STRENGTH MEASURING SENSORS MADE OF ELECTRICALLY CONDUCTIVE ELASTOMERS OPERATING AT RESONANT MODE

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Abstract. *This paper explores the opportunity to work with and investigates the qualities of strength measuring sensors of electrically conductive elastomers at alternative current supply and more narrowly – their work under resonant mode. Surveys have been conducted by means of different methods. Static characteristics U = f(F) and I = f(F) are taken from samples, constructed with different types of electrically conductive elastomers. Analysis of the characteristics and the sensitivity of the sensor has been made depending on the operating frequency, as well as on the magnitude of the applied static force and the type of the used elastomer.*

Keywords: *elastomers, strength measuring sensors, tactile sensors, resonance, sensitivity*

1. INTRODUCTION

The sensors of electrically conductive elastomers (SECE) are a special kind of tactile strength and pressure measuring transformers with a major characteristic – compactness.

Another characteristic is their capability to transform the mechanic interaction of the sensor with the object into an electric signal. The strength measuring sensors react to applying a compressive force to their axis, and a relay, digital or analogue signal is obtained as a result [3].

SECE are applicable in measuring both static and dynamic forces. In the event of elastic deformation caused by external forces, the SECE change their volume and contact resistance

Traditionally, the SECE measuring static forces work in DC mode which reveals their major disadvantages: low sensitivity, non-linear characteristics and hysteresis of residual deformation [5].

Studies of the SECE at an AC power supply in various schemes of connection have been carried out in order to improve their characteristics.

In this paper the opportunity to include SECE in circuits with additional reactive elements is explored. These reactive elements provide a resonant mode which applies maximum voltage prior to the application of external force.

2. THEORETICAL JUSTIFICATION

Rubber is amorphous polymer - highly molecular compound, obtained by polymerization, the molecules of which have greater flexibility. It is used predominantly in highly elastic state as a composite material, which, after vulcanization, turns into rubber [4].

Electrically conductive elastomers are mixtures built on high quality rubber and electrically conductive impurities - carbon (soot, graphite) or metal (gold, silver) particles.

The different number, size and shape of the deposited metal particles alter the characteristics (mechanical and electrical) of the composite materials.

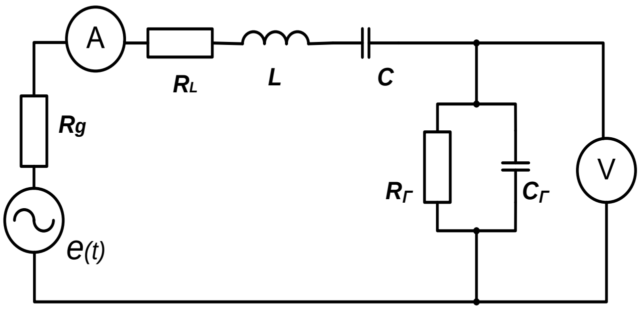
In this study five electrically conductive rubbers with different content of metal particles have been used.

An experiment of using SECE in circuits, working under a resonant mode is conducted, based on the formulation that the voltages on the reactive elements increase several times at a coherent resonance [1].

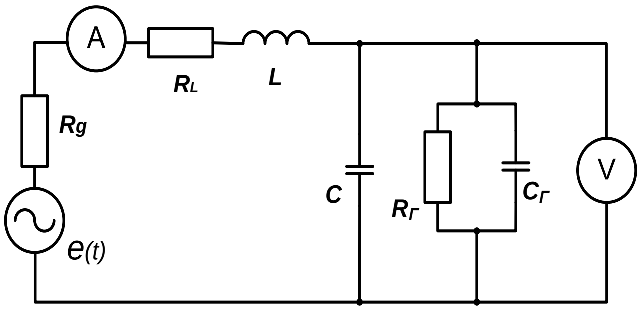
3. DESCRIPTION OF THE EXPERIMENT

Fig. 1 is a schematic diagram of the electrical circuits where SECE are connected and R_L indicates the active resistance of the coil, while R_g is the equivalent output resistance of the sine wave generator.

The electrical parameters of the SECE are presented with the help of the resistor $R_Г$ and the capacitor $C_Г$, connected in parallel. The volume and the contact resistance of the sensor is presented by the resistor, and by $C_Г$- the capacitor, obtained from the sensors constituent structure (metal-elastomer–metal), is denoted.



a) Scheme1



б) Scheme 2

Fig. 1. Equivalent electrical circuits

The studied sensors have the following dimensions - 40/10/1 mm (length, width, thickness). The influence of these dimensions has been examined in previous studies [2].

The experiment for both circuits is conducted in the following sequence:

- the resonant frequency is determined for each sample of SECE without externally applied compressive force;
- the transformative functions $U = f(F)$ are taken for every SECE when static force F from 0 to 10 N is applied for three frequencies – the resonant one and other two around it (one lower and one higher).

4. RESULTS

By combining different values of the reactive elements, resonance is realized in the circuit of the SECE. Values, leading to a well-defined resonance are selected. The resulting amplitude - frequency characteristics are shown in fig. 2 and fig. 3

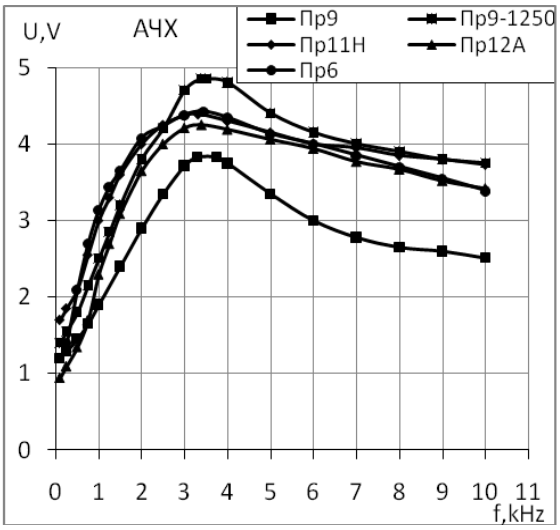


Fig. 2. AFC of SECE for Scheme 1

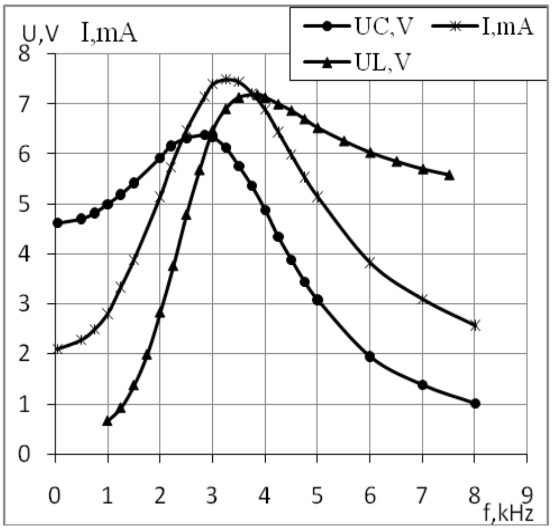
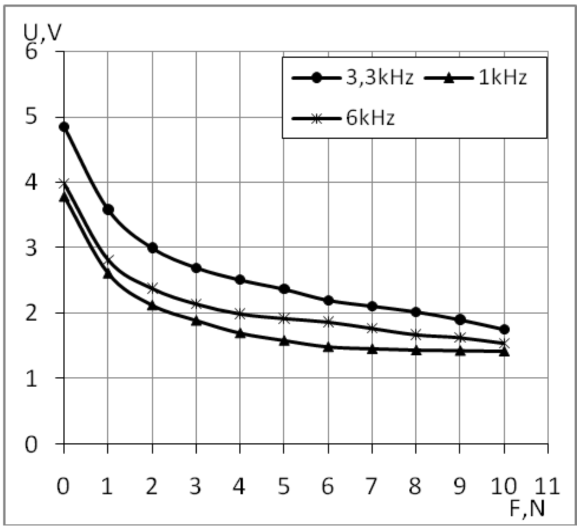


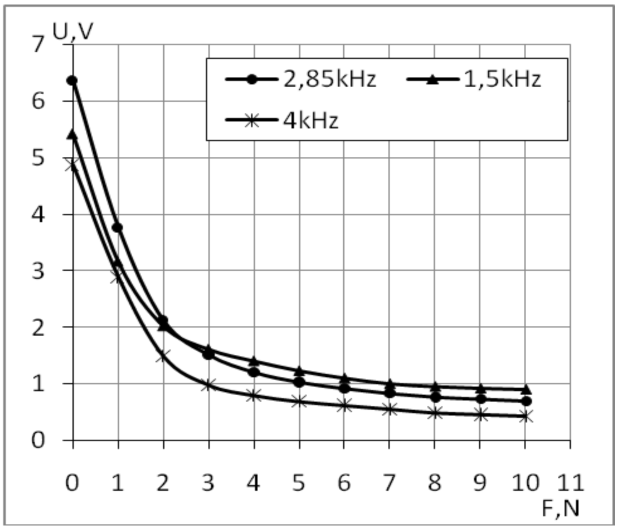
Fig. 3. AFC of SECE for Scheme 2

Frequency responses are taken before the application of the force *F* and the resonant frequencies for the different schemes of connection are recorded. In case of a circuit with reactive elements connected in series $f_0 = 3.3\ kHz$. The experiment is conducted in two different versions for the circuit from fig. 1.b:

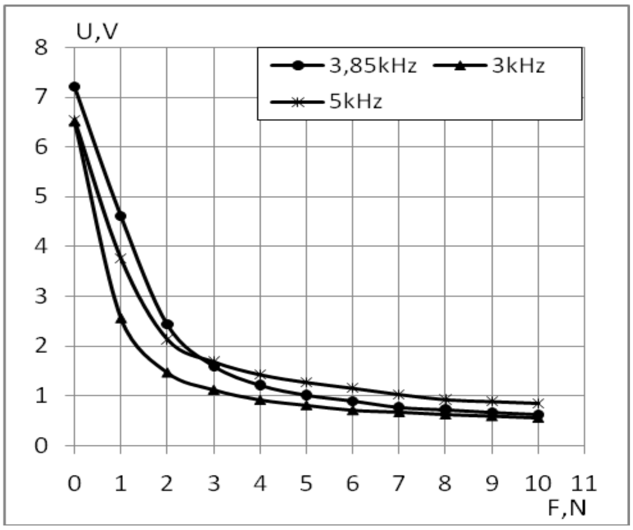
– The capacitor *C* is connected in parallel to the SECE *(C // $C_Г$)* - $f_0 = 2.85\ kHz$;
– The coil *L* is connected in parallel to the SECE *(L // $C_Г$)* - $f_0 = 3.85\ kHz$.



a)



b)



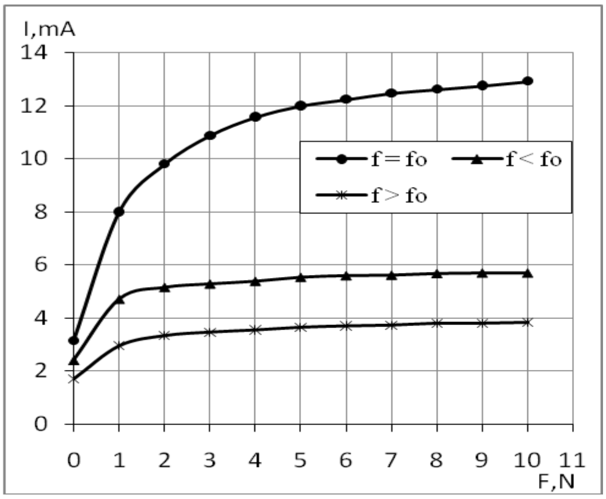
c)

a) Characteristics in case of connecting the reactive elements of SECE in series;
b) Performance in case of connecting the capacitor *C* in parallel to SECE;
c) Performance when connecting the coil *L* in parallel to SECE

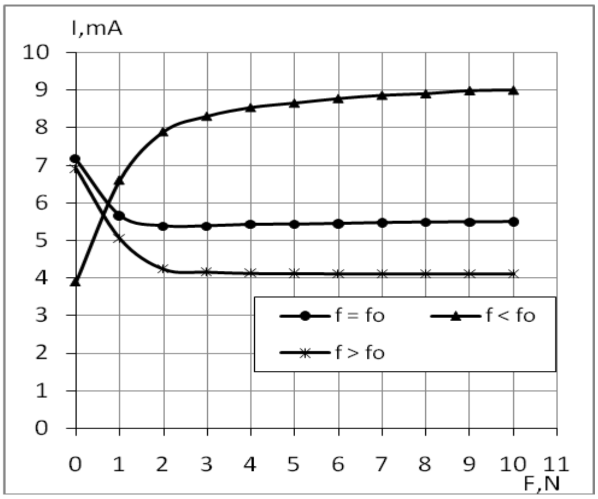
Fig. 4. Conversion function $U = f(F)$

Fig. 4 shows the graphs of the conversion functions $U = f(F)$ during the operation of an external force *F* from *0* to *10 N*. The characteristics are nonlinear, with a greater slope at the beginning of the range (up to $F = 4$ *N*). After this zone the characteristics are linearized and the change of the output voltage decreases. Similar is the degree of sensitivity of the CEE. It has the highest sensitivity, $S > 2$ *V / N*, during the initial force impact when the volume of its resistance changes the most.

Fig. 5 shows the changes in the ongoing currents during the elastic deformations.



a) for Scheme 1



b) for Scheme 2

Fig. 5. Conversion function $I = f(F)$

The sensitivity of the sensor is calculated from the recorded experimental values of the applied voltage on SECE before and after the application of force.

Fig. 6 shows the graph of the sensitivity S of the sensors for the three operating frequencies and the different variants of circuit connection. The results confirm the idea of SECE working under a resonant mode. For all three schemes the highest sensitivity is recorded when SECE work with the resonant frequency.

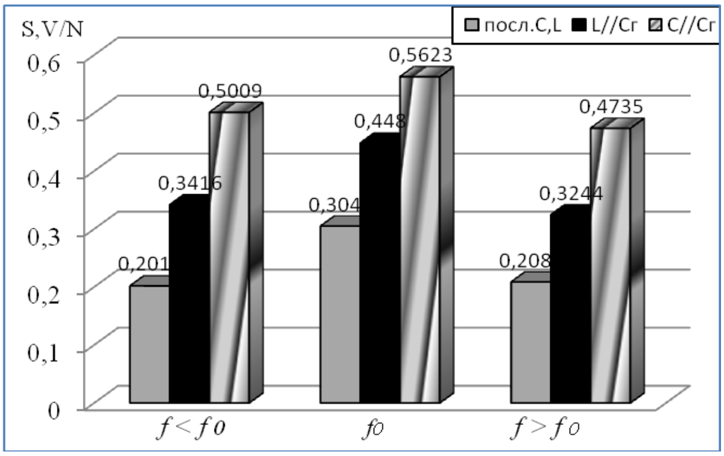


Fig. 6. Sensitivity S for the different frequencies

After analyzing the results of the experiments the conclusion is that the best performance of the sensors has been recorded for Scheme 2 with the coil L connected in parallel with SECE (fig. 1.b, *L//*C_g) *S=0.562 V/N.* This scheme is used for further experiments with sensors built with different types of electrically conductive rubber – Pr9, Pr9-1250, Pr 11N, Pr 12A, Pr6. Fig. 7 shows that the sample Pr9-1250 has the highest sensitivity - *S=0.657 V/N*.

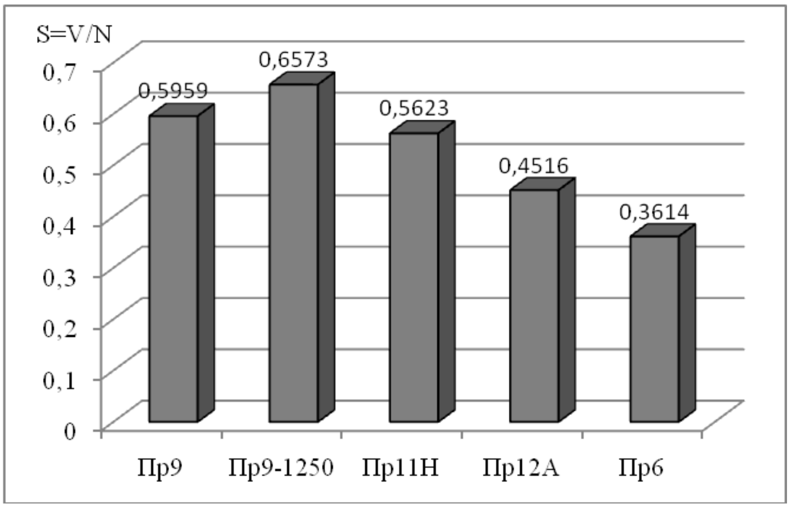


Fig. 7. Sensitivity S for the different samples

5. CONCLUSIONS

The choice of a particular type of sensor according to the specific conditions of application depends on its parameters such as sensitivity, response threshold and static characteristics.

In order to improve the performance of SECE the opportunity to include them in circuits operating under a resonance mode is seized. Various schemes for realization of a resonance mode are implemented. In Scheme 2 the voltage and the current have the characteristics of standard variables at a coherent resonance. This is not so well expressed in Scheme 1 and can be defined as fuzzy resonance.

The analysis of the experimentally obtained values shows improved performance compared to the performance at an AC mode with a frequency, other than the resonant.

Both the type of the electrically conductive rubber and the specific scheme for SECE connection, for which the highest sensitivity is reached, has been defined and this is SECE with electrically conductive rubber Pr9-1250 in a circuit with the coil L connected in parallel(fig.1.b, L // $C_Г$).

The greatest change in the output voltage obtained from SECE is observed with the original force impact. This determines their main application as threshold or signaling devices, as well as for measurement of small forces.

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