The study of contact electrical resistance of coatings on the basis of refractory metal alloys Co-W, Co-Mo, Ni-W, Ni-Mo

G P Gololobov, D V Suvorov, M A Serpova and A S Arefiev
Ryazan State Radio Engineering University named after V.F. Utkin, 390005, Ryazan, Russia
E-mail: gololobov.gennady@yandex.ru

Abstract. The paper presents the research into contact electrical resistance of coatings on the basis of refractory metal alloys Co-W, Co-Mo, Ni-W, Ni-Mo. SEM-images of the tested samples’ surface are presented, and the peculiarities of their microrelief are analyzed. The results of the research are presented as dependencies of contact electrical resistance on the sample electrode pressing force for each type of the surface. The comparative analysis of them is done.

1. Introduction
It is possible to single one of the most important working characteristics out of their wide complex of contact electrodeposits by metals and alloys, used in modern switching devices (magnetically operated sealed switches, MEMS-switchboards, relays, etc.); the most important characteristics are the size and the contact resistance stability. The contact resistance is the main operating parameter and in many respects it defines the operational resource of such type devices [1]. Despite the dependence of this parameter on a number of factors, such as the coating material, the method of its application, the application quality, and the state of the surface in contact; while developing these devices, the main attention is paid to the choice of the material.

During last decades a great amount of contact surfaces has been studied and tested. The contact surfaces were on the basis of rare-earth metals, such as gold and silver, their alloys with a number of alloying components, rhodium and ruthenium and their alloys [1, 2]. However, in many cases it was impossible to obtain the required parameters of the contact, the required erosion resistance, service life and the reliability of switching devices’ work. The significant shortcomings of such type coatings are their mechanical characteristics (solidity, elasticity, melting temperature, etc.) which leave much to be desired, and as a consequence, their propensity to mechanical wear-and-tear, electrical erosion, and contacts’ sticking. It is necessary to mention the high cost of rare-earth metals.

That is why recently contact coatings on the basis of refractory metal alloys W and Mo with the metals of iron group are becoming more and more spread [3-8]. These binary alloys have high wear resistance, corrosion resistance and solidity [9-11]. It is necessary to single out the resistance of these alloys to electrical erosion. The electrical characteristics, in particular contact electrical resistance of the coatings on the basis of these alloys, do not yield to the coatings on the basis of rare-earth metals.

Nowadays there is an opportunity to control the contact electrical resistance of the coatings due to the reasonable choice of the coating as well as due to the change of the technological conditions of their coating.
This scientific-research work is aimed at studying contact electrical resistance of the coatings, developed by us, on the basis of the whole range of refractory metal binary alloys. The data about similar comparative research in well-known sources are absent, thereby, the work is of great theoretical and practical significance.

2. Experiment details
For the research four batches of sample coatings on the basis of Co-W, Co-Mo, Ni-W and Ni-Mo alloys were got. The composition of the electrolytes and the deposition mode are presented in [4], [12], [8], [13] respectively.

The plates of oxygen-free copper of brand Cu-DHP with sizes 1×2 cm and thickness 1 mm were used as the bases. The bases underwent mechanical polishing by a felt circle without using abrasive, and then they were defatted in the solution containing NaOH and Na₂CO₃ in the concentration of 100 g/l for each component at the temperature of 70 °C. Straight before the deposition the bases were dipped into the 15% solution of HCl for 30 seconds and were washed thoroughly in bidistilled water. A platinum plate of 4 cm area served as an anode. The current density varied between 0.005–0.15 A/cm². The set values of electrodeposition current parameters were provided with the help of the potentiostat IPC Pro 3A by Volta (St. Petersburg, Russia). The electrolyte temperature during spreading the coatings in all the experiments was set and maintained constant with the help of the electromagnetic stirring with the heater C-MAG HS 7 digital by IKA (Staufen, Germany) with the system of feedback through the temperature sensor PT 1000 by Thermometrics (Northridge, CA, USA).

The thickness of coatings in each consignment was 6-7 μm. The content of the refractory metal component in all the alloys was maintained at the level of 18-19 atomic percent by using different deposition modes. The deposition conditions provided the minimum level of the crack and coating roughness formation.

For doing the test of contact electrical resistance \( R_c \) a stand was designed in order to measure \( R_c \) under the conditions of contact with the set value of contact pressure force of the sample electrode and the base with the coating. Its structural scheme is presented in Figure 1 a. The picture of the brass sample electrode (probe) is presented in Figure 1 b.

The stand consists of: 1 – the base; 2 – the load; 3 – the sample electrode; 4 – the measuring device (voltmeter); 5 – the source of constant current; 6 – the researched sample.

The electrical resistance was measured according to the four-conductors’ scheme with the use of current and potential conductors. One pair of conductors (current and potential) was connected to the sample at different points; the second pair was connected to the sample electrode. A probe, made from brass with the working surface in the form of a sphere with the radius 1.5 mm (Fig. 1 b), was used as a sample electrode. With the help of the constant current source the required current of 50 mA was set. A voltmeter was used as a measuring device. The research was done using four different loads. Thus, the pressure force of the electrode \( (F_p) \) was 0.2 H, 0.45 H, 0.75 H and 1 H respectively. To do the experiment series of 5 sample surfaces on the basis of alloys Co-W, Ni-W and Co-Mo, Ni-Mo were prepared. For each sample the measurement of the voltage drop in the contact was done at 5 points, the measurement was done 5 times at each point. Further the obtained values were averaged.
Figure 1. The structural scheme of the stand for testing contact resistance of coatings (a) and the image of the sample electrode (b).

Microstructural images were collected using a scanning electron microscope JSM-6610LV by JEOL (Tokyo, Japan) equipped with an energy-dispersive X-ray microanalyzer INCA X-MAX by Oxford Instruments (Abingdon, Oxfordshire, UK), which allowed for determining quantitative elemental composition of the coatings. We used a 30 keV acceleration potential in our experiments. The thickness of coatings was determined by means of cross-section microstructural measurements on the scanning electron microscopy (SEM) images. The relative accuracy of these measurements was estimated within the range of ±3.5%.

3. Results and discussion
It is known [1] that the state of the surface relief can influence significantly the value of the surface contact resistance. That is why at the first stage of the work the research of the surface structure and morphology the obtained samples’ coatings was carried out. A comparative analysis was done.

The SEM-images of the typical surface areas of the researched sample coatings on the basis of alloys cobalt-tungsten, cobalt-molybdenum, nickel-tungsten and nickel-molybdenum are presented in Figure 2.

As it is seen in the SEM-images, the surface relief structure of the coatings of the four alloys under study is different. The surface relief structure of the coating by the alloy Co-W obtained under the given conditions is homogenous enough (Figure 2 a). The basis of the relief structure is the wedge-pyramidal formations with a strongly represented faceting, the lateral sizes of the formations are 0.5 – 1.5 microns. The structure elements arrangement is irregular. The analysis of the SEM-images of the typical surface areas of the sample coatings on the basis of alloys Co-Mo (Figure 2 b) and Ni-Mo (Figure 2 d) do not allow revealing characteristic growing forms of the relief structure. In both cases the relief is composed of different in shape and size separate globule-formations. As it is in the first case, the lateral sizes of separate structure elements do not exceed 1.5 microns. The surface relief structure of the coating by the alloy Ni-W (Figure 2 c) is composed of the formations with the shape close to hemispherical. The arrangement order is also not observed in this case. The lateral sizes of the hemispheres are 0.5 – 1.5 microns.

It is necessary to point out that the roughness of the surface in the presented SEM-images is mainly determined by the sizes of separate elements constituting the relief structure and its value is commensurable in all four studied cases.
At the next stage of the work the research of contact electrical resistance of the sample coatings was carried out. The results of the research are presented in Figure 3 in the form of dependencies $R_c$ on the pressure force of the sample electrode.

**Figure 3.** The dependencies of the contact electrical resistance of the coatings on the basis of alloys Co-W, Co-Mo, Ni-W, and Ni-Mo on the pressure force.
As the figure shows the dependencies in all the cases have a falling character along the whole length. At the range of the force $0.2 - 0.45 \, \text{N}$ the steepness is more represented. At the range $0.75 - 1 \, \text{N}$ there is a more sloping area; and at the value of pressure force $1 \, \text{N}$ the minimum value of the contact electrical resistance is reached.

In general, the dependence of contact resistance $R_c$ on the pressure force corresponds to the conceptions, considered in the work [14], and is described by the following equation:

$$\lg R = \lg k - b \times \lg P,$$

where $P$ is the pressure force on the contact, $[\text{N}]$; $b$ is the constant, depending on the type of contact (for point contacts – 0.5; for linear contacts – 0.6, and for planar contacts – 1.0).

Comparing the obtained results with the scientific research data [1], we may conclude that the decrease of $R_c$ is connected with the increase of the common contact area (current transmission) as a result of surfaces modification and formation of the complementary relief on the contact surfaces. And partially it is connected with the forcing through the oxide films. In this case a steeper area of the curves is determined by physico-mechanical characteristics of this type alloys and by morphological peculiarities of the coating surfaces.

Comparison of the values $R_c$ of the alloys under study shows considerable (for a degree of the value and more) differences of this parameter. The maximum values $R_c$ at the level of $0.33 \, \Omega$ and the maximum range of this parameter change ($0.33 \, \Omega - 0.02 \, \Omega$) with the increase of the electrode pressure force are typical of the coating on the basis of the alloy Co-Mo. The minimum value $R_c$ at the level of $0.004 \, \Omega$ was fixed at the coating on the basis of the alloy Ni-W. The minimum range of this parameter change ($0.015 \, \Omega - 0.004 \, \Omega$) is also typical of this coating.

This great difference in the values of $R_c$ of the researched alloys of one type with similar characteristics, such as electroconductivity, physic-mechanical characteristics (plasticity and elasticity), grain size of the alloy, presence of oxide films, surface roughness, can be explained by the heightened dispersion of the coatings structure and by the inclusion of nonmetal admixtures into the coatings in the process of electrochemical crystallization.

4. Conclusions

During the research we obtained the data on morphological peculiarities of the surface relief and contact resistance of some promising coatings on the basis of refractory metal alloys, such as Co-W, Co-Mo, Ni-W and Ni-Mo. The comparative evaluation and analysis of dependencies $R_c$ on the pressure force of the sample electrode at the range of $0.2 - 1 \, \text{N}$ allowed exposing the alloys with a maximum and a minimum value of this parameter as well as the range of its change for each alloy. The analysis and comparison of the obtained data shows that the coatings on the basis of binary tungsten alloys (Ni-W, Co-W) provide a considerably less value of the contact resistance in comparison to the alloys on the basis of molybdenum (Ni-Mo, Co-Mo) and can be recommended as a functional contact surface for switching devices on the basis of “dry contact” (magnetically operated sealed switches, relays, MEMS-switchboards).

The record low value $R_c$ at the level of $0.004 \, \Omega$ for the coating alloy Ni-W was obtained while using a standard methodology of its measuring.

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