Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Research of a micromechanical accelerometer with three sensitivity axes

Research of a micromechanical accelerometer with three sensitivity axes

I E Lysenko[1], O A Ezhova[1], A V Tkachenko[1,2], D V Naumenko[1]
[1]Southern Federal University, Taganrog 347922, Russia
[2]RF Microsystems, Llc., Taganrog, 347939, Russia

Abstract. Micromechanical linear acceleration sensors are widely used in modern inertial orientation and navigation systems of technical equipment used in industry. The paper presents the developed design of MEMS linear acceleration sensor with three sensitivity axes, modal and static analysis is performed, design parameters are found that ensure equality of natural frequencies along the sensitivity axes, and experimental samples are created and studied.

1. Introduction
The development of modern electronics is associated with the development of devices with low weight, dimensions, low cost, energy consumption and high enough reliability. A microelectromechanical system is a device in sizes from fractions of a micrometer to a millimeter. They consist of mechanical, electrical elements, various drives and sensors located on a substrate of semiconductor or dielectric materials. Micromechanical accelerometers are widely used in modern technical devices for various purposes, specialized aerospace products, household appliances, such as cell phones and new-generation gaming platforms. Therefore, an urgent task today is to improve the mass and size characteristics of mems, provide the possibility of registering linear acceleration of a mobile object along three axes of sensitivity [1-4]. The role of devices based on MEMS technologies in the economy of highly developed countries is constantly growing. Today, the market for devices based on micromechanical systems is 15 billion dollars with an average annual growth rate of 15%. According to forecasts of world analytical agencies, the MEMS market will be worth 40 billion dollars by 2025 [1-4].

2. Design and research of MEMS accelerometer
The design of a linear acceleration sensor with three sensitivity axes was developed. This design is shown in Figure 1. This micromechanical accelerometer is able to register acceleration along three axes of sensitivity using a single sensor element. The developed three-axis single-mass accelerometer consists of inertial mass, movable and stationary electrodes, electric drives and various suspensions consisting of elastic beams. As part of this work, experimental samples of a micromechanical accelerometer were created, shown in Figure 2 [4].A VHDL-AMS description of the developed sensor was developed for behavioral research of dynamic characteristics based on the presented mathematical model. The amplitude of the movements of they when a = 1g and a = -1g is 6 nm along X,Y, and 50 nm along the Z-axis, with a = 10g and b = -10g is 50 nm along X,Y and 450 nm along the z-axis transient displacements of them in the X,Y is equal to 1 msec, Z – 8 msec.

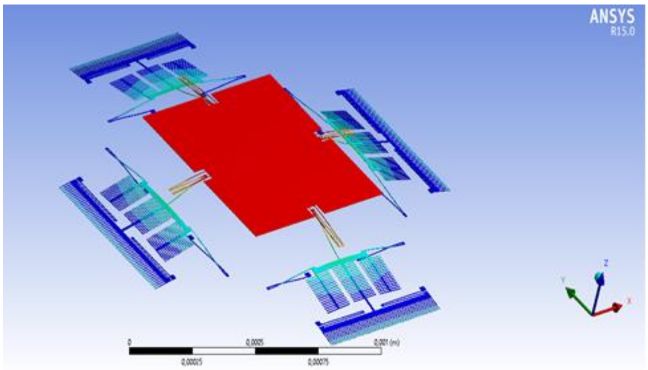

Figure 1. Design of three-axis micromechanical accelerometer

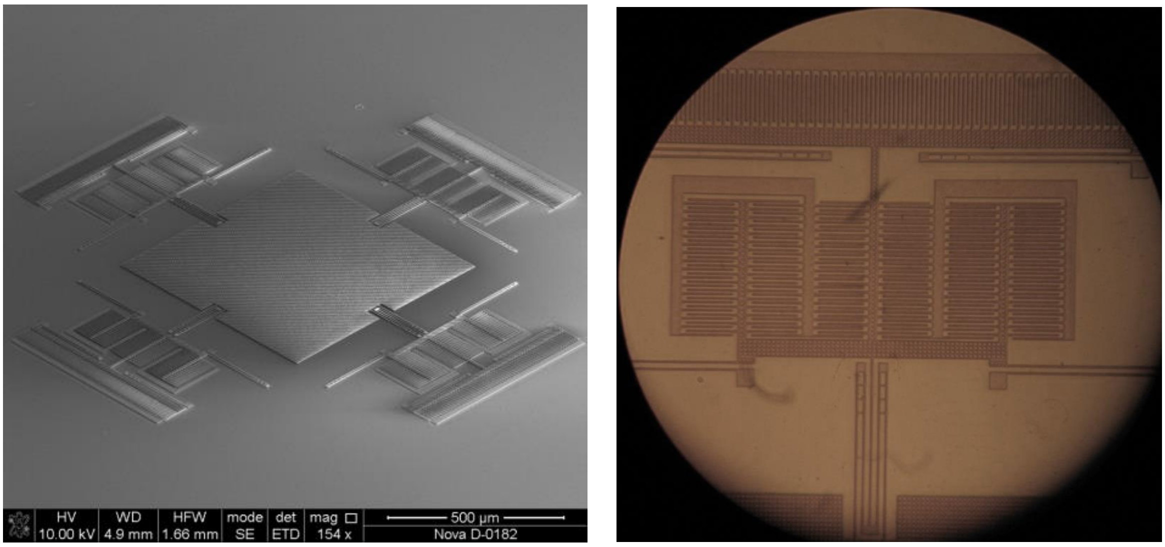

Figure 2. Experimental samples of a micromechanical accelerometer

The simulation results showed that when the acceleration is applied along the X,Y axes, the capacity is 0.5 pF, for Z – 0.07 pF at a = 1g,and for X, Y – 5 FF, for Z – 0.78 pF at a = 10g. The duration of transients when changing the capacitance of the capacitors of the displacement converters at a = 6g is 1 msec, at a = 10g is 1 msec for X, Y and 12 msec for Z. In this work, studies were conducted to determine the error of the developed mathematical model. Simulation of the movement of the sensing element under the action of linear acceleration was performed, the results of which are shown in Figure 3. The Simulation was based on the developed mathematical model using the high-level language VHDL-AMS and numerical simulation using the ANSYS package. The error of modeling the movement of inertial mass under the action of accelerations based on the developed mathematical model in comparison with the results of numerical methods is no more than 5%.

3. Research of design examples

Based on the studies of the developed single-mass design, examples of linear acceleration sensor designs were created. When creating these structures, the goal was to obtain the same natural frequencies along the three axes of sensitivity of the linear acceleration sensor. This will ensure the same sensor response to external influences on the sensitivity axes and the same limit conditions for each axis of sensor malfunction.

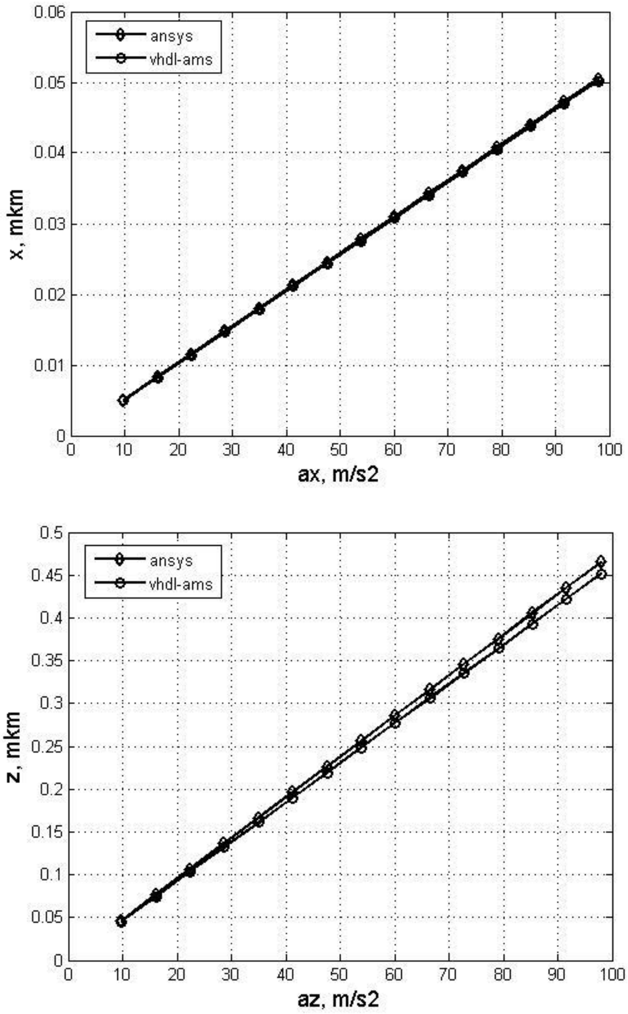

Figure 3. The dependence of the inertial mass movement under the action of acceleration on the X and Z axes

Table 1 shows the design parameters of single-mass micromechanical linear acceleration sensors calculated using the proposed criteria. In the course of research, static and modal analysis of the developed structures was carried out, Figure 4.

Table 1. Design parameters of single-mass micromechanical linear acceleration sensors.

# designs		1	2	3
Length of beams	l_1, µm	188	250	250
Width of the beams	w, µm	1,8	2	3
Range of linear accelerations	$a_{x,y,z,}$,g	±10	±10	±10
Sensitivity	$S_{x,y}$, fF/m/ s^2	41	44	67
	S_z, fF/m/ s^2	11	11	9
Natural frequency	$w_{x.y}$, kHz	5,5	5,9	6,6
	w_z, kHz	5,0	5,2	6,1

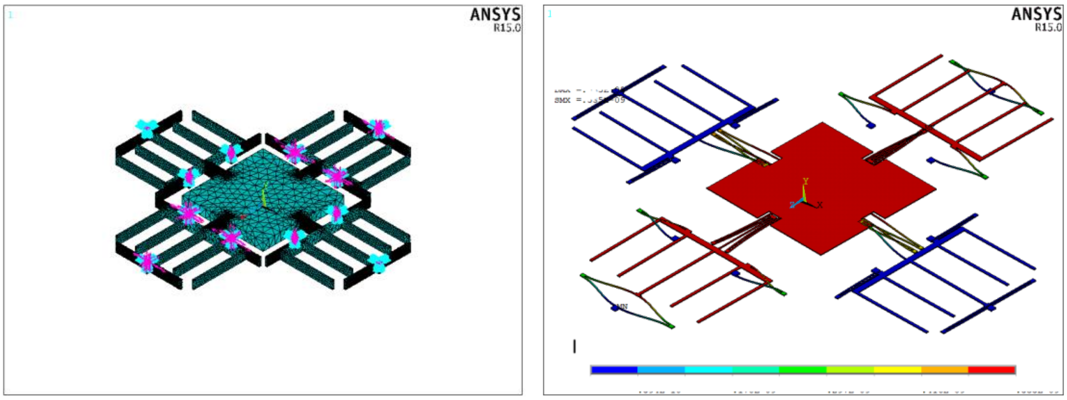

Figure 4. Modeling of design projects of the developed sensor

The simulation results of designed examples have shown that increasing the length of beams of the second type increases the range of motion of the inertial mass in the X, Y without affecting the range of motion of the inertial mass along the axis Z. the Thickness of the structural layer affects the sensitivity of inertial mass along the Z-axis, i.e. the greater the thickness of the structure, the greater the natural frequency on the z axis. Thus, the simulation of the developed projects confirmed the reliability of the previously presented criterion of equality of natural frequencies of vibrations along the axes of sensitivity of the linear acceleration sensor design, i.e. to observe the equality of frequencies, it is necessary to observe the ratio of the thickness of the structural layer, the width and length of the suspension beams of the first, second, and third types.

4. Conclusion

The research of the developed design of the micromechanical accelerometer is carried out. Criteria for equality of natural frequencies of linear acceleration sensor vibrations are developed. An experimental sample of a single-mass sensor was studied. During researches, it is established that the parameters of the experimental samples MEMS accelerometer correspond with requirements: number of axis sensitivity – 3, the range of measured accelerations – ±10 g, sensitivity at least 0.5 fF/g, the level of crosstalk suppression at least 50 dB.

Acknowledgments

The work was supported by the project FENW-2020-0022 to perform scientific research carried out at the expense of the federal budget, in terms of scientific activities on the topic «Development and research of methods and tools for monitoring, diagnostics and forecasting the state of engineering objects based on artificial intelligence».

References

[1] Mounier E and Damianos D 2019 *Status of the MEMS Industry; Market and Technology Report-Sample* (Yole Development Lyon France) pp 1–47
[2] Robin L 2017 *Status of the MEMS Industry* (Tech.Rep.Yole Developpement Phoenix AZ USA) p 2
[3] Lysenko I E 2019 *The results of modelling of a micromechanical accelerometer* (Journal of Physics: Conference Series 1410) 012226 doi:10.1088/1742-6596/1410/1/012226
[4] Ageev O A 2019 *Nanotechnology in microelectronics* ed O A Ageev and B G Konoplev (M. : Nauka) p 511