Study of Low Frequency Noise Parameters of Metal Contacts

D.S. Loginov, O.N. Krutchenko, V.G. Litvinov, T.A. Kholomina, A.V. Ermachikhin, N.B. Rybin, A.R. Semenov
Department of micro- and nanoelectronics
Ryazan State Radio Engineering University
Ryazan, Russian Federation
vglit@yandex.ru

***Abstract*—The noise characteristics of industrial reed switches (relays with magnetic contacts) were studied. The studied relay samples had magnetic contacts that made with the use of Ni-Fe, Au and Ru coatings. It is shown that the type of metal coating of the contacts affects the noise parameters of the reed switches.**

Keywords—low-frequency noise, power spectral density, metal contact, reed switch

I. Introduction

Imperfections and defects in the structure of various elements of modern electronic devices lead to the degradation of their parameters.

One of the most sensitive methods for studying the properties of materials and constructive elements of electronic devices which allow determining the nature of noise and the type of defects is the low frequency (LF) noise spectroscopy. It based on measuring the dependence of the power spectrum density (PSD) of noise on frequency.

The aim of the work was to study the effect of multiple-circuit relays with sealed magnetic contacts (reed switches) on the characteristics of low-frequency noise, as well as features of the surface structure modification of contact parts in the area of their electric contact.

II. Samples and Experimental Equipment

Two experimental sets with magnetic contacts consisted of 10 reed switches MCA-14103 were taken as experimental samples. One of them consisted of reed switches with different contact coatings Au-Ru or Fe. The other one had 10 reed switches based on permalloy contacts consisting of 50% Fe and 50% Ni.

Reed switches had the following geometrical dimensions:

- cylinder length is 14 mm;

- diameter of the cylinder is 2.3 mm;

- reed switch length is 44.7 mm;

- diameter contact details is 0.55 mm.

Reed switches were subjected to multiple from 2000 to 10000 switching cycles.

Reed switches with different number of switching were first investigated by the method of low-frequency noise spectroscopy. After that the glass case of the reed switches was destroyed. The contacts were placed in a vacuum and the specific features of the modification of the structure of the contact surface at the sites of current flow were examined by scanning electron microscopy (SEM).

The measurements of the low-frequency noise spectra were carried out using an automated complex for the study of low-frequency noise spectra using a low-noise preamplifier adapted for the study of low-resistance samples with a gain in the range of 10-1000 and with a constant current through the reed switch 0.1-100 mA. The magnitude of the PSD was measured at a frequency of 1 Hz. The choice of the gain provides the necessary sensitivity of the installation, which allows to obtain a PSD of low-frequency noise in the range of 10^{-2}-10^{4} Hz. The mode of operation was chosen experimentally by the type of dependence of the PSD noise. The functional diagram of the measurement unit is shown in Fig. 1.

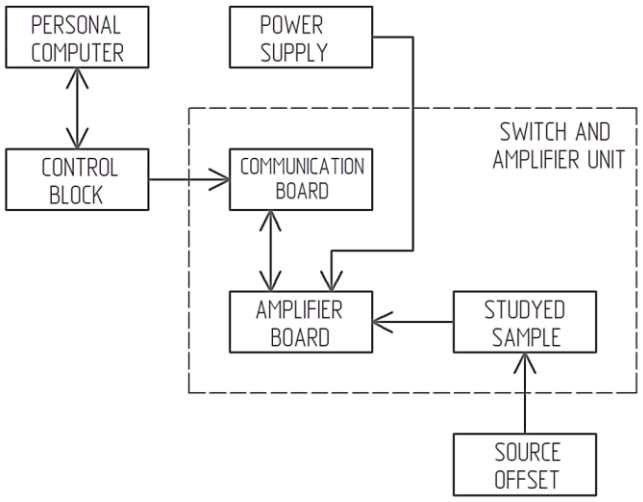

Fig. 1. Functional diagram of the measuring complex

Aging by repeated short-circuiting-disconnecting the relay was used with specially designed device (Fig. 2) which made it possible to close the contacts of the reed switch installed in it with a switching frequency of up to 40 Hz at a direct current I = 0.5 A and a voltage at the load U = 5 V, specified number of times.

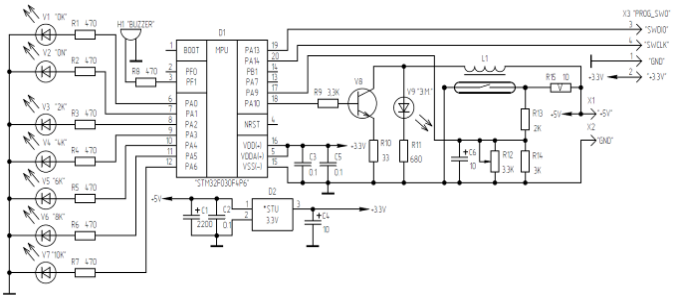

Fig. 2. Schematic diagram of the device for aging of reed switches

The structure of the contact surface before and after testing, and the size of the contact area of the cathode and

anode, was studied by using a JEOL 6610 LV scanning electron microscope.

III. Experimental Results and Discussion

The parameters of the low-frequency noise spectra of the reed switches of the set No. 1 were monitored without their switching tests.

The technical characteristics of the investigated reed switches and the parameters of the low-frequency noise spectra are presented in Table 1 and typical PSD-dependences are shown in Fig. 3.

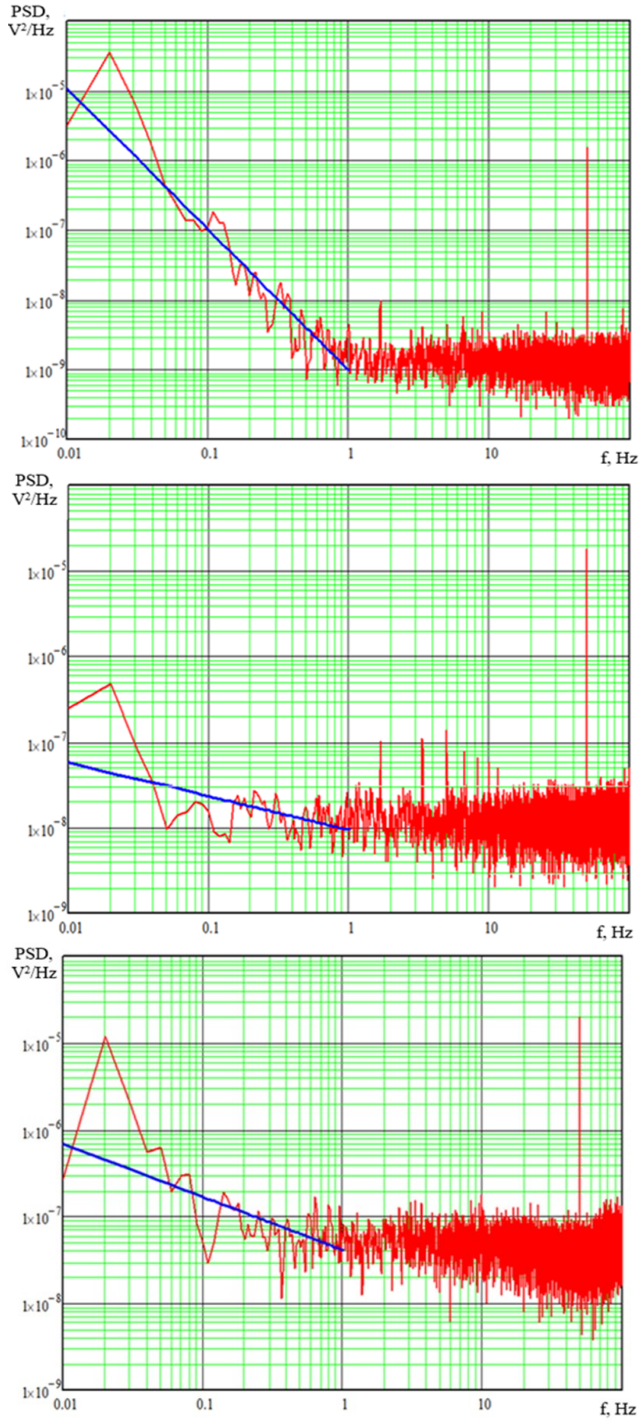

Fig. 3. Low noise spectra of samples 1-3 of the set No. 1 and approximation of spectra by linear regression

TABLE I. Parameters of reed switches of the set No.1 with coating of contacts with various metals and alloys

№	F_a, A	R_g, Ω	F_r, A	Coating	PSD V^2/Hz
1	13	0.08	7	Au-Ru	$2.05 \cdot 10^{-9}$
2	12	0.08	7	Au-Ru	$7.34 \cdot 10^{-9}$
3	15	0.16	6	Fe	$5.22 \cdot 10^{-8}$
4	13	0.12	5	Fe	$8.91 \cdot 10^{-8}$
5	14	0.11	7	Fe	$2.43 \cdot 10^{-8}$

In the table 1: F_a is the actuation force; R_g is the contact resistance; F_r is the power of release. PSD magnitudes at the frequency of 1 Hz are presented.

The most interesting part of the LF noise spectra is in the range of 0.01–1 Hz. In this range a noise has the $1/f^{\beta}$ type. The degree of β according to different authors may be in the range from 0.6 to 2.5 and it is possible to discuss about the nature of the low-frequency noise [1-3]. The obtained experimental data were approximated using the linear regression method and the parameter β was determined. It was found that β values varied for different samples of the set No.1 from 0.4 to 1.6.

The magnitude of the PSD at a fixed frequency (for example 1 Hz) we can conclude that the reed switches coated with noble metals (samples 1 and 2 of table 1) "noisy" less intensely than samples with Fe coated contacts. The PSD of these samples differs by more than an order of magnitude.

The value of the power density of the low-frequency noise correlates with the features of the surface structure of the samples in accordance with the vacancy model of G.P. Zhigal'skii [4]. Coatings of contacts of relays with a smaller amount of metal grains were characterized by a higher intensity of low-frequency noise.

The parameters of the low-frequency noise spectra of reed switches of the set No. 2 were investigated according to another method. Initially the parameters of the set of 10 initial samples were measured. Then 9 reed switches were subjected to switching tests. After testing the spectra of the low-frequency noise as well as the structure of the contact spots of reed switches were investigated again.

Fig. 4 presents examples of the experimental spectra of the low-frequency noise of the initial samples 1, 2, 8.

The contacts of the studied samples from the set No.2 are made of Fe – Ni alloy. The value of the PSD at the fixed frequency (for example 1 Hz) we can conclude that the PSD subjected to switching tests reed switches as a rule an order of magnitude higher than the original.

For each measured sample the contact surface was examined using the SEM (Figures 6–8). The study of the surface made it possible to understand the nature of the change in the PSD due to the different area of contact spots of the anode and cathode. The area of the contact spots of the anode and cathode increases significantly with an increase in the number of switching cycles (Table 2).

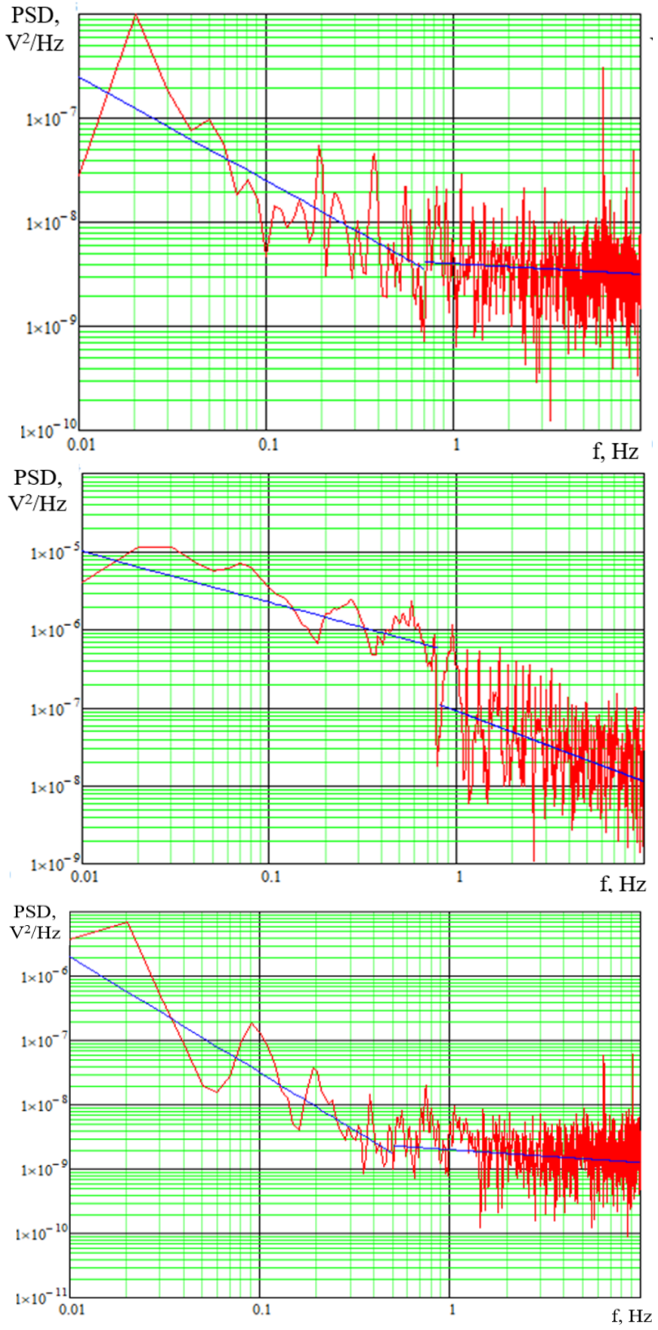

Fig. 4. The spectra of the low-frequency noise of the initial samples 1, 2, 8 of the set No. 2 and the approximation of the spectra by the method of linear regression

Fig. 5 presents examples of the experimental spectra of the low-frequency noise samples of samples 1, 2, 8, subjected to aging.

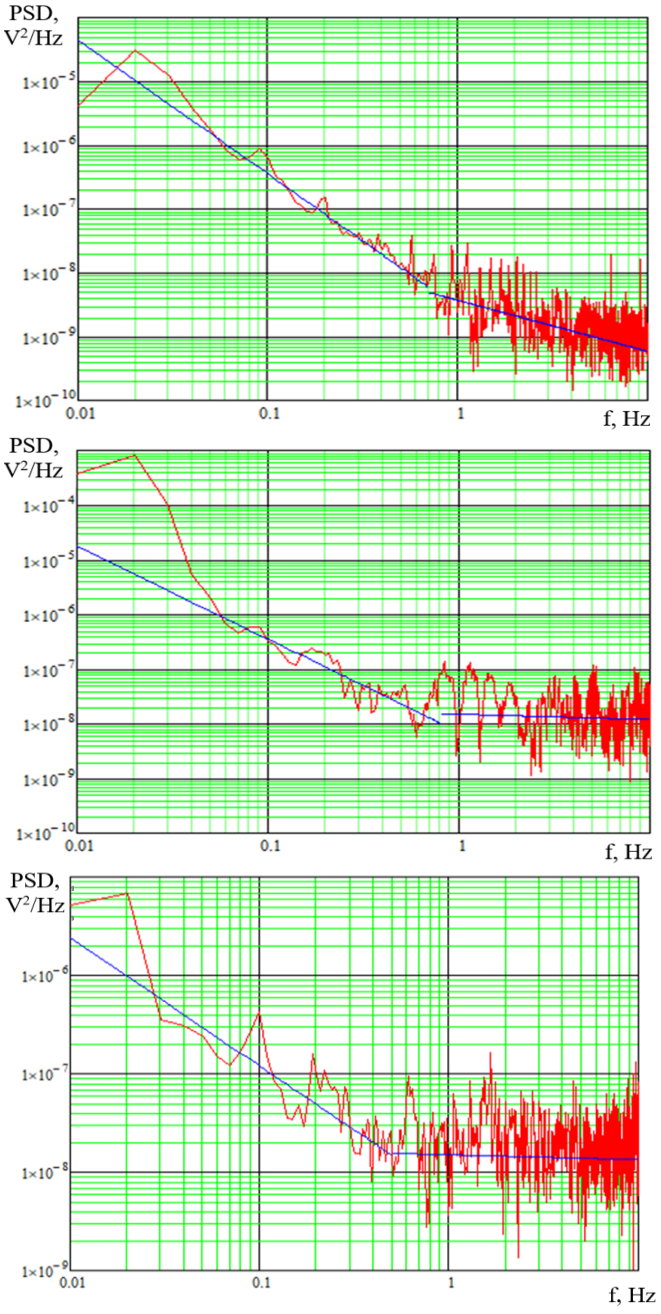

Fig. 5. Low noise spectra of samples 1, 2, 8 of the set No. 2 after testing and approximation of spectra by linear regression

The results of the study of samples of the set No.2 are presented in table 2. In the table 2: $S_{cont.\ cat}$, $S_{cont\ anode}$ are the areas of contact spots obtained and measured using SEM.

TABLE II. PARAMETERS OF REED SWITCHES OF THE SET NO.2

№	PSD V^2/Hz	β	Number of commutation	$S_{cont.\ cat}$ μm^2	$S_{cont\ anode}$ μm^2	PSD V^2/Hz	β
	Initial		*After testing*				
1	$5.64 \cdot 10^{-9}$	1.02	10000	10.47	9.60	$1.42 \cdot 10^{-8}$	2.07
2	$1.78 \cdot 10^{-7}$	0.65	2000	5.75	6.76	$3.68 \cdot 10^{-8}$	1.72
3	$7.93 \cdot 10^{-9}$	0.31	2000	4.79	4.62	$1.93 \cdot 10^{-8}$	0.37
4	$3.21 \cdot 10^{-8}$	1.21	4000	–	–	$2.94 \cdot 10^{-6}$	1.58
5	$1.97 \cdot 10^{-8}$	1.23	2000	5.87	5.45	$8.53 \cdot 10^{-8}$	1.34
6	$3.27 \cdot 10^{-8}$	0.54	10000	16.58	17.74	$5.76 \cdot 10^{-8}$	1.09
7	$2.93 \cdot 10^{-9}$	2.02	4000	11.67	10.77	$2.21 \cdot 10^{-7}$	1.53
8	$5.64 \cdot 10^{-9}$	1.83	4000	6.81	6.22	$1.91 \cdot 10^{-8}$	1.27
9	$6.52 \cdot 10^{-9}$	1.04	10000	4.24	3.72	$1.83 \cdot 10^{-8}$	1.48
10	$1.28 \cdot 10^{-8}$	1.58	-				

It is interesting to note that after aging on the contact coatings growths of various sizes appeared having a rounded shape with a hole inside (anodes) or with a ring-shaped formation (cathodes). The nature of growths is connected with the processes of point melting of the electrode material during switching cycles.

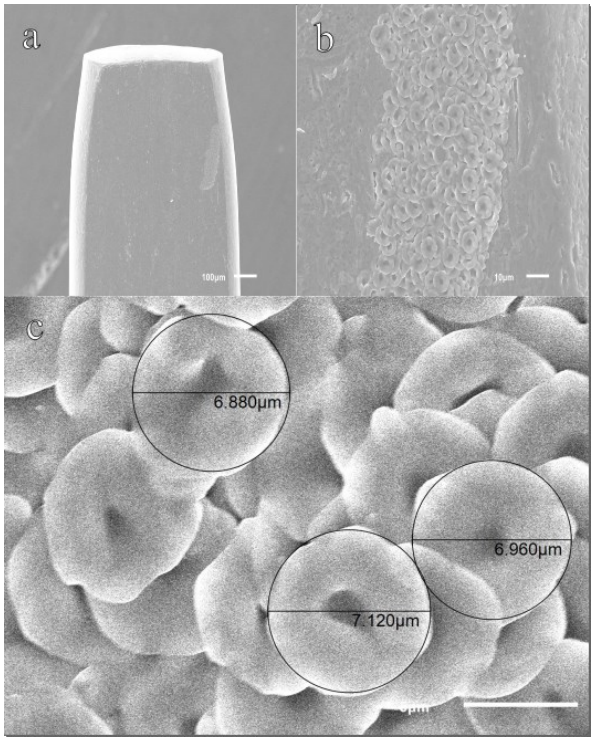

Fig. 6. SEM images of the anode of sample 1 of the set No. 2 (a-general view of the anode, b-artifacts of the contact spot, c- diameters of growths of the contact spot)

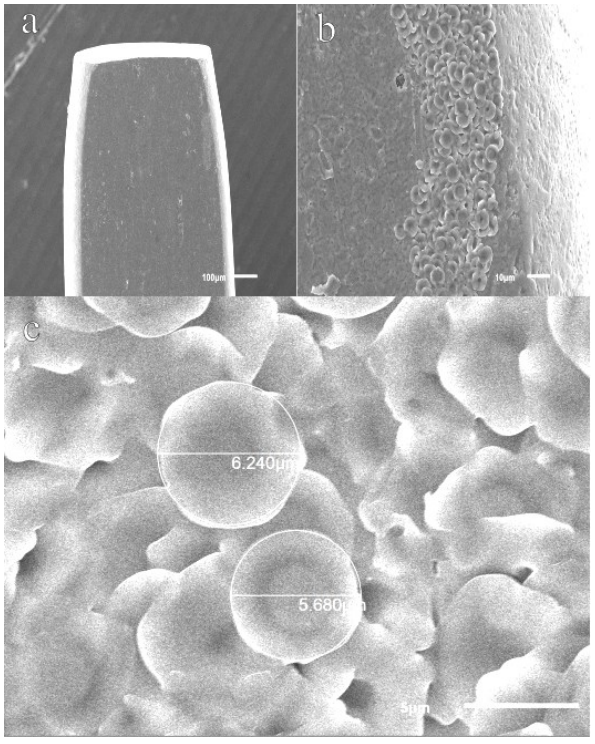

Fig. 7. SEM images of the cathode of sample 2 of the set No. 2 (a-general view of the cathode, b-artifacts of the contact spot, c- diameters of growths of the contact spot)

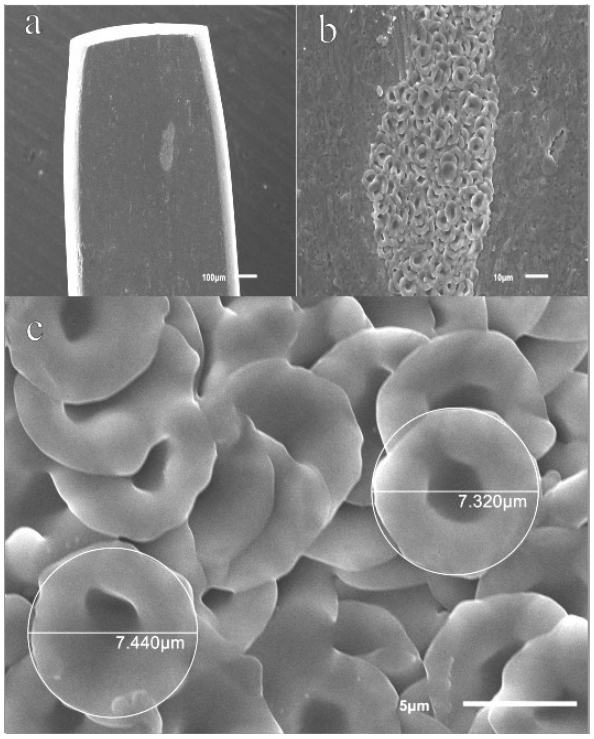

Fig. 8. SEM images of the anode of sample 8 of the set No. 2 (a-general view of the anode, b-artifacts of the contact spot, c- diameters of the growths of the contact spot)

The areas of the cathode and anode contact spots for specific samples approximately coincide. The increase in the number of switching leads to an increase in the area of contact spots with growths.

IV. CONSULSIONS

The results obtained in the work indicate an unambiguous relationship between the characteristics of the spectra of the low-frequency noise from the manufacturing techniques and the characteristics of the reed switches operation.

In this regard, the method of spectroscopy of low-frequency noise can serve as a convenient tool for diagnosing and predicting the reliability of reed switches.

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