Studying the Force Exerted on the Tool-electrode During Machining: A Key Element for Force Feedback Micro-machining Using Spark Assisted Chemical Engraving

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Abstract

Research on Spark Assisted Chemical Engraving (SACE) micro-machining of non-conductive materials has progressed during the past years. Yet no closed loop control of the machining has been developed so far. This paper develops the results found where a correlation between the maximal forces exerted on the tool-electrode tip and the channel profile is found. This is a first step towards the development of force feedback control algorithms or micro-channel machining by SACE.

1 Introduction

Spark Assisted Chemical Engraving (SACE) is a non conventional technology used to machine non-conductive materials based on localised high temperature etching [1]. The work-piece is placed inside a cell, containing a counter electrode and the tool-electrode (usually polarised as cathode) which is positioned directly above the work-piece. When a voltage is applied between the two electrodes, current flows and bubbles form around the tool-electrode eventually coalescing into a gas film. This causes electrical discharges to be generated increasing the temperature in the machining zone and etching the sample beneath the tool-electrode [2, 3].

Recently it was shown that the forces exerted on the tool-electrode during SACE micro-drilling give valuable information about machining status [4]. Till now, no deep analysis of the forces exerted on the tool-electrode tip during 2D machining has been done. In this work, forces exerted on the tool-electrode while machining 2D micro-channels at constant velocity were investigated. The final goal is to correlate these forces with the machining rate in order to build force feedback algorithms to improve machining repeatability.

2 Experimental Set-up

The experimental setup consists of a XYZ Cartesian robot, where the SACE machine head assembly (Fig. 1) is mounted on the Z-axis of the XYZ stage. The work-piece is placed inside a processing cell mounted on the XY axes to align the work-piece relatively to the tool electrode. The electrolyte used was 30%wt NaOH.

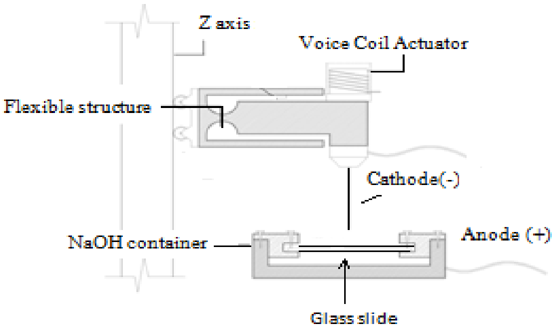

Figure 1: Overview of sace machining set-up

The tool electrode, a stainless steel cylinder (0.5 mm diameter), is connected to the machining head composed of a flexible structure (Fig. 1). The flexible structure can be moved upwards or downwards in the z direction by means of a voice coil actuator. The machining head can be used either as mechanical profile-meter or as a force sensor. During constant velocity 2D machining, the tool electrode moves with a constant pre-set velocity during which the distance between the work-piece and the tool is kept constant. The force acting on the tool is measured using the zero displacement principle: the relative distance between the flexible structure and its base is kept constant by a PID controller (i.e. the voice coil actuator is controlled to provide a force on the tool that is opposite and equal to the force exerted on the tool during machining).

3 Results and Discussion

In order to study the origin of the forces exerted on the tool tip during 2D-machining, the following experiments were conducted. The tool tip was positioned to be 20 microns above the glass work-piece, and then moved down with a speed of 50 microns/sec by a distance of 20microns+*d*, where *d* is the desired channel depth.

Then a voltage of 28 volts was applied between the two electrodes while moving the tool in the XY plane at 50 microns/sec. The tool speed was chosen to be high and the voltage was chosen to be low (compared to traditionally used values) in order to facilitate, in a first step, the investigation of the forces exerted on the tool tip during machining. A number of experiments were conducted and the plot of Fig. 2 is a representative sample of the results obtained. The curves depict the force exerted on the electrode while machining and the depth profile of the channel, measured after machining with the profile-meter function of the machining-head.

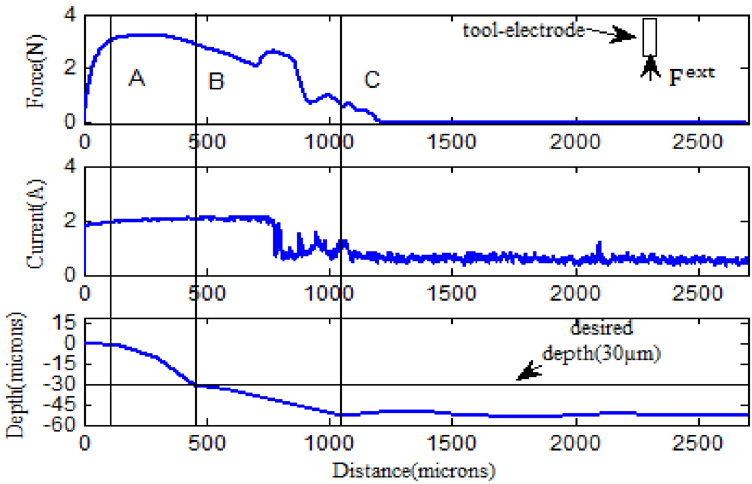

Figure 2: Correlation between the force exerted on the tool- electrode and the depth of the microchannel

As shown in Fig. 2, for the first few microns, machining didn't occur. This can be explained by the fact that it takes time for the temperature of the machining zone to increase (due to the close contact of the tool and work-piece and the low machining voltage selected). Machining started about 50 seconds later at point A. As can be seen from the average current signal, the gas film was formed and broken down continuously so that the discharges rate was very low. As the machining proceeds, the depth increases while the force exerted on the tool decreases. At point B the tool is at the desired depth (30 microns) but the force still exists (around 3 N). At point C, the discharges generated were stable and material removal rate increased causing a gap of 20 microns between the tool and the glass surface. After point C, the forces exerted on the tool tip diminished to zero. It can be concluded that the forces exist on the tool tip even at a gap lower than 20 microns. These forces may be due to the viscous zone that is formed below the tool electrode during machining and to the pressure exerted by the gas film on the tool tip [4].

4 Conclusion

In the present paper, the forces exerted on the tool tip during 2D SACE glass micro-machining were recorded, and it was shown that a correlation between these forces and the current flowing through the electrodes and the channel profile can be established. This is a first step towards our aim in developing force feedback algorithms to produce reproducible channels of different surface roughness based on the application. Studying the force exerted on the tool electrode during micro machining using SACE technology will help to maintain a constant gap between the tool and the work-piece which result in high surface quality of the machined holes and channels. This is of a great interest due to the broad applications that glass micromachining has, including developing micro-fluidic devices, micro pumps and biosensors.

References:

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