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Criteria of Equality of Modal Frequency of Micromechanical Gyroscopes-Accelerometers Sensitive Elements

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Abstract

In this work the topology of the integrated micromechanical sensor of LL-type is developed. Using the condition of equality of modal frequencies of sensitive elements of the micromechanical sensor in both modes along the one axis the criterion of the coincidence is obtained, the criterion of modal frequencies of sensitive elements of the micromechanical sensor in a sense mode along the two axis is obtained, dependences of the ratio of beam length on thickness of a structural layer are showed, the results of numerical simulation of modal frequencies of the micromechanical sensor sensitive element in a drive mode or a sense mode is obtained using the criterion. Using the criterion, it is possible to achieve coincidence of intrinsic vibration frequencies of a sensitive element in a sense mode that provides the same sensitivity to the angular velocities. Coincidence of frequency of forced vibrations in a drive mode with vibration frequencies of a sense mode along both axis of sensitivity can be achieved by using electrostatic elasticity.

Keywords: micromechanical sensor, sensitive elements, modal frequencies, angular velocities, topology

1. Introduction

One of the directions of development of microsystem equipment is development, research and application of micromechanical gyroscopes and accelerometers. Micromechanical sensors of angular velocity and linear acceleration are used widely in modern technical devices of different applications: from the specialized products of aerospace systems and defensive systems to home appliances, such as phones and game platforms of new generation. So, for example, micromechanical sensors in the navigation system with GLONASS or the GPS receiver will allow to keep accuracy and regularity of navigation if the signal from the satellite is lost. In automotive industry the sensors allow to raise level of cars comfort (dynamic traffic control system, anti-lock braking system, navigation system, safety system) (Raspopov, 2007; Anchurin, Maksimov, Golovan, Morozov, & Shilov, 2011; Aravin, Verner, Saurov, & Malcev, 2011; Prokofev & Tihonov, 2011; Timoshenkov & Kulchickij, 2012).

Figure 1 shows the topology of the developed integrated micromechanical sensor of LL-type (Konoplev & Lysenko, 2005).

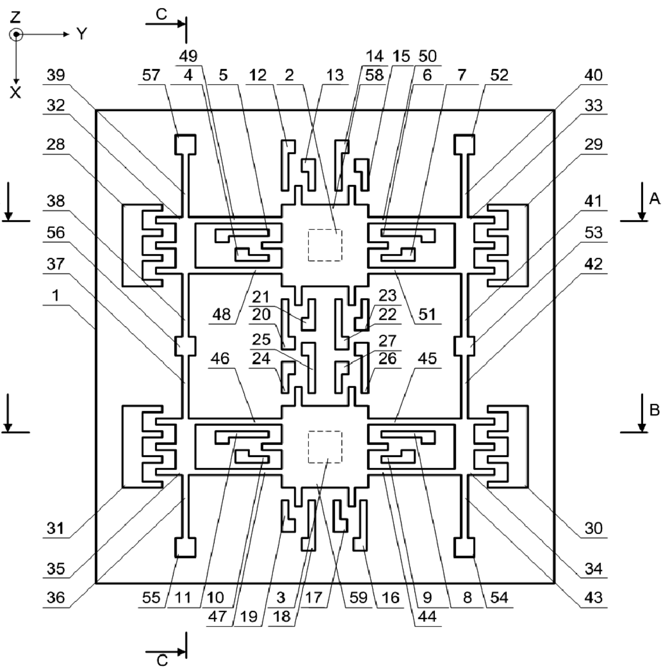

Figure 1. Topology of an integrated gyroscope-accelerometer of LL-type with two sensitive axis

The micromechanical gyroscope-accelerometer (MMGA) contains a substrate 1, fixed electrodes of capacitive displacement transducer 2-27, fixed comb electrodes of electrostatic actuators 28-31, movable comb electrodes of electrostatic actuators 32-35, elastic beams 36-51, anchor 52-57, proof masses 58 and 59. The sensitive element 1 is created by proof masses 58, elastic beams 38-41, 48-51. The sensitive element 2 is created by proof masses 29, elastic beams 36, 37, 42, 43, 44-47. Moving of sensitive elements along the y-axis are performed in a drive mode, and along the x-and z-axis are performed in a sense mode.

2. Problem Statement

As researches show (Lysenko, 2010; Lysenko & Lysenko, 2012; Lysenko, 2013), the parameters that influence on value of the Coriolis force are the mass, amplitude and vibrations frequency of mass. Vibrations frequency of proof mass in a drive mode is inversely proportional to weight of proof mass. Vibrations frequency of proof mass in a sense mode is inversely proportional to the vibrations amplitude of proof mass in a drive mode. Therefore, the weight and the amplitude of vibrations of proof mass being a consequence of the effect of electrostatic forces should be increased to improve the sensitivity of MMGA (Raspopov, 2007; Lysenko, 2013).

On the one hand, since the increase of the weight leads to the increase of substrate area occupied sensitive elements of MMGA, and, as a result, the cost of the device increases. To determine the optimal ratio of these parameters is necessary. Also, a too large areas of proof masses lead to decrease of prime yield, because the moving parts of microsystems components sticks to the substrate when in the last phase of the manufacturing process the etched products are washed (Raspopov, 2007; Lysenko, 2013).

On the other hand, the increase of the weight of mass will affect the resonance frequency of sensitive elements of MMGA negatively and increase the vibrations amplitude of mass. Shock loads and inertial force cause the vibrations amplitude. Another probable problem for "large" proof mass is the high value of the damping coefficients and low values of critical voltage, when there is occurrence of a snap-down effect (Raspopov, 2007; Lysenko, 2013).

As noted above, the Coriolis force depends on the vibrations frequency of proof mass in a drive mode. Therefore, in case the effect of the Coriolis force, the vibrations frequency of sensitive elements of MMGA in both modes should be coincided to increase the vibrations amplitude of proof mass.

3. Results and Discussion

As shown in figure 1, MMGA sensitive element vibrations along the x-axis and y-axis are caused by an identical connections configuration of elastic beams. In addition, if values of beams lengths and cross-sectional area are equal, the necessary coinciding vibrations frequencies could be achieved.

Using the condition of equality of modal frequencies of sensitive elements of MMGA in both modes along the z-axis the criterion of the coincidence is obtained:

$$\frac{L_{b38}^3}{L_{b48}^3} = \frac{w_{b38}}{w_{b48}^3}\left(4h^2 - w_{b48}^2\right) \tag{1}$$

where L_{b38}, L_{b48} – length of beams 38 and 48; w_{b38}, w_{b48} – width of beams 38 and 48; h – thickness of a structural layer.

Figure 2 shows dependences of the ratio of beam length 38 to beam length 48 on thickness of a structural layer.

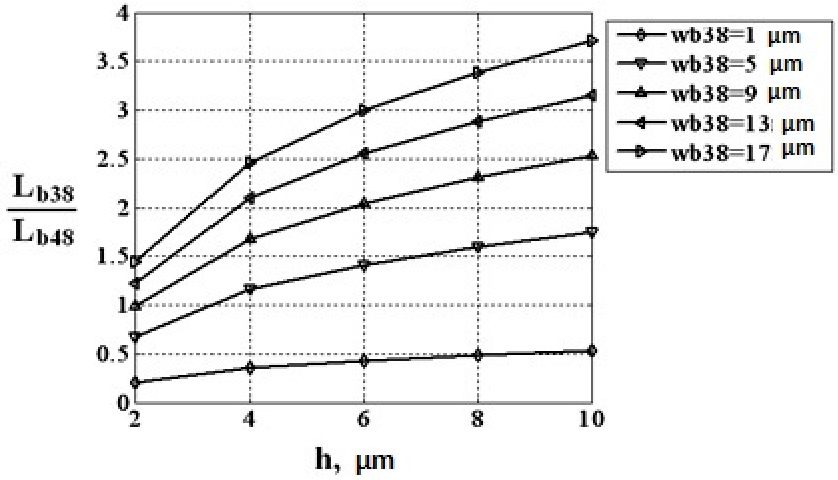

Figure 2. Dependences of the ratio of beam length 38 to beam length 48 on thickness of a structural layer, wb48 = 5 µm

Figure 3 shows the results of numerical simulation of modal frequencies of a sensitive element of MMGA in a drive mode or a sense mode. The elastic suspension of the sensitive element is calculated using the criterion (1), the length of the beam 38.

As shown in Figure 3 and 4 using expression (1) it is possible to achieve coincidence between the vibrations frequencies of the sensitive element of MMGA in a drive mode with the frequency in the a sense mode.

Using the condition of equality of modal frequencies of sensitive elements of MMGA in a sense mode along the x-and z-axis the criterion of coincidence of the modal frequencies is obtained:

$$\frac{L_{b48}^3}{L_{b38}^3} = \frac{w_{b48}}{w_{b38}^3}\left(4h^2 - w_{b38}^2\right) \tag{2}$$

Figure 4 shows the dependence of the ratio of the length of beam 48 to the length of beam 38 on the width of the beam 38.

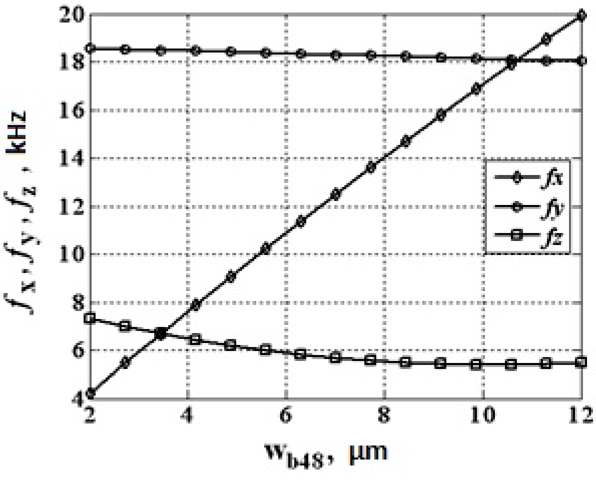

Figure 3. Dependence of frequencies of vibrations of a sensitive element in different modes on length of a beam 38, w_{b48}= 5 µm, h = 6 µm and L_{b48}= 200 µm

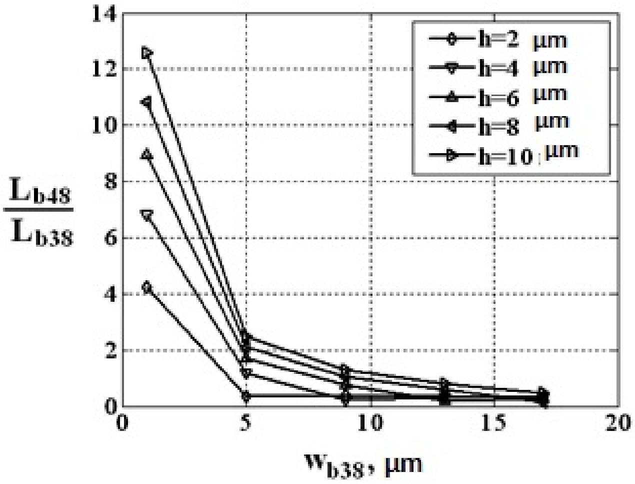

Figure 4. Dependence of the ratio of the length of beam 48 to the length of beam 38 on width of a beam 48, w_{b48}=5 µm

Figure 5 shows the results of numerical simulation of modal frequencies of a sensitive element of MMGA in drive and sense modes, elastic suspension of the sensitive element is calculated using the criterion (2), the width of the beam 48.

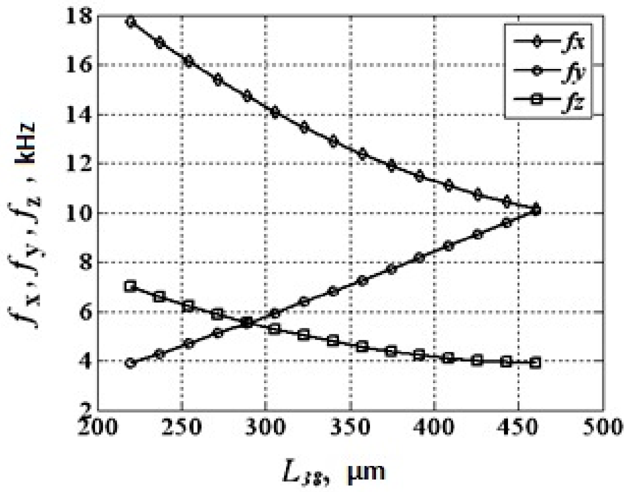

Figure 5. Dependence of vibration frequencies of a sensitive element in drive and sense modes on width of a beam 48, w_{b38}= =5 µm, h=6 µm and L_{b38}=200 µm

As shown in Figure 5 using expression (2) it is possible to achieve coincidence of vibration frequencies of a sensitive element of MMGA in a sense mode along the x-axis with vibration frequencies in a sense mode along the z-axis or in a drive mode.

4. Conclusions

Thus, using expression (2) it is possible to achieve coincidence of intrinsic vibration frequencies of a sensitive element in a sense mode that provides the same sensitivity to the angular velocities. Coincidence of frequency of forced vibrations in a drive mode with vibration frequencies of a sense mode along both axis of sensitivity can be achieved by using electrostatic elasticity (Raspopov, 2007; Pristupchik, 2015).

The obtained criteria of equality of intrinsic vibration frequencies of sensitive elements and the results of the simulation can be used to design MEMS gyroscopes and accelerometers.

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References

Anchurin, S. A., Maksimov, V. N., Morozov, E. S., Golovan, A. S., & Shilov, V. F. (2011). Inertial sensors block. *Journal of Nano and Microsystem Technique (in Russian), 1*, 50-53.

Aravin, V. V., Verner, V. D., Saurov, A. N., & Malcev, P. P. (2011). MEMS high level-a possible way of development of MEMS in Russia. *Journal of Nano and Microsystem Technique (in Russian), 6*, 28-31.

Konoplev, B. G., & Lysenko, I. E. (2005). Integrated micromachined gyroscope. Patent.

Lysenko, I. E. (2010). Integral sensor angular velocity and linear acceleration. Inzhenernyj vestnik Dona. Retrieved from http://ivdon.ru/magazine

Lysenko, I. E. (2013). Modeling of the Micromachined Angular Rate and Linear Acceleration Sensor LL-Type with Redirect of Drive and Sense Axes. *World Applied Sciences Journal, 27*, 759–762.

Lysenko, I. E. (2013). Simulation of three-axis MEMS sensor angular velocity and linear acceleration LR-type. Inzhenernyj vestnik Dona. Retrieved from http://ivdon.ru/magazine

Lysenko, I. E., & Lysenko, A. V. (2012). Integrated sensors of angular velocity and linear acceleration LR-type based on carbon nanotubes. Inzhenernyj vestnik Dona. Retrieved from http://ivdon.ru/magazine

Pristupchik, N., Konoplev, B., Kulikova, I., Klunnikova, Y., & Lysenko, I. (2015). Quantum Tunneling in Mesoscopic Electromechanical Transducers. *Modern Applied Science, 9*, 20-29.

Prokofev, I. V., & Tihonov, R. D. (2011). Nano-and micro-systems to monitor the parameters of movement of vehicles. *Journal of Nano and Microsystem Technique (in Russian), 12*, 48-50.

Raspopov, V. J. (2007). Micromechanical devices. Moscow, Mashinostroenie.

Timoshenkov, S. P., & Kulchickij, A. P. (2012). Application of MEMS sensors in systems of navigation and orientation of moving objects. *Journal of Nano and Microsystem Technique (in Russian), 6*, 51–56.

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