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Simulation of A Two-Axis Micromechanical Gyroscope.

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ABSTRACT

This paper covered the main stages of design and creating a mathematical model of a micromechanical gyroscope with two axes of sensitivity. According to the proposed method of simulation, calculations of their own shapes and frequencies of oscillation of sensing element of gyro were performed. Description of the design on the high-level parameterized language VHDL-AMS was developed. We analysed the gyro design in the CAE system ANSYS. The results obtained in the course of mathematical modelling, satisfy the requirements of the modern micromechanical gyroscope, which is important, given the steady increase in the quality of performance and lower prices for foreign products in the segment. We can use the obtained data in further development of structures taking into account the possibilities of model parameters busting.

Keyword: MEMS, micromechanical gyroscope, design, sensor, mathematical model

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INTRODUCTION

In many segments of commercial MEMS s market inertial and pressure sensors dominate. In part, this is due to the existing problems. Inertia sensors - accelerometers, gyroscopes, multisensor modules and systems based on them - are widely used in navigation, for compensation of other instruments (accelerometers, inclinometers) or stabilization (gyroscopes). Inertial Measurement Units (IMU) are one of the main applications of inertial sensors in a MEMS design [1-3].

For navigation and many of measuring instruments used gyroscopes, high requirements are placed in terms of accuracy and reliability, but often these devices are operated in a relatively soft (eg, In-cab) conditions. In this case, distinction of High-End version from the commercial version will consist in the application of more complex compensation, calibration and redundant circuits to the data fusion algorithms of different types of sensors, but the MEMS part and the whole system will not require a special, non-standard, encapsulation [4-6].

This article describes a micromechanical gyroscope LL-type classical configuration with some improvements, allowing carrying out studies of finished structures without re-release of sensitive elements.

Problem statement

To calculate the amplitude and frequencies of oscillations of sensing elements under the action of electrostatic forces and Coriolis forces of inertia, a mathematical model was developed. It included the calculations of its own forms and natural frequencies of oscillations of sensing elements, calculations of the amplitudes of oscillations of sensing elements under the influence of electrostatic forces and Coriolis forces of inertia [5-7].

Micromechanical gyroscope includes a substrate, the fixed electrodes of capacitive displacement transducers, fixed interdigital electrodes of electrostatic actuators (ESA), the movable interdigital electrodes ESA, elastic beams, pillars, the inertial mass showed in Fig. 1. The sensing element is formed by the inertial mass and the elastic beams. Movement of sensitive elements in the Y-axis in the driving mode and in the X and Z- axes in the sensitivity mode is performed

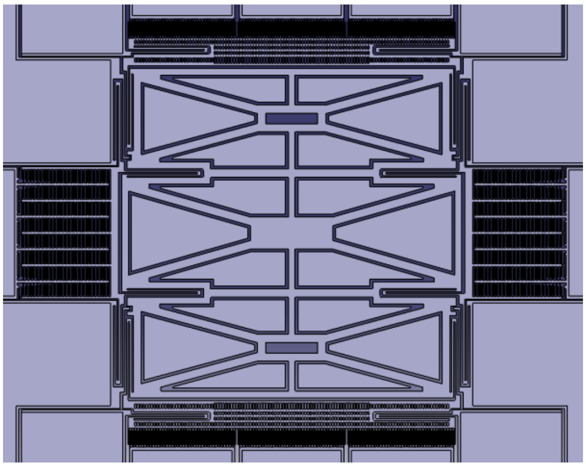

Fig.1. Design of micromechanical gyroscope

Models of capacitance change with vibrations and displacements:

a) IDT converters for:

On X axis:

$$\Delta C\ (\Omega_z, a_x) = N \frac{\varepsilon\varepsilon_0 l\ h}{g^2} x\ (\Omega_z, a_x);$$ (1)

On Y axis:

$$\Delta C\ (U_{\text{con}}, a_y) = N\ \frac{\varepsilon\varepsilon_0 l\ h}{g^2} y\ (F_{\text{el}}, a_y)$$.; (2)

b) For planar transducers for Z axis –

$$\Delta C(\Omega_x, a_z) = \frac{\varepsilon\varepsilon_0 l_e w_e}{g_3 + z\ (\Omega_x, a_z)},$$ (3)

where x, y, z – displacement of sensitive elements under the influence of external factors; ε–relative permittivity of the air gap; ε_0– electric constant; N – is a number of fingers of IDT along the x, y, z axes; h – thickness of the structural layer of the sensor; g–gap between the fingers of IDT of inertial mass along the axis, with the fingers of IDT of fixed electrodes; l –length of the fingers overlap of IDT of inertial mass along the axis, with the fingers of IDT of fixed electrodes; l_e, w_e– length and width of fixed electrodes; g_3–gap between the fixed electrodes and the inertial masses; F_{el} –electrostatic force generated by the electrostatic actuator [1].

It should be noted that under the influence of forces of inertia sensitive elements of the device are moved in one direction, but by the action of Coriolis inertia forces they perform antiphase oscillations relative to each other.

In analogue signal processing, pulse shaping is performing to initiating and maintaining the oscillations of sensing elements of MMG in the motion mode. ASIC also includes a circuit generating and maintaining forced oscillations of the inertial mass of the accelerometer-gyroscope [6-8]. For registration signals due to the influence of external forces is necessary to perform a series of operations:

1) identify signals carrying information about the oscillation and movements of sensing elements separately for motion mode axis and two axes of sensitivity mode;
2) identify signals carrying information about vibrations of sensing elements along driving mode axis under influence of electrostatic forces and along sensitivity mode axis under influence of Coriolis inertia forces ;
3) identify signals carrying information only about the movements of sensing elements along driving mode axis and along sensitivity mode axis under influence of inertia forces.

With capacitance-to-voltage transducers, based on trans-resistive amplifiers, changes of capacities of capacitive displacement transducers are converted into electrical signals in the form of beats, the amplitude of which carries information about the movements and oscillation of sensing elements separately for driving mode axis and two axes of sensitivity mode [7,8].

A feature of this sensor of angular velocities and linear acceleration is that resilient suspension, the inertial mass, movable and stationary interdigital electrodes of electrostatic actuators, fixed electrodes of capacitive displacement transducers are made in a single structural layer. Usage of two supports allows eliminating the mutual influence of the primary and secondary oscillations MMG of sensing elements on each other.

Software methods of analysis of the design

Obtaining of prototypes of small size is simplified with the ability to create the parameterized bulk device models, with possibility of changing of certain parameters. By processing the calculation results, it is possible to observe and draw conclusions about the presence of some of the relationships between the input parameters and output signals. For example in Fig. 2 shows an elastic suspension of the rotor on the axis of motion, in which the value of the length L parameters, of l1 and l2, if desired, can be changed, thereby changing the stiffness of the suspension, which, of course, affects the behavior of the sensor as a whole [8-10].

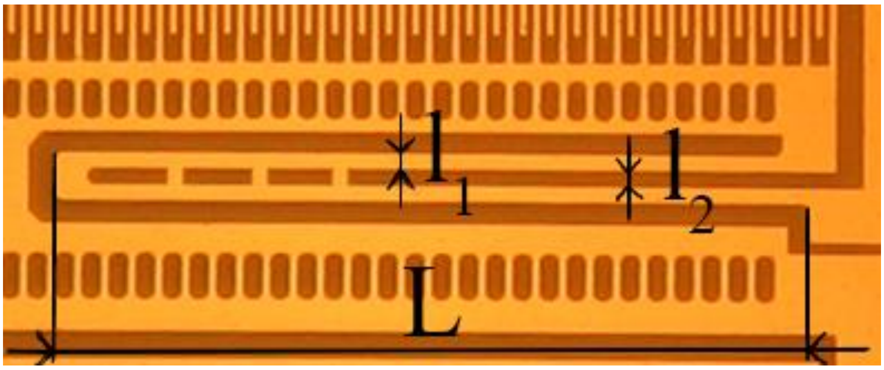

Fig.2. Elastic suspension of the rotor

Fig. 3 shows part of IDT capacitor, which is recording for information about the impact on the system of angular velocities.

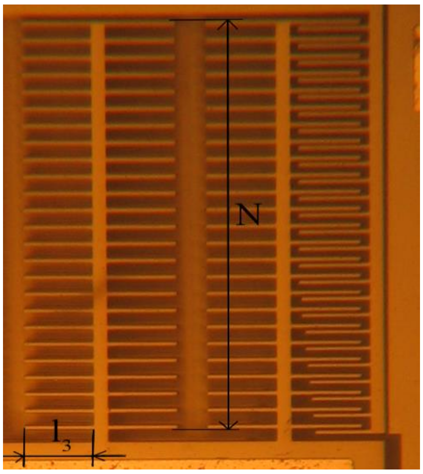

Fig. 3. Rotor of IDT capacitor on the sensitivity axis.

By varying number of fingers N or length of l3 fingers can vary the capacitance located on the MMG sensitivity axis

In addition, the proposed design uses a jumper system, which provide given rigidity .(Fig. 4, in red). The stiffness is changing after removal of elements of the jumper system, and, as a consequence, the operating frequencies. is changing too. As result there is the sensing element with non-given parameters, without much time and cost.

Fig. 4. Elastic suspension of the inertial mass

The total stiffness of the sensing element of the sensor of angular velocity along the axis Z, caused by a series-parallel connection of the elastic beams will be determined by the following expression:

$$k_Z = \frac{2EJ_y J_x}{\left(L_{b1}^3 J_y + L_{b2}^3 J_x\right)}. \quad (4)$$

The angular own frequency of fluctuations the sensor element by the action of the angular MMG Ωx rate will be determined by the following expression [9]:

$$\omega_z = \sqrt{\frac{k_Z}{m_M}}. \quad (5)$$

It is worth mentioning that the creation of a separate structure for the simulation with different parameters, takes a lot of time, but these losses are reducing to minimum, in the presence of a parameterized model [10].

RESULTS

As above mentioned, developed VHDL description of the design works of MMG with modelling under the influence of angular velocities in hAMSter software. In the event of angular velocities Ωx, Ωz vibrates the sensor element along the axis of sensitivity. Displacement amplitude is proportional to the magnitude of the current exposure. Direction of angular velocities will determine the phase of the inertial mass movements [11,12,13].

Fig. 5 and 6 show the results of simulating the operation of micromechanical gyroscope angular velocities under the action.

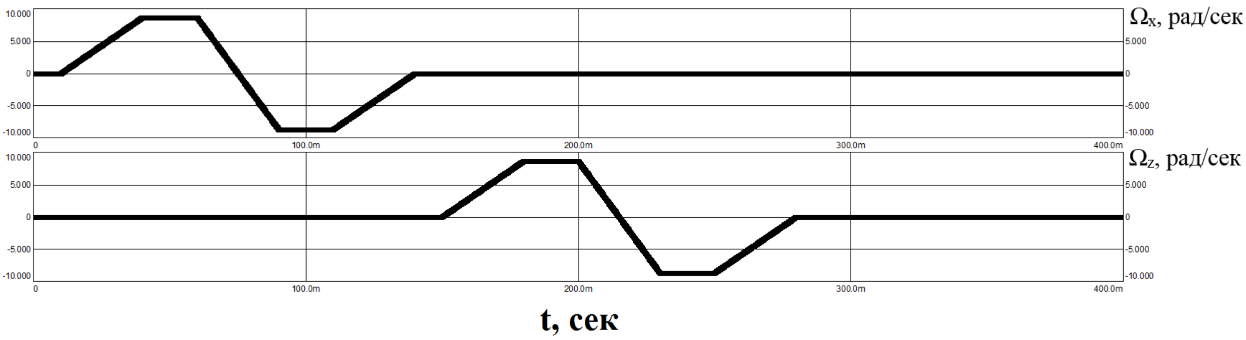

Fig. 5. Changes in angular velocities in the full dynamic range

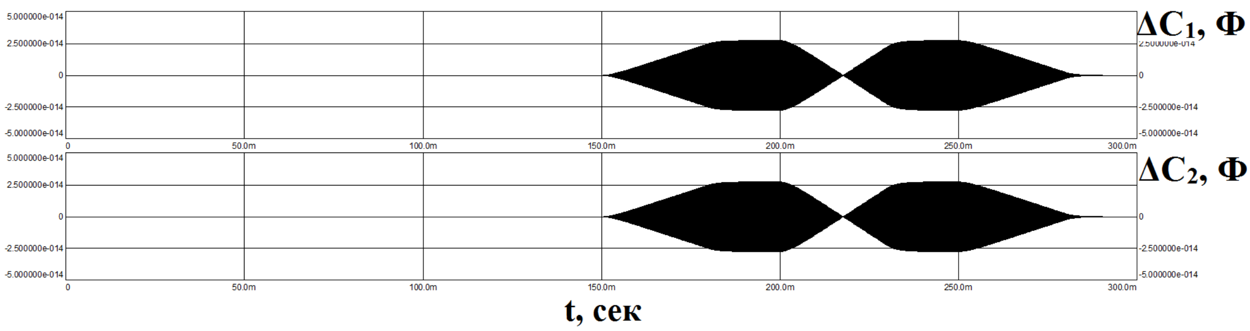

Fig. 6. Changes of capacities of displacement transducers of gyro

The simulation results showed that the initial capacitance of displacement transducers in the X-axis is dozens of fF, and Z-axis is units of pF. Under the influence of the angular velocity, changing of the differential capacitance on sensitivity X-axis is 25 fF, on sensitivity axis Z - 0.6 pF.

The basis for the probabilistic analysis of the impact of technological errors on output device settings in accordance with the procedure [2] is a parametric model of a micromechanical gyroscope. The main elements that determine the static and dynamic characteristics of a micromechanical gyroscope are inertial mass and elastic suspension.

Technological error will make a major contribution to the elements having the minimum size, namely, the width of the elastic suspensions. Therefore, the analysis was carried out for the width of the beams of four elastic suspensions. The output parameters are the maximum movement of the inertial mass for external action for the directions Y and Z.

The numerical experiment was conducted on experiment planning matrix According to the results of the experiment average values of output parameters were obtained and the standard deviation was calculated. Histograms of distribution of output parameters and distribution functions were determined.

CONCLUSION

The developed mathematical model of the multi-axis micromechanical gyroscope is obtained on the basis of the Lagrange second order conditions, and takes into account the cross-sensitivity. Also calculation of own shapes and natural frequencies of oscillation sensing elements and the calculation of the amplitude fluctuations of sensitive elements under the influence of electrostatic forces and Coriolis forces of inertia are performed in the mathematical model.

On the basis of the proposed multi-axis design of a micromechanical gyroscope a mathematical model was developed by constructing parameterized macro geometric and finite element models for the numerical simulation in ANSYS software package, as well as high-level parameterized VHDL-AMS description.

As a result, we can say that the initial capacity of the displacement transducers on the X-axis in the tens of fF, and Z-axis - units pF. Under the influence of the angular velocity changing of the differential capacitance on sensitivity X-axis is 25 fF, on sensitivity axis Z - 0.6 pF.

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