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Acoustic emission signatures of electrical discharge machining

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ABSTRACT

Relative to conventional machining processes, little is known about acoustic emission (AE) from electrical discharge machining (EDM). In light of the significant scope of AE in complementing electrical signals for the monitoring and control of EDM processes, the present research focussed on understanding AE from EDM in fundamental terms. AE waveforms are investigated in both single and sequential discharge formats with reference to pulse parameters, tool materials and dielectric media, to map AE signatures to process mechanisms. AE signals are further interpreted in terms of discharge forces, and the dynamics of gas bubbles observed through high-speed imaging of the gap.

1. Introduction

The small spatio-temporal scales at which complex events transpire in electrical discharge machining (EDM) make it challenging to observe gap phenomena directly. Experimental techniques such as spectroscopy, gas chromatography and X-rays have lately facilitated new insights into process mechanisms [1]. Such techniques however focus on a particular aspect of the process, and are too sophisticated for implementation as process monitoring/control tools in a manufacturing environment.

Acoustic emission (AE) is emerging as a simple technique with the potential to not only reveal the larger picture of the EDM process state, but also adequately resolve individual discharges. The applications of AE for the in-process identification of workpiece height in wire EDM and electrode length in fast-hole EDM were reported in [2]. Recently, AE was also shown to enable the real-time assessment of gap flushing in EDM [3]; in this work, AE was observed to constitute a burst signal when discharges were initiated through the liquid medium, as opposed to their initiation through remnant gas bubbles from prior discharges. AE was thus found to encapsulate unique process information pertaining to the effectiveness with which material is removed at the scale of a single discharge. This highlights the significant scope of the AE technique in complementing the electrical waveforms that are exclusively used now for the monitoring and control of EDM machine tools.

There is a lack of fundamental knowledge on AE from EDM, due to little attention from the machining research community. Ironically, early works on the calibration and development of AE sensors have entailed electrical discharges as a source for generating AE. Likewise, electrical engineers have relied on AE for the detection of catastrophic partial discharges in power transformers. Acquiring AE from EDM is in itself simple, but interpreting it to understand source mechanisms is difficult, given that the embedded information is modulated along the signal path. The objective of the work reported in this paper was therefore to decipher AE arising from EDM in fundamental terms, with a view to mapping pertinent signatures to process mechanisms, and thereby gain new phenomenological insights into EDM.

2. Experimental

In the context of the objective above, the present investigation comprised both single and sequential discharge experiments. Single discharge experiments involved a 2 mm diameter copper wire as one of the electrodes that also functioned as a waveguide for the transmission of AE to the sensor, which had a fairly uniform frequency response in the range of 100–900 kHz. The other electrode was a force transducer with a natural frequency of 200 kHz, which was previously found to effectively capture the evolution of force in EDM [4]. This configuration facilitated the simultaneous measurement of the force and AE signals. Discharges were realized directly on the force sensor, to exploit its entire frequency complement. Experiments were augmented by high speed imaging of the gap, which was instrumental in providing a physical interpretation of the force and AE signals in terms of the dynamics of the gas bubble.

Sequential discharge experiments used a rotating brass disk electrode with a nominal diameter of 200 mm and a thickness of 5 mm. Electrode rotation aided consistent flushing. The workpiece was of AISI 4140 steel (42CrMo4) with sectional dimensions of 18 mm × 4 mm, on to which the AE sensor was fastened. Experiments referred to parameters such as polarity, open circuit voltage, pulse on-time, tool material and dielectric media, the effects of which were quantified in terms of the root mean square (RMS) value.

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3. Results and discussion

AE refers to transient elastic waves generated in a material in response to dynamic mechanical loading. Propagation of these waves induces minute displacements on the surface of the material, which are transformed to a voltage waveform by the AE sensor. Considering the sequence of events in a single EDM discharge from the breakdown of the dielectric fluid to eventual material removal, AE in EDM could potentially be attributed to: the plasma channel, the gas bubble originating from the rapid vaporization of the liquid dielectric in the vicinity of the plasma channel, and the shock waves emanating from the formation, implosion and rebound of the gas bubble (Fig. 1).

AE from dry EDM is insignificant as compared to when using a liquid dielectric [3], which indicates the component of AE arising from the plasma channel to be relatively minor. This is supported by the observation of Garzón [4] that force waveforms from single discharges could indeed register negative values (as discussed later), when the plasma channel is still incident on the electrodes.

A simple experiment was devised to resolve the relative contributions of the remaining elements, viz. the gas bubble and the shock waves (see schematic in Fig. 2). AE sensor 1 was attached to a workpiece across which discharges were struck, such that it is subject to both the shock waves and the gas bubble. AE sensor 2 (of nominally the same characteristics as sensor 1) was attached to another workpiece of the same geometry, which was positioned in close proximity to the gap, so as to capture the influence of just the shock waves without it being in direct physical contact with the bubble. A comparison of simultaneous burst signals from the two sensors clearly shows the influence of the shock waves to be an order of magnitude smaller (Fig. 2). Swapping the sensors confirmed this to be not a sensor-related artefact. AE signal from sensor 1 that predominantly relates to the pressure within the gas bubble is henceforth of greater interest in this work.

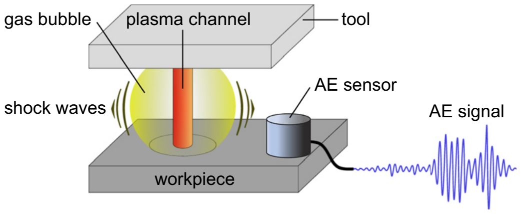

Fig. 1. Potential sources of AE in EDM.

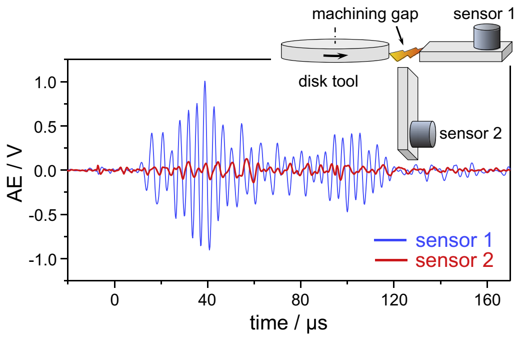

Fig. 2. AE from gas bubble and shock waves (open circuit voltage $\hat{u}_i$ 100 V, discharge current i_e 6 A, on-time t_e 50 µs, oil dielectric).

3.1. *Single discharge experiments*

Fig. 3A shows a typical AE burst from a single discharge. Band pass filtering the signal between 100 kHz and 400 kHz [3] significantly reduced the electromagnetic interference (EMI), a remnant of which but still remains. Although it is noise, the EMI blip usefully marks the breakdown of the dielectric fluid, saving the need to refer to the current/voltage signals. The EMI feature is followed by a time delay that refers to the time taken by the acoustic wave to reach the sensor along the length of the wire electrode. This in turn is followed by two packets of burst activity, similar to that in Fig. 2, although it is the second packet that is of a higher magnitude in this instance. In general, such variability in the relative magnitudes of the packets was characteristic of the AE signals.

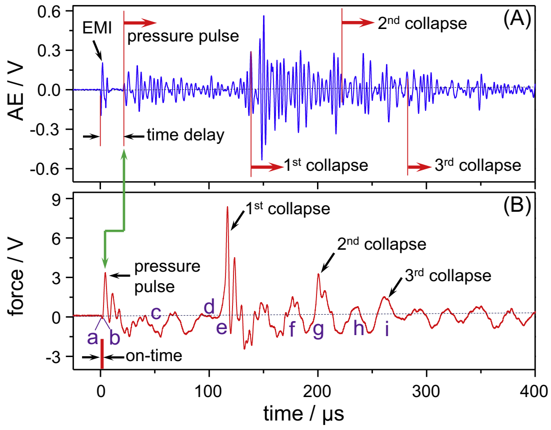

Fig. 3. Correspondence between: (A) AE, and (B) force signals ($\hat{u}_i$ 100 V, i_e 12 A, t_e 2 µs, oil dielectric).

The features in the AE signal can be interpreted by referring to the corresponding force signal (Fig. 3B). Relative to the on-time of 2 µs (shown as a red marker for reference), both the AE and the force signals span a time frame that is ~200 times as long. Symbols (a) to (i) shown in Fig. 3B refer to high-speed snapshots of the time evolution of the gas bubble depicted in Fig. 4.

Fig. 4a and 4b depict the inception and rapid growth of the gas bubble, which manifests a spike in the force signal that signifies the pressure within the gas bubble. The green line in Fig. 3 establishes the correspondence between the force and the AE in consideration of the time delay. By mapping the force signal to the AE signal, the pressure pulse can be seen to initiate a string of AE activity (Fig. 3A). Around the 50 µs mark, the force is rendered negative owing to over-expansion of the bubble (Fig. 4c), brought about by the inertia of the surrounding dielectric fluid. On expanding to its maximum volume, the higher hydrostatic pressure in the dielectric fluid around the bubble causes it to compress (Fig. 4d), eventually leading to its collapse at ~110 µs (Fig. 4e). The bubble collapse registers a significant increase in the force (Fig. 3B), and triggers another train of AE activity (Fig. 3A). The residual energy in the bubble results in two additional cycles of rebound (Fig. 4f and h) and collapse (Fig. 4g and i). Local maxima in the force signal between these events did not correspond to specific events in the high-speed images, and therefore appear to be related to the dynamics of the sensor.

The pressure pulse as well as the several cycles of bubble collapse can be readily identified in the force signal (Fig. 3B), but only the pressure pulse and the first collapse can be

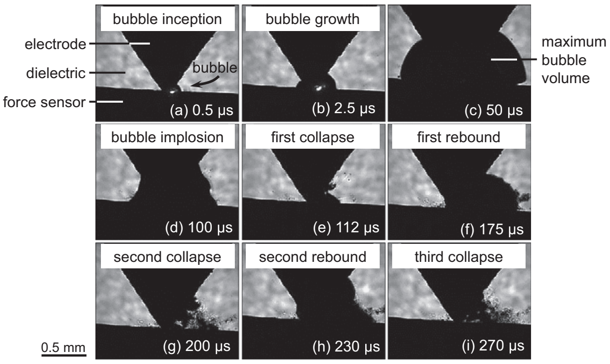

Fig. 4. Stages of bubble expansion, collapse and rebound (the wire electrode tip was shaped to be conical to localize the discharge and thus facilitate imaging).

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