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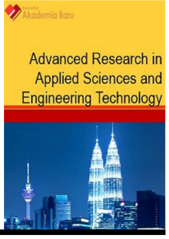
Journal of Advanced Research in Applied
Sciences and Engineering Technology

Journal homepage: www.akademiabaru.com/araset.html
ISSN: 2462-1943



Consistent Machining of Electrical Discharge Machining Power Supply Towards Hip Implant Surface Texturing

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ARTICLE INFO

Article history:
Received 18 January 2018
Received in revised form 6 February 2018
Accepted 8 February 2018
Available online 7 May 2018

ABSTRACT

Electrical Discharge Machining, EDM is one of the technologies used for surface texturing such as the embedded micro-dimples on the metallic acetabular cup. During the machining process, changes in the gap distance may lead to load changes from open to short circuit. Limiting the load current under short circuit conditions and load voltage under open circuit conditions is the requirement in this system. Power supply is one of the elements that controls the process parameters which is related to improve the machining condition as well as Material Removal Rate (MRR). A considerable number of power supply design method were proposed for various EDM application. This research proposed a Switch Mode Power Supply method implementing new design of Flyback power supply which can stabilize the voltage during open circuit condition as well as during discharge condition. Experimental studies were conducted to verify the capability of Flyback power supply by machining eight micro-dimples in lower position and twelve micro-dimples in upper position, both in circular arrangement on metallic acetabular cup. Research conducted shows that the Flyback power supply improve the consistency of MRR when compared to Linear power supply. This may help to predict the machining time, thus improving the production of micro-dimples in required time.

Keywords:
Electrical discharge machining, die-sinking EDM, pulse generator, micro-dimples

1. Introduction

Electrical Discharge Machining (EDM), also known as spark erosion machining is a non-conventional material removal process where the electrode and workpiece do not contact with each other during the machining process. EDM system as illustrated in Figure 1 consists of power generator unit which provide the electrical discharge with control of voltage, current, duration, duty cycle and polarity. A dielectric works as a cooling medium as well as introduces fluid into the discharge zone and flush away debris. Servo system is used to control in feed of the electrode and maintain the gap distance. In EDM, any conductive material regardless of their hardness can be

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machined. Non-physical contact between the electrode and workpiece provide advantages to EDM in eliminating mechanical stresses, chatter and vibration problems during machining [1].

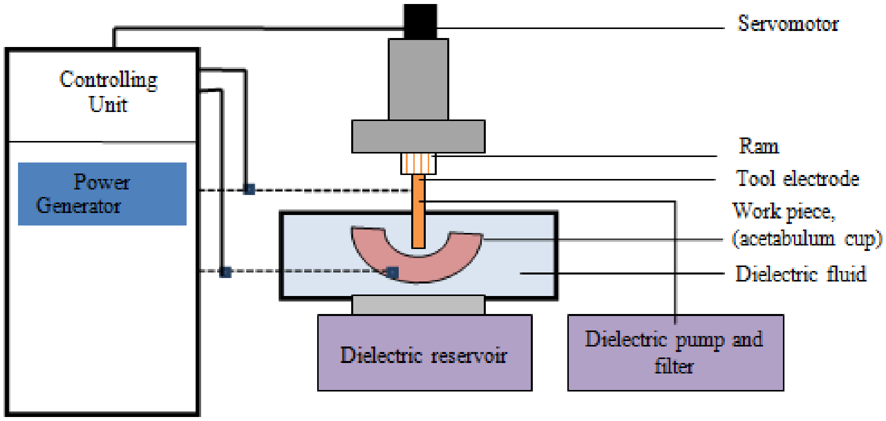


Fig. 1. Electrical Discharge Machining (EDM) system

The EDM process has been given a significant amount of research focus in micro machining especially in machining micro-dimples on hip implant application[2–4]. Micro-EDM has a similar physical characteristic as the EDM except the size of the tool used, the power generator (current and voltage) and the axes movement resolution (X-, Y- and Z- axes) are in micron level [5,6]. Material removal in EDM is realized by thermal action of electrical discharge between the tool and the workpiece. The tool and workpiece are connected to a DC power supply, which the discharge energy released by this power supply is responsible for melting small quantity of material of both electrode and workpiece. This power supply generates high enough voltage to breakdown the dielectric at a very small gap (10-50µm).

Before the striking of the spark, the power supply operated at no load condition as the output sees an open circuit. The EDM servo system then adjusts the position of the electrode to breakdown the dielectric. The power supply sees a negative resistance until the voltage drops to the working gap which is normally ranges from 10-25 V. The current is maintained during this time until the pulse is terminated. The process is repeated at the next cycle. With the working principle stated, enhancing the power supply design that meets the EDM system working principle is the aim of this paper.

The conventional power supplies developed as the current source for EDM are typically traditional Linear power supply. The major drawbacks of this power supply include large volume and low efficiency. In order to solve these problems, resonant-switching power converter is introduced. However, the drawback is when the load resistor of the resonant tank is in high impedance state, the output voltage of the resonant tank is fairly high. The power supply for EDM can be implemented using conventional converter topologies such as buck, buck-boost, single-ended primary-inductance converter (SEPIC) and Flyback power supply. The major concern in buck-boost is it inverted polarity in the output terminal while control complexity and components counts are the disadvantages of SEPIC converter. Buck based topology is preferred for implementing the EDM power supply [7], however due to desirable of low output power , cost saving and less losses, Flyback power supply is suggested for Micro-EDM application [8,9]. Therefore, this study provides an intensive knowledge of using Flyback power supply in Micro-EDM system. Experimental results of using Flyback power supply comparing with Linear power supply are provided by machining micro-dimples on metallic acetabular cup of hip implant as application for surface texturing.

2. Micro- EDM Power Generator

Two types of power supplies were used in this study namely Linear power supply (Transformer based AC to DC converter) and Flyback power supply. Transformer based AC to DC converter has been developed according to Ben Fleming [10] as illustrated in Figure 2. The 230/240 AC input voltage is fed into an input transformer where the incoming line voltage is stepped down to 100 Vac for an EDM idle working voltage. It also isolates the output circuit from the line supply. The isolated AC voltage then rectified to produce uncontrolled 100 DC voltages. The capacitor is used to filter the rectified output.

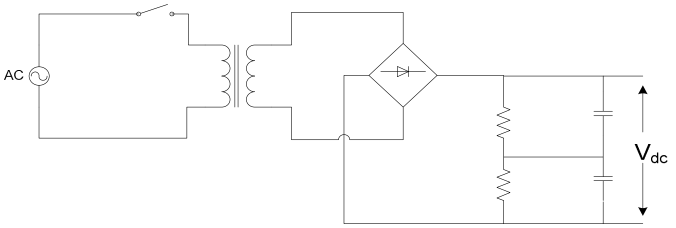


Fig. 2. EDM power supply using Linear power supply [10]

After a relevant literatures study conducted on die-sinking EDM power supply, Flyback power supply has been selected as one of the method to develop power supply using switch mode technology. Flyback power supply is the most commonly used switch mode power supplies (SMPS) circuit for low output power application [11]. The overall circuit topology as discussed in Figure 3 is simpler than other SMPS circuit because of its output power less than 150W.

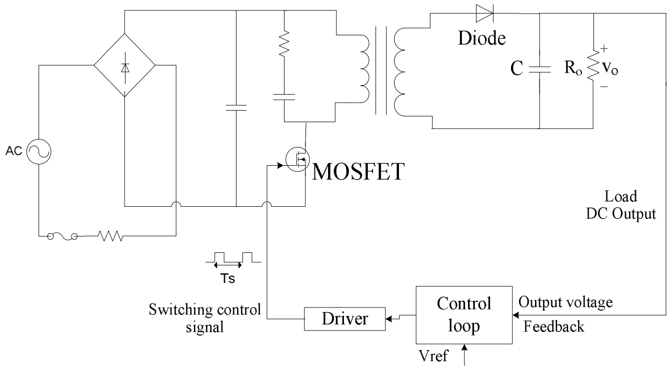
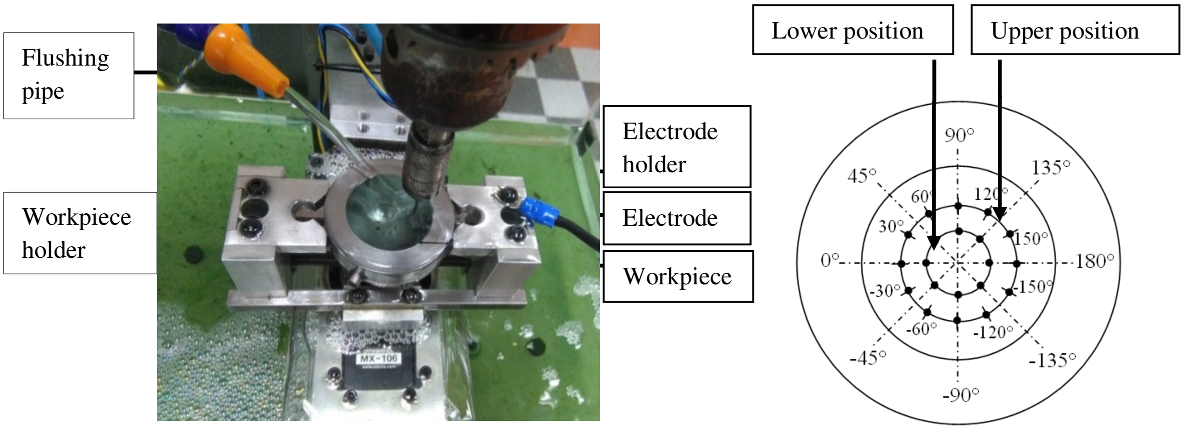


Fig. 3. Schematic diagram of Flyback power supply with a control block

3. Experimental Set Up

A Lab scale Die-sinking EDM system has been developed at Universiti Teknologi Malaysia. This machine is energized by a power supply which can be switched either using Linear power supply or Flyback power supply. The workpiece and the electrode were mounted on a Lab scale EDM machine as shown in Figure 4 (a). In this study, two assumptions were made: (a) temperature and pressure of dielectric fluid were assumed to be constant; (b) current consumption was constant throughout the experiments.



(a) (b)

Fig. 4. (a) Workpiece and electrode mounted on Lab scale EDM Die sinker, (b) micro-dimples arrangements

A set of micro-dimples were machined on the acetabular cup where the diameter of the micro-dimple was the same as the diameter of the electrode which is 1000µm. The acetabular cup was sprayed during the machining process using a flushing pipe. The flushing process helps to remove the particles or any debris inside the micro-dimples. The acetabular cup was hold using a new design of spherical positioning system develop by researcher at UTM [12]. The micro-dimples were divided into two different location namely lower position (8 number of micro-dimples) and upper position (12 number of micro-dimples) as illustrated in Figure 4(b). Mild steel having density of 7.85 g/cm^3 and a melting point of 1523 $^{\circ}$C was used as the workpiece.

4. Result and Discussion

Material Removal Rate (MRR) was calculated based on the measuremet of weight loss from the workpiece. The changes in weight was converted to the change in volume. The weight loss was measured using Shimadzu ATX/ATY Series electronic balance with 0.1 mg accuracy and capable to measure up to 220g. The MRR was calculated by using the volume loss divided by the effective time of machining [13]. Equivalent equation is described in Equation 1.

$$MRR = \frac{(W_b - W_a)\times 1000}{(D_w \times t)} \quad [14] \qquad (1)$$

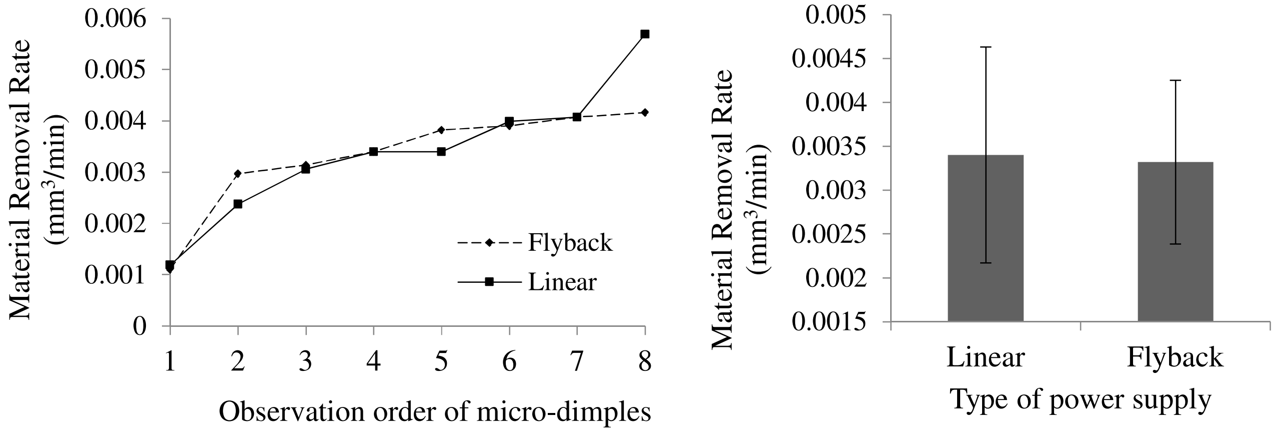
where MRR is the material removal rate (mm^3/min), W_b is the average weight of workpiece before machining (g), W_a is the average weight of workpiece after machining (g), D_w is the density of the workpiece (g/cm^3) and t is the time of machining (min).

Total of 20 micro-dimples have been machined for both Linear power supply and Flyback power supply according to their position as discussed in previous section. Round shape of electrode has been selected for machining micro-dimples because it exhibit maximum MRR subsequent to triangular, diamond and square shape of electrode when machine on mild steel workpice [15]. After a pre-experimental test conducted, machining time was set to 150 minutes for lower position and 210 minutes for upper position. The workpiece was weighted before and after machining and the difference was calculated as weight of material removal. The process was repeated for all micro-dimples on acetabular cup and the data obtained was tabulated in Table 1 and 2 respectively.

Table 1
Comparison of MRR using Linear power supply and Flyback power supply for lower position

DC power supply	Machining time (minute)	Micro-dimples order	MRR (mm^3/min)	DC power supply	Machining time (minute)	Micro-dimples order	MRR (mm^3/min)
Linear power supply	150 (each micro-dimple)	1	0.00340	Flyback power supply	150 (each micro-dimple)	1	0.00297
		2	0.00340			2	0.00314
		3	0.00399			3	0.00391
		4	0.00408			4	0.00110
		5	0.00119			5	0.00340
		6	0.00306			6	0.00382
		7	0.00569			7	0.00416
		8	0.00238			8	0.00408
		Mean, $\bar{x}$	**0.00340**			Mean, $\bar{x}$	**0.00332**
		Sample standard deviation	**0.00123**			Sample standard deviation	**0.000933**

Table 1 illustrates the value of MRR for micro-dimples in lower position (8 numbers of micro-dimples) while Figure 5(a) depicts corresponding graph for MRR. The lowest MRR for Linear power supply is 0.00119 mm^3/min while for Flyback power supply is 0.0011 mm^3/min. The highest MRR for Linear power supply is 0.00569 mm^3/min while for Flyback power supply is 0.0048 mm^3/min. When comparing the mean value, Linear power supply gave highest value of MRR compared to Flyback power supply. However, the standard deviation for Flyback power supply as illustrated in Figure 5(b) gave lowest deviation compared to Linear power supply. This shows that the MRR value using Flyback power supply in lower position is more consistent compared to Linear power supply. This shows that the volume material removed per minutes is consistent for each micro-dimple thus improving their quality in term of depth and diameter. With consistent depth and diameter in the lower position, same amount of lubricant will be trapped thus promote the lubrication activities. This is because the lower position contributes an important effect to lubrication activities of articulating surface between femoral head and acetabular cup. Besides that, this application can be applied to Micro-EDM where time for production is necessary.



(a) (b)

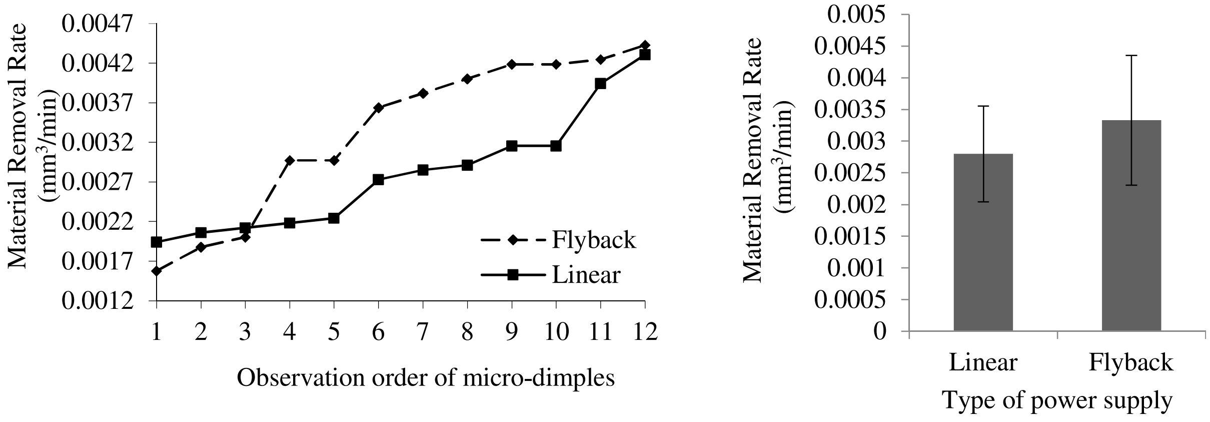
Fig. 5. (a) MRR of lower position micro-dimples, (b) Mean with their respective standard deviation

Table 2 illustrates the value of MRR for micro-dimples in upper position (12 numbers of micro-dimples). As illustrated in Figure 4(a), the location of micro-dimples in upper position is curvier compared to micro-dimples in lower position thus machining time has been increased to 210 minutes in order for round shape micro-dimples can be produced accordingly.

As can be seen in Figure 6(a), the lowest MRR for Linear power supply is 0.00194 mm^3/min while for Flyback power supply is 0.00158 mm^3/min. The highest MRR for Linear power supply is 0.00431 mm^3/min while for Flyback power supply is 0.00419 mm^3/min. When comparing the mean value, Flyback power supply gave highest value of MRR compared to Linear power supply. However, the standard deviation for Linear power supply as illustrated in Figure 6(b) gave lowest deviation compared to Linear power supply. This shows that the MRR value using Linear power supply in upper position is more consistent compared to Flyback power supply. However, in upper position high MRR is desirable to reduce machining time. For Flyback power supply, nine from total 12 micro-dimples gave higher MRR compared to Linear power supply. Thus, Flyback power supply highly suggested to be used to machine micro-dimples on hip implant by considering the volume removed per minutes.

Table 2
Comparison of MRR using Linear power supply and Flyback power supply for upper position

DC power supply	Machining time (minute)	Micro-dimples order	MRR (mm^3/min)	DC power supply	Machining time (minute)	Micro-dimples order	MRR (mm^3/min)
Linear power supply	210 (each micro-dimple)	1	0.00212	Flyback power supply	210 (each micro-dimple)	1	0.00400
		2	0.00431			2	0.00158
		3	0.00394			3	0.00419
		4	0.00194			4	0.00443
		5	0.00315			5	0.00425
		6	0.00224			6	0.00382
		7	0.00273			7	0.00200
		8	0.00291			8	0.00297
		9	0.00206			9	0.00297
		10	0.00285			10	0.00419
		11	0.00315			11	0.00364
		12	0.00218			12	0.00188
		Mean, $\bar{x}$	**0.00280**			Mean, $\bar{x}$	**0.00333**
		Sample standard deviation	**0.000756**			Sample standard deviation	**0.001023**



(a) (b)

Fig. 6. (a) MRR of lower position micro-dimples, (b) Mean with their respective standard deviation

5. Conclusion

Micro-EDM machining of tungsten electrode diameter of 1000µm was performed to machine micro-dimples on acetabular cup. The micro-dimples have been arranged in their position and being machined for 150 minutes and 210 minutes respectively. The weight of the workpiece before and after machining was weighted and the MRR was calculated.

Figure 7 depicts the average value of MRR for both Linear power supply and Flyback power supply. In average the value of MRR for Linear power supply is 0.00340 mm^3/min for 150 minutes machining time and 0.00280 mm^3/minutes for 210 minutes machining time. The difference is 0.00060 mm^3/minutes. While for Flyback power supply, the average MRR value is 0.00332 mm^3/minutes for 150 minutes machining time and 0.00333 mm^3/minutes for 210 minutes machining time. The difference is 0.000001 mm^3/minutes. From the calculated difference between these power supplies, can be concluded that machining micro-dimples using Flyback power supply gave higher MRR as well as provide improvement in its consistency of material removed per minutes. By getting more consistent MRR means that the quantity of material being removed per minutes for each micro-dimple are more precise when Flyback power supply is applied. Therefore Flyback power supply is suggested to be applied to Micro-EDM for machining micro-dimples on hip implant.

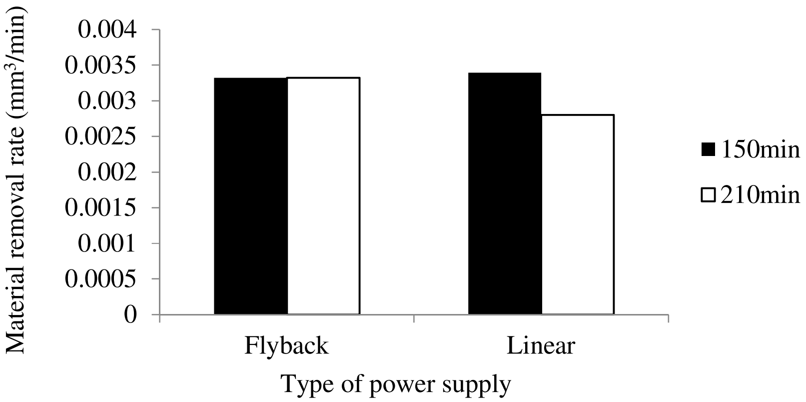


Fig.7. Mean value of MRR for 150 minutes and 210 minutes machining time using Linear and Flyback power supply

Ackowledgement
Authors are grateful to the Universiti Teknologi Malaysia for facilitating this research and for their financial support under GUP grant Vot No: Q.J130000.2545.13H23

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