59^{th} ILMENAU SCIENTIFIC COLLOQUIUM
Technische Universität Ilmenau, 11 – 15 September 2017
URN: urn:nbn:de:gbv:ilm1-2017iwk-100:4

ANALYTICAL MODEL OF CONDUCTIVE GRAPHITE FOAM BASED SENSORS CHARACTERISTICS

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ABSTRACT

Sensors play an important role in the control systems, because they provide the necessary information from surroundings to the controller of an automated systems. Today's sensors are very sophisticated, with high accuracy, fast acquisition rate and good signal-to-noise ratio. But most of these sensors are too much expensive. Low cost sensor for measuring the force (pressure) or the displacement could be realized by utilizing conductive elastomer that exhibits property of changing the electrical resistance when the elastomer is deformed. This paper introduced a novel conductive graphite foam based sensors. The sensors are formed by inserting two thin copper wires within conductive foam, parallel to each other at the two opposite sides. The main problem of conductive foam based sensors is that the force-electrical resistance characteristic, or the displacement-electrical resistance characteristic, of conductive foam is highly nonlinear. This paper presents the analytical model of the conductive graphite foam sensors for measurement of the displacement. By measuring the changes in the electric resistance between two points of the foam and using the developed analytical model it should be possible to accurately estimate the displacement when the conductive foam is deformed.

Index Terms **-**Foam, graphite, sensor, analytical model.

1. INTRODUCTION

Modern and emerging technologies enabled us more comfortable and pleasant everyday life. Appliances which we use today become more and more smart and adjustable to people needs thanks to the development of the fast microprocessors which are able to receive and to process information from the surroundings at a very high frequency. Sensors are elements that have the function to collect these information from the environment and to forward them to the processor for further processing. Today's sensors are very sophisticated, with high accuracy, fast acquisition rate and good signal-to-noise ratio, but most of these sensors are too much expensive. One of the main task for the engineers and researches is to look for new ways to, aquiver, process, and distribute information at the low cost. There are some examples of the low-cost sensor for measuring the force (pressure) or the displacement realized by utilizing conductive elastomer. These elastomers exhibits property of changing the electrical resistance when the elastomer is deformed. Most of previous researchers used a polyurethane foam coated with polypyrrole and polyaniline [1], or a graphene foam [2] to form a pressure sensor, but graphite foam based sensors still remains unexplored

Graphite foam due to its high thermal conductivity, low thermal expansion coefficient, low density, open porosity and chemical resistance was mainly used in vehicle radiators, satellite panels, heat exchangers, etc. Sanchez-Coronado et al. [3] investigated the thermomechanical behavior of graphite foam. There are no many examples of using the graphite foam as a pressure or a displacement sensor. In [4] researchers used a graphite foam as an analogue stroke sensor for measuring the value of the stroke of the compliant fluid actuator used as an adaptive support device for bedded patients, without detail investigation of the behavior of the graphite foam.

This paper introduced a novel conductive graphite foam based sensors. Price for producing this kind of sensors is very low, but the problem is their accuracy. The force-electrical resistance characteristic, or the displacement-electrical resistance characteristic, of conductive foam is highly nonlinear, and unrepeatable when foam is pressed and released, which means that there is certain hysteresis. The main aim of this paper is to develop the analytical model of the conductive graphite foam sensors for measurement of the displacement. By measuring the changes in the electric resistance between two points of the foam and using the developed analytical model it should be possible to accurately estimate the displacement when the conductive foam is deformed.

This kind of low-cost sensors may find application as a pressure sensor in electronic skin (e-skin) sensing systems [5]. He Tian et al. developed laser scribed flexible graphene pressure sensors which could be widely used for artificial e-skin, medical-sensing, bio-sensing and many other areas. Moreover a foam based sensors could be applied in sensing in the wearable environment. Dunne et al. [6] presented foam based sensor for breathing monitoring, shoulder motion monitoring, etc. with sensors embedded into the clothes. To support natural sculpting operations similar to those used when sculpting clay, Smith et al. [7] presented a new input device called Digital Foam based on a conductive foam as an input device to create 3D geometries and perform sculpting operations.

2. FORMING THE CONDUCTIVE GRAPHITE FOAM BASED SENSORS

To form the conductive graphite foam based sensor it is necessary to choose the appropriate size of the graphite foam piece, and insert two copper wires into the graphite foam (Figure 1). Copper wires should not to touch each other, and thus it is recommended to use enamelled copper wire, which ends are cleaned only on the length inside the conductive foam. This will enable electric contact between copper wires and graphite particles inside the foam.

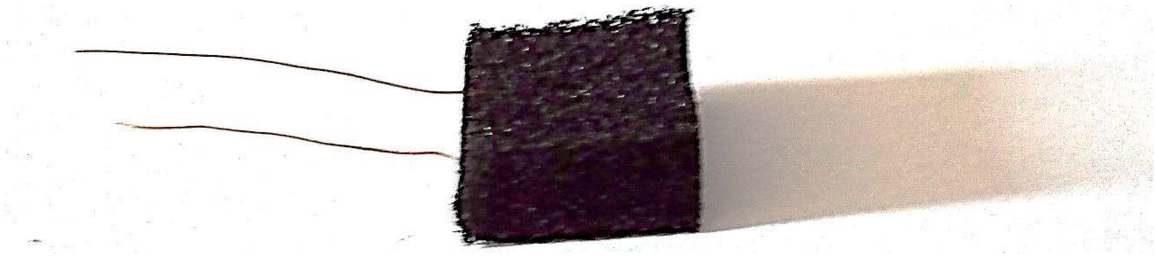

Fig. 1. *Conductive graphite foam based sensors*

Working principle of conductive graphite foam based sensors is based on change in electric resistance when pressure is applied on the foam. When conductive foam is pressed, the graphite particles inside the foam become closer and make better electric contact, which leads to the decrease of the electric resistance. When the foam is released, the graphite particles become more speareted, causing the increase of the electric resistance. Changes of the electric resistance can be transformed into change of voltage by using the Wheatstone bridge (Figure 2). Fixed resistors R_1, R_2 and R_3 and the excitation voltage of the Wheatstone bridge can be chosen to maximize the voltage changes of the bridge, due to electric resistance changes of the sensor. This is useful because most of the acquisition devices are able to measure a voltage instead of electric resistance.

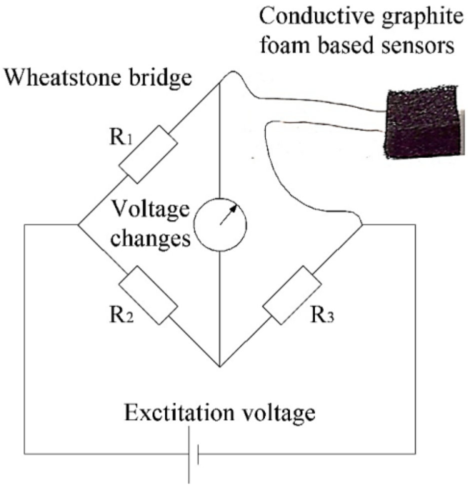

Fig. 2. Connection of the conductive graphite foam based sensor in the Wheatstone bridge

3. INVESTIGATION OF THE CHARACTERISTICS OF THE CONDUCTIVE GRAPHITE FOAM BASED SENSORS

The aim of this research is to investigate the characteristics of the conductive graphite foam based sensors. The main goal is to develop analytical model which describes the dependence between the displacement of the graphite foam when it is pressed and changes in its electric resistance.

3.1 Experimental setup

For the purpose of the measurement, experimental setup shown in the Figure 3 was built. It consists of the inductive displacement sensor (1), graphite conductive foam with copper wires, the sensor (2), electronics with Wheatstone bridge (3), signal amplifier for inductive sensor (4), data acquisition devise NI USB 6363 (5), laptop with appropriate software for collecting the data (6).

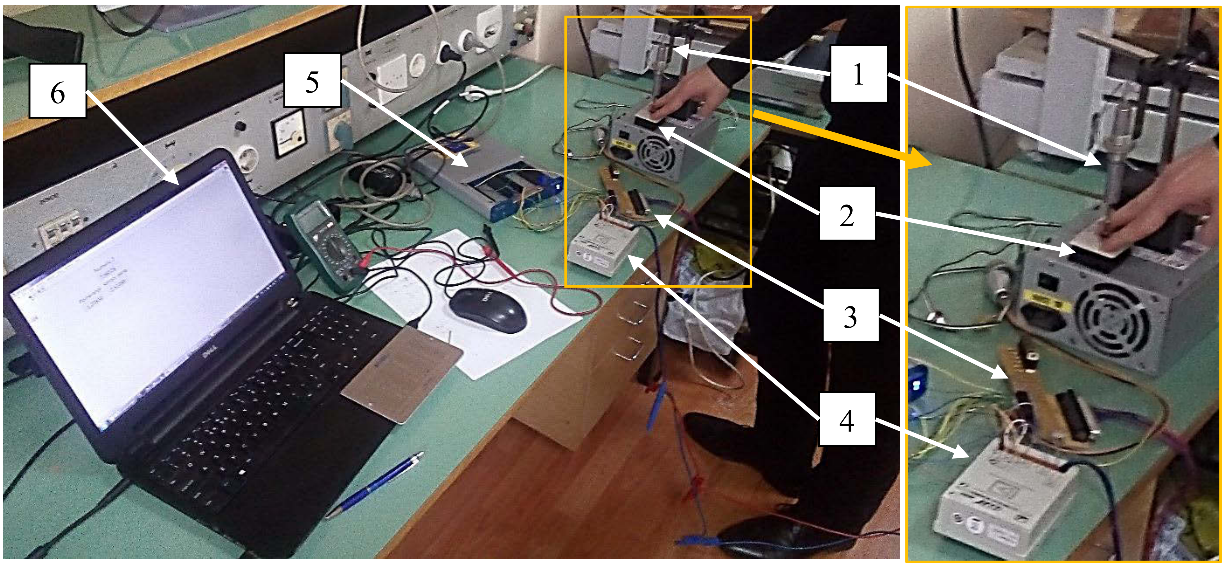

Fig. 3. Experimental setup

Figure 4 shows the graphite foam based sensor in released (a) and pressed position (b).

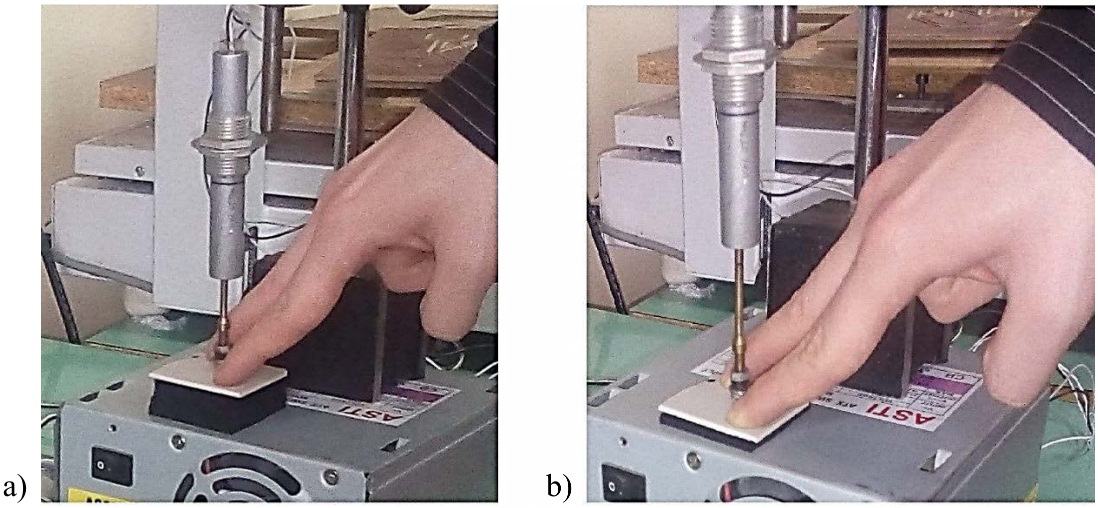

Fig. 4. *Experimental setup with graphite foam based sensor in released (a) and pressed position (b)*

Specimens of the graphite conductive foam with the thickens of 4 mm, 8 mm, 12 mm and 15 mm were tested (Figure 5).

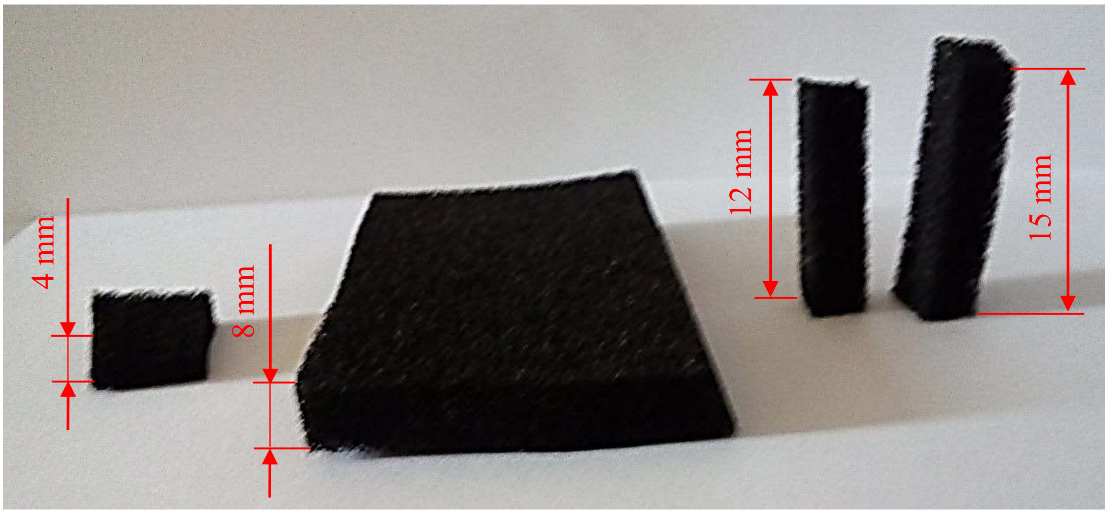

Fig. 5. *Specimens of the graphite conductive foam*

3.2 Representation of the measured data

Graphs on the Figure 6 shows the behavior of the graphite conductive foam, when the foam is pressed and released cyclic. The thickness of the investigated foam sensors are: a) 4 mm, b) 8 mm, c) 12 mm, d) 15 mm. Based on the graphs it can be noticed that voltage nonlinearly changes with the displacement in both directions (when the foam is pressed and relisted) where this change is not repeatable (the foam has hysteresis). This characteristic of the foam sensors shows that these sensors cannot be used in applications which requires high precise measurement. However, developing the mathematical model which will describe dependence of the change in the voltage whit chainage of displacement can help to achieve much precise measurement, and to expand possible usage of this low-cost sensors.

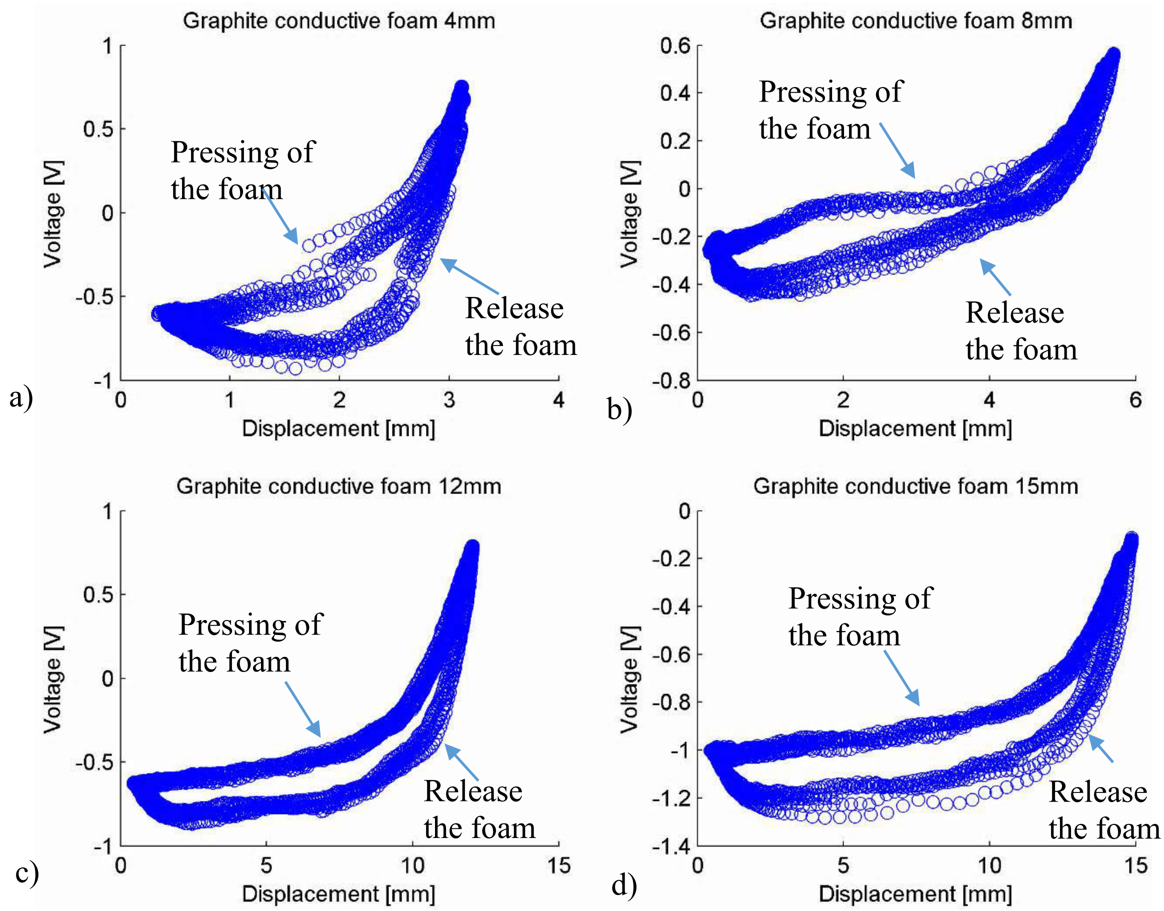

Fig. 6. *Measured change the of voltage of the conductive graphite foam depending of the displacement*

4. MATHEMATICAL MODEL OF THE GRAPHITE CONDUCTIVE FOAM BASED SENSORS

The method of least squares will be used to approximate the measured voltage changes for the applied displacement of the graphite conductive foam. The data for pressing the foam, and for release the foam will be observed separately. Polynomial third-order approximation will be used as an approximation function, and it can be represented as:

$$V(x) = ax^3 + bx^2 + cx + d \tag{1}$$

where V is the voltage, x is the displacement, and a, b, c and d are unknown constants which should be determined. Using measured data and the method of least squares these constants were determined for conductive foam with the thickness of the 4 mm, 8 mm, 12 mm and 15 mm. Figures 7-10 shows the approximated voltage change for the applied displacement of the conductive foam for all investigated thicknesses of the conductive foam, when conductive foam is pressed, as well as when it is released.

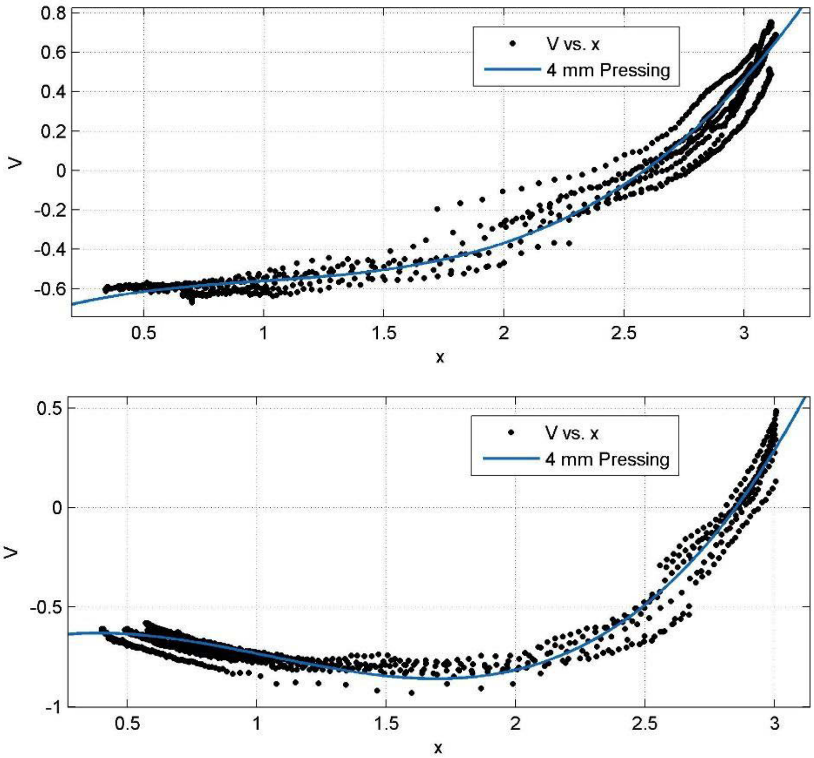

Fig. 7. *Approximated voltage change for the applied displacement of the conductive foam with the thickness of 4 mm. a) pressing of the foam, b) release of the foam*

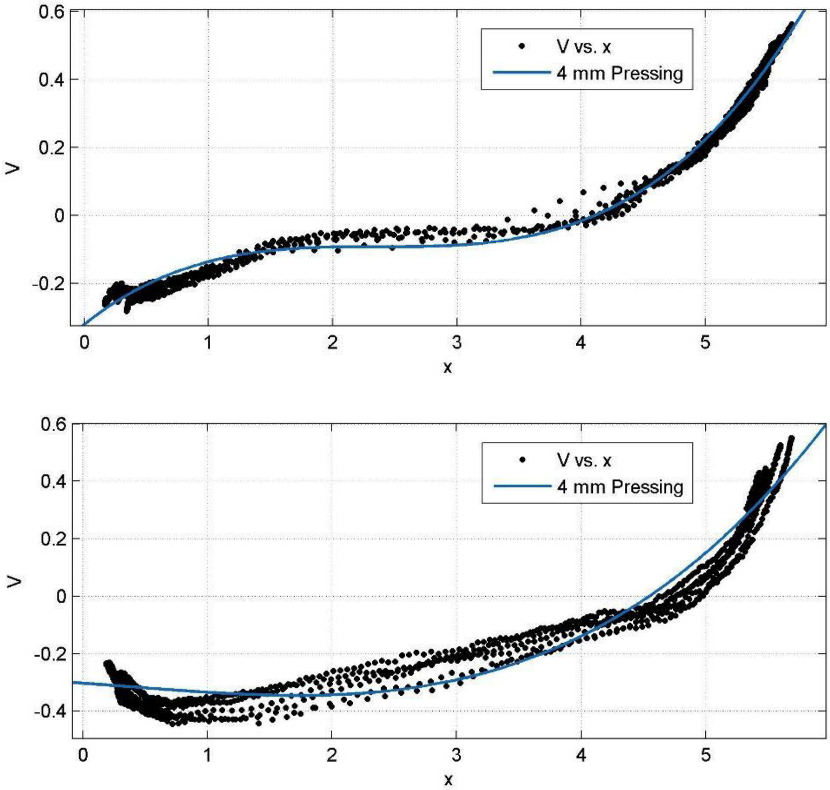

Fig. 8. *Approximated voltage change for the applied displacement of the conductive foam with the thickness of 8 mm. a) pressing of the foam, b) release of the foam*

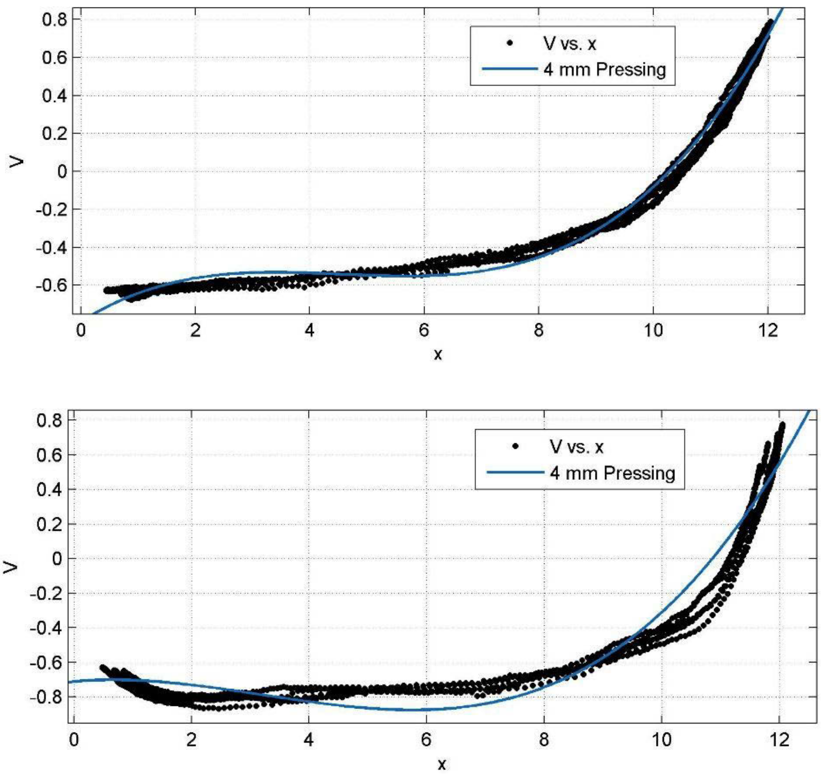

Fig. 9. *Approximated voltage change for the applied displacement of the conductive foam with the thickness of 12 mm. a) pressing of the foam, b) release of the foam*

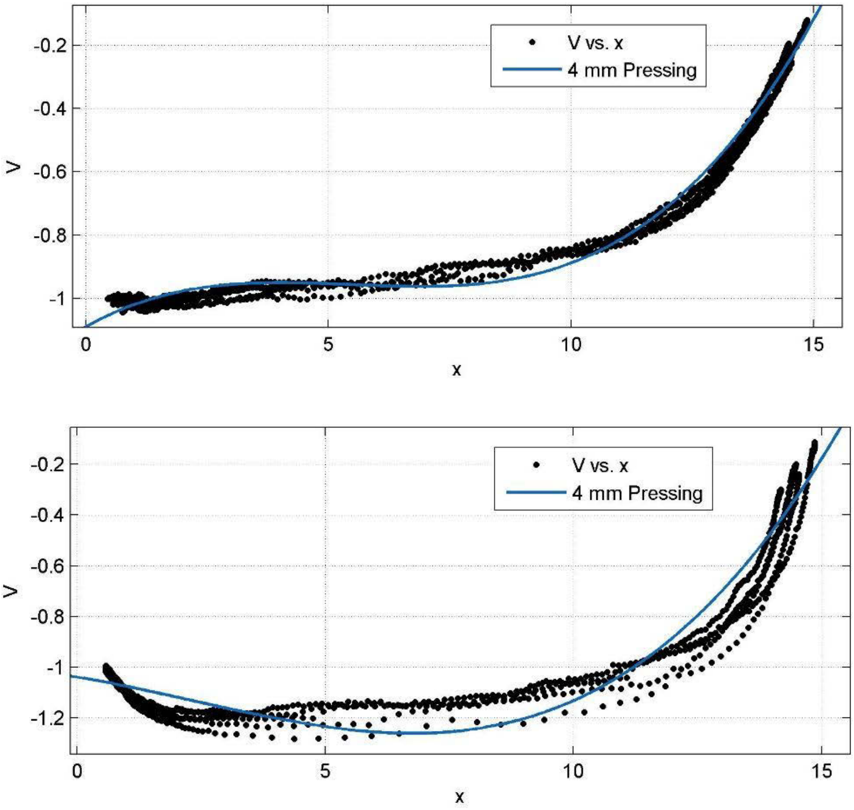

Fig. 10. *Approximated voltage change for the applied displacement of the conductive foam with the thickness of 15 mm. a) pressing of the foam, b) release of the foam*

Values of the constants *a*, *b*, *c* and *d* are shown in the Table 1 for different thicknesses of the foam.

Table 1. Values of the constants a, b, c and d

	a	*b*	*c*	*d*
4mm pressing of the foam	*0.1056*	*-0.3143*	*0.3959*	*-0.7477*
4mm release of the foam	*0.2062*	*-0.6436*	*0.4061*	*-0.7026*
8mm pressing of the foam	*0.01723*	*-0.1223*	*0.2895*	*-0.3212*
8mm release of the foam	*0.0064*	*-0.0079*	*-0.0299*	*-0.3029*
12mm pressing of the foam	*0.0032*	*-0.0449*	*0.1912*	*-0.7919*
12mm release of the foam	*0.0026*	*-0.0254*	*0.0303*	*-0.7102*
15mm pressing of the foam	*0.0010*	*-0.0170*	*0.0863*	*-1.0900*
15mm release of the foam	*0.0007*	*-0.0051*	*-0.0316*	*-1.0390*

5. CONCLUSIONS

This paper presented a novel conductive graphite foam based sensors. The sensors are formed, by inserting two thin copper wires within graphite conductive foam, parallel to each other at the two opposite sides. Working principle is based on the fact that conductive elastomer (conductive graphite foam) exhibits property of changing the electrical resistance when the elastomer is deformed. Changes in electrical resistance can be easily transformed into voltage changes by using a Wheatstone bridge.

This sensors represent a low-cost solution for pressure measurement, or for the displacement measurement in the applications that do not require high accuracy. The main problem of conductive foam based sensors is that the force-electrical resistance characteristic, or the displacement-electrical resistance characteristic, of conductive foam is highly nonlinear and with hysteresis.

The main aim in this paper was to develop a analytical model which will be able to describe the dependency of the voltage changes of the sensor due to the displacement changes in the sensor when conductive foam is deformed. The method of least squares was chosen as an approximation method, and the polynomial of the third-order as an approximation function. Coefficients of the polynomial were determined for the different thicknesses of the conductive foam. Utilization of the mathematical model could help in expanding the fields of application for these low-cost sensors.

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