A Micro Vibratory Stage for On Chip Physical Stimulation and Calibration of MEMS Gyroscopes

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Abstract— This paper presents the design and preliminary test results of a micro actuation and sensing platform to provide on chip physical stimulus for in situ calibration of long-term drifts in scale factor and offset of dual-axis MEMS gyroscopes. The platform consists of a 3-DOF micro vibratory stage that can provide piezoelectric actuation for X/Y-tilting reference stimuli, off-axis motion compensation, analog sensing of applied periodic stimulus, and electrostatic position lock-down for shock protection. Initial characterizations are performed with a commercial MEMS gyroscope (25 mg) mounted on top of the micro motion platform, while its electrical interconnects provided through microfabricated highly-flexible parylene cables. The piezoelectric stage is measured to provide up to 220 degree/sec angular AC excitation, while providing an analog sensing signal to determine the applied stimulus with a precision of 1.2 degree/sec. The estimated scale factor has < 0.8% deviation from rate-table values on the same-model gyroscope samples.

Keywords—Calibration, stimulation, piezoelectric, scale factor drift, bias drift, cross-axis coupling, vibration, packaging.

I. INTRODUCTION

In order to allow exploitation of MEMS gyroscopes in high accuracy strategic applications, it is desirable to integrate on-chip calibration mechanisms and improve their long-term stability against various factors such as time, humidity, shock, and temperature cycling [1]. One emerging approach is to provide controlled on-chip physical stimuli for in situ measurement and recalibration of signal drift (Fig. 1). This approach requires a compact and low-power micro actuator that can produce the required reference calibration signals with minimum wobble while not causing any degradation in gyro performance, as well as an integrated motion sensing method. Recently, micro scale rotary platforms based on magnetoelastic [2], ultrasonic [3], and electrostatic [4] actuation mechanisms have been reported, all with the final goal of applying known rotational rates in continuous (carouseling) or bidirectional dithering (maytagging) mode to a gyroscope payload. However, these microsystems face several challenges yet, such as integration of reliable electrical connections to the rotor, shock protection mechanisms, and minimization of wobble and lateral slop during actuation. In this work, we introduce a piezoelectric multi-axis micro actuation platform to provide periodic vibratory angular excitations on an IMU payload for in situ calibration of its scale factor, while enabling integrated off-axis motion compensation, analog stimuli sensing, and electrostatic position lock-down for active shock protection.

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Fig. 1: Overview of the on-chip physical calibration architecture.

II. DESIGN AND EXPERIMENTAL SETUP

The designed vibratory stage carries the inertial sensor on a 2.3×2.3-mm² sized center platform, which is symmetrically held and actuated by four piezoelectric crab-leg suspensions that are 55-μm thick and 100-μm wide (Fig. 2). The piezoelectric stage is microfabricated via a wafer-level process involving bonding, lapping, and wet-etch patterning of bulk-PZT substrates on silicon (Fig. 3a) [5]. In order to provide actuation and position-sensing simultaneously, two of the piezoelectric arms are utilized to provide X or Y vibratory tilting motion, while the third arm is used to compensate any undesired off-axis motion in the other tilting direction, and the fourth arm is employed for integrated sensing of the applied actuation rate. The moving stage is placed ~25 μm above an electrostatic platform that locks down the stage (V_PULL-IN~100 V) for shock protection whenever a calibration procedure is not performed. A commercially available dual-axis digital output MEMS gyroscope [6] is used as the test sensor on top of the vibratory stage. In order to allow fast prototyping and universal testing of various inertial sensors, the electrical interconnects from the IMU to the testing platform is achieved via microfabricated parylene cables (Fig. 3b). The developed meander-shaped parylene cables are FEA simulated to result < 1% loading in every motion axis compared to the stalling force of the vibratory stage (>1 mN).

Fig. 2: Graphical cross-section of the micro actuation platform.
III. Test Results

To demonstrate that the presented micro actuation platform does not cause any degradation in gyro performance while the electrostatic locking is turned off, two samples of the same gyro model (#1 and #2) are characterized in a rate-table with DC excitation, while one of the devices was integrated on the vibratory stage (Fig. 4). Measured difference in scale factors is < 0.2%, which could be attributed to the statistical variation between different gyroscope samples (3% in datasheet). The first resonance frequency of the motion stage loaded with an inertial sensor of 25 mg payload is > 200 Hz, and the device consumes only < 100 µW within this operation bandwidth even if all the piezoelectric arms are used for actuation. With an excitation amplitude of 20 V at 100 Hz, the stage is measured to provide up to 220°/sec angular AC rate to the gyro (Fig. 5). The piezoelectric sensing signal is characterized with respect to the applied rate, which is simultaneously measured by an optical sensing setup. The sensitivity is measured to be fairly linear, ~11 mV/°/sec.

For demonstration of in situ stimulation and output measurement from a gyroscope sample (#3), the stage is excited at increasing amplitudes at a constant frequency, while the gyro output and piezoelectric sensing signal are recorded simultaneously (Fig. 6). With this setup, the scale factor is determined as 32.6 bits/°/sec, close to the values from other samples characterized on the rate table (32.8 bits/°/sec). The observed shift in offset is possibly caused by the distance between the center of applied stimulus and the gyroscopic, as well as by the high level of applied angular acceleration.

IV. Discussion

For the final goal of on-chip gyroscope calibration, the gain of analog stimuli-sensing signal may not provide sufficient repeatability due to the aging and temporal effects on the piezoelectric properties. Thus, as a future work, the estimation of the applied periodic trajectory needs to be improved by the addition of capacitive threshold sensing and a Kalman filter, which can provide precise determination of certain reference displacements [7]. In addition, the next generation platform is planned to integrate on-chip electrical connections to the IMU without depending on parylene cables, and provide undesired motion compensation in multiple axes simultaneously.

REFERENCES