ORIGINAL ARTICLE

Optimum Machining Condition of Electrical Discharge Machine Through Flyback Power Supply for Machining Hip Implant

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ABSTRACT

Introduction: The hip joint plays a vital role in enabling human daily mobility. One of the main issues that determines the longevity of Metal-on-metal (MoM) hip implants is wear rate. In order to improve lubrication and reducing friction, surface texturing has been widely adopted as a design alternative in implant manufacturing. **Materials and Methods:** Electrical Discharge Machining (EDM) with a flyback power supply was employed in this research to fabricate textured surfaces as this method offers high precision and eliminates burr formation. **Results:** Optimization of these EDM parameters such as VGap, IGap, Ton and Toff, demonstrating the significant influence on performance measures including surface roughness (SR), material removal rate (MRR) and tool wear rate (TWR) and making the process suitable for biomedical applications. **Conclusion:** Among the measured response, MRR was found to be the most dominant factor as it confirmed the uniformity and consistency of material removed. This is essential in achieving reliable textured structures that could improve the tribological performance of MoM hip implants.
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INTRODUCTION

The hip joint is a ball-in-socket articulation between the femoral head and the acetabulum in the pelvis is enclosed by a capsule filled with synovial fluid (SF). This fluid serves as a natural lubricant and acts as a shock absorber (1). With advancing age or in the presence of chronic conditions such as osteoarthritis, rheumatoid arthritis, bone tumors or traumatic injuries, the joint prone to degeneration. In such cases, total hip arthroplasty (THA) is considered the most effective treatment which the diseasd joint is surgically replaced with an artificial implant (2-6). Nevertheless, the average lifetime of hip implants is typically limited to 10-15 years due to wear occurring at the MoM interface make it is often necessitating revision surgery once the implants fails or if there is a complication. For instance, in Original Paper 2000, approximately 152,000 hip replacement were performed, with 13% of them involving revision procedures (7). Therefore, to extend the functional life of implants, reducing wear and wear particle generation is very crucial. From an engineering standpoint, lubrication plays a key role in mitigating wear and this principle has been adopted in implant design through the implementation of textured surface on the acetabular cup surface. Electrical Discharge Machining (EDM) is a widely used non-traditional precision process capable of removing material through successive electrical discharges between an electrode and a conductive workpiece in the presence of dielectric fluid. Its spark-based energy mechanism EDM highly effective for machining hard and wear-resistance materials. Moreover, micro-EDM has proven useful in creating micro-features such as injector nozzles and lubrication holes for biomedical devices. Since EDM is free from mechanical tool forces and vibration effects, it presents a suitable method for fabricating micro dimples on artificial hip joints (8-11). Therefore, this study aims to design and optimize EDM pulse power generator parameters for biomedical application focusing on achieving an optimal balance among material removal rate (MRR), surface crack density and surface finish quality on the machined material. In this study, a Flyback Power Supply topology was implemented to run the EDM pulse power generator. The primary process variables investigated were Gap Current (IGap), Gap Voltage (VGap), Discharge Off Time (Toff) and Discharge On Time (Ton). These parameters were systematically tuned during experimentation to obtain the optimum machining conditions. The IGap and VGap have been adjusted accordingly to form the ideal condition to remove the material. The ratio of Ton and Toff were controlled by adjusting the switching intervals of the discharges pulses, thereby regulating the overall energy input. The collected data were analyzed to evaluate the performance in terms of MRR, surface integrity and machining stability.

MATERIALS AND METHODS

Electrical Discharge Machining (EDM) is a non-traditional machining process in which material is removed in the form of debris means of precisely controlled electrical discharge (sparks) across a narrow gap between electrode and the workpiece materials, typically ranging between 10 and 50 microns [12-14]. This technique has been widely employed as an alternative method for fabricating microstructures. The basic configuration of an EDM system is shown in Fig.1, where both the electrode and the workpiece are connected to a direct current (DC) power supply. A small discharge gap is maintained between the two and dielectric fluid is flushed into this region where spark erosion take place. When a sufficiently high voltage (approximately 50-400 V) is applied, the dielectric fluid undergoes breakdown and becomes ionized which allowing electrons to be emitted from the electrode. As more electrons accumulate in the gap, its resistance decreases, leading to the formation of a spark between the electrode and the workpiece. This sequence occurs within a few microseconds and generates a localized shock wave in the dielectric medium. The resulting electrical and magnetic forces detach molten and softened metal particles from the workpiece surface [15].

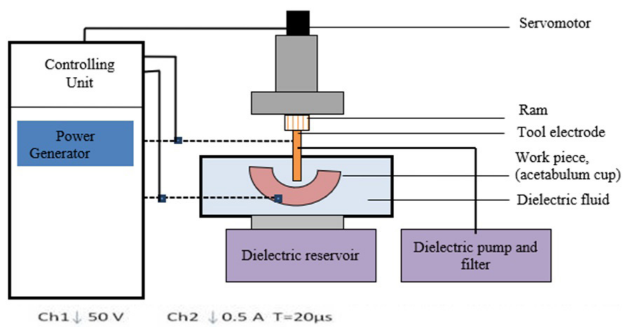

Fig 1: Schematic layouts of basic EDM components (4)

In conventional industrial practice, low current generators are typically employed for machining micro-holes as the affected parts or components can be replaced at relatively low cost. In contrast, for biomedical application such as for artificial hip joints, component replacement is not only complex but also highly expensive. Although commercial current generators can be adapted for such purposes, they often produce undesirable effects including micro-cracks, electrode melting and residual debris on the machined surfaces. Therefore, the design and implementation of the new pulse power generator is expected to minimize these drawbacks and improve the quality of micro pits.

A critical component of the EDM system is the power generator which it delivers controlled pulses to the electrode and workpiece. This unit is responsible for maintain a stable spark gap (stable spark gap is measured on the consistency of the ignition time for every cycle on the pulse ON time, Ton) and ensuring successive and uniform discharges. In conventional EDM systems, the use of high voltage and current often results in local melting of the electrode and unwanted welding between the tool and the workpiece [16].

RESULTS

The performance of two power supply configurations was investigated namely the Linear power supply (Fig. 2) and the Flyback power supply (Fig. 3). Figure 2 shows the gap voltage Vgap and gap current Igap when the Linear power supply is used in the Micro-EDM system, while Figure 3 presents the corresponding signals when the Flyback power supply is applied. In both figures, the gap voltage is plotted in the upper graph whereas the corresponding gap current is shown in the lower graph. As illustrated, two types of voltage can be identified in EDM which are the open circuit voltage and the discharge voltage. The open circuit voltage refers to the potential difference between the electrode and the workpiece which initiates the breakdown of the dielectric insulation.

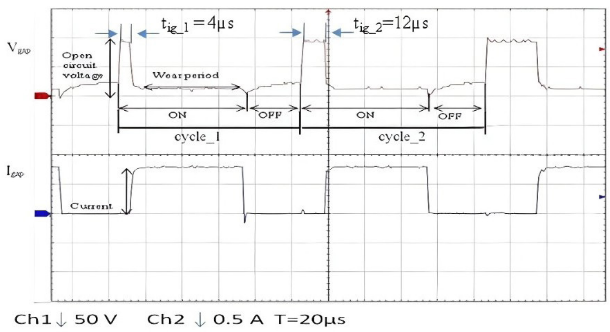

Fig 2: Gap voltage and gap current for Linear power supply shows unstable ignition time.

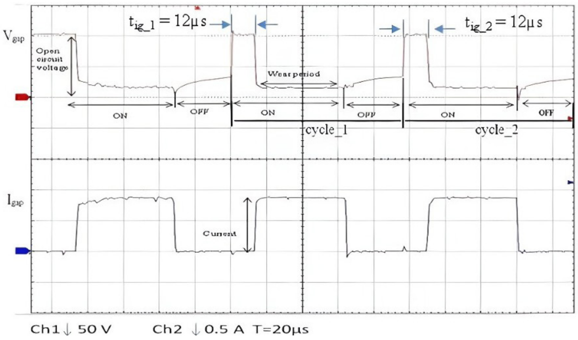

Fig 3: A stable ignition time of Gap voltage and gap current for Flyback power supply.

In this study, the open circuit voltage is approximately 100 V (refer to the gap voltage, Vgap waveform). After a short dielectric breakdown period, the voltage between the electrode and workpiece drops to the working voltage of 15 V and the duration of the discharge is referred to as the wear period. At this stage, current begins to flow through the gap as shown by the gap current, Igap waveform in the lower graph. The current continues until the timer switches OFF. The machining process is carried out entirely during the ON time of the cycle. As observed in Fig. 2, the ignition time of the Linear power supply is unstable across two cycles (cycle_1 and cycle_2) of the EDM process. The ignition time, tig_1, in the first cycle (cycle_1) is 4 µs, which is shorter than tig_2 in the second cycle (cycle_2) at 12 µs. In contrast, for the Flyback power supply (Fig. 3), the ignition time (tig_1 and tig_2) remains constant at 12 µs for two consecutive cycles (cycle_1 and cycle_2). Maintaining a constant ignition time is essential to ensure a normal discharge. When the ignition time is kept stable, the discharge duration also remains constant since the ON time is fixed. This ensures uniform surface roughness for each machined dimple.

All material removal occurs during the ON-time interval. Maintaining a constant ignition time is crucial for achieving stable discharges as it ensures that the discharge duration remains uniform under fixed ON-time conditions. Consequently, the surface roughness and quality of each machined dimple can be kept consistent. A laboratory-scale die-sinking EDM system was developed for this investigation (Fig. 4). The machine was powered by a generator capable of operating with either a Linear supply or a Flyback converter. The detailed parameter settings used in the experiments are summarized in Table 1.

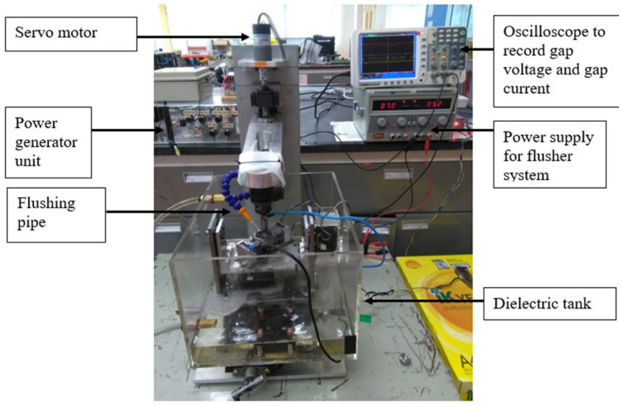

Fig 4: Lab scale Die-sinking EDM system is developed for machining hip implant.

Parameter used	Value set
Current	0.5 - 1.0 A
T_{on}	60 µs
T_{off}	30 µs
V_{oc}	100 V
V_{gap}	15-20 V

Table I: Parameters set up for Lab scale EDM system

Dynamic testing was carried out by running the complete system and setting the desired values for each axis using the Dynamixel configurator software. Subsequently, dynamic parameters were collected by applying different PID values. The collected data as shown in Table 2 include the transition time (time required to reach steady-state condition) and steady-state error. The results show that the P controller and PI controller require less time to reach steady-state compared to the other configurations. This makes these configurations more advantageous than the others and provides justification for further investigation into steady-state error distribution.

	Kp	Ki	Kd	Time to achieve steady state
P	4	-	-	2.2s
PI	3.6	1	-	2.5s
PD	6.4	-	2.4	12.3s
PID	4.8	3.2	1.8	7.5s

Table II: Results of controller parameter vs steady state condition

DISCUSSION

A series of micro-dimples were fabricated on the acetabular cup, with each dimple having a diameter equal to that of the electrode used. During the machining process, the acetabular cup was continuously flushed using a spray pipe to aid in the removal of debris and machining particles from within the dimples. The cup was secured in a workpiece holder that could be rotated to align with the required dimple locations. Fig. 5(a) and 5(b) show examples of acetabular cups textured with eight micro-dimples, produced using the Linear power supply and the Flyback power supply respectively. The electrodes used were 500 μm and 1000 μm in size with the machining time set to 210 minutes.

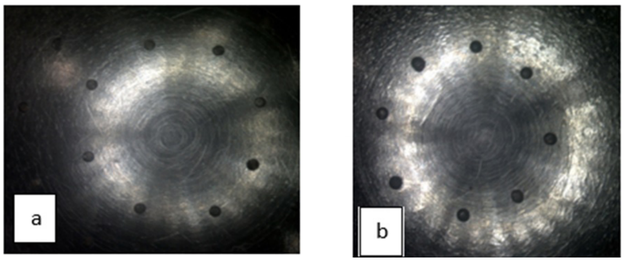

Fig 5: Example of micro-dimples diameter of 500 μm machined using
(a) Linear power supply (b) Flyback power supply

For the Linear power supply, with a 500 μm electrode, the measured dimple diameters in two trials were 541.07 μm and 573.13 μm. With a 1000 μm electrode, the dimple diameters in two trials were 1077.51 μm and 1110.72 μm. From visual inspection, the dimple diameters were uneven and could only be represented by an average measurement. For the Flyback power supply, with a 500 μm electrode, the dimple diameters in two trials were 524.63 μm and 523.01 μm. With a 1000 μm electrode, the dimple diameters were 1047.51 μm and 1043.74 μm. A clear observation can be made that all micro-dimples were sharp according to the electrode shape. However, the diameters were inconsistent with the Linear power supply while they were nearly consistent with the Flyback power supply. This indicates that the Flyback power supply is more efficient for machining micro-dimples. Therefore, the Flyback power supply is recommended when size consistency is the main objective in micro-dimple production.

CONCLUSION

The Flyback power supply was compared with the Linear power supply to determine the optimum machining conditions for hip implant fabrication where EDM parameters such as VGap, IGap, Ton and Toff were tuned for a low-power generator. The Flyback power supply provided consistent discharge durations, Ton and Toff, with a percentage error of 25% compared to 54.5% when using the Linear power supply. A short discharge duration between 45 μs and 60 μs was found to be optimum for achieving higher MRR while reducing machining time for micro-dimple fabrication on hip implants. Unstable machining conditions with the Linear power supply were evident from the variation between the lowest and highest MRR values which was about 0.00528 mg/min whereas with the Flyback power supply, the difference was only 0.00375 mg/min. A consistent MRR is advantageous as it enables machining time to be predicted and minimized, which is essential for producing micro-dimples on hip implants.

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