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Finite-element predictive 3D modelling and optimization of membrane-based thermoresistive MEMS accelerometers

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ABSTRACT

A three-dimensional numerical model of a thermal accelerometer with a thermal resistance effect in a sensitive element on a thin-film multilayer membrane based on MEMS technology has been developed and tested. The change in temperature difference on thermistors in the acceleration range from 1 to 10g and the applicability of the proposed technological solution for the implementation of thermal inertial systems are analyzed. The results obtained can be used for the optimization and development of a multi-axis thermal accelerometer.

Keywords: MEMS, accelerometer, thermistor, COMSOL Multiphysics, physical modeling

INTRODUCTION

The scope of applications of the linear acceleration MEMS sensors is constantly growing. Nowadays each smartphone is equipped with built-in accelerometers and gyroscopes, and, according to Yole Développement estimations [1], the MEMS accelerometer market is about 1.5 billion dollars and will not decrease in the coming years. Unmanned aerial vehicles (drones) and Internet of Things should become the next market drivers and further expand the application areas for MEMS sensors, including accelerometers. In addition to increasing sensitivity and reducing costs, modern accelerometers require high reliability, resistance to dynamic and shock loads and a significant reduction in weight and size. MEMS technology has long established itself in the field of mass production of sensors. There are several types of MEMS accelerometers that measure acceleration using different physical phenomena [2], each of which has its advantages and disadvantages. In this work we propose the thermoresistive MEMS accelerometer, which measures the heat distribution under acceleration instead of measuring the deviation of the moving mass. Avoiding the use of moving parts offers a lot of advantages in terms of sensor reliability, impact resistance and zero-g offset stability [4-12].

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MODEL

The model requires the interaction of three different physical modules, including the Joule effect, the heat dissipation and the effect of the laminar flow. The interactions between the different modules are presented in Figure 1.

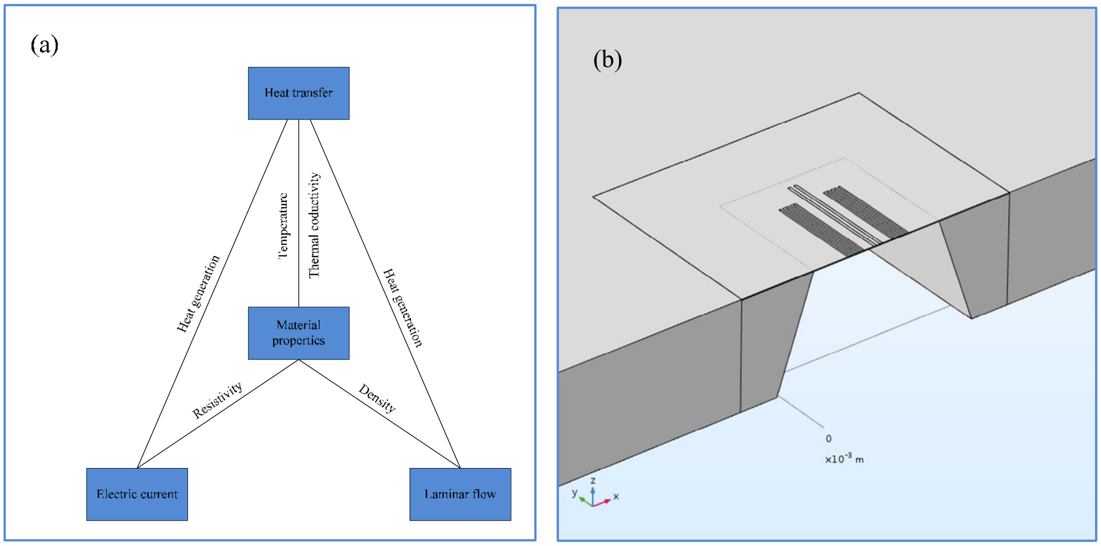

Fig. 1. (a) Physical modules and their interaction. (b) 3D view of the membrane-based sensitive element of the thermoresistive MEMS accelerometer in COMSOL MultiPhysics.

Algorithm of the interaction of physical modules is presented in Figure 1a. «Electric current» module calculates the distribution of electric current in central resistor. Based on these data, «Heat transfer» module determines heat generated by current in central resistor and dissipation of the heat power in atmosphere. In turn, «Material properties» module calculates density of atmosphere on every point and transmit this data to «Laminar flow» module. Laminar flow apply force to atmosphere, which redistributed by the different density.

A simulation of a simplified model of a single resistor in the atmosphere was carried out and the temperature difference for different gas volumes (pipe diameters) was considered. The measurements were carried out for the following diameters 0.1mm-1.5mm with a step of 0.1mm, as well as 1mm-15mm with a step of 1mm. An example of heat distribution in a simplified model is shown in Figure 2.

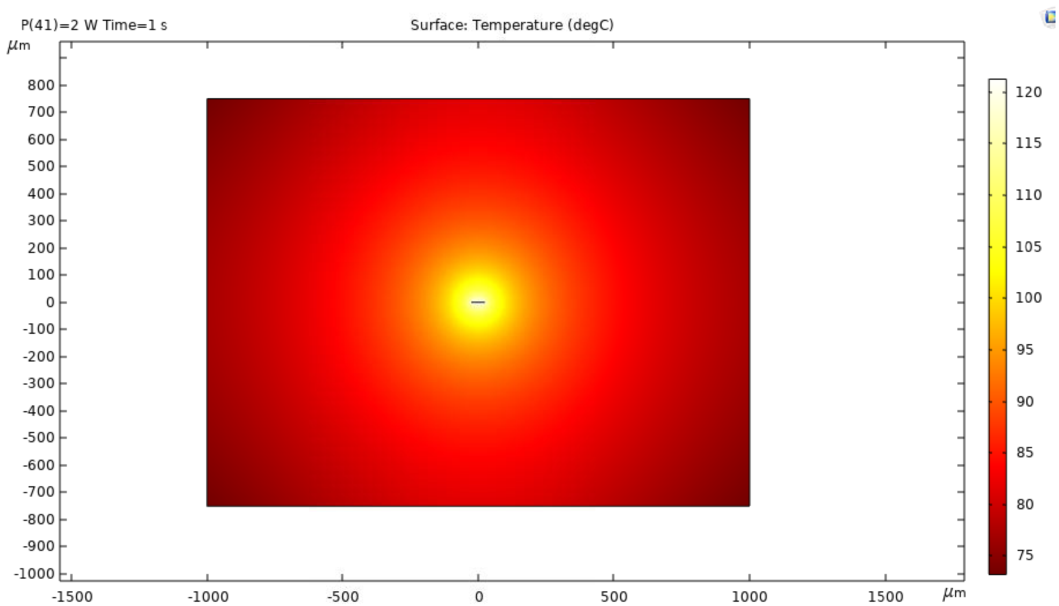

Figure 2. 2D model of the thermal accelerometer based on a single resistor.

RESULTS

Based on the developed model of the thermal accelerometer, the following results were obtained. The simulation was performed for 0.018 W of input power and acceleration range from 0 to 100 m/s^2. The time dependence of the temperature drop on the lateral thermistors and the experimental thermal profile across the sensitive thermoresistive element on a thin silicon membrane were obtained (see Fig. 3).

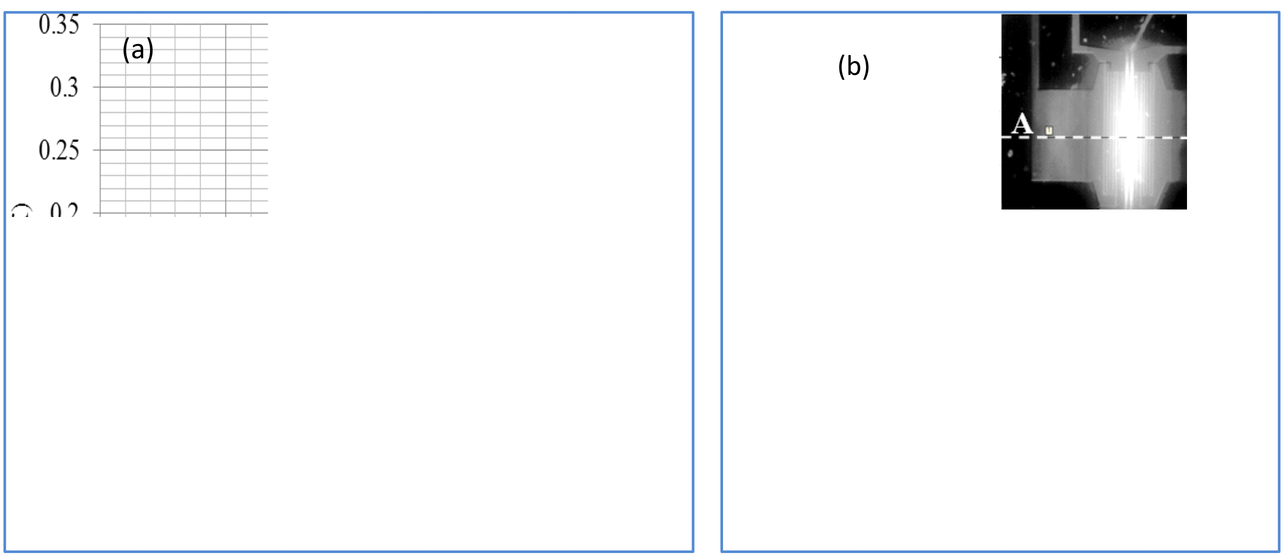

Fig. 3. (a) Time dependence of the temperature drop on the lateral thermistors of the MEMS accelerometer as a function of acceleration. (b) Experimental thermal profile due along the A-A cross-section of the sensitive thermoresistive element due to its current heating in the absence of horizontal acceleration.

The temperature profile across the cross-section line of sensitive element of the accelerometer (Fig. 4) is presented in Fig. 5. The profile of the temperature difference during acceleration at 0 and 100 m/s^2 is shown in Figure 6.

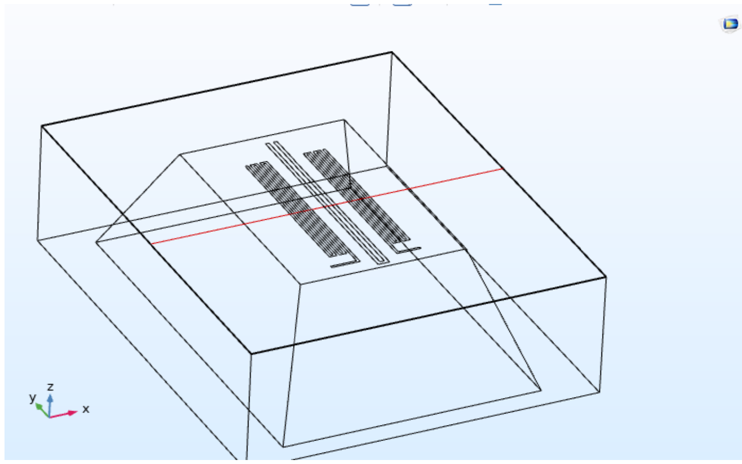

Fig. 4. Cross-section of the sensitive element of thermal accelerometer.

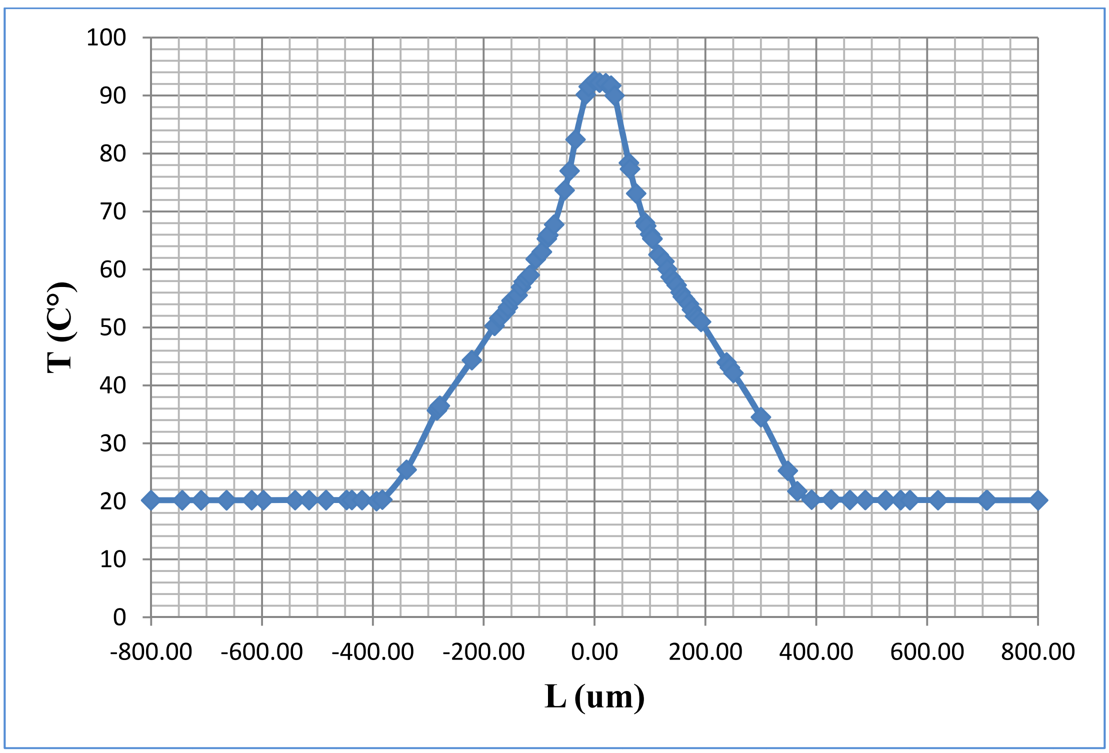

Fig. 5. Temperature profile across the cross-section of sensitive element in the thermal accelerometer.

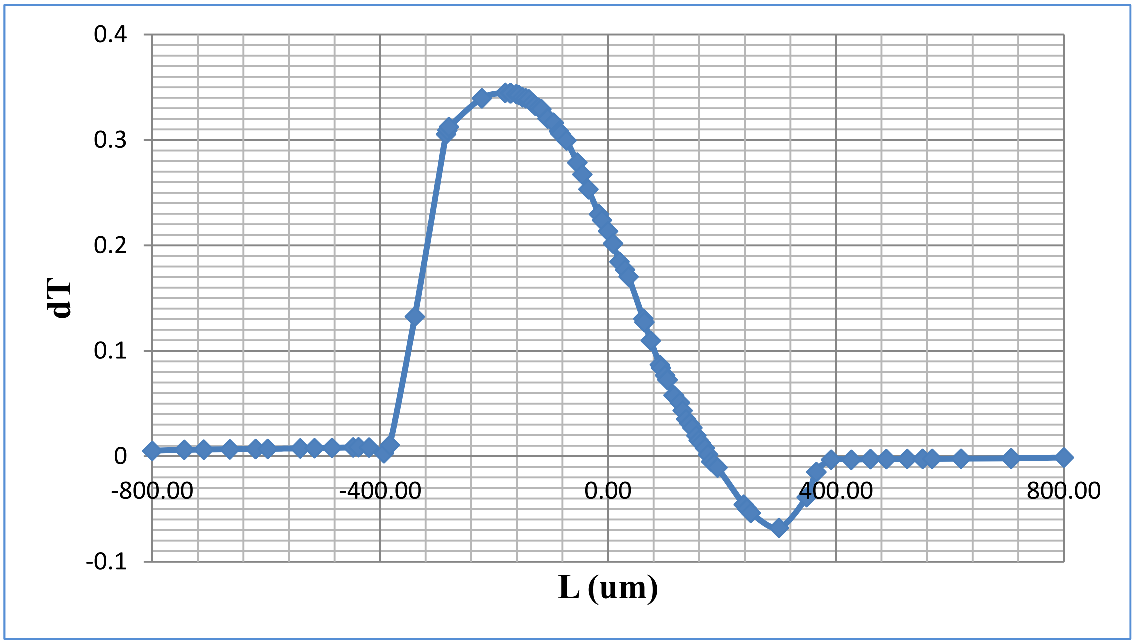

Fig. 6. Difference between the temperatures at the accelerometer points at zero acceleration and at 100 m/s^2, diameter of tube is 20mm.

For the simulation based on a simplified model of accelerometer (see Fig. 4), the following parameters were used. The simulation was carried out for the acceleration range from 0 to 100 m/s^2 in the presence of 1g of the earth's gravity directed downward. As a result of the simulation, curves were obtained showing the temperature difference at each point of the cross section shown in Figure 7, at the accelerations indicated above. The results can be seen in Figure 8.

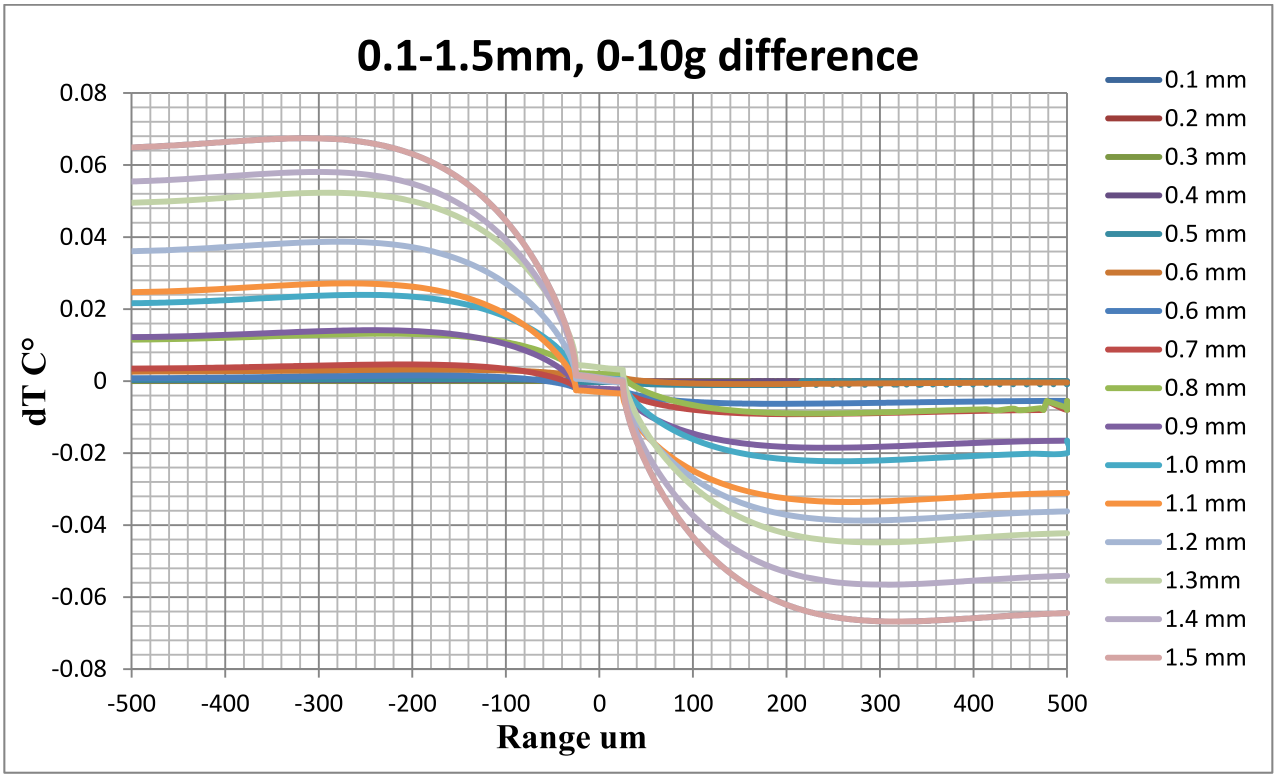

Fig. 7(a). Temperature difference between zero and 10g acceleration depending on the list of small tube diameters: from 0.1 to 1.5 mm.

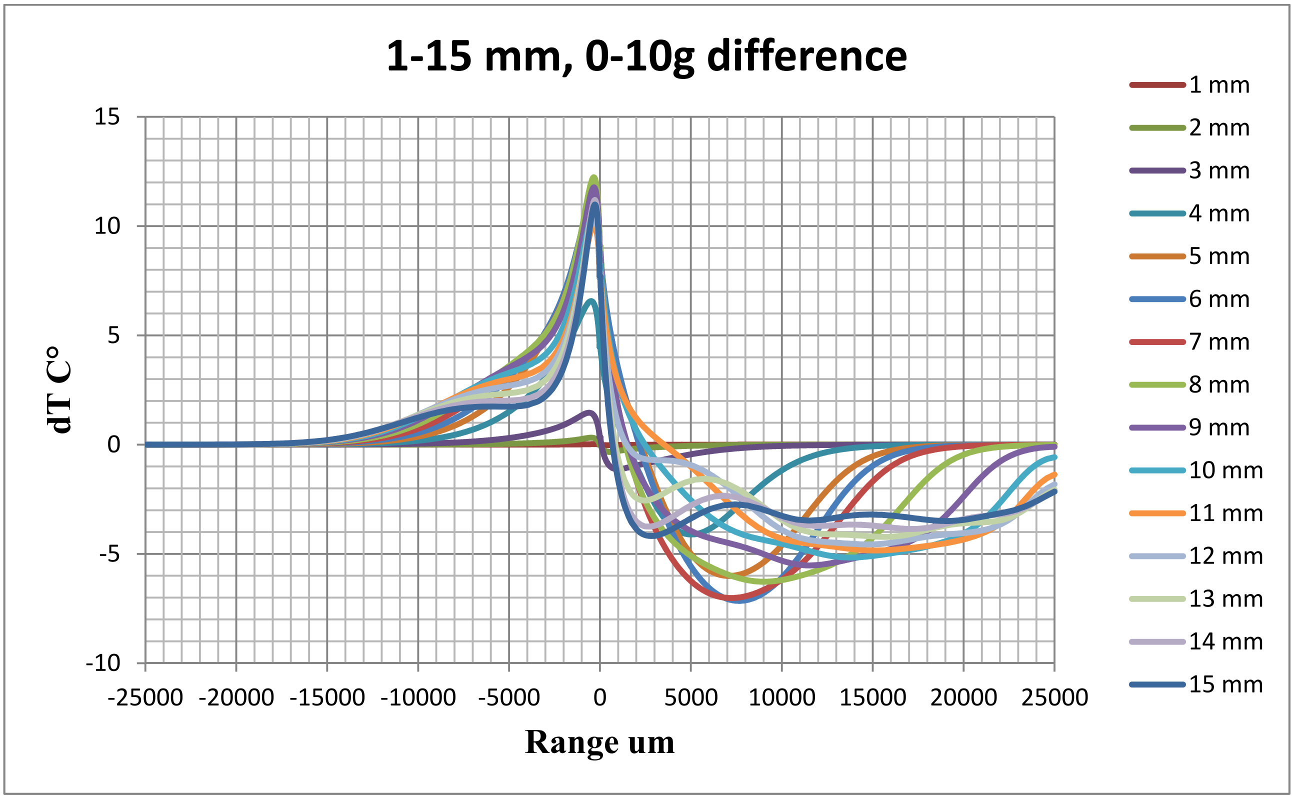

Fig. 7(b). Temperature difference between zero and 10g acceleration depending on the list of large tube diameters: from 1 to 15 mm.

Based on these data, a temperature difference was calculated between points with maximum temperature and symmetrical around zero point. The results are presented in Fig. 8.

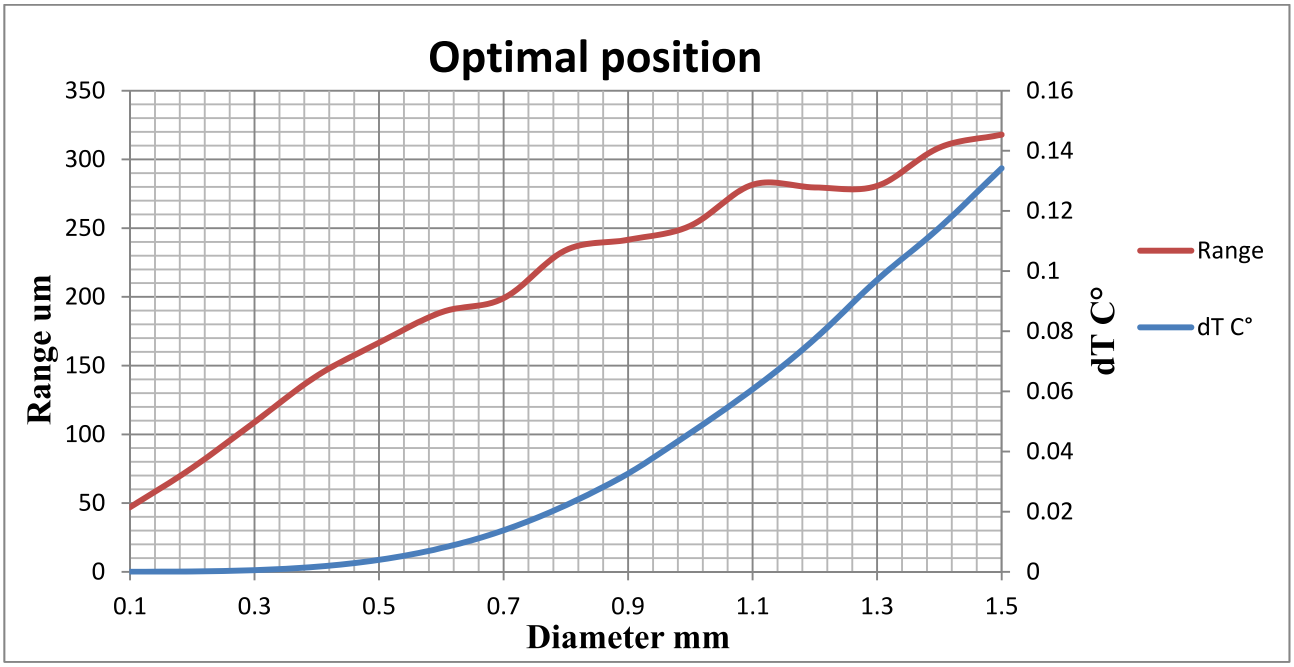

Fig 8(a) Optimal position of the thermal resistors from the center for achieving maximum sensitivity, depending from the small tube diameter (from 0.1 to 1.5 mm).

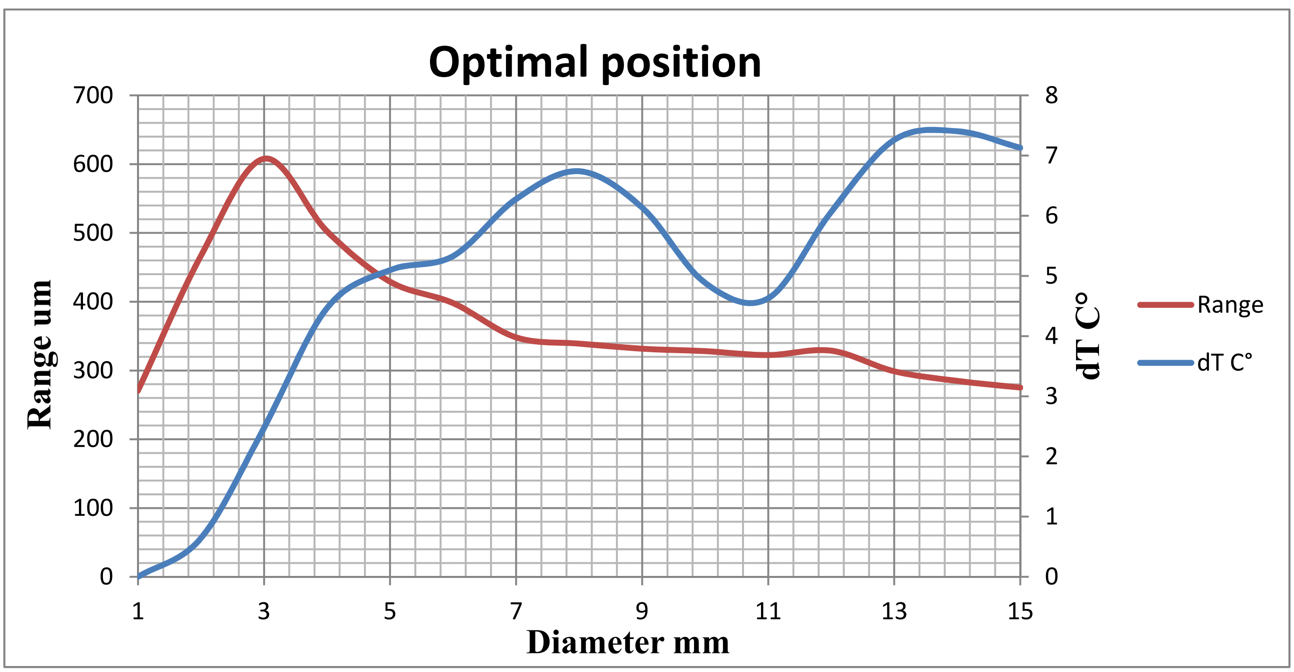

Fig. 8. (b) Optimal position of the side thermal resistors from the center for achieving maximum sensitivity, depending from the large tube diameter (from 1 to 15 mm).

CONCLUSIONS

Numerical simulation of the characteristics of thermoresistive MEMS accelerometer was carried out using the finite-element three-dimensional model of thermal gas dynamics of the device. This model was developed in Comsol MultiPhysics software based on fitting the simulation results to the experimental data of the thermal distribution in the sensing element of MEMS accelerometer [3] in the absence of horizontal acceleration. The presented model can be used in the future to evaluate the performance of various topologies of the thermal MEMS accelerometer in order to increase its sensitivity. As a result of the 2D simulation, it can be concluded that the sensitive resistors are optimally positioned for maximum sensitivity at different volumes of the working gas. The sensitivity of the device is proportional to the temperature difference, therefore an increase in the diameter of more than 5 mm is not rational. When choosing a diameter below this, it is necessary to choose the largest diameter available from, to obtain the largest possible temperature difference on the measuring thermistors.

ACKNOWLEDGMENTS

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REFERENCES

[1] Yole Developpement, “Status of the MEMS Industry 2015”, Yole Developpement, France, 2015.

[2] V. Narasimhan, H. Li and M. Jianmin. "Micromachined high-g accelerometers: a review". J. Micromech. Microeng., 25, p. 033001, 2015.

[3] N. Djuzhev, D. Novikov and V. Ryabov. “Application of the streamlined body for properties amplification of thermoresistive MEMS gas flow sensor”. Solid State Phenomena, 245(201), pp. 247-252, 2016.

[4] R. Mukherjee· P. K. Guha· P. Mandal “Sensitivity improvement using optimized heater design for dual axis thermal accelerometers.” Microsyst Technol DOI 10.1007/s00542-015-2658-5, 2015

[5] R. Mukherjee , J. Basu, P. Mandal, P. K. Guha “A review of micromachined thermal accelerometers” Department of Electronics & Electrical Communication Engineering, Indian Institute of Technology Kharagpur, Kharagpur 721302, India, 2017

[6] COMSOL Multiphysics v5.4 http://www.comsol.com

[7] J. Bahari, A.M. Leung "Micromachined three-axis thermal accelerometer with a single composite heater" Institute of Micromachine and Microfabrication Research, School of Engineering Science, Simon Fraser University, 8888 University Dr., Burnaby, British Columbia V5A 1S6, Canada, 2011

[8] C.L.M. Everhart, K.E.Kaplan, M.M.Winterkorn, H.Kwon, J. Provine, M. Asheghi, K.E.Goodson, F.B.Prinz, T.W.Kenny, "HIGH STABILITY THERMAL ACCELEROMETER BASED ON ULTRATHIN PLATINUM ALD NANOSTRUCTURES" Stanford University, Stanford, USA, 2018

[9] T.Dinh, H.-P.Phan, A.Qamar, P.Woodfield, N.-T.Nguyen, D. V. Dao "Thermoresistive Effect for dvanced Thermal Sensors: Fundamentals, Design Considerations, and Applications" JOURNAL OF MICROELECTROMECHANICAL SYSTEMS

[10] X.B. Luo, Y.J. Yang, F. Zheng, Z. X. Li, Z. Y. Guo, "An optimized micromachined convective accelerometer with no proof mass" JOURNAL OF MICROMECHANICS AND MICROENGINEERING, 2001.

[11] S.S. Wang, X.H. Gong, B. Nie, W.Z. Yuan, H.L. Chang, "A MICROMACHINED FLUIDIC REDUCED NERTIAL MEASUREMENT UNIT USING THERMAL EXPANSION FLOW PRINCIPLE"

[12] R.Zhua, H.Ding, Y.Sub, Z.Zhoua, "Micromachined gas inertial sensor based on convection heat transfer" Sensors and Actuators A 130–131 (2006) 68–74