In-situ characterisation of the probing force of contact stylus profilers using a micromachined nanoforce actuator

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Abstract

A micromachined nano-force actuator developed by PTB is proposed in this paper for in-situ determination of the probing force generated by a stylus instrument. Due to the high closed-loop resolution of the nano-force actuator, probing forces below 10 µN (i.e. the lower force range of stylus profilometers) can now be quantitatively investigated with a resolution of only some nanonewtons. The principle of the actuator, the calibration procedure for stylus probes and preliminary results will be presented and discussed.

1 Introduction

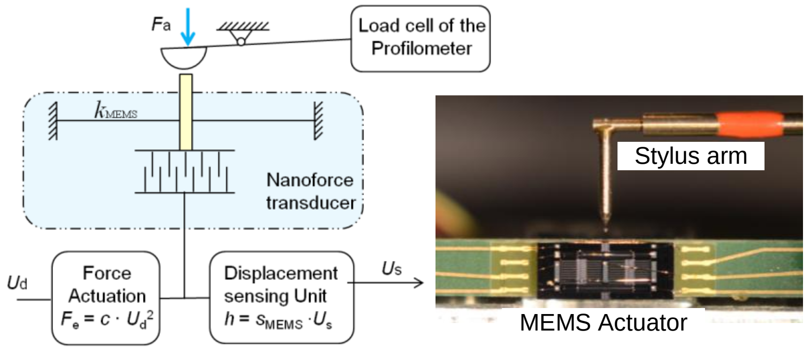
Contact stylus profilometry has long been utilized for the dimensional measurement of various specimens not only in industrial but also in scientific fields. The actual measurement accuracy of a contact stylus profiler depends on the measurement conditions (e.g. scanning speed, tip radius), the mechanical properties of the specimen under test and the applied probing force [1]. Therefore careful characterisation of the force generation system of a stylus profiler so as to further improve the measurement uncertainty of contact stylus profilers has drawn more and more attention.

To date, commercially available force calibration standards for stylus profilers have already been developed, e.g. cantilever-based force standard from SiMetrics [2], with which the probing force of roughness measurement devices, indentation instruments and various profilometers can be calibrated within the force range up to mN. However, due to the difficulty in precisely locating the probing position on the reference spring, the calibration uncertainty using cantilever-based force standards is, in general, relatively low (no better than 5 %).

In the recent years, to keep up with the demands for the precise measurement of dimensions of specimen consisting of soft materials (e.g. polymers), contact stylus surface profiling with low stylus probing force has been highly desired. It is noticeable that a few commercially available stylus profilometers offer the capability of probing forces down to submicronewton, which impose, in return, higher requirements on the performance of currently available force calibration systems for contact stylus instruments.

2 Principle

In this paper a micromachined nanoforce acuator recently developed by PTB [3] is applied to characterize the probing force of a contact stylus profilometer. As shown in Fig. 1(a) the nanoforce transducer is realized on basis of a lateral comb-drive configuration, featuring high closed-loop force sensitvity (down to nanonewton range) whilst relatively wide bandwidth (up to kHz range).



(a) Schematic of the in-situ force characterisation system

(b) Photography of the key experimental setup

Figure 1: In-situ calibration of the probing force of a contact stylus profilometer using a micromachined nanoforce actuator.

Once the stiffness k_{MEMS} of the suspending system of the MEMS actuator and the sensitivity S_{MEMS} of its in-plane displacement sensing unit have been carefully calibrated, the probing force F_a of the tactile profiler acting on the main shaft of the MEMS actuator can be determined as follows:

$$F_a = k_{MEMS} \cdot S_{MEMS} \cdot U_{s}. \qquad (1)$$

in which U_s is the electronic signal from the displacement sensing unit of the MEMS actuator during calibration.

3 Preliminary experimental results

To demonstrate the feasibility of the in-situ force characterisation approach shown in Fig. 1(a), a prototype of the PTB nanoforce actuator [s. Fig. 1(b)] is positioned under the contact stylus of a contact profilometer (P-11, KLA-Tencor), which features nominal probing force down to 5 µN. With our home-developed stiffness calibration system, the fundamental specifications of the nanoforce prototype have been found to be: k_{MEMS} = 31.6 N/m, and S_{MEMS} = 328.0 nm/V.

The typical force characterization procedure is detailed in Fig. 2:

(1) The MEMS actuator is used in its initial conditions, and then the contact stylus is engaged onto the main shaft of the MEMS actuator, and held for a short period (e.g. T_{hold1} = 10 s in Fig. 2),

(2) the probing force (e.g. F_a = 5 µN in Fig. 2) is then applied to the MEMS actuator, and maintained for an adequate period (e.g. T_{hold2} = 100 s in Fig. 2), so as to evaluate the force/displacement stability of the profilometer, finally

(3) the probing force of the profilometer is removed, and an additional hold time (e.g. T_{hold3} = 40 s) is used to investigate the stability of the MEMS-prototype within the measurement chamber of the profilometer under test.

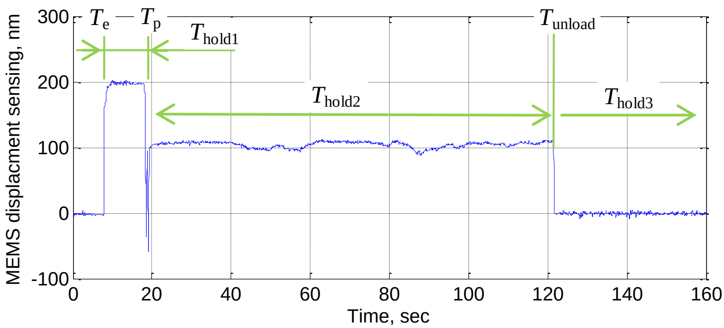


Figure 2: Inspection of the dynamic settling of the probing force of a contact stylus profilometer (T_e – Engagement point, T_p – Time point when probing force is applied, T_{unload} – unloading point).

From Fig. 2 it can be seen that, even under the condition of an open-air measurement, the displacement sensing unit of the MEMS actuator demonstrates high stability of 1.7 nm (1σ), which corresponds to a closed-loop force sensing resolution of about 38 nN (1σ). The probing displacement fluctuation of the profilometer under test amounts to 4.5 nm, which indicates a probing force fluctuation of 0.13 μN (1σ @ 100 s). In addition, thanks to the relatively wide bandwidth of the nanoforce actuator, the dynamic probing force settling procedure of the profilometer under test can be now clearly revealed (see also Fig. 2).

A series of probing forces of the stylus profilometer within the low-force range (5 μN < F_a < 34.3 μN) have been applied to the nanoforce prototype. The measured probing forces F_m are illustrated in Fig. 3. It can be seen that the measured probing force of the stylus profilometer under test has a relatively small deviation (of about 2 μN) from the nominal force.

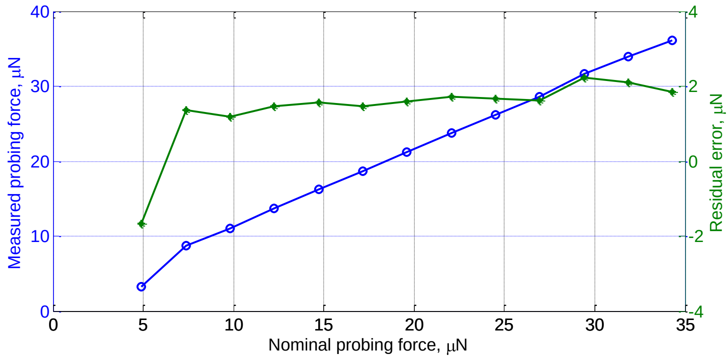


Figure 3: Measured probing force of a contact stylus profilometer with a nanoforce sensor

4 Conclusion and acknowledgement

A MEMS-based miniature nanoforce actuator is demonstrated to be capable of in-situ characterisation of the probing force of a contact stylus profilometer with a sub-micronewton resolution. Further extension of the force calibration range with the MEMS nanoforce actuator is under consideration.

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References:

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