Effect of Capacitance on Electrical Discharge Machining Using an RC type Pulse Generation Circuit

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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 efficiency. 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 effect of capacitance on the EDM process. 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, EDM, machining, MRR.

I. 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. 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. An example of such a case is where the material being machined is too hard to be machined by other machining processes. This is because there is excessive tool wear and the material removal rate in EDM is very low as compared to other machining processes.

EDM is arguably one of the most accurate manufacturing processes available for machining complex or simple shapes and geometries [2]. The EDM process is illustrated in Figure 1.

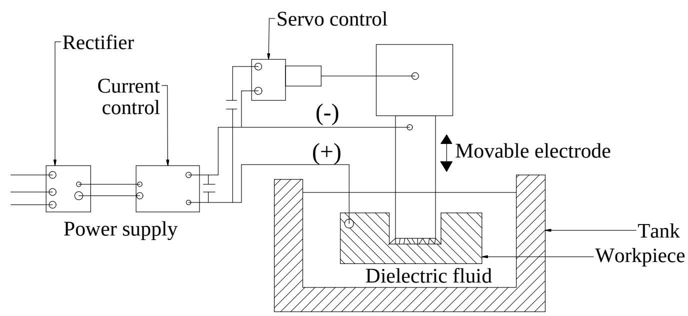

Fig. 1. Illustration of the EDM process

II. PREVIOUS WORKS ON EXPERIMENTAL INVESTIGATION AND MODELING OF 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

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current and voltage depended on the electrode material when the other machining conditions were kept constant. However, the other machining parameters do change during machining process and cannot be assumed constant.

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Scott *et al* [6] 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* [7] 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 [8]. 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* [9] 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* [10] 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* [11] 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* [12] 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* [13] 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.

III. 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

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

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Differentiating equation 1, then

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

Thus, equating equations 2 and 3 gives

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

Integrating both sides,

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

In Laplace transform,

$$sI = CV(s) \tag{6}$$

IV. EXPERIMENTAL SETUP

The experiments were conducted using an EDM machine fabricated in JKUAT. Various identical workpieces of the same material (mild steel) were machined using different machining parameters as indicated in the Table 3 below. The workpieces were uniform and from the same material. The samples were each machined for 30 minutes in order.

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. 2. Machining parameters

V. RESULTS AND DISCUSSION

Table 3 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 machined sample. 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 resistance of the machine is not known, the pulse frequency was not calculated.

From Figure 4 above, it can be noted that, increase in the spark gap voltage led to reduction in root mean square (rms) surface roughness. It can be observed from the Figure that, at a gap voltage of about 45V, the root mean square surface roughness was the highest. It can also be noted that, as the gap voltage approaches 40V, the rms surface roughness is reduced.

The rms surface roughness of the machined workpiece was observed to increase with the increase in spark gap current as shown in Figure 5. However, it was noted that the material removal rate increased with increase gap current. It was also noted that the increase in surface roughness reached a maximum at a gap current of about 1.8A. This also shows the period at which the material removal rate was maximum after which it falls down gradually with further increase in current. From Figure 6, it can be observed that, the surface roughness increases with increase in the applied capacitance. During the experiments, it was also observed 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.

From Figure 7 and since all the samples were machined for the same period of 30 minutes, comparison of the depths of cut of each machined sample indicates the material removal rate. The material removal rate is seen to have been highest

Sample	Gap Current (A)	Applied Capacitance (μF)	Gap Voltage (V)	RMS Surface Roughness (μm)	Depth of Cut (mm)
1	1.0	55	60	12.6	1.73
2	1.0	110	60	13.4	1.77
3	1.0	165	60	13.5	1.80
4	1.0	220	60	13.7	1.83
5	1.5	275	50	13.8	1.80
6	1.5	330	50	14.2	1.87
7	2.0	440	40	14.2	1.93
8	1.7	510	50	14.4	2.03
9	1.8	620	45	14.5	2.05
10	2.2	640	45	14.7	2.05
11	1.8	730	45	15.1	2.11

Fig. 3. Machining parameters

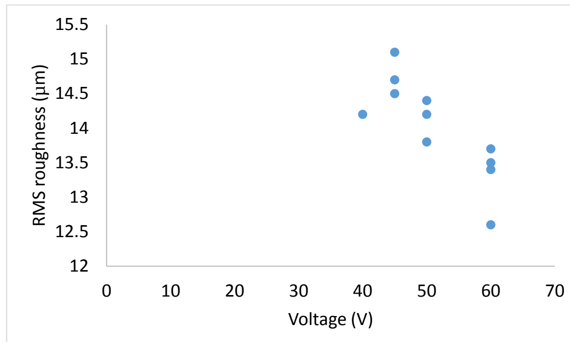

Fig. 4. Effect of voltage on surface quality

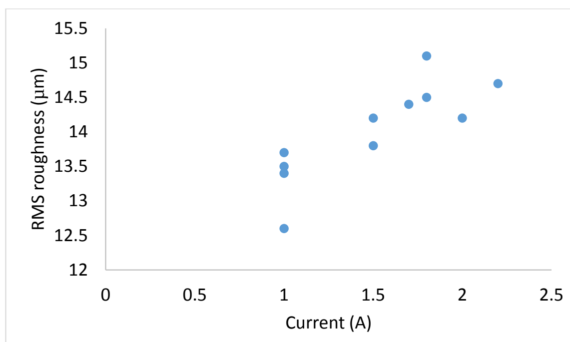

Fig. 5. Effect of current on surface quality

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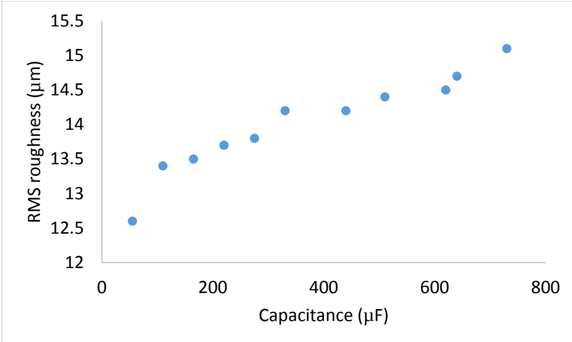

Fig. 6. Effect of capacitance on surface quality

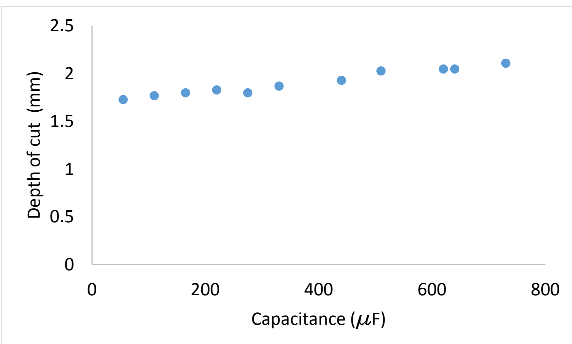

Fig. 7. Indication of MRR with increase in capacitance

when the values of the capacitance and the spark gap current were high. During this time however, the value of spark gap voltage was low.

VI. CONCLUSIONS

The effect of increasing capacitance in EDM machining has been found to be poor quality surface finish and improved material removal rate. However, in most cases in machining, there is always a compromise between the material removal and the surface 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.
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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REFERENCES

[1] Zhang Q.H., Du R., Zhang J.H., Zhang Q.B., "An investigation of ultrasonic-assisted electrical discharge machining in gas," *International Journal of Machine Tools and Manufacture*, vol. 46, pp. 1582–1588, 2006.

[2] Huang J.T. and Liao Y.S., "Optimization of machining parameters of wire-EDM based on grey relational and statistical analysis," *International Journal of Production*, vol. 41, no. 8, pp. 1707–1720, 2003.

[3] Shabgard M. R., Seyedzavvar M. and Nadimi Bavil Oliaei S., "Influence of input parameters on characteristics of EDM process," *Journal of Mechanical Engineering*, vol. 2, pp. 123–135, 2006.

[4] Carlo Ferri, Atanas Ivanov and Antoine Petrelli, "Electrical measurements in micro-EDM," *Journal of Micromechanics and Microengineering*, vol. 18, pp. 1–13, 2008.

[5] Tarng Y. S. Ma S. C. and Chung L. K., "Determination of optimal cutting parameters in wire electrical discharge machining," *International Journal of Machine Tools and Manufacture*, vol. 35, no 12, pp. 1693–1701, 1995.

[6] Scott F. Miller, Albert J. Shih and Jun Qu, "Investigation of the spark cycle on material removal rate in wire electrical discharge machining of advanced materials," *International Journal of Machine Tools and Manufacture*, vol. 44, pp. 391–400, 2004.

[7] Yongshun Zhao, Xingquan Zhang, Xianbing Liu, Kazuo Yamazaki, "Geometric modeling of the linear motor driven electrical discharge machining (EDM) die-sinking process," *International Journal of Machine Tools and Manufacture*, vol. 44, pp. 1–9, 2004.

[8] Pecas P. and E. Henriques, "Influence of silicon powder-mixed dielectric on conventional electrical discharge machining," *International Journal of Machine Tools and Manufacture*, vol. 43, pp. 1465–1471, 2003.

[9] Bulent Ekmekci, A. Erman Tekkaya and Abdulkadir Erden, "A semi-empirical approach for residual stresses in electric discharge machining (EDM)," *International Journal of Machine Tools and Manufacture*, vol. 46, pp. 858–868, 2006.

[10] Jin Wang, FuzhuHan, Gang Cheng, Fuling Zhao, "Debris and bubble movements during electrical discharge machining," *International Journal of Machine Tools and Manufacture*, vol. 58, pp. 11–18, 2012.

[11] Nizar Ben Salah, Farhat Ghanem, Kais Ben Atig, "Numerical study of thermal aspects of electric discharge machining process," *International Journal of Machine Tools and Manufacture*, vol. 46, pp. 908–911, 2006.

[12] Seiji Kumagai, Naoki Sato and Koichi Takeda, "Combination of capacitance and conductive working fluid to speed up the fabrication of a narrow, deep hole in electrical discharge machining using a dielectric-encased wire electrode," *International Journal of Machine Tools and Manufacture*, vol. 46, pp. 1536–1546, 2006.

[13] Muniu J. M., Ikua B. W., Nyaanga D. M. and Gicharu S. N., "investigation on applicability of diatomite powder-mixed dielectric fluid in electrical discharge machining pocesses," in *Sustainable research and innovation conference proceedings*, vol. 4, pp. 280–288, 2012.