Electric Discharge Machining : Modelling and Current Advanced Developments in Aerospace

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Abstract

Electrical discharge machining (EDM) process is one of the most commonly used nonconventional precise material removal processes. This paper presents the modeling of material removal rate and surface roughness of Electrical discharge machining process and their variation with circuit parameters. For carrying out the experiments, a numerically controlled electrical discharge machine was used. The paper also briefly describes the current techniques and trends in EDM and its applications in the field of aerospace.
Keywords: Discharge, Dielectric, Die-Sink, Electro-Thermal, Material Removal Rate, Ram, Surface Roughness, Wire-Cut

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I. NOMENCLATURE

1) EDM Electric Discharge Machining
2) MRR Material Removal Rate, mm3/min
3) HAZ Heat Affected Zone
4) SR Surface Roughness
5) TWR Tool Wear Rate, mm3/min
6) MS Mild Steel
7) I_o Spark Current, Amp
8) V Spark Voltage, Volts
9) t_{on} Pulse on time in sec
10) T time taken for machining
11) Δw Weight difference before and after machining, grams

II. INTRODUCTION

Electric Discharge Machining EDM is an electro-thermal non-traditional machining process, where electrical energy is used to generate electrical spark and material removal mainly occurs due to thermal energy of the spark in the presence of a dielectric fluid. This discharge occurs in a voltage gap between the electrode and work piece. Heat from the discharge vaporizes minute particles of work piece material, which are then washed from the gap by the continuously flushing dielectric fluid.

EDM is also referred as spark machining, spark eroding, burning, die sinking or wire erosion where a material removal happens only due to electrical discharge. EDM is mainly used to machine difficult-to-machine materials and high strength temperature resistant alloys. Work material to be machined by EDM has to be electrically conductive. EDM has low material removal rates compared to chip machining.

The benefits of EDM include:

1) EDM is a non-contact process and generates no cutting forces, thus allowing the fabrication of small and fragile components.
2) Intricate details and superior finishes are possible.
3) EDMs have in-built memory allowing the production of intricate parts with minimum human intervention.

EDM is capable of machining hardened material materials without distortion or breakage, and has found applications in aerospace, automotive and tool and die industries.

- Nozzles for fuel injection systems require high quality parts with extreme tolerances.
- For cooling hole, airfoil surface precision machining of aircraft / rocket components (Rotating Disks, Rings, Turbine Blades, Combustion Chambers, etc).

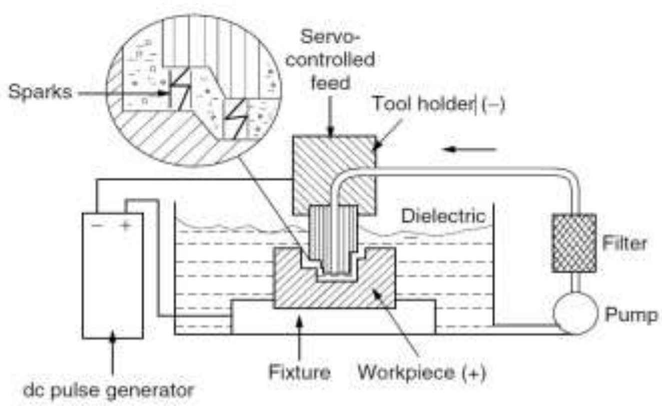

Fig. 1: Schematic of a Die-sink EDM process with spark generation

A. Die-sink /Ram /Vertical EDM

In Ram EDM, the electrode/ tool is fixed to the ram which is usually connected to negative pole of a pulsed power supply. The work piece is connected to positive pole. The work is positioned so that there is gap between it and the electrode. The gap is filled with dielectric fluid. On the supplying power, Direct current of range in 1000 flows across the gap causing erosion of material from the tool and the work piece.

The spark temperature can range from 7,000˚C to 12,000˚C. As the erosion continues, the electrode advances into the work while maintaining gap to generate spark.

B. Wire-Cut EDM

The wire-cut EDM process uses a consumable, electrically charges wire to affect very fine and intricate cuts. The process is mainly deployed in cutting fine details in stamping and blanking dies. It uses a continuous-traveling vertical wire under tension and thus electrode wear is not a problem.

III. MATERIALS AND METHODS

For carrying out the experiments, a numerically controlled Die-sink electrical discharge machine Electronica Smart ZNC was used. The ZNC could be could be controlled with programs along the Z axis, i.e. Z-vertical axis-control and was operated manually along the x and y axis.

A. Electrode Material: Copper (Cu) Work-piece material: Mild Steel MS

1) Equipment

Electric Discharge Machine has the following major parts:

- x − y table along with work table
- Power generator and control unit with a display
- Dielectric Reservoir with pumps & valves circulation system
- Working tank with work holding device
- Tool chuck
- Servo System to feed the tool

2) Specifications

Table – 1
Specification

Parameter	*Setting Value*
I_O	*35 A*
V_O	*415 V, 3 phase, 50 Hz*
Power Rating	*4 kW*
Best Surface Finish	*0.5 µRa*
Minimum Electrode Wear	*0.3 %*
Pulse on time t_{on}	*2.2µsec / 10 steps*

The machining experiments were performed with Copper electrodes having positive polarity. Commercial machine oil was used as a di-electric fluid. The machining operation were done by carrying out the machining process to give a depth of 1 mm to the work-piece.

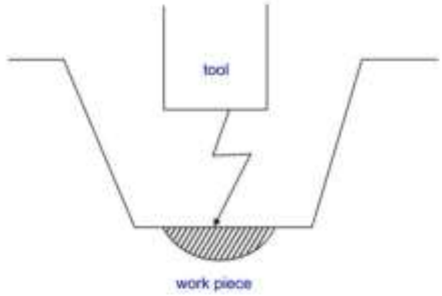

Fig. 2: Schematic representation of crater formation in EDM process

The amount of metal removed was measured by taking the difference in the work-piece before and after electrical discharge machining.

Material Removal Rate (MRR) in mm^3/min Volumetric Electrode Wear (VEW) in mm^3/min and Electrode Wear Ratio (EWR) are calculated by the following formulas:

$$MRR = \frac{1000 * w_w}{\rho_w * T}$$

$$VEW = \frac{1000 * w_e}{\rho_e * T}$$

$$EWR = 100 * \frac{VEW}{MRR}$$

where w_w is the work-piece weight loss in gms, w_e is the electrode weight loss in gms, ρ_w is the work-piece material density in gm/cm^3, ρ_e is the electrode material density in gm/cm^3 and T is the machining time in min.

IV. MODELLING MRR

Material removal in EDM mainly occurs due to localized heating by point source in small time duration. Such heating leads to crater formation as shown in Fig. 4.1 The molten crater is assumed to be hemispherical in nature with a radius *r* which forms due to single spark. Thus, material removed in a single spark cycle can be expressed as

$$V_m = \frac{2}{3}\pi r^3$$

$$\textit{Energy of single spark, } E_s = V \times I \times t_{on}$$

Also, material removed in single spark is assumed to be proportional to spark energy.

$$V_m \propto E_s$$

The material removed is proportional to the spark energy.

$$MRR \propto V \times I \times t_{on}$$

V. MODELLING SURFACE ROUGHNESS

Surface finish is a product quality issue in EDM.

$$h_m = r$$

$$V_m = \frac{2}{3}\pi r^3$$

$$\Rightarrow r = h_m = \left(\frac{3}{2}V_m\right)^{1/3}$$

Assumption: Sparks occur side by side as shown in Fig. 2

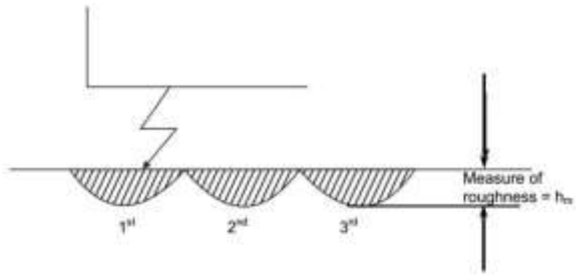

Fig. 3: Schematic representation of sparks in EDM process

I_O	t_{on}	*V*	*T*	Δw	*MRR*	*SR*
10	*500*	*50*	*13.673*	*0.93*	*0.00866*	*0.491*
20	*1000*	*60*	*7.600*	*1.04*	*0.0174*	*0.509*
30	*1500*	*60*	*15.143*	*1.188*	*0.00099*	*0.532*
30	*1000*	*70*	*14.233*	*1.244*	*0.0111*	*0.541*
40	*2000*	*40*	*8.531*	*1.418*	*0.0211*	*0.565*
50	*3000*	*50*	*8.305*	*1.322*	*0.0202*	*0.552*

VI. OBSERVATIONS MACHINED WORK-PIECE SAMPLES

The EDM operation was performed on two different Mild Steel plates using a cylindrical tool. Figure 3 and 4 shows cylindrical grooves machined of different diameters and variations in surface roughness.

Fig. 4: Work piece after machining

VII. RESULTS

The variation of material removal rate and surface roughness versus spark current I_o, spark voltage V and pulse on time t_{on} was plotted and fitted using OriginPro.

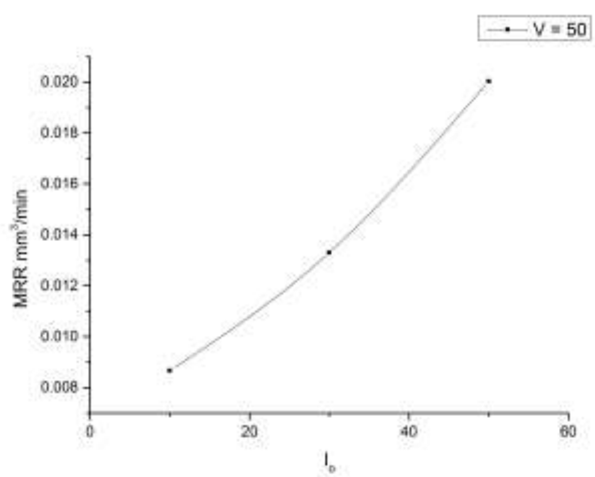

Fig. 5: Variation of MRR with spark current

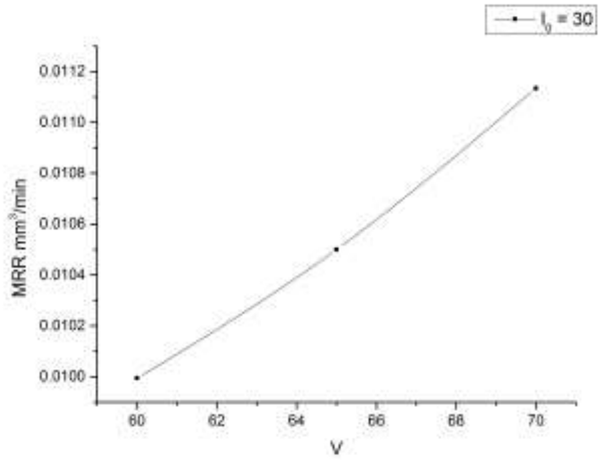

Fig. 6: Variation of MRR with spark voltage

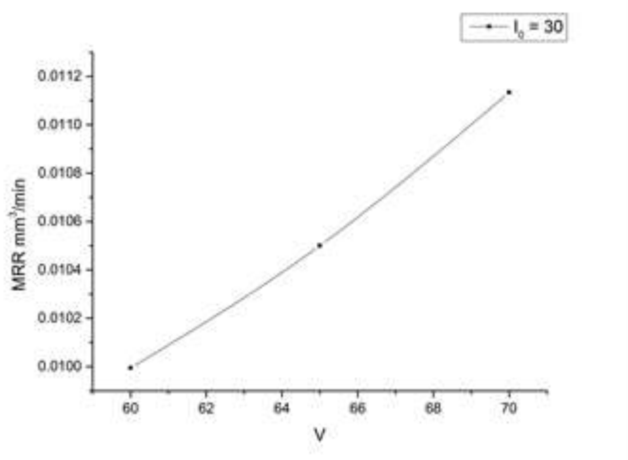

Fig. 7: Variation of MRR with pulse on time

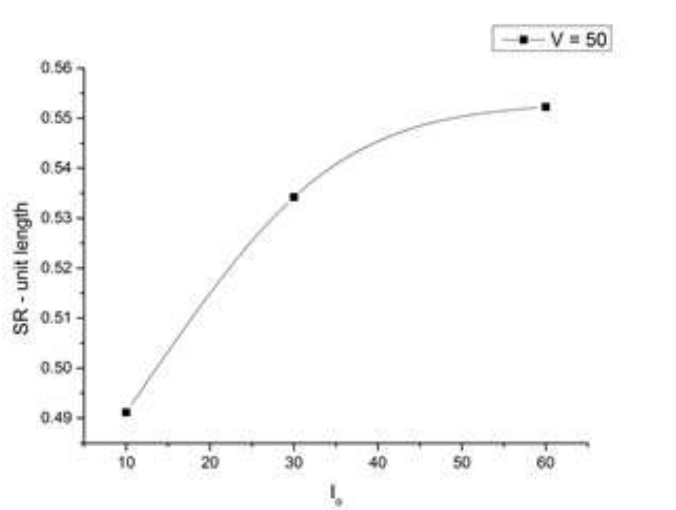

Fig. 8: Variation of SR with pulse on time

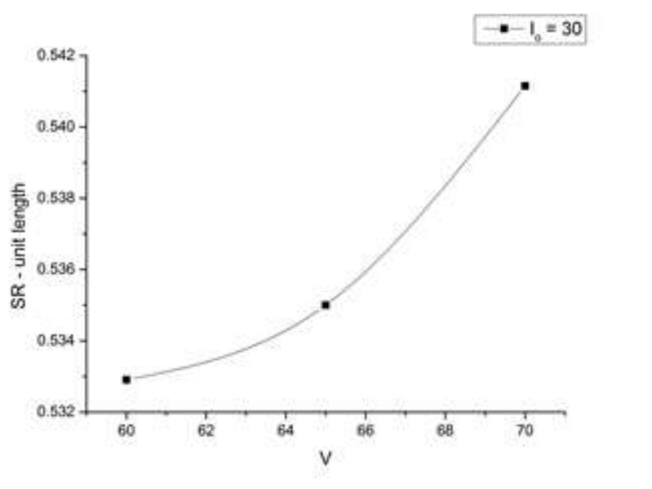

Fig. 9: Variation of SR with pulse on time

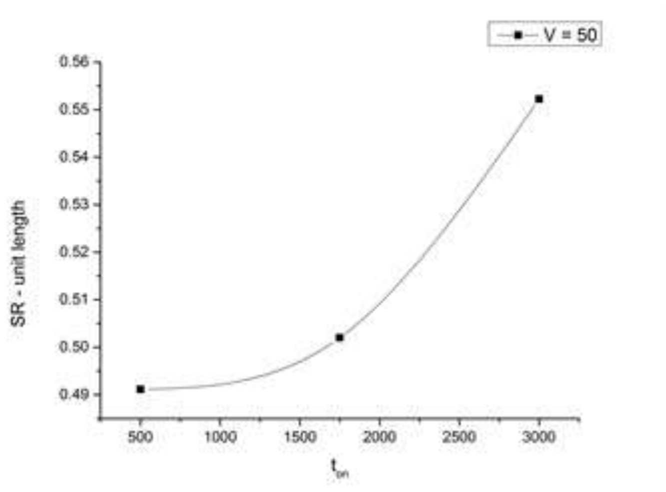

Fig. 10: Variation of SR with pulse on time

VIII. Conclusions

The effects of machining parameters on the Material Removal Rate and the Surface Roughness are calculated.

1) It is observed that material removal in the machining process is directly proportional to the spark energy.

$$MRR \propto SparkEnergy$$
$$SparkEnergy = VIt_{on}$$

Thus, MRR increases with increase in

- voltage
- current
- increase pulse on time and
- decreases pulse off time.

Note: Some part of the spark energy is lost in heating the di-electric and the rest is used for the spark erosion.

2) The surface roughness in EDM increases with increase in spark energy and the surface finish can be improved by decreasing voltage, current and pulse on time.

Surface Roughness in EDM would increase with increase in

- Spark Energy
- current
- voltage
- increase pulse on time

– gap distance between work piece and the electrode

IX. ADVANCEMENTS IN AEROSPACE

Aerospace industries rely on precision manufacturing techniques to drill deep, shaped and curved holes as even slightest misalignment could be catastrophic. Techniques like wire EDM machining and EDM hole drilling are deployed for machining intricate shapes, tough alloys, and very tight tolerances involved components from PCB mounting fixtures to engine turbine blades and everything in between, high precision, high quality aerospace parts.

A. Early Days

It was discovered the EDM process damaged the surface of the components being machined which was a result of the heat generated by the EDM process, and and formed recast layer and Heat Affected Zone (HAZ). This could contain micro cracks that could cause stress failures of critical components. Surface integrity, thereby safety of EDM machined aerospace components was a problem,thus requiring post-EDM secondary processing such as machining (grinding, milling) and chemical etching, or both increasing delivery times, as well as adding extra costs.

B. Improvements

Detailed testing has shown modern EDM machines leave no measurable HAZ. Micro-cracks are almost non-existent. These machines can produce components with finishes measuring microns, tolerances in the submicron range and leave the surface of any part with virtually no damage.

During the 1980s and 1990s, EDM generators continued to be refined. More advanced circuits were used to eliminate noises, control spark generation, monitor spark gaps and automatically make continuous adjustments. These produced lesser recast, smaller HAZ and a better surface integrity. These refinements resulted in a more stable, predictable, and safe process.

C. Recent Industry Test Results

Recently, aerospace manufacturers such as Lockheed Martin have conducted testing to determine advances in EDM tech- nology have improved the surface integrity of EDM-machined components.

Wire EDM machining was performed on titanium components using Zinc coated wire with variable surface finish. After the cut, no measurable HAZ was produced.

D. Cutting Complex Geometries

EDM has been used for decades to manufacture aerospace parts including engine, fuel system, and landing- gear components, as well as other high-stress, high-temperature parts.

E. Turn While Burn: Eliminating Secondary Operations

Turn While Burn technology allows for the machining of highly complex 3D aerospace part shapes and eliminates performing secondary operations on separate machines. The system uses a high precision, servo-controlled programmable indexer.

F. CUT 1000/Oiltech: The World's Most Accurate Wire EDM

Wire diameters have been reduced to as small as 0.0008 inches allows for high levels of autonomy to boost productivity and efficiency, and fine-hole drilling machines can produce clean, accurate holes measuring 11 microns in diameter.

G. High Performance in a Compact Design

The high-speed Z-axis pulse rates, together with high acceleration speeds provide aerospace manufacturers with faster part processing, longer electrode life and superior surface finishes.

H. iQ Technology : Near Zero Electrode Wear

iQ Technology builds a protective layer onto graphite electrodes to practically eliminate wear. iQ Technology allows aerospace manufacturers to use very thin vane-type electrodes to produce extremely fine, stepped narrow slots without fear of electrode deterioration.

I. High-Speed EDM Drilling

The Agie Charmilles ISPG proven generator technology provides intelligent technology settings for entry/exit machining and cylindrical control resulting in superior surface and profile quality while maintaining high speeds and minimum electrode wear.

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