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Real-time evaluation of gap flushing in electrical discharge machining

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ABSTRACT

This paper reports on acoustic emission (AE) from electrical discharge machining (EDM) in the context of gap flushing, and demonstrates its sensitivity to gap contamination from both metallic debris and gas bubbles. AE is further shown to relate to the local medium (liquid or gas bubble) through which individual discharges occur, and hence comprise unique and valuable process information on the effectiveness with which material is removed at the scale of a single discharge. This enabling technology is readily implemented for the in-process quantification, monitoring and optimization of flushing, and may constitute the basis for flushing-related adaptive control of EDM.

1. Introduction

Of the many factors that determine process stability and productivity in electrical discharge machining (EDM), the role of flushing cannot be overstated. Given the small inter-electrode gap width and the often-complex machining geometry, indices such as the pressure and flow rate of the dielectric fluid do not necessarily reflect the actual extent of useful dielectric flow through the working gap. It is hence of interest to develop monitoring techniques that quantify gap flushing in EDM.

Jeswani [1] proposed an optical method for the on-line measurement of gap contamination that relies on the absorption of a light beam as it passes through a sample of the dielectric fluid. Frei et al. [2] suggested an indirect approach wherein the gap state was assessed with reference to the average ignition time delay, which for a given electrical field intensity, was found to be related to the volume concentration of particulate contaminants in the fluid. These techniques did not consider gas bubbles in the inter-electrode gap that affect the process significantly. Imai et al. [3], on the other hand, did investigate the effect of gas bubbles, considering that the transmission of ultrasonic waves through a liquid decreases monotonically with an increase in the volume fraction of gas in it. This technique is but unfortunately insensitive to the presence of metallic debris in the gap, the role of which is not insignificant in EDM. Furthermore, this method is limited by the need to synchronize and stream the ultrasonic waves through the gap during the pulse off-time, for it to not interfere with or be influenced by the process.

Despite its predominant influence in EDM, there is presently a lack of a technology for the in-process monitoring and quantification of gap flushing, which is practicable enough for easy integration into commercial machine tools. This is of particular importance, given that flushing need be maintained within limits that correspond to the optimal debris concentration, in order to maximize machining performance. In this context, this research explored the feasibility of the application of acoustic emission (AE) from EDM for assessing gap flushing. AE has long been well developed for the monitoring of most machining processes. For some inexplicable reason, AE in reference to EDM has however received little attention, except for the recent application of AE in the mapping of discharge location [4], and for detecting workpiece fracture during EDM of brittle materials [5,6]. This is rather surprising considering that experienced EDM operators do often "listen" to the process to gain a sense of process stability, notwithstanding that AE from EDM is manifest in a frequency band that is well above the audible spectrum [4].

This paper initially presents results that demonstrate the efficacy of AE for the real-time quantification, monitoring and optimization of gap flushing. This is followed by a discussion on the nature of AE in EDM, as it relates to fundamental process mechanisms pertinent to flushing.

2. Experimental

Experiments entailed a rotating copper disk electrode with a nominal diameter of 154 mm and a thickness of 6.35 mm, which was used to machine a mild steel plate workpiece of thickness 3.2 mm and width 25.4 mm (Fig. 1). The disk was trued in-place to essentially eliminate the radial run-out, toward ensuring a stable process. Use of a rotating disk electrode enabled quantifiable and consistent dielectric flushing along and across the machining gap. Based on the technology recommendations from the machine tool manufacturer that maximizes the removal rate in consideration of the machining area and the electrode/workpiece material combination used, experiments involved an electrode-positive polarity, a gap voltage of 75 V, a pulse current of 4.4 A, a pulse on-time of 154 μs and a pulse off-time of 37 μs, unless indicated otherwise.

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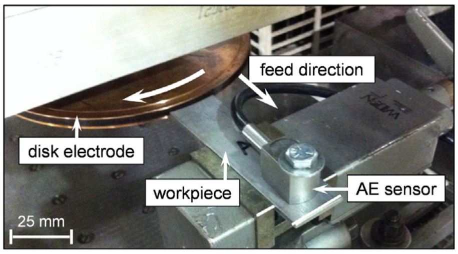

Fig. 1. Experimental configuration.

AE was captured using a commercial sensor with a fairly uniform frequency response in the range of 100–900 kHz. The voltage was subject to a 450 kHz low-pass filter to discard the components arising from electromagnetic interference [4]. The signal was accordingly acquired at a sampling frequency of 5 MHz, and was amplified at a gain chosen to not saturate the amplifier. Simultaneous to the acquisition of AE, current and voltage waveforms were also recorded. The AE signal was characterized in terms of its frequency content, as well as the root mean square (RMS) value computed using a time constant of 200 ms.

3. Results and discussion

3.1. Application

Results of experiments conducted at different electrode peripheral speeds to vary the level of gap flushing are shown in Fig. 2. The material removal rate (MRR) was measured for a machining time of 10 min. Similar to the calculation of RMS AE, a time constant of 200 ms was used to compute the RMS current. The RMS values represent an average of 5 measurements, each of 1 s duration; the variability in the RMS index was less than 5% of the respective mean value.

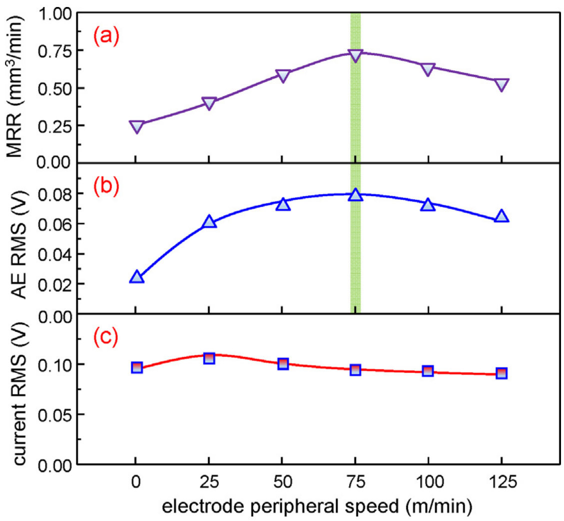

Fig. 2. Effect of electrode peripheral speed on: (a) MRR, (b) AE RMS, and (c) current RMS.

The maximum in the MRR characteristic (Fig. 2a) is a consequence of the optimal debris concentration that relates to the most effective mode of material removal. At very low levels of flushing, accumulation of machining debris in the gap results in short circuits and localized arc discharges that compromise the stability of the process, resulting in a low MRR. As the level of gap flushing improves, spark discharges with a finite time delay that refer to more effective material removal tend to predominate, which enhances the MRR. At peripheral electrode speeds higher than the optimal value, the MRR exhibits a decreasing trend as a certain level of gap contamination is essential for the breakdown of the dielectric fluid to initiate discharges.

From reviewing the relative trends in Fig. 2, it is immediately evident that the AE RMS (Fig. 2b) scales with the MRR, and exhibits an excellent correspondence in terms of the optimal peripheral speed. Such a correlation was non-existent in the RMS current (Fig. 2c); investigations indicated no systematic correspondence with the ignition time delay either. In terms of gap flushing, this highlights the potential of AE in complementing the electrical signals that are exclusively used at the present time for the monitoring and control of modern EDM machine tools.

Fig. 3 presents time domain samples of the raw AE for three electrode peripheral speeds. Acoustic events are few and feeble at a low speed of 0.5 m/min (Fig. 3a). At the optimal speed of 75 m/min (Fig. 3b), there is significant AE comprising a multitude of bursts. At a speed of 125 m/min which is higher than optimal (Fig. 3c), not only are the amplitudes of the AE bursts relatively smaller, there are also several pockets of time that are evidently devoid of any AE activity. This is an indication of the difficulty in initiating and sustaining discharges in the dielectric fluid that is being perturbed by the rapid flow.

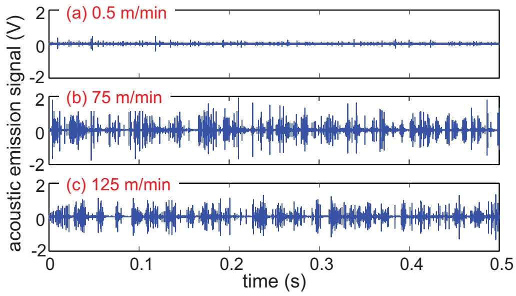

Fig. 3. Raw AE signals corresponding to various peripheral speeds.

With a view to augmenting the tests presented above, an enclosed space around the machining gap was artificially contaminated with iron powder of a nominal size of 30 μm to simulate typical EDM debris. Fig. 4a refers to the baseline AE frequency spectrum when the electrode peripheral speed was 7.2 m/min, with the gap relatively free of any contamination. Introduction of the iron powder in the vicinity of the gap can be seen to precipitate a notable reduction in the magnitudes of the AE signal across the entire frequency band (Fig. 4b). The fluid in the gap regaining a part of its dielectric strength after 2 min of machining using the rotating electrode is indicated by the corresponding increase in the acoustic activity (Fig. 4c). This increment does not however bring it up to par with the level seen in Fig. 4a, due to the general increase in the contamination of the dielectric fluid at large. This demonstrates the responsiveness of the simple AE technique, and its advantage over the intricate ultrasonic wave transmission technique proposed in [3], which is insensitive to the presence of metallic debris in the gap.

Having investigated the effect of flushing and gap contamination on the AE signal, it was of interest to examine the related effect of varying the active frontal machining area at a constant discharge current (Fig. 5; when indicated, error bars denote ±1 standard deviation throughout this paper). It is indeed intriguing to note that at the optimal electrode peripheral speed of 75 m/min, the RMS AE characteristic exhibits a maximum at a current density of 10 A/cm^2,

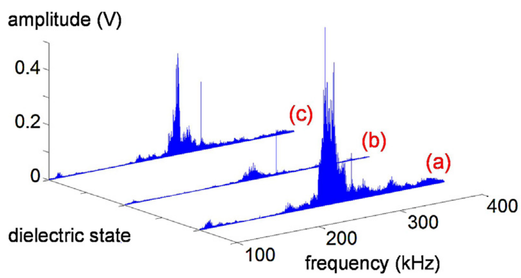

Fig. 4. Effect of gap contamination on the frequency spectrum of the AE signal.