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RC - generator circuit pulse analysis for micro-EDM of high aspect ratio nitinol bores

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Abstract

Pulse analysis and characterization is of paramount importance in micro-Electrical Discharge Machining (micro-EDM) since it offers an insight into process behaviour and generates valuable information that is either new or not availed by machine manufacturers. Apart from its non-contact nature and its ability to machine intricate shapes on electrically conducting materials regardless of their hardness, micro-EDM is also suited for machining high aspect ratio bores with a high degree of accuracy and repeatability. However, process behaviour differs with varying bore depths due to factors like the chosen machining parameter set, workpiece and tool electrode properties as well as changing flushing efficiency which affects debris removal and consequently affects pulse behaviour. In this study, a detailed analysis of pulses collected during micro-EDM of high aspect nitinol bores is presented. Pulses are collected at different bore target depths and varying machining parameters including open circuit voltage as well as discharge energy level machine settings. Afterwards, the pulses are analysed in order to identify optimal and short circuits as well calculation of exact discharge energies. Results realised reveal that the TiO_2 layer on nitinol's surface, the choice of electrode and increasing depths all have an effect of the pulse behaviour and consequently affect the effectiveness of the nitinol erosion process.

Nitinol, micro-EDM, pulse analysis, process optimisation

1. Introduction

Micro-EDM's strengths include its ability to machine accurate features with aspect ratios as high as ~15 for die-sinking, ~25 for drilling, ~10 for milling and ~100 for Wire-micro-EDM [1]. To achieve this, regulation of pulse discharge energy, defined using Equation 1 is key, among other factors. For higher accuracies, energy induced by one pulse should be as low as possible.

$$W_e = \int_0^{t_e} u_e i_e dt \qquad (1)$$

Where W_e denotes discharge energy [J], t_e the pulse duration [s], u_e the discharge voltage [V] and i_e the discharge current [A].

Whereas the RC pulse generators commonly applied in Micro-EDM can generate pulse-on-times less than 100 nanoseconds [2], their discharge frequencies are rather low owing to the time required to charge the capacitor, which in turn affects the generator's working efficiency [3]. Another limitation of the RC circuit is its inability to control the pulse interval thereby subjecting the workpiece to possible thermal damage if, with the dielectric strength having not recovered after discharge, current continues to flow via the same plasma channel in the gap without charging the capacitor [3]. To address these challenges, more insight into pulse behaviour is required as this information is useful for process optimisation including possible design of additional machine modules [4].

2. Methodology

Experiments were undertaken on a Sarix T1-T4 micro-EDM machine using deionised water dielectric fluid, 455 rpm spindle rotation, a gain of 8, a gap voltage of 75 V and 100 kHz charge frequency. Bores with a 3 mm target depth were machined on a nitinol rod using 0.6 mm tungsten carbide (WC) and copper (Cu) electrodes. In order to ensure reproducibility, every experiment was repeated thrice whereas for comparison purposes, bores were also machined on a WC workpiece. For each experiment, pulses were collected at target depths of 0.1 mm, 0.5 mm, 1 mm, 1.5 mm, 2 mm, 2.5 mm and 3mm using a Tektronix DPO4104 digital oscilloscope with a Tektronix P6139A voltage probe and a Tektronix TCP312 current probe. Afterwards, MatLab® was used to analyse the pulses to establish their number and variation with increasing target bore depths. Moreover, material removal rate (MRR) and tool wear rate (TWR) were analysed in 0.5 mm target depth intervals in order to establish the effect of pulse behaviour changes on micro-EDM's output performance parameters.

3. Results and Analysis

Figure 1 shows typical current and voltage signals from micro-EDM of nitinol using a copper electrode and applying an open circuit voltage, u = 100 V. For discharge machine setting CF8 (~140 µJ), optimum current pulses peaked at around 23 A. However, it is evident that quite a few pulses peaked at lower currents with a further analysis revealing a mean pulse of 16 A.

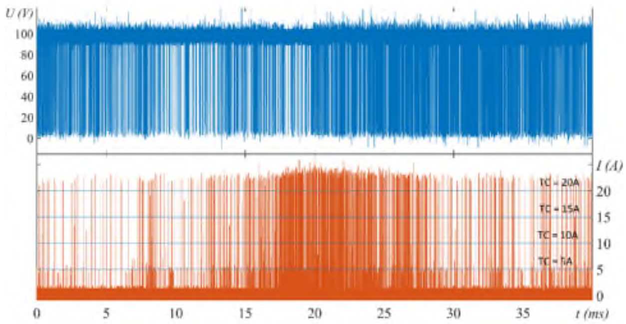

Figure 1: Current and voltage pulse signals for µEDMed nitinol using a copper electrode, u = 100 V and 0.1 mm target depth

In order to investigate the probability of realising a full discharge, 4 different pulse count trigger levels, denoted by TC in this study, were investigated. These were i = 5 A, 10 A, 15 A and 20 A. Figure 2, reveals that most of the discharges that do not reach peak current are in the range of 5 A to 10 A (20% - 40% of optimum peak current). Only a minimal pulse count drop was noted after TC = 10 A whereas pulses with peaks lower than 5A were not considered.

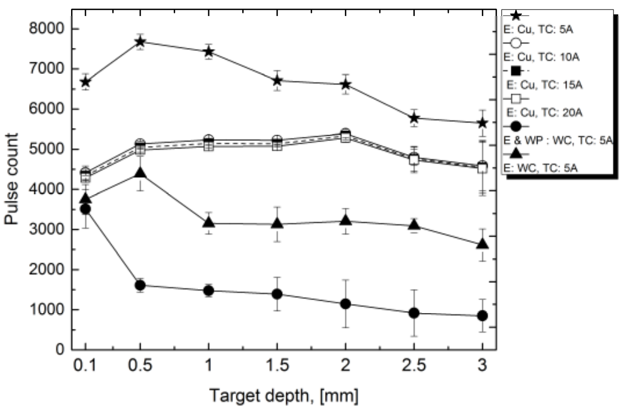

Figure 2: Current pulse count for different target depths for u = 100 V (nitinol workpiece used unless otherwise stated in the key). E denotes electrode and WP denotes the workpiece used

3.1. Nitinol's pulse formation behaviour

Figure 2 reveals that, while machining with similar electrodes, the pulse count in nitinol is higher than that in tungsten carbide (WC). Also, machining nitinol with a copper electrode results in a higher pulse count than while using a WC electrode owing to copper's superior conductivity. Moreover, for nitinol workpiece, a lower pulse count was recorded at a 0.1 mm target depth as opposed to the pulse count at 0.5 mm. This is in huge contrast to the pulse count from WC which reduces drastically from 0.1 mm target depth to 0.5 mm. This phenomenon confirms that the TiO_2 layer formed on nitinol's surface, though important for passivation, makes it harder to machine nitinol's surface as it inhibits pulse formation. Afterwards, pulse counts decrease with increasing target depth.

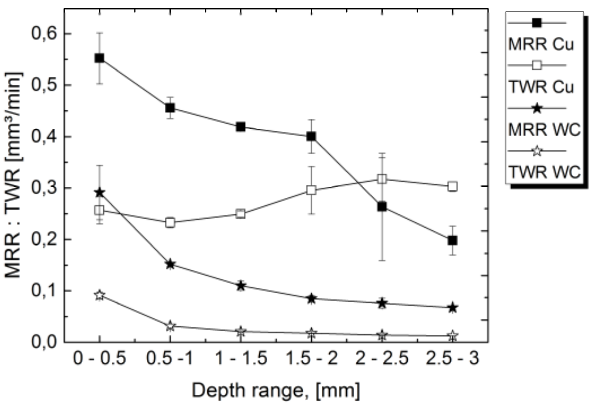

Figure 3: MRR and TWR for different target depths for nitinol machined with a copper and WC electrodes and u = 100 V

3.2. Significance of tool electrode material

From the experiments, it was observed that while machining nitinol using WC tool electrode, the process was quite erratic with numerous short circuits as well as tool electrode retractions from the machining surface. This explains the lower pulse count while using WC electrode as seen in Figure 2. However, when a copper electrode is used, the process was smooth with hardly any tool retractions which explains the considerably higher MRR achieved. On the flipside however, copper produces so much tool wear owing to its lower melting point than WC thus requiring a lot of wear compensation. In the 1.5 – 2 mm target depth range, it can be seen that TWR actually exceeds MRR, something which was consistent for all analysed experiments. Whether this phenomenon occurs in lower discharge energy levels is a subject for further research. On the other hand, while using a WC electrode, despite lower MRR, TWR is considerably lower and reduces with increasing depth which suggests that WC is a more suitable candidate for high aspect ratio bore machining than copper.

3.3. Effect of higher discharge current and voltage

Varying the discharge energy level and voltage had no observable effect on the amount of pulses counted. However, as shown in Figure 4, an increase in the discharge energy level results in a higher MRR although this advantage seems to decrease with increasing target depth suggesting that secondary factors like flushing become more influential to the process with increasing machining depth.

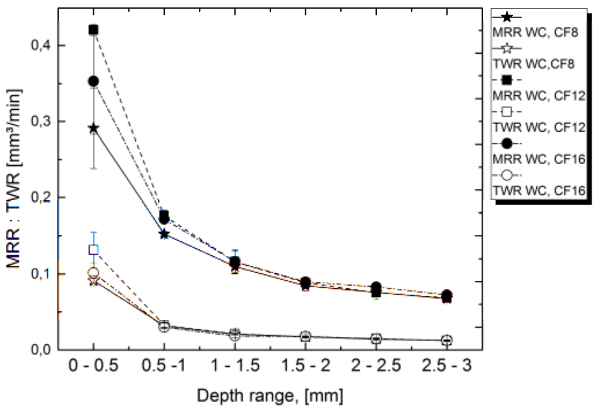

Figure 4: MRR and TWR for different energy levels and u = 100 V

4. Conclusions

In this study, it can be shown that increasing bore aspect ratio affects both pulse counts as well as process stability. The effect of factors such as workpiece and tool electrode material, surface layers and varying input parameters has been established thus this study forms a good basis for nitinol micro-EDM process optimisation.

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