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Mode analysis for long, undamped cantilevers with added diamond tips of varying length for fast roughness measurements

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Summary:
In this article we present an FEM analysis of the change in resonance behaviour of 5 mm long piezoresistive cantilevers when they are modified with pencil shaped diamond tips of varying length. In a setup with glued cantilever base the length of the fixed bearing was examined as well. Simulations show that for a free cantilever base length of one fifth of the base no base oscillations occur. Base oscillations only occur for higher order modes of resonance with free base lengths greater one fifth.

Keywords: FEM, Mode analysis, diamond tips, piezoresistive Si-cantilever, roughness measurements

Introduction

For traceable roughness measurements in high aspect ratio microstructures the national metrology institute Physikalisch-Technische Bundesanstalt developed a profilometer [1] that makes use of cantilevers with integrated Si-tips and piezoresistive strain gauge [2]. This *Profilescanner* is a promising candidate for miniaturization of roughness measurements on-the-machine. In industrial applications measurement speed is to be minimized, therefore an analysis of the sensor behaviour for high traverse speeds is in order.

Probe system with CAN50-2-5

The probe attachment is shown in figure 1. A CAN50-2-5 cantilever (CiS Forschungsinstitut für Mikrosensorik, Germany) is glued to a holder and wire bonded on the same side, leaving a free length of the cantilever base L_1 and a fixed bearing length L_2 (see fig. 2).

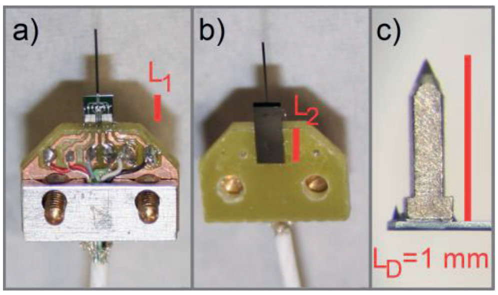

Fig. 1. holding plate for cantilever a) top view with bond wires, length of free cantilever L1 Si base b) bottom view, glued length L2 of Si base c) added pencil shaped diamond tip of length LD

This holder is then applied to the Profilescanner setup and brought into contact with a sample surface. The cantilevers have a piezoresistive Wheatstone bridge at the connection point between cantilever and its Si base. A pencil shaped diamond tip is attached to the end of the cantilever, substituting the function of the wear prone Si tip (see fig. 2).

Surface Induced Excitation of Cantilevers

Independent of the nature of surface-probe interaction and neglecting other sources of excitation, the frequency of excitation *f* for a cantilever scanning over a sample is directly proportional to the traverse speed *v* of the probe over the sample

$$f = \frac{v}{\lambda_s}$$

where λ_S denotes the geometric wavelength of the sample surface [3]. Measuring with higher traverse speeds thus leads to a shift of excitation frequencies. To estimate if this may shift the excitations near resonance and induce distortions in our probe system, we computed the eigenfrequencies of the system.

FEM Modeling

The FEM simulation program *COMSOL Multiphysics* (version 5.3) was utilized to vary the parameters of the added diamond tip and the fixed bearing of the glued Si base. An eigenfrequency study for a geometry as shown in figure 2 was performed, using the *COMSOL solids* module. It searches for complex analytical solutions λ of the eigenvalue problem

$$-\rho\,\omega^2 u = \nabla S$$

$$-i\,\omega = \lambda$$

with ρ the material density, $\omega = 2\pi f$ the real eigenfrequencies of the system and u the displacement field. The first 10 eigenfrequencies for all combinations of the following parameters were computed:

L_D in mm: 0.4 / 0.6 / 0.8 / 1.0 /1.2 / 1.4 / 1.8 / 2.0

L2 in mm: 2.5 / 3.0 / 3.5 / 4.0

Where L_2 was a fixed bearing. Additionally, all L_2 were computed for the cantilever without added pencil shaped diamond tip, denoted as $L_D = 0$. Higher values or smaller steps for L_2 where not of interest, since the bonding pads on the cantilever must be visible to be bonded, and since the gluing of the base to the holder is done manually.

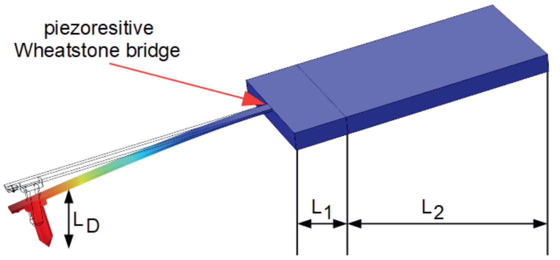

Fig. 2. geometric model of CAN50-2-5 type silicon cantilever with added pencil shaped diamond tip of length L_D. Silicon base with free length L_1 and fixed bearing length L_2. Position of piezoresitive measuring bridge marked with red arrow. Shape of cantilever's first mode shown in pseudo colors.

Results

All simulations show a shift of eigenfrequencies to lower values for longer diamond tips, as expected for an oscillating beam with one-sided added mass. Two modes are shown exemplary in figures 3 and 4.

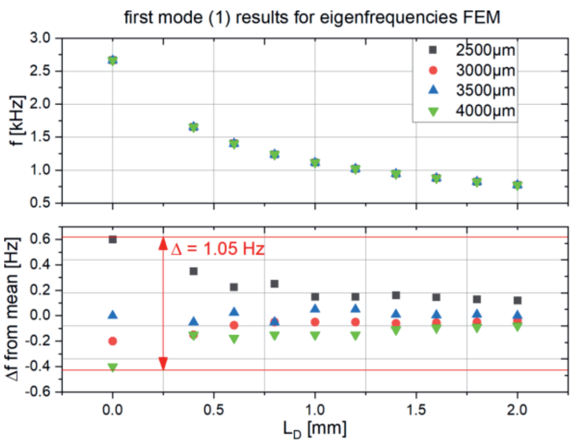

Fig. 3. FEM simulation results for first modes of probing system. Insignificant influence of fixed bearing length.

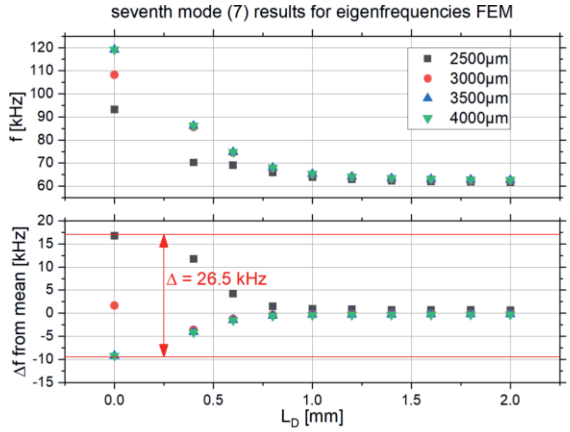

Fig. 4. FEM simulation results for seventh modes of probing system. First mode of 10 with significant influence of fixed bearing length.

Only higher order modes showed base oscillations after point examinations at the piezoresistive Wheatstone bridge. For all fixed bearing lengths $L_2 > 3.0$ mm the base oscillation was non-existent for all 10 simulated modes.

In conclusion only a combination of a cantilever base glued with a free length of the base greater than 1 mm and surface induced excitations in higher modes $n > 6$ can lead to a distortion of the bridge signal.

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