Investigation influence of switching tests coatings of magnetically controlled contacts on the surface structure

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Abstract. The results of spectral noise power density measurements of reed switches 10 samples with and without Au-Ru coating are analyzed. The dependences of the spots area formed during switching tests on the electrodes on various noise parameters are constructed.

1. Introduction
Modern electronics are based on many different types of contacts. The important task during the developing electronic devices is to study the properties of the contacts used. The main requirements for switching devices are reliability, high switching life and ease of maintenance.

The lower limits of electronic devices sensitivity are often determined by the noise of the current and voltage in them. The useful signal may become unavailable if the noise level in the instrument is too high. On the one hand the noise that occurs in electronic solid-state devices limits the dynamic range of performance characteristics. On the other hand, low-frequency noises caused by current or voltage fluctuations provide information about the features of the electronic device internal structure.

Diagnostics of devices based on low-frequency noise spectra is a tool that allows to predict the service life of electronic components. Analysis of the low-frequency noise spectra allows to draw conclusions about the state of the system and the processes occurring in it. The experiments used the developed by the authors of this article automated complex of low-frequency noise spectroscopy [1, 2].

2. Methods and Samples
The purpose of this work is to study the correlation of the structure features of contact spots on the surface of magnetically controlled contacts (a batch of 10 reed switches) with the spectrum shape parameter $\beta$ that is the slope coefficient of the low-frequency section of noise spectrum.

The experimental study of magnetically controlled contacts characteristics was carried out in several stages. Measurement of the PSD low-frequency noise of the initial samples and mathematical processing of the obtained results were executed firstly. After that repeated switching of magnetic contacts in different modes, measurement of the PSD low-frequency noise of magnetic contacts subjected to repeated switching, mathematical processing of the results, investigation of the surface of the contact material using SEM microscopy were done. The structure and morphology of the samples were studied using a JEOL JSM-6610LV scanning electron microscope (SEM) in the secondary electronic imaging mode with an accelerating voltage of 30 kV.
3. Results and Discussion

The frequency dependences of the PSD of low-frequency noise are characterized by the presence of a change in the slope of the curves in the low-frequency region (Figure 1). At frequencies up to 1 Hz the LF noise spectrum obeys the $1/f^\beta$ law. The index $\beta$ of the spectrum shape was determined by approximating the dependence of the low-frequency noise PSD versus a frequency. The calculated index $\beta$ in our experiments varied from 0.5 to 3 for different samples. Figure 1 shows the low-frequency noise spectrum of one of the samples of the studied batch.

![Figure 1](image1.png)

**Figure 1.** Low-frequency noise spectrum of magnetically controlled contacts

After switching tests contact spots were formed on the surface of the contacts. There were growths of different sizes having a rounded shape with a hollow inside. The SEM image of one of the samples is performed in Figure 2.

![Figure 2](image2.png)

**Figure 2.** SEM images of contacts: a, d-general views of the cathode and anode, respectively, b, e-cathode artifacts and speckled views of the cathode and anode, respectively, c, f-growths on the surface of the contacts
Tables 1 and 2 show the parameters of the reed switch prototypes before and after switching tests respectively [1]. Where PSD of low-frequency noise is the value measured at a frequency of 1 Hz; \( \beta \) is the index of the shape of the spectrum or the degree of linear approximation of the initial part of the spectrum, \( S_k \) and \( S_a \) are the areas of contact spots on the cathode and anode, respectively, \( d_k \) and \( d_a \) are the average diameters of growths on the metal surfaces of contacts after their switching tests measured using SEM.

On the basis of the obtained data the dependences characterizing the correlation of the slope coefficient of the initial section of the LF noise spectra \( \beta \) with the area of the spots and the diameter of the growths are constructed. Separate dependencies for samples with Au-Ru coating (samples 1 – 5) and without coating (samples 6 – 10) are constructed.

**Table 1. Parameters of low-frequency noise of samples before conducting switching tests at a frequency of 1 Hz [2]**

| №  | \( R_\text{г}, \text{Ohm} \) | \( \text{PSD}, \mu \text{V}^2/\text{Hz} \) | \( \beta \) | Sample description |
|----|-----------------|----------------|------|-----------------|
| 1  | 0,08            | \( 5,64\cdot10^{-9} \) | 1,02 | contact detail -Ni (52 weight %)-Fe; Au-Ru coating |
| 2  | 0,08            | \( 1,78\cdot10^{-7} \) | 0,65 | contact detail -Ni (52 weight %)-Fe; Au-Ru coating |
| 3  | 0,08            | \( 7,93\cdot10^{-9} \) | 0,31 | contact detail -Ni (52 weight %)-Fe; Au-Ru coating |
| 4  | 0,08            | \( 3,21\cdot10^{-8} \) | 1,21 | contact detail -Ni (52 weight %)-Fe; Au-Ru coating |
| 5  | 0,08            | \( 1,97\cdot10^{-8} \) | 1,23 | contact detail -Ni (52 weight %)-Fe; Au-Ru coating |
| 6  | 0,11            | \( 3,27\cdot10^{-8} \) | 0,54 | contact detail - Ni (52 weight %)-Fe |
| 7  | 0,11            | \( 2,93\cdot10^{-9} \) | 2,02 | contact detail - Ni (52 weight %)-Fe |
| 8  | 0,16            | \( 5,64\cdot10^{-9} \) | 1,83 | contact detail - Ni (52 weight %)-Fe |
| 9  | 0,12            | \( 6,52\cdot10^{-9} \) | 1,04 | contact detail - Ni (52 weight %)-Fe |
| 10 | 0,15            | \( 1,28\cdot10^{-8} \) | 1,58 | contact detail - Ni (52 weight %)-Fe |

**Table 2. Parameters of low-frequency noise of samples after conducting switching tests at a frequency of 1 Hz [2]**

| №  | Number of switchings | \( S_k, \mu \text{m}^2 \) | \( S_a, \mu \text{m}^2 \) | \( \text{PSD}, \mu \text{V}^2/\text{Hz} \) | \( \beta \) | \( d_k, \mu \text{m} \) | \( d_a, \mu \text{m} \) |
|----|----------------------|----------------|----------------|----------------|------|----------------|----------------|
| 1  | 10000                | 10,47         | 9,6           | \( 1,42\cdot10^{-8} \) | 2,07 | 6,99         | 6,68         |
| 2  | 2000                 | 5,75          | 6,76          | \( 3,68\cdot10^{-8} \) | 1,72 | 5,96         | 7,04         |
| 3  | 2000                 | 4,79          | 4,62          | \( 1,93\cdot10^{-8} \) | 0,37 | 7,1          | 6,13         |
| 4  | 4000                 | –             | –             | \( 2,94\cdot10^{-6} \) | 1,58 | –            | –            |
| 5  | 2000                 | 5,87          | 5,45          | \( 8,53\cdot10^{-8} \) | 1,34 | 7,27         | 5,92         |
| 6  | 10000                | 16,58         | 17,74         | \( 5,76\cdot10^{-8} \) | 1,09 | 6,44         | 7,1          |
| 7  | 4000                 | 11,67         | 10,77         | \( 2,21\cdot10^{-7} \) | 1,53 | 7,04         | 6,4          |
| 8  | 4000                 | 6,81          | 6,22          | \( 1,91\cdot10^{-8} \) | 1,27 | 7,38         | 6            |
| 9  | 10000                | 4,24          | 3,72          | \( 1,83\cdot10^{-8} \) | 1,48 | 6,96         | 6,48         |
| 10 | –                    | –             | –             | –               | –    | –            | –            |
Figures 3 and 4 show the dependences that characterize the correlation of the spot area on the anode with the index $\beta$. The dependences connecting the spot area at the cathode with the $\beta$ had a similar character.

**Figure 3.** Dependence that characterizes the correlation of the spectrum shape index $\beta$ with the area of the contact spot on the cathode for reed switches with an Au-Ru coating after switching tests

**Figure 4.** Dependence that characterizes the correlation of the spectrum shape index $\beta$ with the area of the contact spot on the cathode for uncoated reed switches after switching tests

Analysis of the data shown in Figures 3 and 4 shows that the spread of the spot area on the anode for uncoated reed switches is wider than for Au-Ru coated reed switches. Conducting switching tests generally preserves the general trend of dependencies. Based on these data it can be assumed that reed switches with Au-Ru coating have higher reliability and stable performance characteristics.
Note that the growth of the spectrum shape index correlates with the increase in the resistance of the samples. Apparently, there is an increase in scattering on structural defects in particular at the interface of conductive coatings. It leads to a decrease in conductivity and an increase in the number of mobility fluctuations (the spectrum shape index $\beta$) [3]. Similar results are given in [4] where low-frequency noise in conducting films and contacts was studied. According to [5] the greater mechanical stresses of the conductive films, the greater value of the index $\beta$ is characteristic of them. Compare the dependence that characterize the correlation of the average diameters of growths on the electrodes with the index $\beta$ for reed switches with an Au-Ru coating and without a coating (Figures 5, 6). For samples of reed switches with an Au-Ru coating a greater spread of the index $\beta$ values is characteristic which is explained by a large spread of internal mechanical stresses inside the film. However, the spread of the average diameters of the growths is almost the same for samples with an Au-Ru coating and without a coating. The areas of the cathode and anode contact spots for specific samples are approximately the same. The same number of pulses applied to reed switch samples during testing corresponds to approximately the same contact spot area.

![Figure 5](image1.png)

**Figure 5.** Dependence that characterizes the correlation of the average diameters of growths on the electrodes with the spectrum shape index $\beta$ after switching tests of uncoated reed switches

![Figure 6](image2.png)

**Figure 6.** Dependence that characterizes the relationship of the average diameters of growths on the electrodes with the spectrum shape index $\beta$ after switching tests of uncoated reed switches
4. Conclusions

Based on the results obtained it can be concluded that the features of the surface and structure of the samples (the occurrence of increased mechanical stresses) determine the nature of the occurrence and the parameters of the spectral characteristics of low-frequency noise. It is associated with fluctuations in carrier mobility during scattering at structural defects (the interface of coatings, vacancies) in the conductive coatings of reed switches. It correlates with the vacancy model of G. P. Zhigalsky [4, 5].

The correlation obtained in this work indicates a relationship between the parameters of magnetic contacts with different coatings, the technological modes of their formation, the characteristics of the low-frequency noise spectra and the surface structure of the samples. The developed technique based on low-frequency noise spectroscopy can serve as a tool for diagnosing the quality and predicting the reliability of magnetic contacts.

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