presence of a dielectric fluid. In this process, the material removal is done electro thermally by a series of successive discrete discharges between electrode and the work piece[1].

Material removal rate (MRR) is an important performance measure in EDM process. Since long, EDM researchers have explored a number of ways to improve and optimize the MRR. The research work in this area shares the same objectives of achieving more efficient material removal coupled with a reduction in tool wear and improved surface quality[2].

This paper deals with the experimental investigation on High speed steel by EDM process using a special copper electrode as the tool. The influence of discharge current, pulse-on time, duty factor on material removal rate (MRR) has been studied.

Keywords: Electrical discharge machining (EDM), FEM, Material removal rate (MRR), Electrode wear Rate (EWR), Duty cycle, Gap current

I. INTRODUCTION

Electrical Discharge Machining (EDM) is nontraditional machining process where, no physical cutting forces between the tool and the workpiece. It is high precision metal removal process using thermal energy by generating a spark to erode the workpiece. The workpiece must be a conductive electricity material which is submerged into the dielectric fluid for better erosion. EDM machine has wide application in production of die cavity with large components, deep small diameter hole and various intricate holes and other precision part[3].

In the Die -Sinker EDM Machining process, two metal parts submerged in an insulating liquid are connected to a source of current which is switched on and off automatically depending on the parameters set on the controller. When the current is switched on, an electric tension is created between the two metal parts. If the two parts are brought together to within a minimum gap, the electrical tension is discharged and a spark jumps across. Where it strikes, the metal is heated up so much that it melts[4].

1.1 Working Principle of EDM

The working principle of EDM process is based on the thermoelectric energy. This energy is created between a workpiece and an electrode submerged in a dielectric fluid with the passage of electric current. The workpiece and the electrode are separated by a small gap called spark gap. Pulsed arc discharges occur in this gap filled with an insulating medium, preferably a dielectric liquid like hydrocarbon oil or de-ionized (de-mineralized) water [5-8]. There is no mechanical contact between the electrodes during the whole process. Since erosion is produced by electrical discharges, both electrode and workpiece have to be electrically conductive[5]. Thus, the machining process consists in successively removing small volumes of workpiece material, molten or vaporized during each discharge.

It has been found from the experimental investigation that in case of material removal rate (MRR), electrical and thermal conductivity are the primary influencing factors. The high electrical conductivity facilitates the sparking process and increases effective pulses which increase material removal rate (MRR).

In this process the metal is removed from the workpiece due to erosion caused by rapidly recurring spark discharge taking place between the tool and work piece. Fig 1 shows the mechanical set up and electrical set up for electro discharge machining. A thin gap about 0.025mm is maintained between the tool and work piece by a servo system shown in fig 1.1. Both tool and work piece are submerged in a dielectric fluid. Kerosene/EDM oil/demineralized water is very common type of liquid dielectric although gaseous dielectrics are also used in certain cases[6-7].

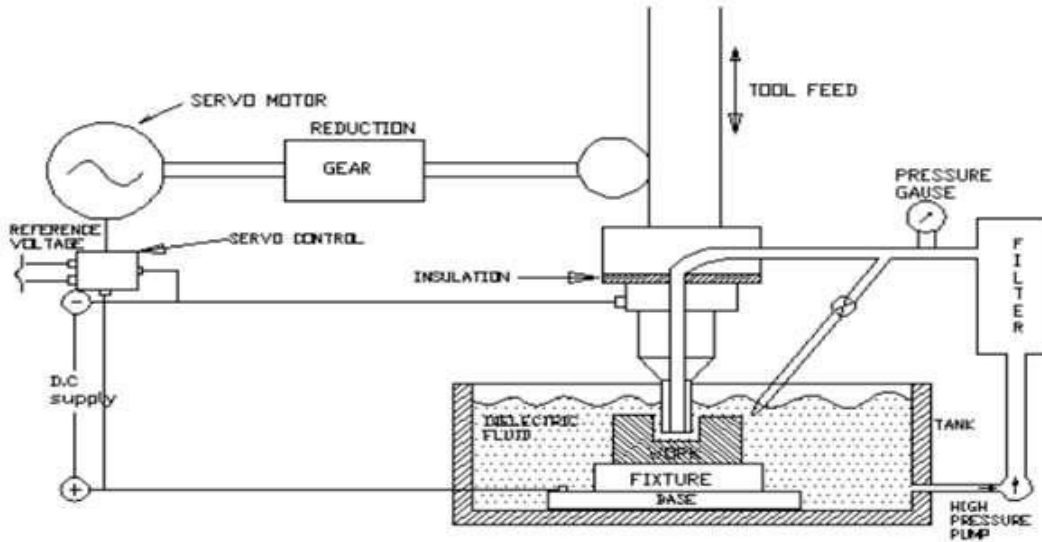


Fig.1 Electric discharge machine

The tool is made cathode and work piece is anode. When the voltage across the gap becomes sufficiently high it discharges through the gap in the form of the spark in interval of 10 micro seconds and positive ions and electrons are accelerated, producing a discharge channel that becomes conductive. It is just at this point when the spark jumps causing collisions between ions and electrons and creating a channel of plasma. A sudden drop of the electric resistance of the previous channel allows that current density reaches very high values producing an increase of ionization and the creation of a powerful magnetic field[8]. The moment spark generated, sufficient pressure developed between work and tool as a result of which a very high temperature is produced and at such high pressure and temperature that some metal is melted and eroded. Such localized extreme rise in temperature leads to material removal. Material removal is due to instant vaporization of the material as well as due to melting. The molten metal is not removed completely but only partially.

As the potential difference is withdrawn as shown in the Fig. 2, the plasma channel is no longer sustained. As the plasma channel collapse, it generates pressure or shock waves, which evacuates the molten material forming a crater of removed material around the site of the spark.

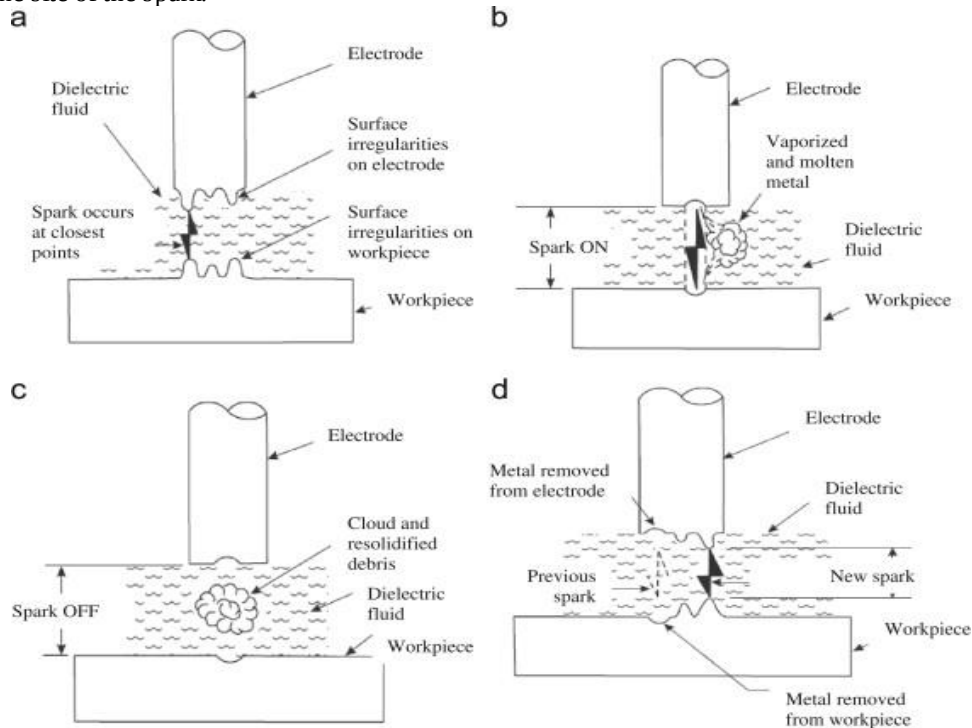


Fig.2: Working Principal of EDM Process

2. Important parameters of EDM

There are different parameters like spark on time, spark off time, breakdown voltage, gap current, duty cycle etc. Which are play very vital role in erosion of material are presented below.

1. Spark On-time (pulse time or Ton): The duration of time (μ s) the current is allowed to flow per cycle. Material removal is directly proportional to the amount of energy applied during this on-time. This energy is really controlled by the peak current and the length of the on-time.
2. Spark Off-time (pause time or Toff): The duration of time (μ s) between the sparks (that is to say, on-time). This time allows the molten material to solidify and to be wash out of the arc gap. This parameter is to affect the speed and the stability of the cut. Thus, if the off-time is too short, it will cause sparks to be unstable.
3. Arc gap (or gap): The Arc gap is distance between the electrode and workpiece during the process of EDM. It may be called as spark gap. Spark gap can be maintained by servo system.
4. Discharge current (current I_p): Current is measured in amp Allowed to per cycle. Discharge current is directly proportional to the Material removal rate.
5. Duty cycle (τ): It is a percentage of the on-time relative to the total cycle time. This parameter is calculated by dividing the on-time by the total cycle time (on-time plus off time).
6. Voltage (V): It is a potential that can be measure by volt it is also effect to the material removal rate and allowed per cycle. Voltage is given by in this experiment is 50 V.
7. Over cut : It is a clearance per side between the electrode and the workpiece after the marching operation.

2.1 Tool Material

Tool material should be selected such that it should not undergo more wear due to impingement of positive ions. It should have high electrical and thermal conductivity. There would be less volume removal or tool wear and thus less dimensional loss or inaccuracy for the same heat load and same tool wear by weight[9].

And the localized temperature rise should be less by 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.

2.2 Work Material

EDM is capable of machining geometrically complex or hard material components, that are precise and difficult-to-machine such as tool steels, composites, super alloys, ceramics, carbides, heat resistant steels etc. , of whatsoever hardness. There are different types of tool material made using the EDM method and the tool steel Contains carbon and alloy steels that are particularly well-suited to be made into tools. Their suitability comes from their distinctive hardness, resistance to abrasion, their ability to hold a cutting edge, and/or their resistance to deform at elevated temperatures (red-hardness)[10-11]. Tool steel is generally used in a heat-treated state. Tool steels are made to a number of grades for different applications. In general, the edge temperature under expected use is an important determinant of both composition and required heat treatment. The higher carbon grades are typically used for such applications as stamping dies, metal cutting tools, etc. are made with EDM.

2.3 Dielectric fluid

Material removal mainly 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[12]. Dielectric medium is generally flushed around the spark zone. It is also applied through the tool to achieve efficient removal of molten material.

The dielectric fluid has the following functions:

- (a) It helps in initiating discharge by serving as a conducting medium when ionised, and conveys the spark. It concentrates the energy to a very narrow region.
- (b) It helps in quenching the spark, cooling the work, tool electrode and enables arcing to be prevented.
- (c) It carries away the eroded metal along with it.
- (d) It acts as a coolant in quenching the sparks.

II. STUDY OF INDUSTRIAL EDM OPERATION

The Experiment has been carried out to gain the in depth knowledge of the EDM and to study realistic applications.

In Sureliya industries, Rajkot job work is conducted using the **EDM, Model S-25, SPARKONIX (I) PVT. LTD (Spark erosion)** the polarity of the electrode was set as positive while that of workpiece was negative. The dielectric fluid used was EDM oil (specific gravity- 747.7167 kg/m^3). The EDM consists of the following parts:

- Dielectric reservoir, pump and circulation system.
- Power generator and control unit.
- Working tank with work holding device.
- X-Y working table
- The tool holder
- The servo system for feeding the tool.



Fig.3: Set up of workpiece and tool

2.1 Selection of Workpiece for Experiment

The work piece material is High speed steel. It is capable of cutting metal at a much higher rate than carbon tool steel and continues to cut and retain its hardness even when the point of the tool is heated to a low red temperature. Tungsten is the major alloying element which gives red hardness but it is also combined with chromium, molybdenum, vanadium and cobalt in different amounts. At many places it is replaced by cemented carbides but it is still widely used for the manufacture of taps, dies, twist drills, reamers, saw blades and other cutting tools[13,14].

Table No. 1 Thermal and Structural Properties of Material

SR. NO.	PROPERTIES	VALUE
1	$k \text{ (W/mK)}$	40.2
2	$\rho \text{ (kg/m}^3\text{)}$	8691
3	$C \text{ (J/kg K)}$	419
4	$\alpha_t \text{ (/K)}$	11.7×10^{-6}
5	$E \text{ (GN/m}^2\text{)}$	208
6	$T_m \text{ (}^\circ\text{C)}$	1965

7	v	0.3
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2.2 Tool Design

The tool material used in EDM can be of a variety of metals like copper, brass, aluminum alloys, silver alloys etc. The tool material used in this experiment is copper and workpiece as a HSS. The work piece is in the shape of a rectangular having a dimension 25 mm × 15 mm × 10 mm.

TABLE No.2 RESULTS OF EXPERIMENT

Run No	Ip (A)	t _{on} (μs)	t _{off} (μs)	Spark Radius (μm)
1	10	32	9	0.025
2	12	38	9	0.031
3	14	48	9	0.036
1	10	32	9	0.025
2	12	42	9	0.031
3	14	52	9	0.036

III-DETERMINATION OF MRR USING ANALYTICAL METHOD

Material removal rate (MRR) is the rate at which the material is removed from the workpiece. Electric sparks are produced between the tool and the workpiece during the machining process [15]. Each spark produces a tiny crater and thus erosion of material is caused.

The MRR is defined as the ratio of the difference in weight of the workpiece before and after machining to the density of the material and the machining time.

$$MRR = \frac{\text{Volume of crater}}{\text{Pulse time}} = \frac{V_c}{t_{on} + t_{off}}$$

t_{on} = Pulse on time

t_{off} = Pulse off time

Where, V_c = Volume of Crater is given by

$$V_c = \frac{\pi}{6} Z_c (3r_c^2 + Z_c^2)$$

Where, Z_c = Depth of molten metal

r_c = Radius of Crater

Now to find out radius of crater the following equation is used:

$$r_c = R_{pa} - \frac{kT_m \Pi R_{pa}^2}{F_a UI} - \frac{R_{pa}^2}{2\sqrt{\Pi \alpha t_{on}}}$$

Where, k = Thermal Conductivity (W/mK)

T_m = Melting Temperature (°C)

R_{pa} = Spark radius (μm)

F_a = Constant of die electric fluid

U = Gap Voltage (V)

I = Gap Current (A)

α = Thermal Diffusivity

To find out the spark radius the following equation is used:

$$R_{pa} = (2.04 \times 10^{-3}) I^{0.43} t_{on}^{0.44}$$

Table 3. Comparison of analytical and simulated results

Run No.	Ip (A)	t _{on} (μs)	t _{off} (μs)	Spark Radius (μm)	MRR (mm ³ /min) Analytical Result	MRR (mm ³ /min) Present Simulated Result	Percentage error (%)
1	8	28	9	0.022	12.26	12.5	0.12
2	10	38	9	0.017	13.26	13.6	0.13
3	12	48	9	0.020	13.33	13.55	0.13
1	8	28	9	0.022	11.54	11.80	0.11
2	10	38	9	0.017	13.98	14.25	0.14
3	12	48	9	0.020	18.29	18.85	0.18

IV ANALYSIS AND DISCUSSION OF MRR

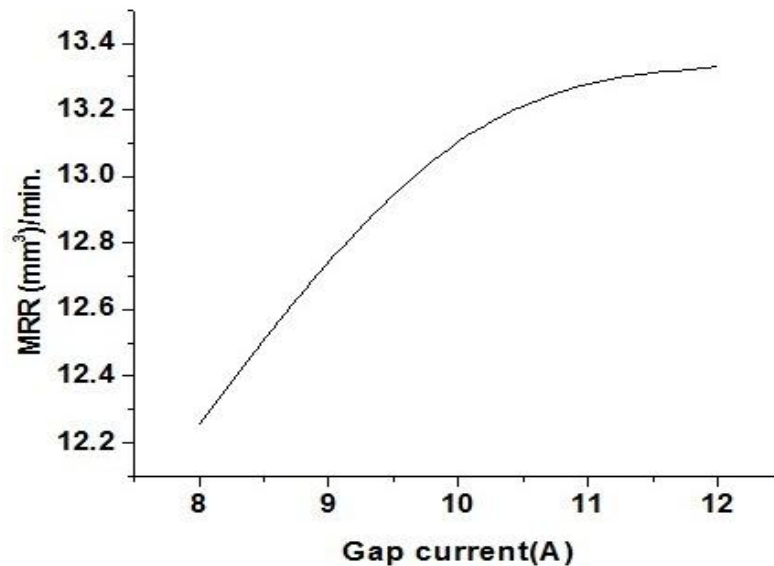


Fig.4 MRR Vs. Gap current

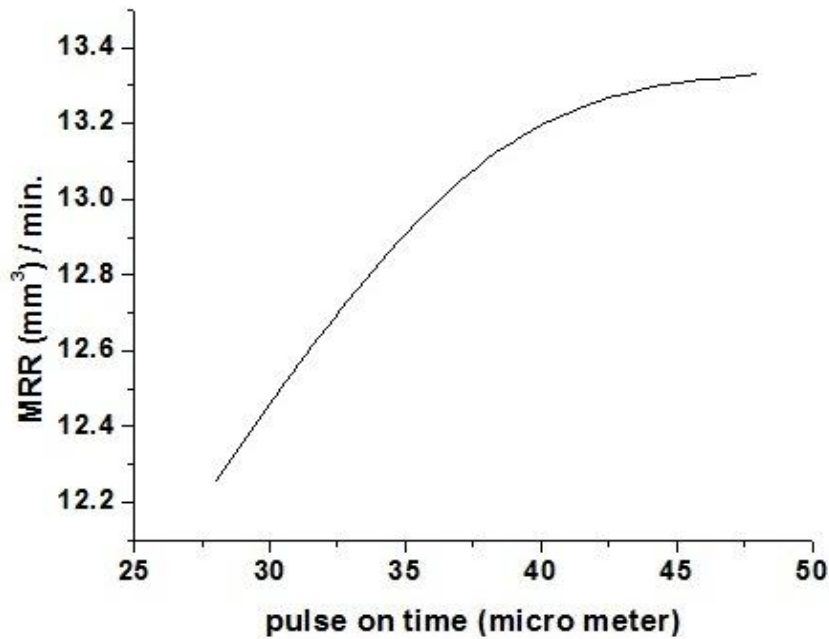


Fig.5 MRR Vs. Pulse on time

The MRR increases as the current increases throughout the entire range. In case of pulse on time, the MRR first slightly increases up to 38 μ s and then increase constantly till 48 μ s because of as increasing in gap current and pulse on time spark stimulated on the surface is supplementary so the material removal rate also increases. The increase in temperature rise is directly proportional to the increase in current due to high heat flux value which leads to higher compressive thermal stress es.

VALIDATION OF SIMULATION MODEL

The validation of the simulation model is performed by comparing the MRR calculated using analytical calculations with the simulated results. The series of simulation has been carried out and the inputs used are listed in the table Fig. 5 and 6 Shows the compared results for the validation.

The higher material removal rate (MRR) will result in better machining performance rate.

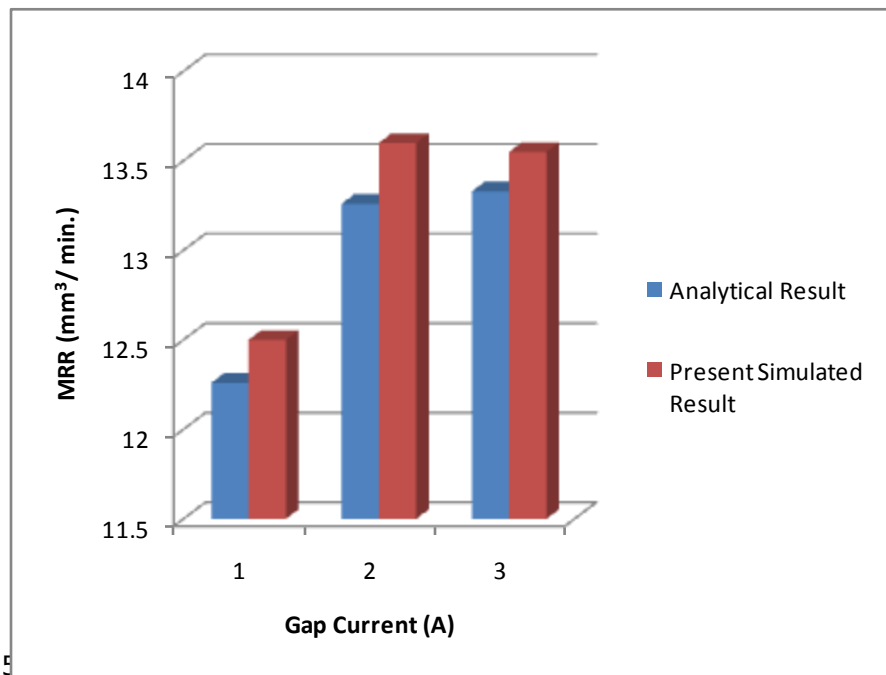


Fig. 6 Graph for 1mm

Depth

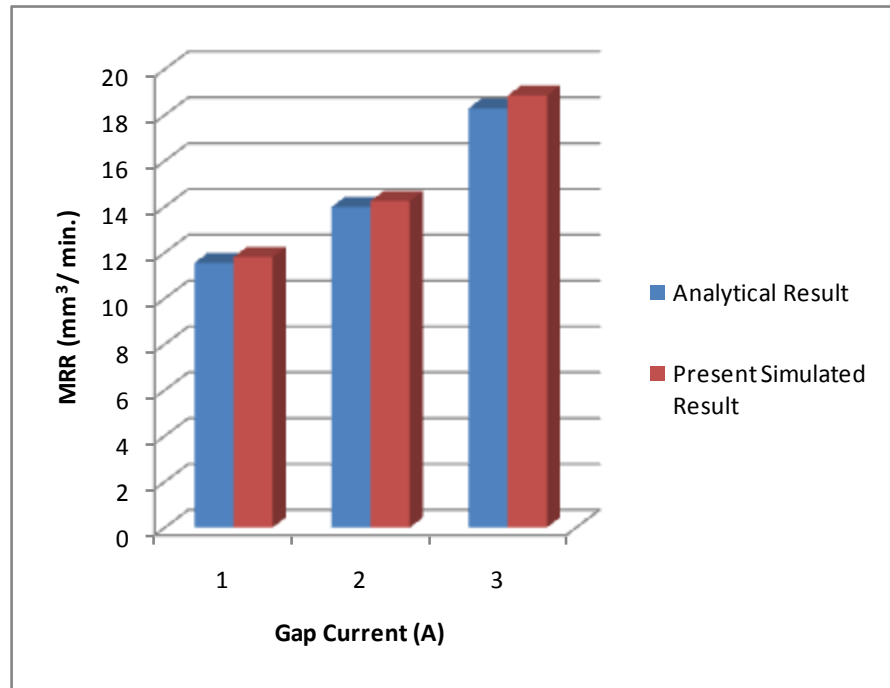


Fig 7. Graph for 0.5 mm Depth

CONCULATION

There is difference in the value of MRR between the analytical and simulated results as it is due to the fact that in analytical method parabolic isotherm is assumed for MRR calculations but in the case of simulation work the isotherm is not exactly parabolic. The higher material removal rate (MRR) will result in better machining performance rate and the interaction effect of Pulse on time and Gap current is significant on Material Removal Rate.

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