# Low Energy Non-Contact Electrical Discharge Measurement System on a Micro-manufacturing Platform

J L Montgomery
*SmalTec International, USA*
jmontgomery@smaltec.com

**Abstract:**

This paper investigates the development of an on-board micro-electrical discharge circuit, at pico-Joule energy levels (5-20 volts, 10 pF), acting as an automated 3-D micro-metrology system. This process detects micro-amps of electrical flux within a µEDM circuit. This affords the ability of non-contact, non-destructive surface measurement. By using the µEDM abilities, various sensor probes can be manufactured on-line to measure any machined forms. Due to the non destructive nature of the process, combined with the double V-groove mandrel holder of the SmalTec platform, each manufactured sensor probe can be removed from the platform and later returned for additional measuring with little necessary positional calibration. This process allows micro-manufactured parts to be measured *in situ,* and verified prior to removing the part from the machining platform.

## 1 Introduction

Probes of two geometries (flat and rounded cylinder) were used in this study to find parameters for metrology on various materials and forms. Each of these probes was formed by the µEDM system [1]. Various energy levels, feed rates, and detection sensitivities were tested. Four materials basic to the micro-machining industry (stainless steel, molybdenum, gold, and platinum) were used for the tests. The testing was done with a focus on two fundamental aspects; repeatability and surface deformation. It was determined that with specific probe geometries and feed rates each material could be repeatedly measured (up to 100 times) with a standard deviation of 100nm. This testing was accomplished in an operating machine shop, using a standard µEDM dielectric fluid (EDM30) and with no additional cleaning processes between trials of either the sensor probes or the test materials.

## 2 Electrical Properties of µEDM Metrology

A µEDM circuit is primarily a machine tool but, it is also a crude sensor. An active circuit measures the current level, detecting when the tool is in contact with the work-piece, and reacts accordingly. In general, as the tool approaches the work-piece, it does work removing material. Any contact with the work-piece completes a circuit, allowing current to flow freely. When this is detected the control circuit retracts the tool from the surface, re-establishing a working distance for the electric field. The tested circuit focuses on this sensing capability. It is designed to detect minute current variations [µA], which occur when the circuit's capacitor charges, or discharges, as the tool simply approached the surface, prior to a spark event or contact. This new sensing capability allows for a response to occur upon proximity to, instead of contact with, a surface, and without the surface deformations of prior EDM referencing.

The electrical variables believed to have the most impact on surface deformation were energy, voltage polarity, and discharge sensitivity. It was assumed that energy would have the most impact upon surface deformation as seen when previous uses of EDM sensing was used for referencing [2], limiting repeatabilty. Table 1 shows the electrical variables and their rate of impact on surface deformation.

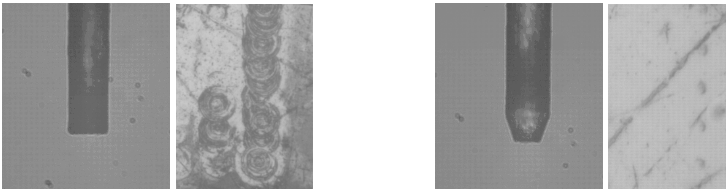
Table1: Prime Tested ElectricalVariables

| **Variable** | **Range** | **Impact** | | |
|---|---|---|---|---|
| Energy | 5-20V [10pF] | High [0-5V] | Low [5-20V] | High [>20V] |
| Polarity | Positive of Negative | High | | |
| Sensitivity | 10-90% rise time | Low [10-75%] | | High [>75%] |

It was discovered that below 20V (10pF), and above 5 volts (10pF) the energy level had little impact on surface detection. However, higher voltages increased the chance of dielectric breakdown and stray discharges creating tell-tale EDM marks. Lower voltages were less reliable as they were below the 5V supply of the sensing circuit reducing the sensing capability. It was also found that the sensitivity of the discharge circuit was nearly inconsequential. If the sensitivity was set too high, the system could be triggered by impurities in the flushing medium. Voltage polarity had the greatest impact on surface deformation. It was determined that the optimal sensing voltages for most probes was -5 to -10 volts with respect to the substrate.

## 3 Electrode Form

Two electrode forms were chosen for this experiment, a straight 90 degree cylinder, and a rounded conical cylinder. The shape of the sensing surface had a great impact on the non-contact characteristic of the process. Figure 1 shows how a flat probe was more prone to surface contact, while a rounded probe was more reliably non-contact.



**Flat Probe and Results (<u>600X</u>)** **Rounded Probe and results (<u>3000X</u>)**

Figure 1: How electrode shape impacted surface deformation on Platinum

It was determined that lower feed rates were necessary for flat sensors to achieve comparable results with more rounded sensors. The figure 1 probes were both run at 5mm/min.

## 4 Measurement Repeatability

Repeatability is a key aspect of this paper as prior μEDM sensing caused surface erosion, altering future positioning [3]. The non-destructive nature of this process removes the inadequecies of μEDM as used as a referencing tool. Figure 2 shows a 50 sample segment of how the process repetitively measured a single line.

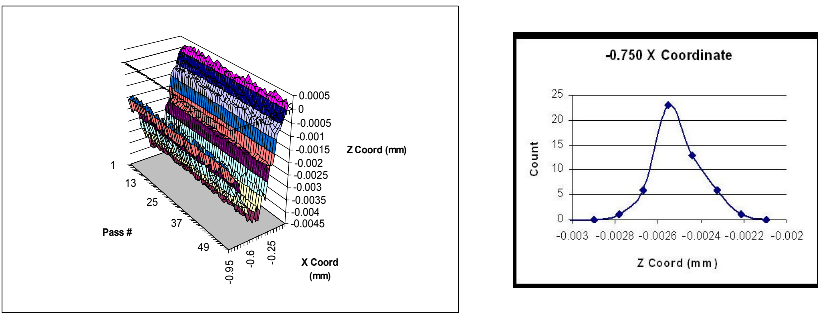



Figure 2: 50 samples of a single line and the standard distribution of a single point

The standard deviation of the line measurements was in the range of 100nm, with a maximum of 150nm and a minimum of 80nm.

## 5 3-D Form Measurement

As a final test of the process a work-piece (figure 3a) was measured and checked for imperfections. This polished nozzle was measured using a brute force algorithm and then plotted separately. The hope of this mapping was to expose any inconsistencies, or shelves, created by the conventional machining process. The result is the graph of a smooth form (figure 3b). The part was later inspected (1000X) for 'witness' marks and none were found.

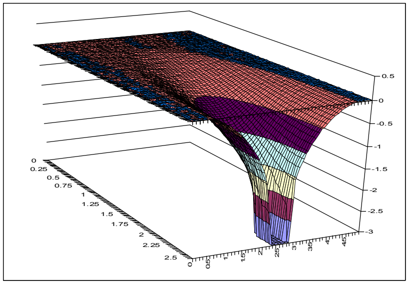



Figure 3: A Carbide nozzle (a) and a cut-away of its mapped form (b)

## 6 Conclusion:

There is a strong body of empirical evidence showing that the µEDM circuit can be an effective metrology tool. The prime variables affecting the process are voltage polarity, energy and probe shape. Other variables were found to be inconsequential except at the extremes, while others, with the optimization of electrode form, were shifted to benefit the process, such as feed rates and voltage potentials.

**References:**

**[1]** M. Kawada, K. Mitsui, "Fabrication of Probes for Profile Measurement of Micro-EDM Manufactured Components." *Nanotechnology and Precision Engineering,* issue 2, 2004, Pages 124-131

**[2]** P. Bleys, J. Kruth, B. Lauwers, A. Zryd, R. Delpretti, C. Tricarico, "Real-time Tool Wear Compensation in Milling EDM." *Manufacturing Technology,* Volume 51, Issue 1; 2002, Pages 157-160

**[3]** S. Bigot, et al. "A Study of the micro EDM electrode wear" *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science* May 1, 2007 vol. 221 no. 5 605-612