DOI 10.5162/SMSI2020/A6.3

Higher-Mode Contact Resonance Operation of a High-Aspect-Ratio Piezoresistive Cantilever Microprobe

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Summary:
In this work, a long slender MEMS cantilever sensor for higher-order contact resonance tactile-sensing applications is described. The design is focused on enabling high-speed measurements on large workpieces. To excite high-order out-of-plane bending modes of the cantilever, heating resistors integrated into the sensor are used as actuators. Their positions are optimized to allow for an efficient resonant excitation of the sensor, as confirmed by finite-element modelling (FEM).

Keywords: MEMS, microprobe, thermal actuator, piezoresistive cantilever, contact resonance

Motivation

The continuing digitalization of industrial production causes a need for high-speed methods to measure form, roughness and mechanical properties on-the-machine [1]. Tactile microcantilevers, such as depicted in Fig. 1, have been shown to be able to measure at velocities up to 15 mm/s and are, thus, promising for this application [2].

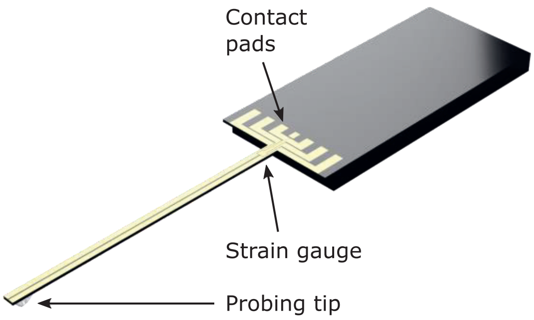

Fig. 1. Render of the microprobe design.

To further develop such microprobes, a European EMPIR project is being funded [3]. One of the aims of this project is to design new sensors which are optimized to efficiently measure mechanical properties of samples using contact resonance (CR) techniques. These sensors shall then be calibrated on reference samples.

Evaluation of different vibration modes

To evaluate the performance of different CR modes, first measurements were conducted using a commercial CAN50-2-5 probe (CiS Forschungsinstitut für Mikrosensorik GmbH, Erfurt, Germany) which was mounted on a PL055.30 chip-size piezoactuator (Physik Instrumente (PI) GmbH und Co KG) [4]. The resulting data is analyzed to determine the resonance mode that results in the best compromise between measurement speed and resolution.

Design of the microprobe

The design is based on previous work [5] that is extended by implanted heating resistors. The outer dimensions remain unchanged and are listed in Tab. 1. An overview of the design is shown in Fig. 2.

Tab. 1. Geometrical and material properties of the microprobe.

Parameter	Symbol	Value
Length	L	5 mm
Tip position	L_1	4.95 mm
Strain gauge position	L_{WB}	185 µm
Width	w	200 µm
Thickness	b	50 µm
Density	ρ	2330 kg/m³
Young's modulus [6]	E	169 GPa

Similar to the design described by Yu et al. [7], we utilize one heating resistor at the clamped end of the cantilever and an additional one at L_{HR2}, near the center of the cantilever.

Additionally, a probing tip is located at L_1, near the free end of the cantilever.

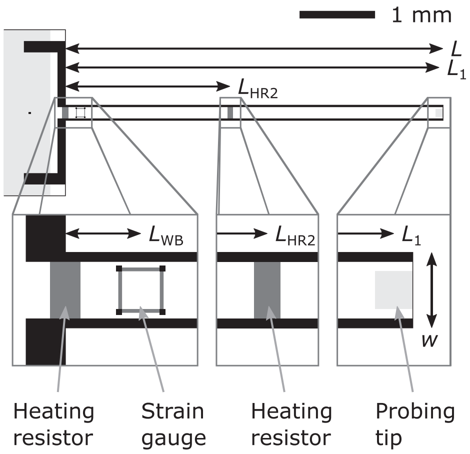

Fig. 2. Overview of the sensor design. The metal contact lines are not shown to maintain visibility.

To counteract thermal coupling described in [8], the distance between the first heating resistor and the strain gauge is increased to 100 µm compared to approximately 30 µm used in [8].

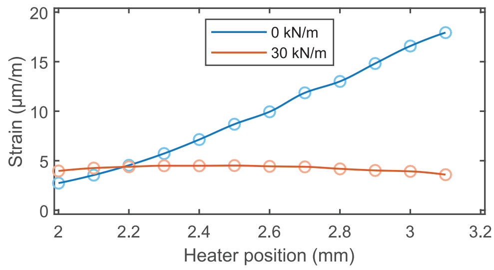

Fig. 3. FEM amplitude of strain at L_{WB} upon resonant actuation depending on the position of the second heating resistor L_{HR2} for $k_c^* = 0$ and $k_c^* = 30\ kN/m$.

As shown in Fig. 3, the optimal distance of the second heating resistor from the clamped end of the cantilever is $L_{\mathrm{HR2}} = 2.2\ \mathrm{mm}$, which will ensure uniform signal amplitudes for a range of materials (contact stiffness up to $k_c^* = 30\ \mathrm{kN/m}$) when using third-mode CR.

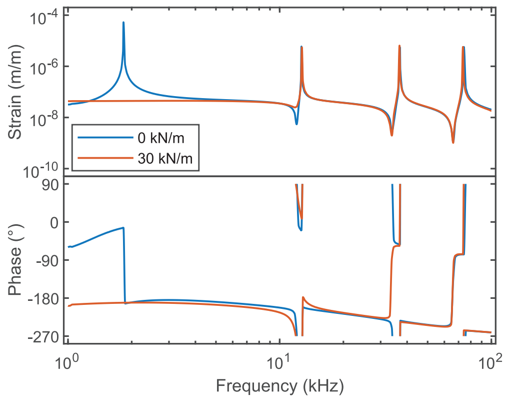

Fig. 4. FEM frequency response of strain at L_{WB} for $k_c^* = 0$ and $k_c^* = 30\ kN/m$.

As depicted in Fig. 4, the CR spectra of the probe are simulated showing similar amplitudes of the modes at $k_c^* = 0$ and $30\ \mathrm{kN/m}$. The frequency range for third-mode CR is found to be 37 kHz to 74 kHz for the accessible measuring range of k_c^*.

Fabrication and Test

For comparison with the FEM results, sensor samples are fabricated using our in-house bulk-silicon micromachining process. This process uses seven lithography masks to realize the novel cantilevers. The behavior of the sensor in CR mode during scanning operation will be measured and compared with FEM.

Acknowledgements

This project has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme under no. 17IND05 MicroProbes.

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