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First measurements of onset of tip flight for micro-probes with diamond and Silicon tips for fast roughness measurements

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Abstract

Cantilever-type silicon microprobes with integrated silicon tips and piezoresistive signal read out have been successfully tested without force control for high speed roughness measurements up to 15 mm/s. To reduce wear of the silicon tips, diamond tips are mounted to the microprobes. The diamond tips exhibit a higher mass and thus, lead to an earlier onset of tip flight. The contribution presents first measurement results of silicon and diamond tip microprobes in force controlled mode to determine the onset of tip flight, which poses a limit to the maximum traverse speed. For comparison the tip flight behavior of a conventional stylus instrument is also investigated.

Keywords: in-line metrology, on-the-machine measurements, long cantilevers, high speed measurement, microprobe, diamond tip, silicon tip, tip flight

1. Introduction

Roughness measurements of surfaces are widespread applications for stylus profiler instruments, important in industrial and general research. In recent years the trend to bring those measurements into the production line has created a demand for high scanning speeds to reduce the overall production time. The PTB Profilescanner system's ability to traceably measure roughness in high-aspect-ratio microstructures, e.g. holes with diameters down to 50 µm and depths up to 5 mm makes it an interesting new candidate to bring it on-line [3]. However for fast measurements the probing tip suffers a considerable wear. Moreover, also tip flight is observed for high traverse speeds [1]. To obtain a better understanding of the processes causing tip flight in the Profilescanner, corresponding first measurements have been undertaken.

For comparison also measurements with a conventional commercially available stylus instrument, a Tencor P17, are carried out. These measurements were made in the force controlled mode. In order to compare the results with those of the Profilescanner, also the Profilscanner measurements were carried out in the force controlled mode. This mode does not deliver high scanning speeds, since the z-table used, is too slow. Nevertheless this measurement mode is important for users, since it allows precise topography measurements without scratching the surface. Moreover, this mode does not allow very high scanning speeds like those possible in the open-loop mode.

2. Tip flight

Tip flight or stylus flight describes a disturbing behaviour of probing tips in stylus instruments and scanning probe microscopes when the tip looses contact to the surface for a short time.
This poses a problem for roughness measurements that have to be done fast or with small probing forces for delicate samples. Morrison [4] described the phenomenon and gave a traverse speed limit for tip-surface contact loss. The Morrison model assumes a sinusoidal surface structure and a pivoting stylus though and can thus only be used as an approximation here:

$$\omega^2 A = \frac{3}{m} F_{tip} + \frac{3}{2} g$$

with $\omega = \frac{2\pi\, v}{\lambda}$ the oscillation frequency of the tip, where v denotes the allowed maximum traverse speed and λ the spatial wavelength of the sample; A the amplitude of the sinusoidal surface, m the mass of the stylus; F_{tip} the static probing force of the stylus on the surface and g the gravitational acceleration. One can see that force and speed are dependent on each other and the force is proportional to the square of the traverse speed.

3. Experimental setup

A depth setting standard EN3_5 with well defined edges was probed with a Tencor P17 stylus profiler and the PTB Profilescanner (s. figure 1), both in force-controlled mode. The standard consists of a copper block with diamond turned steps of different heights with a 15 µm Ni layer, covered by an additional layer of 5 µm Cr. The chosen edges had heights of 100 µm and 10 µm for the P17 and the Profilescanner measurements respectively. The edge angles were 45°. To ensure that the tip is not damaged, the scanning direction was chosen from the upper to the lower, since Si-probing tips can take heavy damage when driven against a steep wall. For different traverse speeds and tip forces measurements over a measurement length of 3 mm for the 100 µm edge and over 0.75 mm for the 10 µm edge were carried out. The P17 stylus instrument was operated with a tip of 2 µm radius and 45° opening angle. On the Profilescanner CAN50-2-5 Si microprobes with Si tips of approximately 50° opening angle and with diamond-tips of 2 µm radius and 90° opening angle were used.

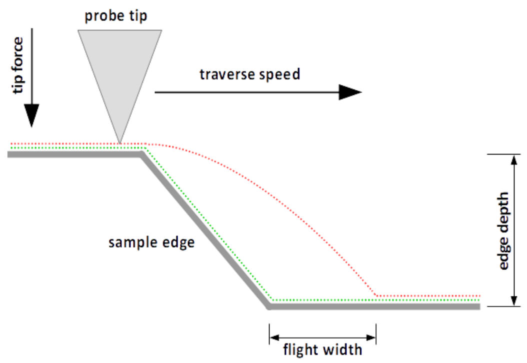

Figure 1. General overview of setup for tip flight measurement. If the probe tip moves along a sample edge (grey) with traverse speed too high or tip force too low it looses contact and flies (red line). True imaging of the sample (green line).

To image the sample edge for later comparison and to judge if tip flight occurred, a profile with small traverse speed and high tip force was taken. All measurements were taken on the same sample position.

A normalized flight width w_f was defined for different traverse speeds and tip forces on the samplel:

$$w_f = \frac{l_{flight}}{l_{edge}}$$

with l_{flight} the flight width (s. Fig. 1) and l_{edge} the edge depth. As exemplified in figure 1, only flight widths that exceeded the edge width were taken into account.

4. Experimental results

The P17's parameter space for speed and force (2 µm/s ≤ v ≤25 mm/s, 0.5 µN ≤ F ≤ 50 µN) was measured. Results of tip flight are shown in figure 2.

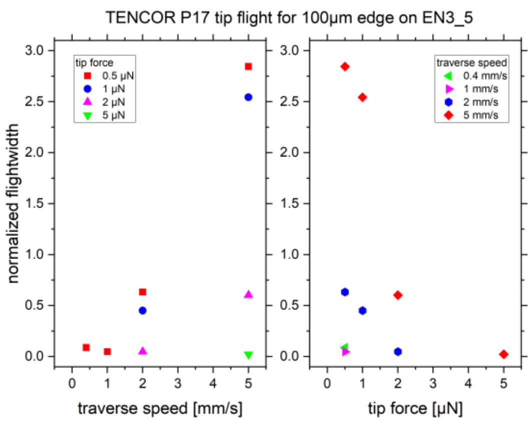

Figure 2. Normalized flightwidth of a Tencor P17 stylus profiler for different traverse speeds and tip forces. Measured on depth setting gauge EN3_5. Higher tip forces and lower traverse speeds were measured, but showed no flight behaviour.

For forces higher than 5 µN and traverse speeds smaller than 400 µm/s no tip flight was observed. Roughness measurements done in accordance to EN ISO 3274 with probing forces of 750 µN are thus of no concern.

For the Profilescanner tip flight measurements for a low, nondestructive probing force of F = 15.8 µN and different traverse speeds were carried out for the Si- and the diamond tips (s. figure 3). The traverse speed of the diamond tip at which tip flight sets in is smaller than that of the Si tip: $v_{flight, Si}$ = (225 ± 25) µm/s and $v_{flight,Diamond}$ = (210 ± 30) µm/s. This is like expected, du to the higher mass of the diamond tip.

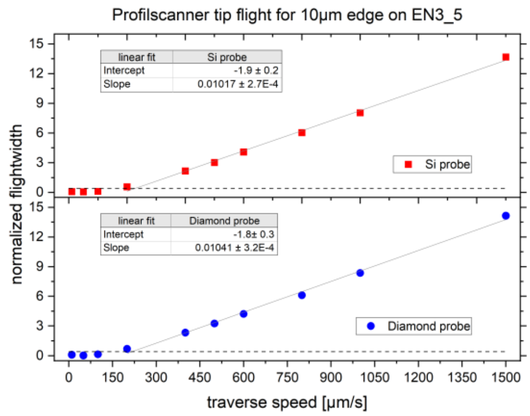

Figure 3. Normalized tip flight widths of the PTB Profilescanner for different traverse speeds and probing tips (depth setting standard EN3_5, probing force 15.8 µN).

The tip masses are approximated as m_{Si} ≈ 4.0·10^{-10} kg and $m_{diamond}$ ≈ 2.3·10^{-8} kg, but the cantilevers mass $m_{cantilever}$ ≈ 1.17·10^{-4} kg outweighs both tips by several orders of magnitude. Predictions from the Morrison equation for the 10 µm step height (A = 5 µm, λ/4 = 10 µm) give a much higher allowed traverse speeds of v ≈ 58 mm/s. The deviation from model to experiment is 3 orders of magnitude due to the close-loop mode used here.

5. Summary and outlook

We have demonstrated tip flight as a regularly occurring phenomenon in stylus instrument measurements for a commercially available stylus profiler as well as for the Profilescanner for low probing forces and high traverse speeds in the force-controlled mode. For a low probing force of 16 µN we found the onset of tip flight for a Si and a diamond tip at approximately 200 µm/s. Much higher maximum traverse speeds are expected in the open-loop mode. These investigations will be carried out in the near future.

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