Validation of On-machine Microfeatures Volume Measurement Using Micro EDM Milling Tool Electrode as Touch Probe

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Abstract

In micro electrical discharge milling, process parameters have to be empirically calibrated in order to achieve high precision machining; to this end, on-machine measurement of the material removed is of paramount importance. The capability of electrical discharge machines in detecting electrical contacts between the electrodes can be exploited to perform dimensional measurements, using the tool electrode similarly to the touch probe in a coordinate measuring machine. In this work an investigation of the accuracy of the on-the-machine volume measurements in a micro electrical discharge milling setup is carried out and an evaluation of the error affecting on-machine measurements is provided.

1 Introduction

Micro electrical discharge milling (µEDM milling) is a particular configuration of µEDM where material removal is achieved exploiting electrical discharges occurring between two electrodes and microfeatures are fabricated driving a cylindrical tool electrode along tool paths as in conventional milling operations [1].

Since material removal and tool wear rates are strongly dependent on specific working conditions, it is necessary to calibrate process parameters before proper machining in order to produce high precision micro features. Accurate determination of the amount of material removed from both tool and workpiece is thus of paramount importance. To this end, on-machine volume measurements are needed, especially to implement self-learning procedures for process parameters optimization.

In commercially available EDM machines it is possible to exploit the short-circuits detection system that is used for the electrical discharge machining process also to obtain dimensional measurements. In previous works, the short-circuit detection system has been adopted for roundness deviation evaluation [2] and the repeatability and reliability of tool length measurements performed with this method has been assessed [3]. However the use of the short-circuit detection system and the tool electrode to perform coordinate measurements similarly to a touch probe in a CMM have not been reported yet and a metrological validation of this micro EDM measuring method is missing [4].

2 Errors induced by imperfections in the machined geometry

On-machine volume measurements based on coordinate measurements by the tool electrode are mainly influenced by the dimensional measurement capability of the µEDM system and by the most relevant imperfections present in machined features, such as surface roughness, walls draft angle and corners rounding. Experiments were performed on a Sarix SX-200 µEDM machine. The probe used for on-machine measurements was fabricated with SX-200 wire dress unit and characterized with the optical sensor of a Werth Video-Check-IP 400 multisensor CMM.

A circular pocket with a diameter of about 515 µm and a depth of about 440 µm was machined on a block of mould steel by µEDM milling using a 300 µm tungsten carbide tool electrode and a finishing set of process parameters. Then the workpiece was cross sectioned in correspondence to the centre axis of the hole. SEM images (figure 1-A) and confocal measurements show that floor and wall surfaces have comparable but non negligible surface roughness. As a consequence, when the cylindrical tool-probe is used to measure the diameter and depth of the cavity it touches the burrs around the craters instead of the average profile of surfaces, producing a systematic under-estimation of the quantity of material removed during the erosion of the pocket. The volume per unit of surface was estimated and it was evaluated that up to 0.7% less volume was measured because of surface roughness. The corners rounding radius on the floor of the pocket (figure 1-B/C) was measured with the optical CMM (measured radius: 45 µm); then the related over-estimation of the pocket volume was evaluated to be within 1%. The angle of inclination of the walls of the pocket (figure 1-C) was measured with the optical CMM to be about 0.7

degrees; as a result, in the worst case the associated volume measurement error for these specific geometries is 3%.

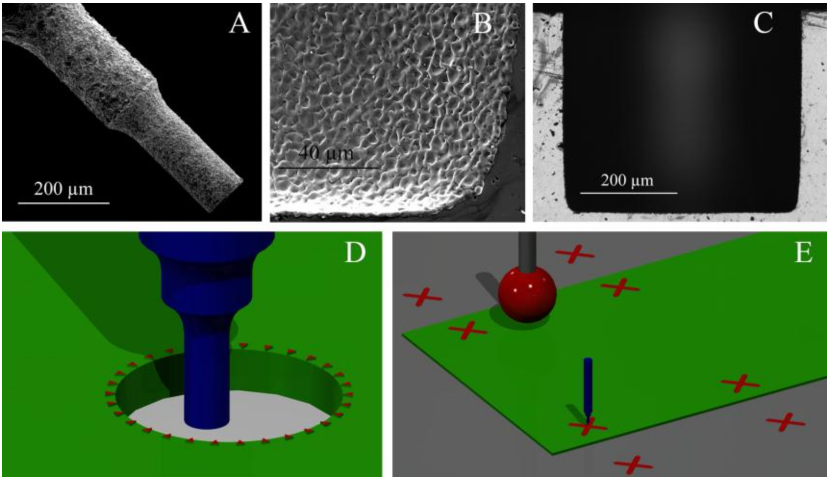

Figure 1: SEM image of the tool-probe used for on-machine measurements (A). SEM image (B) and micrograph (C) of a cross sectioned blind hole machined by µEDM. Distribution of measured points on: (E) a step specimen, obtained assembling a calibrated gauge block having a nominal height of 100 µm on a larger flat surface, and (D) a through hole with a diameter of about 500 µm machined by µEDM.

3 Determination of dimensional measurements uncertainty

The uncertainty of dimensional measurements performed by the µEDM milling machine was determined following the experimental method standardized in ISO 15530-3 [5], through 20 repeated measurements of calibrated workpieces. To this end, the diameter of a calibrated through-hole was measured on the µEDM machine, acquiring 30 points equally spaced along the circumference as in figure 1-D, while the height of a calibrated step specimen was measured as in figure 2-E. Reference calibrations of the diameter and height were performed using the Werth multisensor CMM mentioned before.

The experiments showed that the expanded uncertainty (coverage probability of 95%) for depth measurements is equal to 1.3 µm and the standard deviation of the 20 repetitions is 0.26 µm, while for diameter measurements the expanded uncertainty is equal to 1.9 µm and the standard deviation is 0.5 µm, after the correction of a systematic error, quantified in 3.1 µm.

4 Discussion and conclusions

Analysing the results, the most relevant quantity influencing the accuracy of on-machine volume measurements is the slope of the walls. This measurement error contribution depends not only on the extent of the walls slope, which is proportional to the aspect ratio, but also on the depth at which the diameter of the pocket is measured. Theoretically it is possible to calculate the exact depth where to measure the diameter to nullify the measurement error associated to wall slope: given the small value of the draft angle, this level can be approximated to half of the hole depth. Corners rounding radius and surface roughness, instead, are constant for a given set of process parameters; hence the associated errors are mainly dependent on the volume and surface-to-volume ratio of the measured cavity. The measurement method showed a good repeatability, but a significant systematic error was found in the diameter measurement. Correcting this systematic error allows measurement uncertainties below 2 µm (coverage factor k=2).

In conclusion, this work showed that it is possible to perform on-machine volume measurements with relative errors below 3%, which is acceptable for calibration of process parameters.

References:

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