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The Performance of a Resistance-Capacitance Type Pulse Generation Circuit in Electrical Discharge Machining

Karanja Kabini[1]*, Sile K. Bojer[2], Bernard W. Ikua [1], John M. Kihiu [1], George N. Nyakoe[1] and James W. Wamai[1]

[1]*School of Mechanical, Manufacturing and Materials Engineering, JKUAT, P.O. Box 62000-00200, Nairobi.*

[2]*Friedrich Alexander Universität Nürnberg Erlangen, Technical Faculty.*

**Corresponding Author - Email: skkabini@gmail.com.*

Abstract The Electrical Discharge Machining (EDM) Process is complex in nature partly due to the mechanism of material removal, and, partly due to the presence of many machining parameters. This complexity of the EDM process has undermined its full potential drastically reducing its applications. In turn, this has led to relatively higher consumption of electrical energy, longer machining periods, higher rate of electrode wear and lower surface quality of the finished product. Various researchers have used varied approaches with the aim of optimizing the process. However, most of these researches have focused on optimization of one or at most two parameters and have used either fuzzy logic control techniques or modeling approaches. Others have used purely predictive and non-realtime approaches. All of these do not offer the advantage of realtime control of the process. This paper focuses on experimental work carried out to establish the performance of Resistance-Capacitance (RC) pulse generation circuit in the EDM process. Several machining experiments were conducted using RC type of pulse generator on EDM machine and the data recorded and analyzed to test the performance of this type of pulse generator. It was found that, increase in capacitance led to poorer quality of the surface finish and increased MRR. It was also observed that, the amount of capacitance to be used would depend on the required MRR and surface quality. This is part of an ongoing research who's aim is to study the EDM process with a view to designing a controller that is capable of improving the process' efficiency by optimizing all the machining parameters in realtime.

Keywords Capacitance, electrical discharge machining, machining, material removal rate

1. Introduction

Electrical discharge machining (EDM) is a thermal machining process, capable of accurately machining parts from conductive materials irrespective of the material's hardness or parts that have complex shapes. EDM is a very desirable manufacturing process when machining fewer products or high accuracy is needed and is, especially well-suited for cutting intricate contours or delicate cavities such as molds that would be difficult to produce using mechanical means such as grinding or milling [1]. The EDM process is used to produce tools that aid in mass production. EDM also is arguably one of the most accurate manufacturing processes available for machining complex or simple shapes and geometries [2]. However, the efficiency of the EDM process is low and as such, it is only used when the cost and time of machining are not a major consideration. This is because there is excessive tool wear and the material removal rate in EDM is very low as compared to other machining processes.

This research aims at optimizing the EDM process with a view to achieving the best MRR and quality of the surface finish. The EDM process is illustrated in Figure 1.

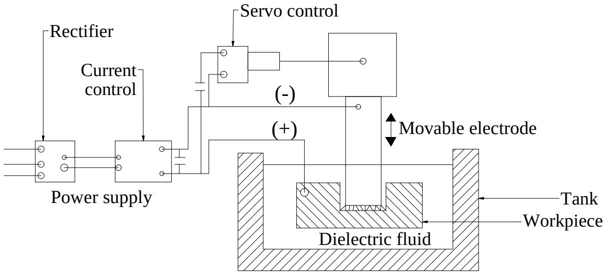

Fig. 1. Illustration of the EDM process

2. Overview of Some Previous Works on EDM

Shabgard *et al* [3] investigated the influence of electrical discharge machining input parameters on the output characteristics of the process. The process characteristics including machining features, i.e., material removal rate, tool wear ratio, arithmetical mean roughness, and surface integrity characteristics comprising of the thickness of white layer and the depth of heat affected zone in machining of AISI H13 tool steel were investigated. The results showed that, when machining AISI H13 tool steel,

- Increase in pulse on-time led to increase in material removal rate, surface roughness, as well the white layer thickness and depth of heat affected zone
- Maintaining constant level of discharge energy, high pulse current and low pulse on-time led to reduction in the white layer thickness and depth of heat affected zone on the surface of the machined workpiece

A study on optimal cutting parameters in wire EDM where a feed-forward neural network was used to associate the cutting parameters with the cutting performance was conducted by Tarng *et al* [4]. A simulated annealing (SA) algorithm was applied to neural networks for solving the optimal cutting parameters based on a performance index. Experimental results showed that the performance of wire-EDM would be greatly enhanced using this approach.

Scott *et al* [5] investigated the effects of spark on-time duration and spark on-time ratio, on material removal rate (MRR) and surface integrity of four types of materialsDuring the wire EDM process, five types of constraints on the MRR were used. These were due to short circuit, wire breakage, machine slide speed limit, and spark on-time upper and lower limits. An envelope of feasible EDM process parameters was generated for each work-material. This process envelope was used to select process parameters for maximum MRR and for machining of micro features. Results of Scanning Electron Microscopy (SEM) analysis of surface integrity showed that the envelope was an effective tool in the selection of the EDM machining parameters for maximum MRR and good surface finish in micro-machining.

Yongshun *et al* [6] developed a geometric model of the linear motor driven EDM process based on Z-map method. The model was employed to calculate the minimum gap distance required for sparking to occur and also analyze the possibility of spark generation between the workpiece and electrode surfaces. The final machined surface topography was then predicted by the model. The influence of peak current and discharge duration on the average surface roughness was also simulated. Experimental work verified the effectiveness of the developed geometric model.

Pecas and Henriques studied the influence of silicon powder mixed dielectric in EDM [7]. Using the silicon powder mixed dielectric, the performance of EDM was investigated. The improvement was assessed through quality surface indicators and process time measurements, over a set of different processing areas. The results showed positive influence of the silicon powder in the reduction of the operating time, required to achieve a specific surface quality, and in the decrease of the surface roughness, allowing the generation of mirror-like surfaces.

Bulent *et al* [8] used a semi-empirical approach to model residual stresses in electric discharge machining (EDM). Layer removal method was used to measure the residual stress profile as a function of depth beneath the surface caused by die sinking type EDM. Cracking and residual stresses were studied on samples machined at long pulse durations. A modified empirical equation was developed for scaling residual stresses in machined surfaces with respect to operating conditions.

Debris accumulation in the discharge gap cause a poor machining stability and low production efficiency. Jin *et al* [9] investigated debris and bubble movements during EDM process. Experimental devices using transparent materials were used to observe debris and bubble movements. Based on the observations, the mechanism of debris and bubble exclusion during consecutive pulse discharges was analyzed, and the effects of the electrode jump height and speed on the debris and bubble movements investigated. It was found that during an electrode down time, the bubble expansion was the main factor that excluded the debris from the spark gap. At the beginning of consecutive pulse discharges, the bubbles excluded the debris from the gap. As the discharge continued, the bubbles ability to exclude the debris became weak, resulting in a debris aggregation in the gap and, thus, an unstable machining. Finally, it was observed that the electrode jump speed affected the mixing degree of the debris and oil.

Nizar *et al* [10] numerically studied thermal aspects of EDM process. The numerical results concerning the temperature distribution due to the process were presented. From these thermal results, the MRR and the total roughness were deduced and compared with experimental observations. The comparison showed that, taking into account the temperature variation of conductivity was of crucial importance and gave the better correlations with experimental data.

Seiji *et al* [11] used a combination of capacitance and conductive working fluid to speed up the fabrication of a narrow, deep hole in metals using EDM process. This was done by use of a dielectric-encased wire electrode, as opposed to the conventional pipe electrode. The dielectric jacket was used to completely suppress unnecessary secondary discharges occurring between the sidewalls of the wire and the fabricated hole. The effectiveness of the combination of conductive working fluid and a capacitor connected to the work piece and the tool electrode was examined. Although electrode wear was severe, machining speed in this case was twice as fast compared with fabricating a hole (without a capacitor and saline water in a 20 mm thick carbon steel block).

Muniu *et al* [12] investigated the applicability of diatomite powder-mixed dielectric fluid in EDM process. In the research, the effect of diatomite powder suspended in distilled water was investigated using graphite as the tool electrode on mild steel workpiece. The process parameters that were used were peak current, pulse-on time and powder concentration. Results showed that, the suspension of diatomite powder in dielectric fluid improved the performance characteristics of conventional EDM process.

3. Theory of Operation

The EDM machine that was used has a capacitive type of pulse generator. The charge across a capacitor is given by

$$Q = CV \tag{1}$$

given that the current through a capacitor is given by

$$I = C\frac{dV}{dt} \tag{2}$$

Differentiating equation 1 gives

$$\frac{dQ}{dt} = C\frac{dV}{dt} \tag{3}$$

Thus, equating equations 2 and 3 gives

$$I = \frac{dQ}{dt} = C\frac{dV}{dt} \tag{4}$$

Integrating both sides,

$$\frac{1}{C}\int Idt = V \tag{5}$$

this implies that

$$C = \frac{1}{V(t)}\int I(t)dt \tag{6}$$

Thus the capacitance (C) is directly proportional to the current (I) and inversely proportional to voltage (V). This is seen in the results obtained during machining.

It is also worth noting here that, the frequency of the pulse signals generated was not constant and it reduced with increase in capacitance. This is so because;

$$f = \frac{1}{2\pi RC} \tag{7}$$

However, since the load resistance of the machine is not known, the pulse frequency was not calculated and is subject for further research.

4. Experimental Setup

The experiments were conducted using an EDM machine fabricated at JKUAT. A photograph of the EDM machine is shown in Figure 2. The machine uses a resistance-capacitive type of pulse generator for machining, and kerosene as the dielectric fluid. The ram is driven by a stepper motor with a drive circuitry that senses short and open circuit and adjusts the stepper motors motion accordingly. A graphite tool was used for machining.

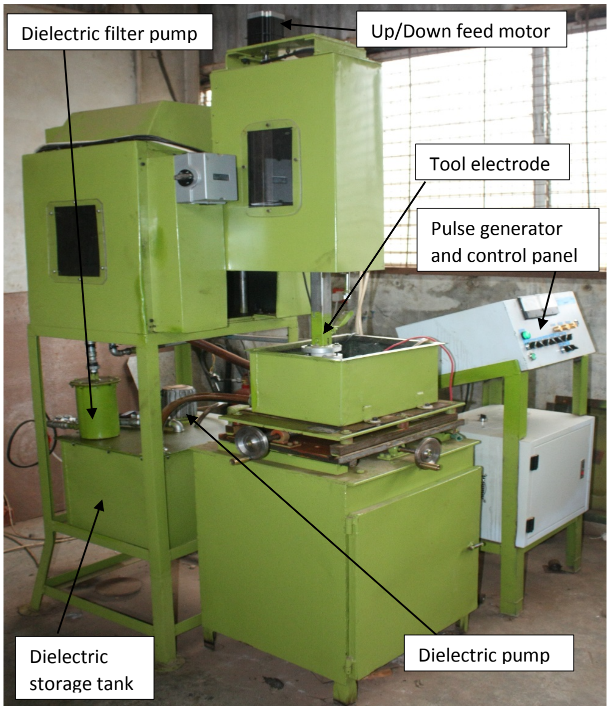

Fig. 2. Photo of the EDM machine

Several identical workpieces of the same material (mild steel) were machined using different values of capacitances as indicated in the Table 1. The samples were each machined for 30 minutes and the resultant parameters tabulated in Figure 2. The values of voltage, current and capacitances were recorded. The surface roughness was analyzed using a Mitutoyo SJ-301 surface roughness tester.

The material removal rate was calculated from Figure 3. The area of the cross section of the machined profile was calculated and multiplied with the the depth of the cut to obtain the volume of the material that was removed for each of the machined workpieces. Then, the volume was divided with machining time to obtain the material removal rate for each of the workpieces. The cross sectional area of the profile was found to be 504 mm^2.

Table 1. Machining parameters

Sample	Applied Capacitance (μF)	Machining time (s)
1	55	180
2	110	180
3	165	180
4	220	180
5	275	180
6	330	180
7	440	180
8	510	180
9	620	180
10	640	180
11	730	180

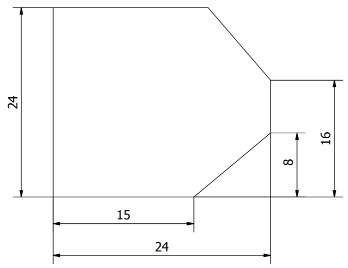

Fig. 3. Profile of the machined feature

5. Results and Discussion

Table 2 shows the applied and measured parameters in EDM machining while using a capacitance type pulse generator. The resultant gap voltage and current are indicated for each sample that was machined. It is worth noting that, when the capacitance was increased, the resultant gap voltage decreased and the gap current increased as expected.

Table 2. Machining parameters

Sample No.	Gap Current (A)	Applied Capacitance (μF)	Gap Voltage (V)	Surface Roughness (μm) RMS	Material Removal Rate (mm^3/min)
1	1.0	55	60	12.6	29.06
2	1.0	110	60	13.4	29.74
3	1.0	165	60	13.5	30.24
4	1.0	220	60	13.7	30.74
5	1.5	275	50	13.8	30.24
6	1.5	330	50	14.2	31.42
7	2.0	440	40	14.2	32.42
8	1.7	510	50	14.4	34.10
9	1.8	620	45	14.5	34.44
10	2.2	640	45	14.7	34.44
11	1.8	730	45	15.1	35.45

A photo of the machined surface is shown in Figure 4. From Figure 5, it can be seen that, the surface roughness increased with increase in the applied capacitance.

During the experiments, it was also seen that, the sparking process was more spontaneous when the capacitance was high. This in turn lead to faster machining time because the material removal rate increased.

Fig. 4. A photograph of a machined specimen

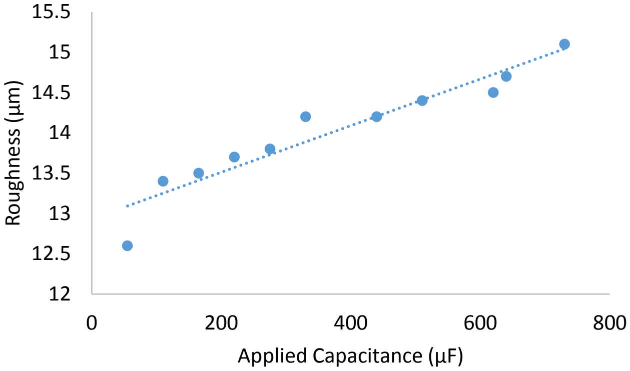

Fig. 5. Effect of capacitance on surface quality

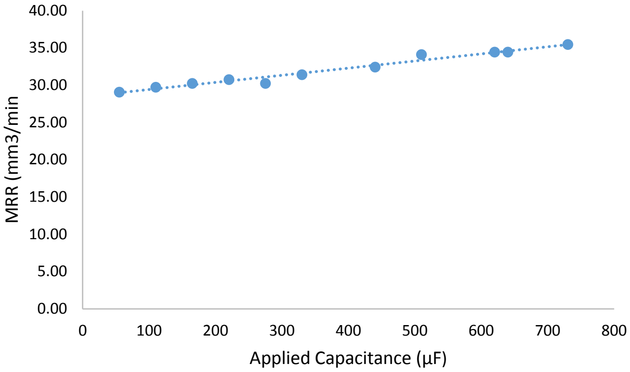

Fig. 6. Indication of MRR with increase in capacitance

From Figure 6 the material removal rate is seen to have been highest when the value of the applied capacitance was high. The vice versa is true. This could be attributed to the prolonged arcing that was seen when the capacitance was high.

6. Conclusions

Increasing capacitance in EDM machining lowers the quality of surface finish. However, the material removal rate is higher with increase in capacitance. In this case of electrical discharge machining using the resistance-capacitance type of pulse generator, there has to be a compromise between the material removal and the surface of the quality.

Further research will be carried out to determine the optimum values of current and voltage for machining without compromising on any of the two. These results will eventually be used in the design of a robust controller for the optimization of the EDM process.

Notable also is the limitation of the pulse type generator in that, when capacitance is adjusted, the gap current and voltage are not adjustable. Future works will involve the use of a transistorized pulse generator for the EDM machine.

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