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Low frequency measurements using piezoresistive cantilever MEMS devices – the problem of thermal drift

Grzegorz Jóźwiak[a]*, Daniel Kopiec[a], Teodor Gotszalk[a], Piotr Grabiec[b], Ivo Rangelow[c]

[a]*Wroclaw University of Technology, Wroclaw 50-370,Poland*
[b]*Institute of Electron Technology, Warsaw 02-668, Poland*
[c]*Technische Universitat Ilmenau, Ilmenau 98693, Germany*

Abstract

In the presented work, the system and computer algorithms for low-frequency measurements with piezoresistive cantilever MEMS/NEMS devices are presented. The proposed solution enables low-frequency calibration and measurements in the presence of thermal drift. Applied analog and digital circuits solve a problem of a saturation of the response of a cantilever piezodetector. We also propose an algorithm, which enables further removal of the drift's influence by the digital post-processing of a read signal. The results of 1/f noise measurements of a series of piezoresistive microcantilevers are presented. Shown 1/f noise spectra were measured and estimated by a data acquisition system utilizing digitally controlled electronics capable of removing the thermal drift. The results consistence with the theory confirms the validity of the presented approach.

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Keywords: MEMS/NEMS, piezoresistive readout, thermal drift, signal processing

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1. Introduction

Microcantilevers are very attractive microelectromechanical systems (MEMS). They are used as scanning probes and transducers in biochemical sensors [1-5]. Their advantages increase if they are fabricated as microcantilevers arrays, that function as highly selective biochemical sensors or high throughput scanning probe microscopy (SPM) systems. Microcantilevers may operate in passive and active modes. The passive mode, in case of which a cantilever

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* Corresponding author. Tel.: +48-071-320-3525 ; fax: +48-071-328-3504 .
E-mail address: grzegorz.jozwiak@pwr.edu.pl

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static deflection indicates the scale of observed phenomena. In chemical sensing such a deflection is usually caused by surface stress induced by molecules attached to the surface of a cantilever. In SPM application a cantilever deflection is caused by measured interactions. They are many ways to measure a cantilever's deflection. Utilization of piezoresistive sensing is one of possibilities. Its main advantage is the simplicity and low costs of read-out electronics.

The greatest weakness of piezoresistive detection is its sensitivity to temperature. Drift caused by the temperature impact on the gauge factor and a side effect of a thermal expansion can strongly disturb operating conditions in low frequencies' range. The unbalancing of a piezoresistive bridge, which is usually used in piezoresistive detection, may even cause the saturation of a read signal at the preamplifier stage. The simplest solution addressing this problem is based on application of high-pass filter, which removes most of the drift impact. But such a simple treatment cannot be applied to problems such as a 1/f noise calibration or low-frequency deflection measurements. For these problems filtration removes almost all information present in the signal. To overcome these difficulties, we proposed the system in which a signal offset is controlled digitally and the remaining drift impact is subtracted by a numerical procedure.

2. Methodology

In order to prevent the amplifier from saturation, the microprocessor control system was designed. It is based on ATmega32 microcontroller, which uses analog to digital and digital to analog converters to control the offset at each amplification stage (see Fig. 1). The goal of a control algorithm is to keep an output signal in some predefined range. The controller does not operate continuously. It starts compensation, when the *A1*, *A2*, *A3* signals are outside some predefined range. While the compensation is turned on, the data acquisition is paused. The compensation algorithm tries to obtain zero offset of the OUT signal. After period of time equal to the regulator time constant, the compensation is turn off and signal to the data acquisition system is sent. This signal indicates that measurements may be resumed. Thanks to this system, measurements results are not affected by large drift. The small changes of the offset of OUT signal are removed by further data processing.

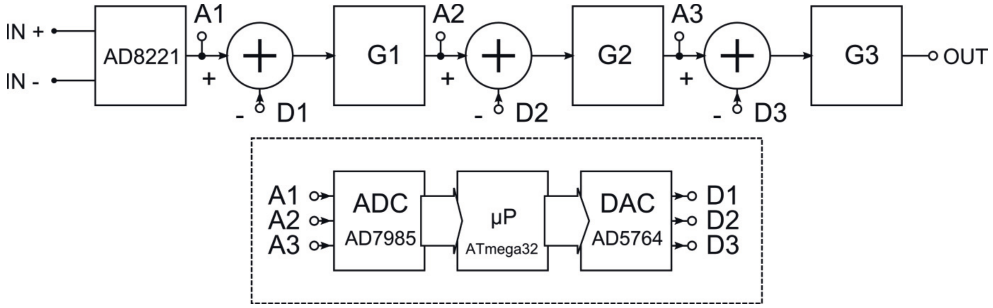

Fig. 1. Automatic system for compensation of thermal drift. At each preamplifier stage the offset is measured and canceled, if it exceeds predefined voltage level. The process of compensation is supervised by a signal processing system based on an ATmega32 microcontroller. The system prevents from drift induced saturation of the preamplifier output.

By application of Woodbury identity [6], the continuous linear fitting is applied to remove the slow changes in the OUT signal. It may be replaced by higher order curve at the cost of slightly increased complexity. In the described experiment the linear trend removal was enough to obtain satisfactory results.

In Fig. 2 the preamplifier circuitry is presented. At the top board, amplifiers are mounted. This solution enables changing applied amplifiers without redesign of the whole system. This fact facilitates tuning of the system to different applications.

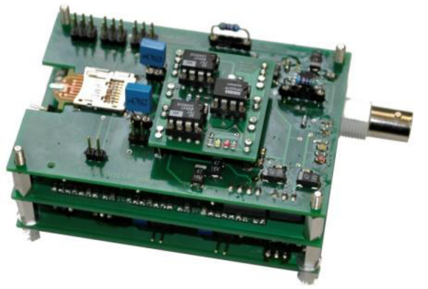

Fig. 2. Circuitry for an automatic compensation of a thermal drift

3. Experiment description

A piezoresistive cantilever, that was used in the experiment, was fabricated in the Institute of Electron Technology in Warsaw. It is presented in Fig. 3. The cantilever has piezoresistive readout and gold pad, which is used for electrochemical sensing.

The goal of experiment was to measure 1/f noise of the piezoresistive readout, which is a Wheatstone bridge. Due to fabrication uncertainties, the bridge is not perfectly balanced, so we observe some offset voltage at the diagonal. Since 1/f noise measurements need a preamplifier with the high gain (about 100000 V/V), even small offset causes saturation of preamplifier output. 1/f noise is also low frequency signal, so high pass filtering cannot be used to remove the bridge offset. This is a problem for which the proposed preamplifier is an ideal solution.

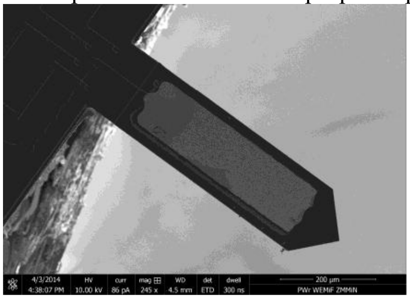

Fig. 3. SEM image of the piezoresistive cantilever, for which 1/f noise characteristics are shown in the Fig.4a.

The signal from the preamplifier is acquired by National Instruments NI6251 data acquisition card and analyzed further by a homemade software. There, the stochastic signal is filtered by continuous line fitting as described in section 2. Linear fitting removes small drift that remains after compensation. After that, the power spectrum is estimated by means of periodogram averaging Welch algorithm [7]. The spectra were measured for different values of the bridge bias U_B. All spectra were fitted by Hooge model of 1/f noise [8]. In Fig. 4a the estimated spectra and the theoretical fit are presented. The excellent model agreement with measured spectra proves the quality of the proposed solution.

Additionally, in Fig. 4b the compensation process was registered. Bridge offset was changed, due to increase of the bias voltage. Additionally, increased bias caused that the temperature of the cantilever and the signal started to drift. At the beginning, the offset signal was uncompensated and the preamplifier output was saturated (10 V was the preamplifier supply). Then, the compensation process was initiated and the exponential response of the regulator is observed. At the end, the offset is removed and the regulator is turned off. The compensation process needs about 10 ms to remove the offset caused by the thermal drift. This regulation is turned on every time, when one of the *A1*, *A2*, or *A3* signals exceeds the ±0.1 V.

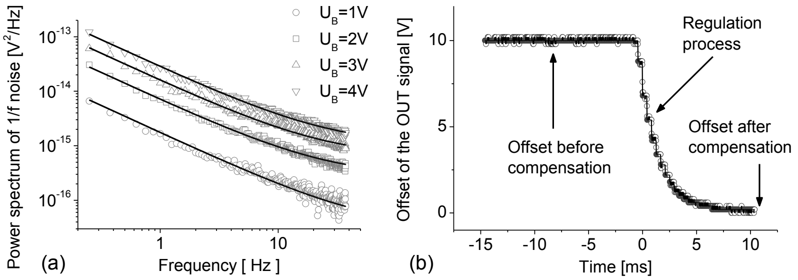

Fig. 4. Results obtained by the proposed system. (a) An estimated power spectrum of 1/f noise measured for the piezoresistive cantilever presented in Fig. 3. Measurements were performed for different values of bias voltage of piezoresistive bridge by the system presented in the Fig. 1 and Fig.2. Solid lines show the quality of fit of the Hooge's 1/f noise model to the estimated power spectrum. (b) The exponential time response of the digital controller. The compensation algorithm needs about 10 ms to remove the offset from the OUT signal.

4. Conclusion

In the paper, the system for low frequency measurements by means of a piezoresistive cantilever is presented. The preamplifier with automatic drift removal is described. Built in digital controller is designed. It automatically subtracts bridge offset when the predefined value is exceeded. The data acquisition software is able to remove the remaining signal changes by linear, squared or cubic curve fitting.

The performance of the system was demonstrated by measurements of 1/f noise of piezoresistive cantilever. The power spectra was estimated for different values of bridge bias. The Hooge model was fitted to spectra registered for all bias levels. Single parameter related to both Hooge constant and carriers concentration explained all estimated spectra. It is the proof that registered signal is not affected by the drift even for very small amplitudes of measured low frequency signals.

Acknowledgements

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References

[1] D. Filenko et. al., Experimental setup for characterization of self-actuated microcantilevers with piezoresistive readout for chemical recognition of volatile substances, Rev. Sci. Instrum. 79 (2008) 094101

[2] T. Gotszalk, P. B. Grabiec and I. W. Rangelow, A novel piezoresistive microprobe for atomic and lateral force microscopy, Sensors Actuators A 123-124 (2005) 370 – 378

[3] M. Woszczyna et. al., Y. Sarov, Quantitative force and mass measurements using the cantilever with integrated actuator and deflection detector, Microelectronic Engineering 86 (2009) 1043 – 11045

[4] M. Woszczyna et. al, Thermally driven piezoresistive cantilevers for shear-force microscopy Microelectronic Engineering 86 (2009) 1212 – 1215

[5] K. Kolev et. al., Complex (As2S3)(100-x)(AgI)x chalcogenide glasses for gas sensors Sensors and Actuators B 143 (2009) 395 – 399

[6] Max A. Woodbury, Inverting modified matrices, Memorandum Rept. 42, Statistical Research Group, Princeton University, Princeton , 1950, 4pp MR 38136

[7] P. W. Welch, The use of fast Fourier transform for the estimation of power spectra: A method based on time averaging over short, modified periodograms, IEEE Trans. Audio Electroacoustics, vol. 15, no. 2, pp. 70-76, 1967.

[8] F.N. Hooge, 1/f noise sources, in: J. Sikula, M. Levinshtein (Eds.), Advanced Experimental Methods for Noise Research in Nanoscale Electronic Devices, Kluwer Academic Publishers, Dordrecht, 2004, pp. 3-10