



Determination of force to displacement curves using a nanopositioning system based on electromagnetic force compensated balances



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ARTICLE INFO

Article history:

Available online 3 March 2014

Keywords:

Nanopositioning system
Force displacement measurement
Spring constant
Electromagnetic force compensated balances
AFM cantilever

ABSTRACT

This paper discusses a novel nanopositioning system which is based on an electromagnetic force compensated balance. In addition to the positioning the actuating force can also be measured. This enables the measurement of force displacement curves of springs with a wide variety of spring constants. The measurement range of the spring constants is up to 10^9 N/m with a maximum resolution of about 0.01 N/m. Compared to other principles for measuring the spring constant the introduced method is more sophisticated. Both force as well as the displacement can be measured traceable with one sensor simultaneously.

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1. Introduction

In the past years the calibration of force–displacement curves (spring constant) of AFM cantilevers respectively the force–signal curves (force sensitivity) of cantilever type microforce sensors became a common interest in metrology. This is especially shown by the amount of work including the development of calibration stages and measurement strategies as well as performed calibrations and international comparisons [1–11].

The spring constant or the force sensitivity of such cantilevers is given by the manufacturer but with a high uncertainty. State of the art of determining the spring constants of AFM-cantilevers is a computation based on their geometrical and physical properties. Due to tolerances mainly in the geometry, the computed spring constants have a high uncertainty. There are several ways to calibrate those cantilevers. Some implicit methods are described and compared in [3,12]. A more sophisticated method is

the determination of the force to displacement curve of such cantilevers as described in [1,2,6–11,17,13].

The presented methods enable the possibility to measure the spring constant with a much lower uncertainty reaching uncertainties down to 1% [2,11]. For such calibrations the setup basically consists of two central parts: A nanopositioning and measurement system of the deformation and a measurement of the acting force.

Common nanopositioning systems such as piezo actuators are capable to position samples and work pieces very precise and reproducible. The nanopositioning and nano-measuring machine which was developed at the Ilmenau University of Technology uses voice coils and an interferometer for the positioning in the z-direction [14]. A direct determination of the acting force on the sample is not possible. One possibility to determine force displacement curves of springs such as atomic force microscope (AFM) cantilevers is to displace the cantilever using a nanopositioning system and to measure the resulting force on the cantilever by a high precision balance [1,4,7–9] (see Fig. 1a). A comparable principle can also be used for the calibration of force transducers as described in [13].

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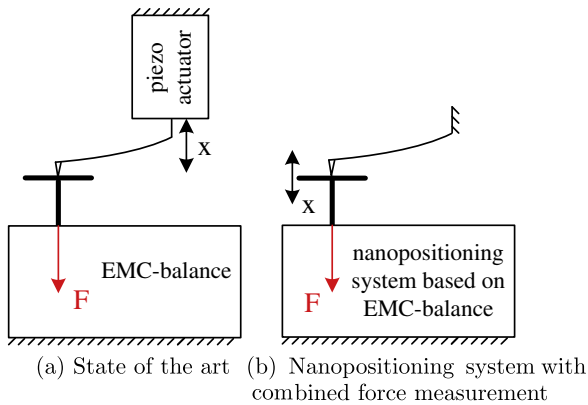


Fig. 1. Principles for the determination of spring constants.

Another concept is based on an electrostatic force compensated system. Here the capacitor is used to set the force and the displacement. The displacement is measured with a laser interferometer [10,6]. This principle is very similar to the system discussed in this paper. Based on this electrostatic force system piezo sensor cantilevers have been calibrated and then used as transfer standard [15].

Also based on electrostatic forces a MEMS-based nano-force actuator can be used to determine the spring constant of AFM-cantilevers. The displacement is measured with a commercial AFM-microscope. With such a system it is possible to determine spring constants in a range of 0.01–100 N/m [17].

The presented nanopositioning system is based on a modified commercial balance system with EMFC. The position of the weighing pan can be set to any value in the measurement range with high resolution and reproducibility. In addition to that the acting force on the weighing pan can be determined (see Fig. 1b). This enables the possibility to determine both displacement and force simultaneously. The advantage of the system is that also non-linear spring constants, hysteresis and even strong non-linear force–displacement relationships (such as stick slip effects of mechanical guiding and adhesive effects [19,20]) can be determined.

2. Nanopositioning system

2.1. Principle

Electromagnetic force compensated (EMFC) balances are state of the art of commercial weighing technology for the determination of forces and masses with high accuracy. The schematic setup of such a balance is shown in Fig. 2. The schematic includes an interferometer for the displacement measurement of the weighing pan. The interferometer was added to the commercially available EMFC balance WZA245-NC from Sartorius Weighing Technology GmbH (Göttingen) [22].

If a force is applied on the weighing pan (1), the conversion lever (2) deflects. The conversion lever is coupled by a coupling element (3) to the pan carrier (4). The pan carrier is guided by a parallel guiding system (5). A compensation

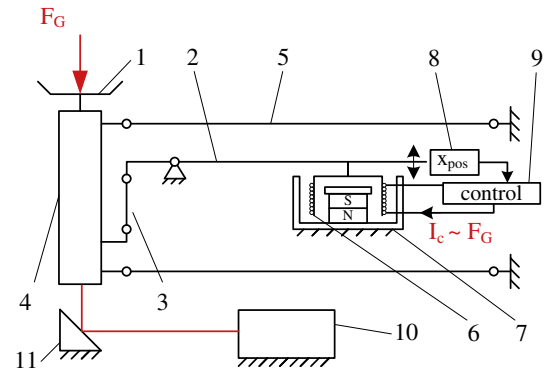


Fig. 2. Principle of EMFC weighing system; (1) weighing pan, (2) conversion lever, (3) coupling element, (4) pan carrier, (5) parallel guiding system, (6) compensation coil, (7) permanent magnet, (8) position sensor, (9) control loop, (10) interferometer, and (11) deflection mirror.

coil (6) is attached to the conversion lever and immersed in a permanent magnet (7). The position of the conversion lever is measured by an optical position sensor (8). A control loop (9) controls the position of the conversion lever by setting the current of the voice coil, generating a Lorentz force. If the conversion lever is in equilibrium, the current is proportional to the force applied on the weighing pan. The output signal of the position sensor is proportional to the deflection of the conversion lever [21].

Additionally the position of the weighing pan is measured by an interferometer (10) from SIOS Meßtechnik GmbH (Ilmenau) [23]. The laser beam of the interferometer is reflected by a deflection mirror (11). The conversion lever in commercially available EMFC weighing systems is controlled to a fixed zero position. The innovation of the presented system is that the set point (position signal) can be set to any value in the moving range of the balance. Consequently the displacement of the conversion lever can be set to any value in its moving range. The principle of the control loop of the nanopositioning system is shown in Fig. 3.

The output signal of the EMFC balance is the differential voltage of the position sensor which is proportional to the position of the conversion lever (U_{pos}). This voltage is measured with a high precision digital multimeter and fed into

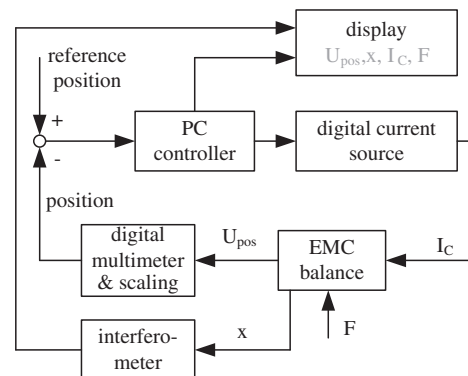


Fig. 3. Principle of control loop of nanopositioning system.

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