A NOVEL SYSTEM OF PRIMARY OSCILLATIONS FOR MICROMECHANICAL GYROSCOPE

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Abstract. The paper proposes a novel system of primary oscillations produced by the microelectromechanical (MEMS) gyroscope. This system is based on a synchronous detection of the current passing through the power capacitances of MEMS gyroscope. This detection method enables the excitation and stabilization of primary oscillations during two measuring cycles. The proposed system of primary oscillations also enhances the operation speed and the accuracy of frequency control, and reduces the ambient temperature effect on the stability of the scaling factor of the MEMS gyroscope.

1. Introduction

A microelectromechanical (MEMS) gyroscope is an integrated circuit unit which is placed onto a crystalline silicon substrate (silicon wafer) comprising different-type MEMS structures and electronic components necessary for measuring angular velocities [1-4].

Whatever configuration of such a system which uses the Coriolis effect is proposed, it should have a subsystem which generates the mechanical motion (primary oscillations) of the inertial mass in the microgyroscope (MG) [5-7]. The functioning principles of this subsystem greatly determine such important MG parameters as its readiness time after switching, conversion factors of angular velocities and their resistance to destabilizing factors, conversion errors [8-11].

Various types of microactuators are used to provide the motion of the MG inertial mass along the selected axis. To these types belong electrostatic vibratory drives in which the interaction between MEMS structures and electronics is performed via a single capacity transmitter or a differential capacity transmitter.

Traditionally, two groups of comb electrode structures are used to provide the motion of the inertial mass and stabilization of primary oscillations [12-15]. The first group includes driving electrodes of the microactuator, while the second comprises driving feedback electrodes which gather measurement information in order to control and stabilize the primary oscillations. The primary oscillation control is performed by the phase-locked looped system (PLLS) that results in long-term transition processes and reduces the operation speed. Changes in the ambient temperature cause changes in PLLS parameters, thereby leading to the decrease in the amplitude stability, frequency of primary oscillations and, as a consequence, the stability of the scaling factor of the MEMS gyroscope.

This work proposes a novel system of primary oscillations produced by the MEMS gyroscope and describes it by a method of synchronous detection of the current passing through the power capacitances of MEMS gyroscope. This detection method provides the excitation and stabilization of primary oscillations during two measuring cycles.

2. System of primary oscillations

Figure 1 shows a schematic of the MG configuration and figure 2 contains the structural circuit of the excitation and stabilization system of MG primary oscillations.

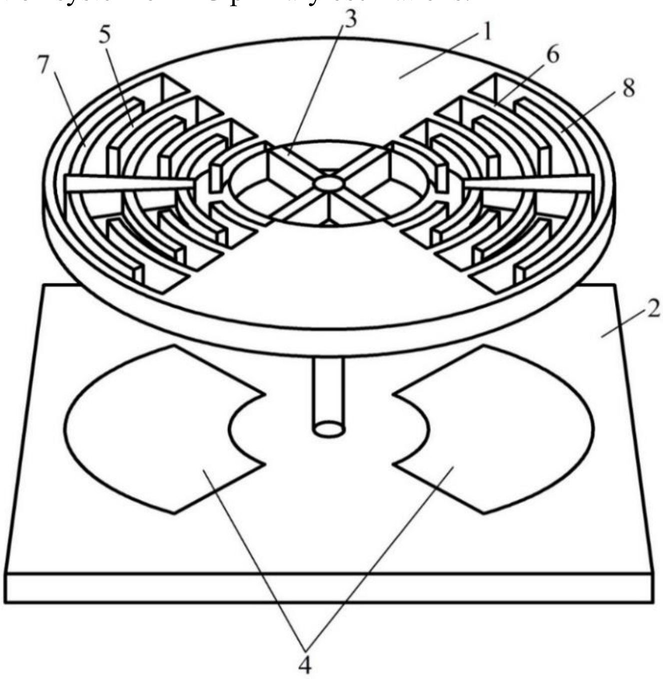

Figure 1. The MG configuration).

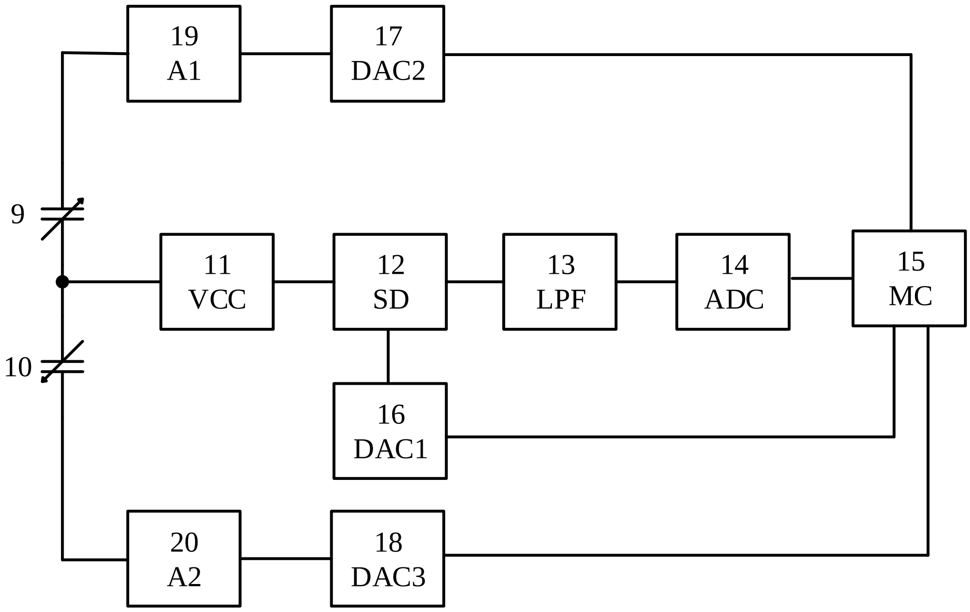

Figure 2. The structural circuit of the excitation and stabilization system).

The microgyroscope comprises the moving mass *1* which represents a disc movable relative to the support frame *2*. The moving mass is mounted to the support frame by spring elements *3*. Two ends of these spring elements are rigidly mounted to the moving mass *1*, whereas another two are mounted to the support frame *2*. Spring elements *3* are placed in the gyroscope such that to enable primary and secondary angular oscillations of the moving mass *1*. The former occur around *Z*-axis which is perpendicular to the plane of the moving mass *1*. The latter occur around *X*- and *Y*-axes within the plane of the moving mass *1*.

Stationary electrodes *4* are fixed to the support frame *2,* opposite to each other. Together with electrodes mounted to the bottom side of the moving mass, these electrodes form flat capacitors which are capacity transmitters of secondary angular oscillations of the moving mass *1* relative to the support frame *2.* The output of the capacity transmitter is connected to the gathering information unit.

Opposite to each other, movable comb electrodes *5, 6* are mounted to the moving mass *1,* which in combination with stationary comb electrodes *7, 8* form capacitors *9, 10* of the electrostatic comb drive. These stationary comb electrodes are shown in Figure 2.

The excitation system of MG primary oscillations operates as follows. The excitation and stabilization of MG primary oscillations are performed in two stages. The first stage includes setting the input parameters for the first digital-to-analog converter *16* (DAC 1) *via* the interface by the microcontroller *15* (MC). The following equation is used for setting these input parameters:

$$U_{r1}(t) = U_{rm}\sin(2\omega t)\,, \tag{1}$$

where U_{rm} is the voltage amplitude at the output of the DAC *1*, V; ω is the voltage frequency, rad/s.

At the same time, the input parameters are set for the second digital-to-analog converter *17* (DAC 2) *via* the interface by the microcontroller *15* (MC). The following equation is used for setting these input parameters:

$$U_1(t) = U_m\sin(\omega t) + U_0\,. \tag{2}$$

The input parameters for the third digital-to-analog converter *18* (DAC 3) are obtained from the following equation:

$$U_2(t) = U_m\sin(\omega t + \pi) + U_0\,. \tag{3}$$

where U_m is the voltage amplitude, V; U_0 is the constant bias voltage, V.

The DAC 2 output voltage $U_1(t)$ is received by the input of the amplifier *19* (A1) and thus becomes stronger. The amplified output voltage $U_1(t)$ from A1 amplifier is received by the condenser *9* of the MG comb drive. The condenser *10* of the MG comb drive receives voltage from the DAC 3 output. This voltage is amplified by the second amplifier *20* (A2). As a result, the current flows through condensers *9* and *10* of the comb drive and then it flows to the input of the voltage/current converter *11* (VCC) and converts into the analog voltage. The output voltage from the voltage/current converter *11* is supplied to the first input of the synchronous detector *12* (SD), while the voltage from the first digital-to-analog converter *16* is supplied to its second input. The low-pass filter *13* (LPF) filtrates the voltage from the synchronous detector *12* which is then digitalized by the analog-to-digital converter *14* (ADC). The digitalized voltage U_p which is proportional to the inphase component of the total current flowing through the comb drive condensers *9* and *10*, delivers to and stores in the microcontroller *15*.

At the second stage, the output parameters of the digital-to-analog converter *16* are set by the microcontroller *15 via* the interface using the following equation:

$$U_{r2}(t) = U_{rm}\cos(2\omega t)\,. \tag{4}$$

The procedures of the first stage are then repeated. The digitalized voltage U_q which is proportional to the quadrature component of the total current passing through the comb drive condensers *9* and *10*, delivers and stores in the microcontroller *15*.

The following equations are used by microcontroller *15* to compute the phase shift φ in the total current passing through the comb drive condensers *9* and *10:*

$$\varphi = \arctan\left(\frac{\lim_{T\to\infty} 1/ET\int_0^T U_I(t)U_{r2}(t)dt}{\lim_{T\to\infty} 1/ET\int_0^T U_I(t)U_{r1}(t)dt}\right), \quad (5)$$

where $U_I(t)$ is the output voltage from the voltage/current converter, V; E is the denominator of the synchronous detector, V; T is the time of integration, s.

When the phase shift is not equal to 90° which correspond to the maximum amplitude of MG primary oscillations, microcontroller *15* computes their resonance eigen-frequency as

$$\omega_r = \frac{\omega + \omega\sqrt{1+4Q^2\tan(\varphi)^2}}{2Q\tan(\varphi)}, \quad (6)$$

where Q is the quality factor of the primary oscillation channel of MG.

Next, microcontroller *15* changes the frequency ω *via* the interface at the output of the second digital-to-analog converter *17* and the third digital-to-analog converter *18* by the estimated value of the resonance eigen-frequency of MG primary oscillations.

Thus, the excitation and stabilization of primary oscillations around *Z*-axis occurs during two measuring cycles.

Under the rotation (angular velocity) of the support frame *2* around *X*- and *Y*-axes, Coriolis forces appear and enable the moving mass *1* to execute secondary angular oscillations around *X*- and *Y*-axes. Amplitudes of these oscillations are proportional to the measured angular velocities and convert into electric signals by capacity transmitters. The latter are formed by the stationary electrodes *4* fixed to the support frame *2* and movable comb electrodes fixed to the bottom side of the moving mass *1*.

3. Conclusions

The system of primary oscillations produced by the microelectromechanical gyroscope was proposed on the basis of synchronous detection of the inphase and quadrature components of the total current passing through the comb drive electrodes. Calculations of the resonance eigen-frequency produced by MG primary oscillations allowed us to excite and stabilize the primary oscillations at two measuring cycles. This was because the resonance eigen-frequency was mathematically calculated independently of changes in the ambient temperature, that increased the stability of the scaling factor of the MEMS gyroscope. One synchronous detector and one analog-to-digital converter were used to detect both inphase and quadrature components of the total current. The removal of the phase-locked looped system from the structural circuit of the excitation and stabilization system resulted in its simplification and the enhancement of the gyroscope reliability.

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