METHOD AND MEANS OF MEASURING SMALL QUANTITIES OF ELECTRICAL RESISTANCE

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Abstract. *The paper presents the results of developing simulation of a system for measuring small quantities of electrical resistance using technology of microelectromechanical systems (MEMS). It also offers the analysis and evaluation of the results. The authors established the dependence of residual voltage (as the output parameter of measuring system) on controlled resistance (as input parameter of measuring system core) during the process of balancing the electric bridge circuit.*

Keywords: MEMS, electric resistance, electric bridge circuit

METODA I SPOSÓB POMIARU MAŁYCH WARTOŚCI REZYSTANCJI ELEKTRYCZNEJ

Streszczenie. *Artykuł przedstawia wyniki symulacji opracowanego systemu do pomiaru małych wartości rezystancji elektrycznej wykorzystującego układy MEMS. Przedstawiono także analizy oraz ocenę wyników. Opisano zależność napięcia szczątkowego (jako parametr wyjściowy systemu pomiarowego) od rezystancji mierzonej (jako parametr wejściowy systemu pomiarowego) podczas procesu równoważenia mostka.*

Słowa kluczowe: MEMS, rezystancja elektryczna, mostek elektryczny

Introduction

The rapid development of microelectromechanical systems (MEMS) [1÷5] technologies in recent decades is conditioned by several advantages of these technologies, such as: micron size of active components, high reliability, functionality, integration simplicity, low power consumption and others. However, using MEMS requires measuring small quantities of electrical resistance due to the micron size of the components, made by these technologies. Thus, the considered task needs to be solved by developing new or improving the existing methods of measuring small quantities of electrical resistance that could accurately capture the fluctuations of electrical resistance in microelectromechanical systems.

1. Problem analysis

Several methods of electric resistance measurement and their analysis in terms of their suitability for solving the considered problem of measuring small quantities of electric resistance that arises when using MEMS technology are described in the work [6].

One of the criteria for selecting a method of electric resistance measurement in order to solve the considered problem is a simple hardware implementation and automation, as well as a very flexible mechanism of adaptation by changing parameters of the investigated object.

Thus, as a result of the analysis of several methods [6], electric bridge methods were selected as the most suitable for solving the problem of measuring small quantities of electric resistance, since they possess necessary qualities, and also allow us to compensate the impact of conjunctive wires and contact points on the impact of conjunctive wires and contact points on measurement results. In addition, bridge methods have a very flexible mechanism of automatization of the measuring process, so they can be easily adapted to the needs of MEMS.

2. Structure of a bridge circuit-based measuring system for measurement of electric resistance

Overall structure of the system for measuring small quantities of electric resistance is shown in Figure 1.

The bridge circuit of electrical resistance measuring is the core of the measuring system (Fig. 1). A measuring system works as follows: residual voltage ΔU in the neighborhood of electric bridge equilibrium point enters the input of the first stage positive and negative voltage comparator (see Fig. 1). Triggering one of them makes the mechanism of increasing or decreasing the quantity of controlled resistance $R3$ of electric bridge with resistance shop run respectively. It starts providing the reset of the pulse counter; and then the next work cycle of the system is carried out. In case the value of residual voltage is not large enough to be caught by one of the first stage comparators, it enters the input of an amplifying unit. At its output we will have the already enhanced residual voltage $\Delta U'$, which can be captured by one of the second stage positive or negative voltage comparator. In the result of triggering one of them, respectively, the mechanism of increasing or decreasing the quantity of controlled resistance $R3$ of electric bridge with a resistance shop starts providing the reset of the pulse counter. And then the next work cycle of the system is carried out until the pulse counter becomes equal 2. The increase of value of the pulse counter occurs when neither of the comparators of the first and second stages was triggered during the work cycle.

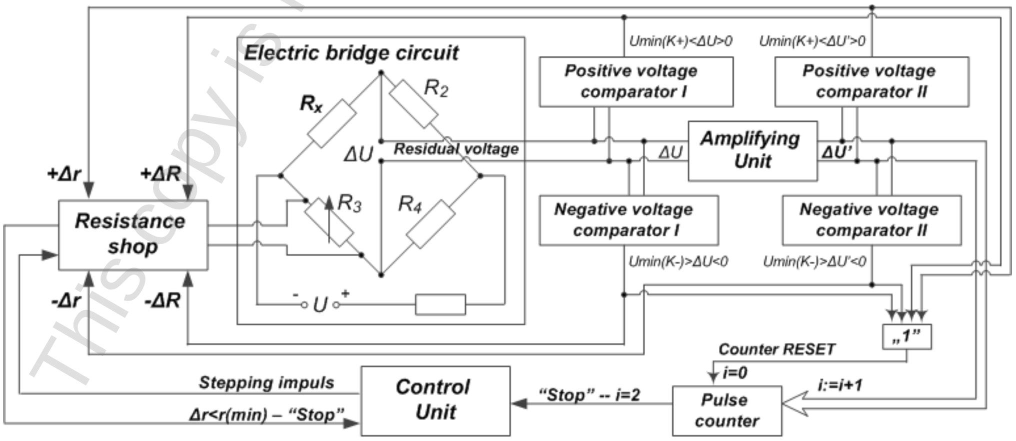

Fig. 1. The structure of the measuring system based on the bridge circuit of electric resistance measuring

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3. Work simulation of the measuring system

To analyze the functioning of the developed measuring system and establish the regularities of behavior of its main parameters, let's perform simulation of the measuring system working process on a specific example.

Suppose we need to measure the value of unknown resistance Rx = $1.5826 \cdot 10^{-4}$ ohms. And the values of the key parameters of the measuring system are as follows: power supply voltage of electrical bridge Ep = 12 V, value of resistance R2 = 0.01 ohms, value of resistance R4 = 1500 ohms, the absolute value of comparator threshold voltage is 0.001 V; amplification factor of amplifying unit k = 10 000.

The initial value of controlled resistance R3 = 10 ohms.

The following Table 1 presents the values of the measuring system key parameters at each iteration of simulation.

Table 1. Values of the key parameters of the measuring systemduring its work simulation process

No of working cycle	ΔU, V	R3, Ohm	Cascade No	Pulse counter
1	+1.07E-1	10	I	0
2	+2.91E-2	20	I	0
3	-4.83E-2	30	I	0
4	-4.06E-2	29	I	0
5	-3.29E-2	28	I	0
6	-2.52E-2	27	I	0
7	-1.75E-2	26	I	0
8	-9.77E-3	25	I	0
9	-2.02E-3	24	I	0
10	+5.73E-3	23	I	0
11	+4.96E-3	23,1	I	0
12	+4.18E-3	23,2	I	0
13	+3.40E-3	23,3	I	0
14	+2.63E-3	23,4	I	0
15	+1.85E-3	23,5	I	0
16	+1.08E-3	23,6	I	0
17	+3.02E-4	23,7	II	0
18	-4.73E-4	23,8	II	0
19	-3.95E-4	23,79	II	0
20	-3.18E-4	23,78	II	0
21	-2.40E-4	23,77	II	0
22	-1.63E-4	23,76	II	0
23	-8.53E-5	23,75	II	0
24	-7.75E-6	23,74	II	0
25	+6.98E-5	23,73	II	0
26	+6.20E-5	23,731	II	0
27	+5.43E-5	23,732	II	0
28	+4.65E-5	23,733	II	0
29	+3.88E-5	23,734	II	0
30	+3.10E-5	23,735	II	0
31	+2.33E-5	23,736	II	0
32	+1.55E-5	23,737	II	0
33	+7.75E-6	23,738	II	0
34	~	23,739	X	1
35	~	23,739	X	2

4. Simulation results of the developed system for measuring small quantities of electric resistance

The performed simulation process of the developed measuring system allows investigating the behavior of the key system parameters, such as residual voltage ΔU and controlled resistance $R3$, and to establish the dependence of the output parameter - the residual voltage ΔU, from the corresponding input parameter of measurement system core - controlled resistance $R3$. Let's take a deeper look at the basic results of the modeling process.

Fig. 2 below shows a variance graph for residual voltage ΔU at each iteration of the measuring system working process.

Fig. 3 also shows a variance graph of residual voltage coming to the first and second stage comparators, taking into account the residual voltage of the additional amplification process.

Fig. 4 shows a cycle after cycle change of controlled resistance at every stage of the bridge circuit balancing process.

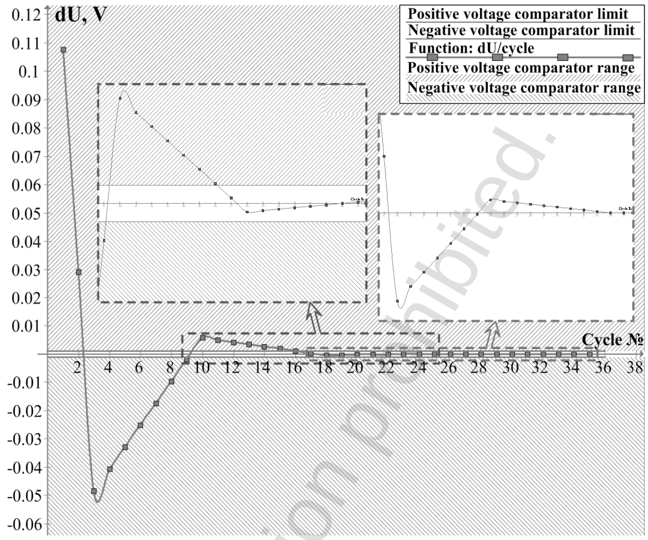

Fig. 2. Variance graph of residual voltage ΔU during the working process of the measuring system

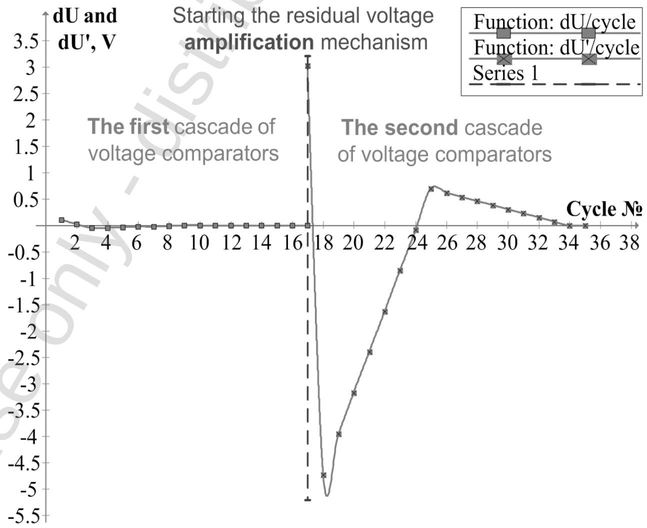

Fig. 3. Variance graph of residual voltage with regard to the amplification process and cascade mechanism detection of residual voltage

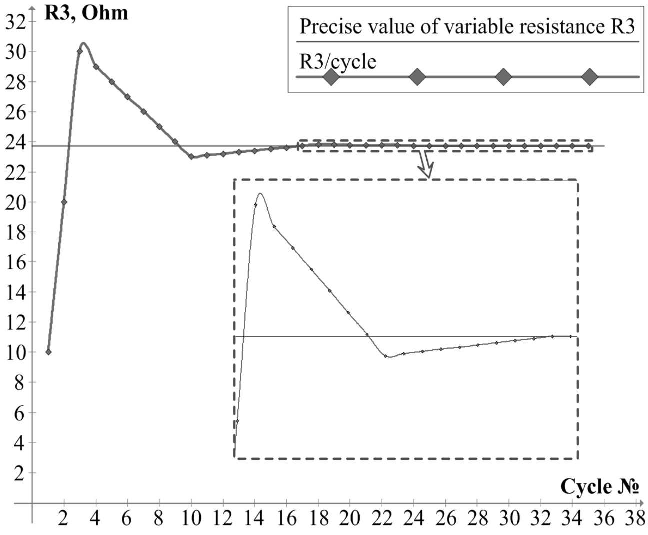

Fig. 4. Variance graph of controlled resistance during the bridge circuit balancing process

Fig. 5 shows the graph of dependence the absolute value of residual voltage $\left|\Delta U\right|$ (|dU|) from controlled resistance $R3$.

The built graph of the dependence of the absolute value of residual voltage $\left|\Delta U\right|$ (|dU|) on controlled resistance $R3$ (Fig. 5) is a model of behavior of all measuring systems, because it makes it possible to determine dependence of the output parameter (residual voltage ΔU) from the corresponding measuring system core input parameter (controlled resistance $R3$). Model of system behavior (Fig. 5) has a "pendulum" character (looks like a damped symmetric oscillation), which fully meets the technical essence of the weighing transformation method, that is a basis of the developed system — the bridge circuit of electrical resistance measurement.

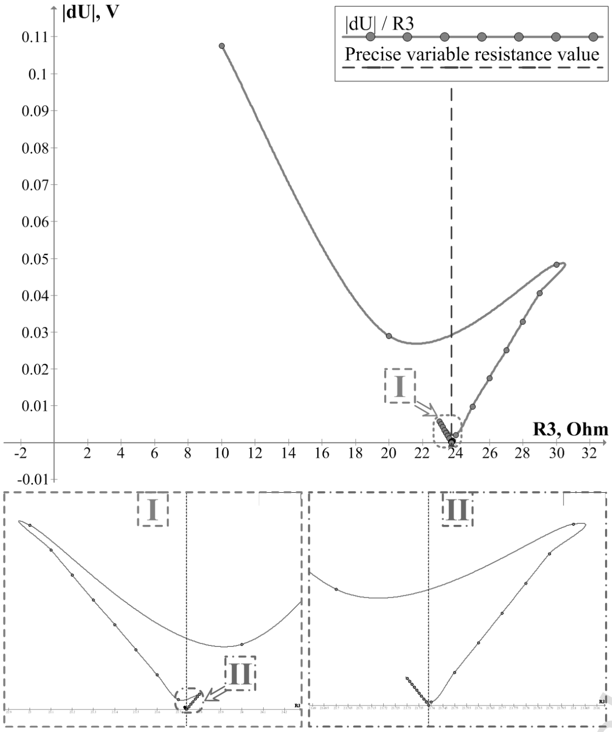

Fig. 5. Graph of dependence of the absolute value of residual voltage $\left|\Delta U\right|$ *(|dU|) on controlled resistance* $R3$

5. Conclusion

The authors developed a working model of a system of measuring small quantities of electrical resistance and carried out its analysis and evaluation. They also defined the regularities of distribution of residual voltage values throughout the measuring system workflow and the value of controlled resistance in the bridge circuit balancing process. The work determines the the output parameter (residual voltage) dependence on the corresponding input parameter of the measuring system core (controlled resistance).

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