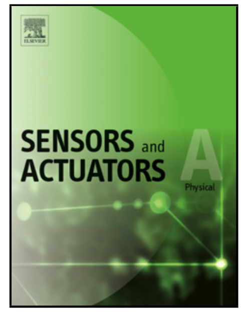

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Design and Test of A Micromachined Resonant Accelerometer with High Scale Factor and Low Noise

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Highlights

- The MRA's scale factor is analyzed and increased from 66.30 Hz/g to 244.15 Hz/g.
- Frequency noises associated with the resonator vibration amplitude are analyzed.
- The prototype's noise and resolution are 0.38 μg/$\sqrt{\text{Hz}}$ and 0.63 μg, respectively.

***Abstract*:** This paper describes the design, fabrication and experimental evaluation of a silicon micromachined resonant accelerometer that demonstrates high sensitivity and low noise. The device is fabricated with the silicon-on-glass micromachining technology and vacuum packaged to permit the double-ended-tuning-fork resonators operated at extremely high quality factor, up to 3.5×10^5. Structure optimization of the one-stage micro-lever, resonator and bearing beam is discussed to produce a high scale factor of 221.67 Hz/g, which is confirmed by the measured value of 244.15 Hz/g at a full scale range of ±15 g. Various frequency noise sources are modeled and discussed to explain the acceleration measurement noise associated with the vibration amplitude of the resonator and further optimize the drive voltage. By setting an optimized drive voltage at 10 mV, the measured noise and resolution of the MRA prototype are 0.38 μg/$\sqrt{\text{Hz}}$ and 0.63 μg, respectively. Compared to other reported MRAs, this accelerometer benefits from the optimization of the device geometry dimensions and the applied drive voltage, which exhibits both high scale factor and low noise.

Keywords: *resonant accelerometer; scale factor; noise; vibration amplitude; nonlinear vibration; frequency measurement*

1. Introduction

Micromachined accelerometers have been widely used in numerous applications such as inertial navigation [1], consumer electronics, vehicle safety [2] and land seismic acquisition [3]. Micromachined resonant accelerometer (MRA) is a type of high-precision inertial sensor based on accurate force-frequency characteristics of the high-Q resonators. When an input acceleration acts on the proof mass, the inertia force along the sensitive axis causes the inherent frequency shifting of two resonant beams on both sides of the proof mass in the opposite directions. The change in differential frequency is proportional to the input acceleration within a certain measurement range. The MRA is very attractive for high-precision applications due to its high sensitivity, low noise, large dynamic range and insensitivity to disturbances as a result of direct frequency output [4-6].

Silicon-based MRAs have drawn much attention of researchers with various MRA devices reported in the literature. Among them, much attention has been focused on high performance applications, such as high-precision inertial navigation and low noise seismic data acquisition. Early development of a inertial-grade MRA was reported by Draper Laboratory (USA) for navigation and guidance applications [7]. The test data showed a scale factor stability of better than 1 ppm and a bias stability of less than 1 μg by precise temperature control. A novel design of the two-stage micro-lever mechanism was proposed in 2005 by University of California, Berkeley, USA [8]. The developed MRA prototype showed a scale factor of 158 Hz/g with a relatively small proof mass area (0.27 mm^2). Recently, Pohang University of Science and Technology (South Korea) presented a novel robust resonant accelerometer without micro-levers, of which the Q-factor reached up to 3.7×10^5 [9]. University of Cambridge (UK) reported recently a high-sensitivity resonant accelerometer for seismic acquisition, of which the scale factor was as high as 18816 Hz/g within an ultra-low range of ±0.05 g [10]. The measured acceleration noise, including ambient vibration effect, was 3.22 μg/$\sqrt{\text{Hz}}$ and the intrinsic noise floor of the resonator was only 144 ng/$\sqrt{\text{Hz}}$. Nanjing University of Science and Technology (China) and National University of Singapore jointly designed a CMOS read-out circuit for their resonant accelerometer [11]. The measured noise level was reduced down to 2 μg/$\sqrt{\text{Hz}}$, which is the lowest noise result ever reported.

It is known that noise level is an important performance parameter for inertial-grade MRAs which directly limits the attainable resolution. Increasing the scale factor is an effective method to reduce the sensor noise [8, 12-14], where the scale factor is defined as the change in differential frequency per unit input acceleration. Large scale factor is also desirable because it decreases the degree of frequency stability required to resolve a given acceleration level [7]. Currently, much attention has been focused on the optimization of various micro-lever mechanisms to achieve high sensitivity while the interaction effect within the sensing structure was neglected [8, 14]. Moreover, the noise analyses of the MRA are focused mainly on the phase noise in most of the published works [15-18]. Although the amplitude-to-frequency conversion of the resonator operated at nonlinear vibration mode has been modeled [19], the noise characteristics associated with vibration amplitude need to be further verified experimentally. How to set an optimal vibration amplitude for the automatic amplitude control (AAC) loop and thus minimize the overall accelerometer noise is one of the most challenging aspects in design of a high-performance MRA [16, 20].