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In-situ measurement of electrochemical jet machining using low coherence interferometry

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Abstract

The ability to provide surface texturing at the micrometre to millimetre scale is of growing interest in many high-value manufacturing applications, for example, improving a components ability for heat transfer, chemical sensing, wettability and bio-mimicking. Electrochemical Jet Machining (EJM) has shown promise for performing surface structuring, providing material removal via electrochemical dissolution. This gives benefits of being able to machine without introducing stress hardening or thermally affected regions and for processing shear resistant materials.

Current quality control processes for EJM involve an offline approach to verify adherence to design tolerances. This requires removal of the part from the machining setup and cleaning which is time consuming and error prone if re-machining is required. Offline approaches do not allow for adaptive control feedback to be implemented during the machining process, which requires an in-situ measurement system.

Implementation of in-situ depth sensing modalities in the EJM environment capable of real-time, accurate measurements is difficult using commercially available systems. This is due to hostile operating conditions, from electrolyte flushing and tight geometry constraints. However, Low Coherence Interferometry (LCI) is a measurement technique that has shown promise for operating in non-ideal environments through its use in biological imaging. Additionally, LCI benefits from easy integration into fibre optic systems allowing for small sensor footprints and has been demonstrated to effectively work in a range of operating mediums. The work presented here investigates the feasibility of applying a fully fibre enclosed common-path LCI sensor within EJM.

Low Coherence Interferometry, Metrology, Electrochemical Jet Machining, Process Control

1. Introduction

New modes of machining focussing on incorporation of surface texturing for improvement of component efficiency for heat transfer, wettability and wearability are becoming increasingly commonplace in high-value manufacturing designs. This has led to an increased demand for machining processes capable of adapting to these requirements. Electrochemical Jet Machining (EJM) is one such technology which has potential to meet such manufacturing demands [1]. Capable of performing multiscale form and texture machining using electrochemical dissolution and benefiting from being able to machine without introducing stress hardening or thermally affected regions, and for processing shear resistant materials.

Current limitations in the ability to control EJM is a major limiting factor supressing the widespread acceptance of the technique. Reliable in-situ metrology has long been held as the ultimate goal of manufacturing engineers, able to provide real-time process feedback control and validation of part conformance to design tolerances. Low coherence interferometry (LCI) is an optical ranging technique which has shown promise for performing accurate surface profile measurements in industrial environments as shown through previous work in non-ideal and aqueous domains [2-4]. LCI has also found use in the field of bioscience where it is known as optical coherence tomography for performing tomographic measurements on the surface and interior of the human body demonstrating the robustness of this technique as a sensor in harsh environments [5].

The work presented here demonstrates an initial investigation into the integration of an LCI sensor operating with a fully-fibre common-path configuration, to EJM. Demonstrating accuracy of measurement within a high-speed liquid jet for stability and profiling measurements of EJM processed microstructures.

2. Experimental setup

The setup shown in Figure 1, illustrates the EJM system and integrated LCI sensor. The LCI system is fully-fibre enclosed with a common-path being used for the reference and sample signal leg, thus reducing sensitivity to vibrations, thermal fluctuations and humidity, and removing the requirement for dispersion compensation between signals [6]. This system consists of a super-luminescent diode (EXS210068-01, Beratron GmbH), with a 3-dB bandwidth of 58 nm, central wavelength of 853 nm and an emitting power of 5.14 mW at 160 mA.

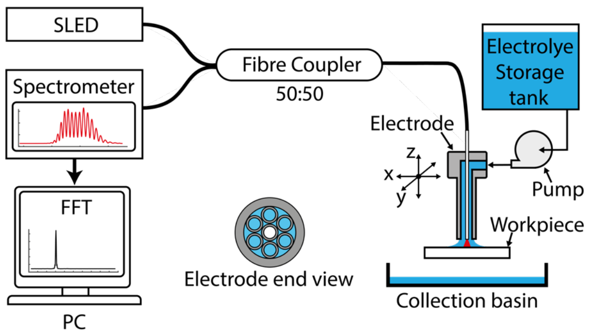


Figure 1. Experimental setup showing LCI situated in an EJM electrode

A single mode fibre coupler with a splitting ratio of 50:50 was used for the beam splitting and coupling. The sensing end of the interferometer is a bare lensless fibre consisting of core and cladding with a diameter of 125 ± 1 µm, providing a numerical aperture of 0.13, resulting in a confocal parameter of 83.51 µm and $1/e^2$ transverse resolution of 5 ± 0.5 µm.
Such a deployment enables the positioning of the sensor end co-axially inside the electrode of the in-house constructed EJM system.
To locate the fibre within the electrode of inner diameter 1.2 mm it is first threaded into a brass micro-tube with an outer and inner diameter of 0.5 mm and 0.3 mm respectively. A honeycomb type structure was created around the central tube as shown in Figure 1, this allows for the electrolyte flow to be flushed without direct interaction with the fibre providing robust alignment of the fibre distal end to the sample. The electrode is attached to a 3-axis motorised translation stage (Zaber Technologies: X-LSM025A). The LCI sensor was calibrated through offset distance comparison via a Renishaw XL-80 interferometer (accuracy assured to ± 0.5 ppm) to act as a traceable reference measurement for the LCI system.

3. Results and Discussion

Initial investigation concentrated on observing distance measurement in air of a sample with a set stand-off from the end of the fibre of 313.54 µm, and then during load whilst a water jet was initiated with successful hydraulic jump as is present in EJM systems. The results can be seen in Figure 2, where for the first ~ 30 seconds measurements are performed in air and show minimal variance in results ($2\sigma = \pm\, 0.02$ µm). Once the jet is activated as shown from the right hand side of the red dashed line in Figure 2 a period of mechanical stabilisation occurs for approximately 20 seconds before levelling out. The signal also has a larger fluctuation relative to the in-air measurement due to vibrations from the liquid jet flow but still of the order ($2\sigma = \pm\, 0.22$ µm). The data in Figure 2 has had refractive index compensation applied to the in water jet region however, an offset of approximately 1.7 µm between air and liquid jet measurements remains. The results in Figure 2 demonstrate the ability to provide suitable stability to the fibre to stay located at an unvarying offset from the sample object with data integrity showing minimal signal loss during liquid jet flow. Fluctuation in signal value is present with increased randomised noise present during the water jet operation due to vibration of the fibre end.

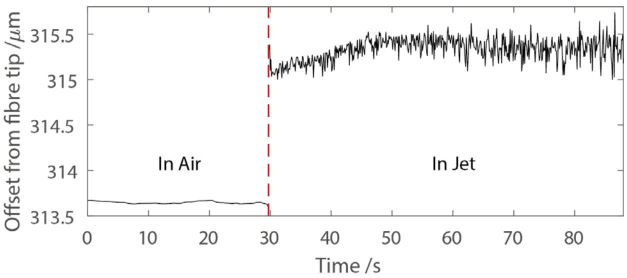
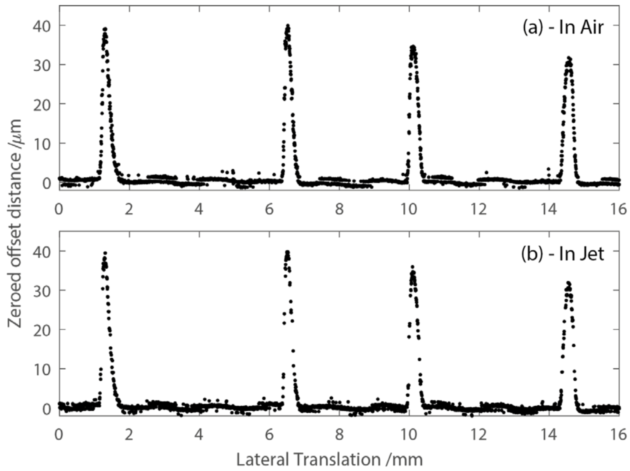


Figure 2. Measurement stability with jet turned off in air shown on the left-hand side of the dashed red line and with liquid jet turned on as shown on the right-hand side of the dashed line over time.

Investigation into measurement of EJM processed structures was conducted. Figure 3 shows profiling measurements taken across an Inconel sample with 4 trenches electrochemically machined into the surface (provided by Nottingham university's EJM research group), performed in air and within an active liquid jet. Initial stand-off distance from the sample surface was ~360 µm, translational steps of 4 µm were taken across 16 mm providing trench depths as shown in Figure 3.



Medium	Trench 1	Trench 2	Trench 3	Trench 4
Air /µm	39.47	39.79	35.96	31.89
Water Jet /µm	39.08	39.95	34.64	31.73

Figure 3. Zeroed depth profile of surface pattern generated using EJM, (a) Profile measured in air with liquid jet turned off, (b) Profile measured whilst liquid jet activated. The table shows trench depths corresponding to the shown peaks from left to right.

It can be seen from Figure 3 that measurements in air and in a liquid jet were able to successfully capture the cross-sectional profile of the 4 trenches. Some data loss is present during water jet operation though accurate capture of the trench heights was achieved under both measurement conditions.

4. Conclusion and Summary

This work defines the application of a custom LCI system for performing measurements of EJM processed structures within a high-speed liquid jet flow. This shows the potential of such a configuration to operate in industrial domains with applications for synchronous measurement of components and in-situ measurement during machining processes such as EJM. Future work will further investigate and evaluate measurement in liquid jets and within EJM processes for online control of machining processes.

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