In-stitu determination of the spring constant of soft AFM cantilevers using a MEMS nanoforce transducer

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Abstract

To measure the spring constant of AFM cantilevers an “active reference spring (ARS)” method based on a well-developed MEMS nano-force transducer has been developed at PTB. In the case of calibration of soft cantilevers, analytical and experimental analyses indicate that the tip-surface interaction between an AFM cantilever and the MEMS-transducer during calibration procedure will influence the calibration result. In this paper, based on the ARS method, an additional low-amplitude high-frequency vibration is added to the quasi-static deflection of the cantilever in order to suppress the negative influence of the sliding friction between AFM tip and MEMS transducer. The first experimental results verify the feasibility of this method.

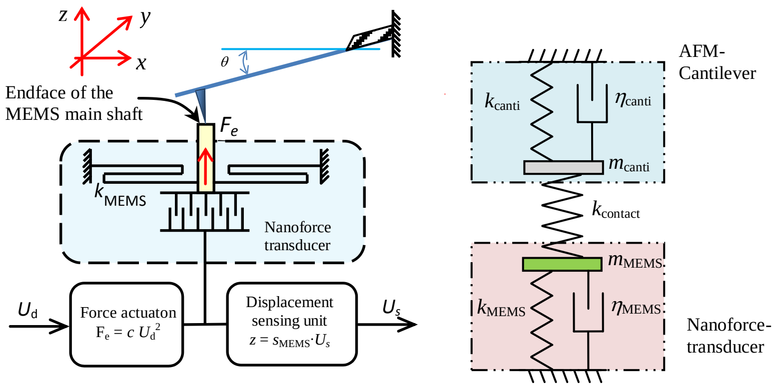
1. Introduction

Quantitative nano-mechanical measurements using atomic force microscopy (AFM) demand that the mechanical performance of AFM cantilevers in use, especially their normal spring constant, be carefully calibrated. The determination of the normal stiffness has therefore gained much interest, yielding plenty of cantilever stiffness calibration methods [1-3] in the last more than two decades. Among them, the static approach to determine the cantilever normal stiffness, i.e. direct measurement of the bending deflection of an AFM cantilever under varying test force, features a straightforward principle, ease of realization and potential for traceable measurement, and thus has been continually investigated by several metrology institutes. In the recent years, an “active reference spring (ARS)” method based upon a well-developed MEMS nano-force transducer has been developed by PTB [4]. The ARS method features direct and in-situ determination of the “on-site” spring constant of cantilevers. A calibration uncertainty better than 5 % can be achieved when the cantilever has a spring constant ranging from 0.1 N/m to 50 N/m.

Analytical and experimental analyses indicate that for soft cantilever calibration using the ARS method, the tip-surface interaction between the AFM cantilever and the MEMS-transducer during calibration procedure will influence the calibration result.

2. Principle

Figure 1 shows the fundamental schematic of the ARS method for cantilever calibration with a single-axis (z-axis) MEMS nanoforce transducer and the equivalent model [4]. The MEMS force transducer employs a lateral electrostatic comb-drive for force generation, displacement and force sensing.



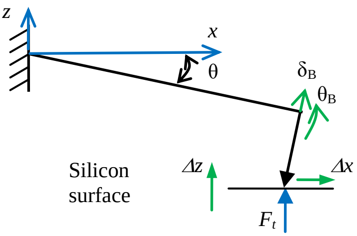
(a) Schematic of the ARS cantilever calibration system

(b) The typical equivalent mechanical model in the case of frictionless tip-surface contact

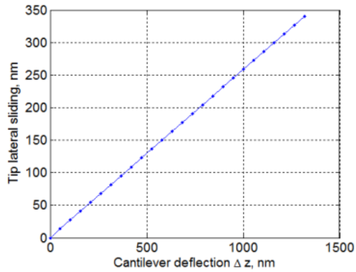
Figure 1: Schematic of the ARS cantilever calibration system and the equivalent mechanical model

Experimental practices have already proved that the equivalent mechanical model for describing the ARS cantilever calibration procedure works well for cantilevers with relatively high stiffness (i.e. $k_{canti} > 1$ N/m), in which the tip-surface sliding during calibration procedure is generally negligible.

In the case of calibration of a soft cantilever using the ARS method, however, since the cantilever deflection tends to be relatively large (e.g. on the order of µm range), and the lateral tip-surface sliding becomes evident, therefore the caliration results suffer usually from the inflence of the quasi-static frictional tip-surface contact. As shown in Figure 2(b), for a 12° tilted cantilever with a tip height about 15 µm, the lateral tip sliding (Δx) amounts to larger than 250 nm when the cantilever deflection is about 1 µm.



(a) Simplified analytical model



(b) Tip lateral sliding during cantilever deflection (ANSYS simulation result)

Figure 2: Analytical investigation of the cantilever deflection and its lateral tip sliding

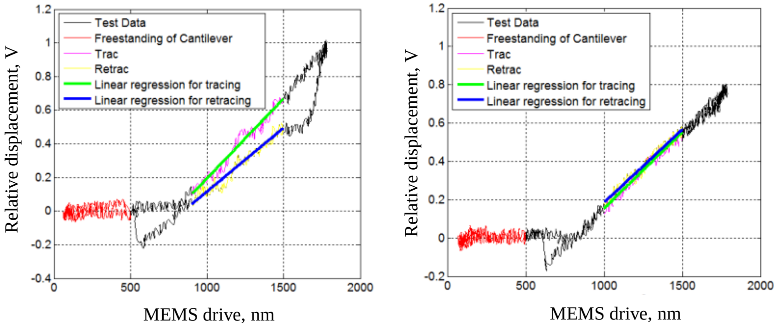
Taken into consideration that the kinetic friction force between two surfaces in contact is generally much less than the corresponding quasi-static friction force under the same normal force, it is therefore proposed that an additional low-amplitude high-frequency vibration between the AFM tip and the MEMS test surface is introduced during the calibration procedure. This suppresses the negative influence of the tip-surface quasi-static sliding friction on the calibration result.

3. First experimental results

A proof-of-principle experiment has been carried out, in which a one-dimensional nano-force transducer [4] is mounted on a 3-axis NanoMax stage, and employed to characterise soft cantilevers.

Figure 3 shows the typical measurement curves obtained for a rectangular cantilever (PPP-CONTR, PointProbe® Plus Contact Mode, NANOSENSORS™) with a nominal cantilever length of 450 µm and a nominal spring constant of about 0.2 N/m. Using the fundamental ARS method, it can be seen clearly from Fig. 3(a) that the loading and unloading curves have quite different slopes, due to the quasi-static tip-surface lateral sliding. The static friction coefficient between the AFM silicon tip and the MEMS silicon surface is found to be $\mu_{static} = 0.6$.

A 200 Hz x-direction vibration with about 30 nm amplitude generated from the 3-axis NanoMax stage is then introduced to the calibration system during the whole ARS measurement procedure. The typical measurement result is illustrated in Figure 3(b), from which one can see that the loading and unloading curves tend now to be identical. Detailed analysis indicates that the kinetic friction coefficient between the AFM tip and MEMS surface is reduced to $\mu_{kinetic} = 0.09$.



(a) Typical calibration curve for a rectangular cantilever using the fundamental ARS method

(b) Calibration curve for a rectangular cantilever using the ARS method with an additional x-modulation

Figure 3: First experimental results without and with x-direction vibration

4. Summary

In this paper, our effort to further extend the capability of the quasi-static ARS method for the stiffness calibration of soft cantilevers is proposed. First experimental investigations have verified the proposed approach.

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