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Contamination of µCMM stylus tips: on-machine inspection

Xiaobing Feng[1], Cyril Lacorne[1], Gustavo Fernandes[1], Simon Lawes[1], Peter Kinnell[2]

[1]*The University of Nottingham*
[2]*Loughborough University*

Email: xiaobing.feng@nottingham.ac.uk

Abstract
Contamination adhered to the surface of a µCMM stylus tip significantly impairs the dimensional accuracy of a µCMM system. Regular cleaning of the stylus is essential to minimising the dimensional error but little data exists for determining appropriate cleaning intervals. This study investigates the build-up of contamination on the µCMM stylus tip during probing procedures. Experiments were conducted on surfaces with controlled contamination for 18 different conditions to study the impact of surface morphology and contact pressure. Quantitative results showed that surface texture due to the difference in machining processes was more influential than surface roughness in determining contamination rate, and that higher contact pressure led to greater contamination. However, contamination rate was observed to vary significantly, suggesting a probabilistic mechanism for contamination adhesion. As such, predictive methods may not offer a reliable threshold for determining cleaning intervals. To that end, a technique for on-machine imaging has been proposed to work in-line with the µCMM and inspect surface contamination as it builds. Using epi-illuminated optical microscopy with focus stacking, debris of less than 300 nm in size was detectable.

Keywords: stylus contamination, debris imaging, µCMM

1. Introduction

Measurement of geometrical characteristics of precision parts is often conducted on a micro-coordinate measurement machine (µCMM) due to its superior reliability compared to optical measurement systems. During measurement, contact between the stylus and the sample is likely to cause debris to attach to the stylus tip [1-4], introducing error to the measurement. As the size of the stylus tip approaches that of a foreign contaminant, the effect of contamination induced error becomes more significant. Debris a few micrometres in size may cause dimensional errors that are orders larger than the specified uncertainty of a µCMM. It is therefore essential to keep the stylus as clean as possible. In previous studies [1, 5] the authors have investigated on the effectiveness of several cleaning techniques in removing contamination from µCMM stylus tips and found snow cleaning to be effective, safe and uniquely suitable. Subsequently, a prototype snow cleaning device has been [6] developed by the authors for the cleaning of µCMM stylus tips. However, little data exists for determining appropriate cleaning intervals, which should be frequent enough to keep the stylus reasonably clean but not too frequent as to severely impact measurement throughput. To find the appropriate cleaning interval, this study investigates the contamination build-up rate on the stylus tip during measurement. Section 2 describes the experiments conducted to study the impact of surface morphology and contact pressure. Section 3 discusses the findings. And section 4 presents a solution for on-machine stylus inspection. Section 5 concludes the contributions of this study.

2. Contamination experiments

An experimental study has been conducted to determine the contamination build-up rate during measurement under various conditions. This section presents the experimental setup, variables and analysis methods involved in the study.

2.1. Samples, probing conditions and variables

Despite lack of published work on contamination build-up rate during measurement, it may be influenced by several factors such as surface characteristics of the sample surface and probing conditions. An observation from industrial practice is that self-calibration procedures often probe the same point or area repeatedly. Contamination rate may vary when probing is repeated at one location, or at a new unprobed location each time. Machining processes often leave a distinct texture on the surface, potentially affecting the mechanism of debris transfer from the sample to the stylus. Roughness of the sample surface and probing conditions such as probing mode and contact pressure also directly affect contamination build-up. This study was focused on the effect of sample surface characterisations and contact pressure.

The samples used in the experiments were precision surface references (Rubert & Co, Microsurf series) representing surfaces made with various machining processes and controlled levels of surface roughness. Each sample has undergone the following preparation procedure, emulating a production process to ensure consistent contamination:

(1) cleaned with isopropanol in an ultrasonic bath for 5 minutes;
(2) immersed in used cutting fluid (ROCOL V-cut EP) for 5 minutes;
(3) left to dry in the air for 5 minutes, and
(4) cleaned again with isopropanol in an ultrasonic bath for 5 minutes.

The Mitutoyo CMM Euro-C-A121210, Renishaw probe head PH10M, probe modules TP200SF (standard force), TP200LF (low force) and styli with ruby spheres of 0.3 mm and 1 mm diameter were used in the probing procedures. Given that the contact pressure of the CMM cannot be adjusted at will and is not easily measured, high and low contact pressure conditions were achieved by varying stylus tip diameters, probing orientation and probe modules.

Controlled experiments were conducted with independent variables listed in table 1. In each experiment, a cleaned stylus was used to probe on the sample repeatedly and the stylus was examined regularly to determine contamination build-up. To observe variability within a set of conditions, a number of probing rounds were conducted for each condition.

Table 1. List of variables involved in the experiments.

Variables	Values
Machining process	grinding, EDM, milling
Surface roughness/µm	0.4, 0.8, 1.6, 3.2
Stylus tip diameter/mm	0.3, 1.0
Contact pressure level	low, high

2.2. Quantification of contamination

The stylus tip was examined with a Hitachi S-2600N scanning electron microscope (SEM) using the back-scatter detector. SEM images of the stylus tip were collected, processed with Fiji (ImageJ) using thresholding methods, and analysed to determine the amount of contamination. Because the contamination was examined using 2D images, contamination was quantified as the amount of surface area covered by debris instead of the actual volume of debris.

3. Results and discussion

The effect of probing an area repeatedly can be seen in Figure 1, where each probing round consisted of 100 contacts.

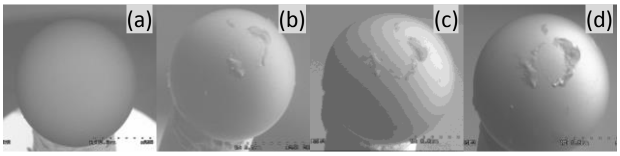

Figure 1. Stylus tip of 0.3 mm diameter (a) before probing, (b) after 3rd probing round, (c) after 8th probing round and (d) after 1st probing round on a new location.

Contamination continued to build up on the stylus tip after each probing round. However the build-up rate plateaued after 3 to 5 rounds as the contamination barely grew between 3rd and 8th round. This indicates that most debris on the location has been picked up by the stylus. In contrast, once the stylus started probing on a new location, contamination resumed to build up at a noticeable rate, as shown in Figure 1(d).

Figure 2 illustrates the amount of contamination on the stylus tip after probing 50 contact points on samples of various machining processes and surface roughness values.

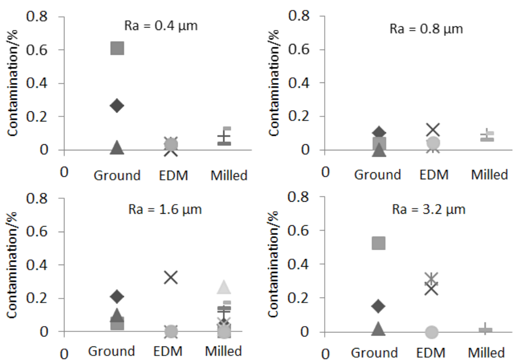

Figure 2. Stylus contamination after probing various samples: each data point shows the contamination after 50 contacts with a cleaned stylus.

Contamination rate varied significantly both between and within experimental conditions, due to several possible reasons such as non-homogeneous particle density on each probed location, distortion on the SEM image and error in quantifying debris with only 2D projection. To further examine the variance in data, tests were repeated 9 times (instead of 3 times) for one condition (milled surface, Ra=1.6 µm). The results were stilled widely spread, indicating that the contamination adhesion process itself is highly stochastic. Despite the variance in the data, machining process was observed to be more influential on contamination build-up than surface roughness. In addition, variance in the build-up rate was more strongly affected by sample surface characteristics than average rate.

Furthermore, higher contact pressure was found to correlate with higher contamination rate. In some cases, a considerable portion (5%) of the stylus tip was contaminated after only 50 contact points.

4. On-machine stylus inspection

Given the variant nature of contamination rate, it may be more effective to regularly examine the stylus for debris than relying on a predictive model. Since SEM is very slow and disruptive of the measurement setup, it is necessary to develop a fast and convenient inspection technique to work in-line with the µCMM and inspect surface contamination as it builds. However, inspection of a specular sphere with high slope presents several challenges. An inspection solution was therefore proposed that achieves high resolution using a microscope and addresses the limited depth-of-field with the focus stacking method. The resulting image was then analysed to evaluate the size of debris. Figure 3 (a) shows the results obtained using a Nikon microscope (LV100ND) with 20X objective and proprietary software Zerene Stacker.

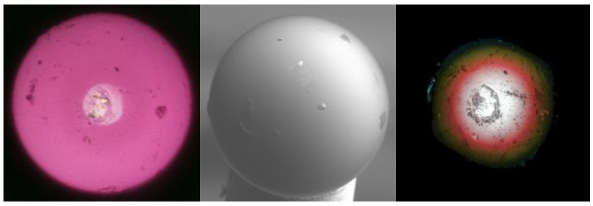

Figure 3. Images of a 0.3 mm diameter stylus tip obtained using (a) proposed solution, (b) SEM and (c) confocal microscope.

Using the proposed solution with a 20X objective debris as small as 1 µm in size was able to be identified, and as small as 0.3 µm in size at 50X. For a full hemispherical field of view the resolution is close to an SEM or a confocal microscope and unlike these two complex systems, the inspection can be achieved conveniently on-machine and at lower cost.

5. Conclusions

This study investigates the contamination rate on µCMM stylus tips during measurement. Experiments have been conducted to determine the effect of sample surface and probing condition on contamination rate. When repeatedly probing on the same location, contamination rate plateaued after 3~5 rounds of 100 contacts. Contamination continued to build up as long as new locations are probed. Large variance in contamination results was observed, suggesting that debris adhesion is highly stochastic in nature. Machining process was found to be more influential on contamination rate than surface roughness, and variance in the build-up rate was more strongly affected than the average rate. To facilitate regular examination of contamination, a stylus inspection technique has been proposed and has demonstrated on-machine inspection capability, good performance and low cost.

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