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Pre- and post-service microhardness measurements of electrical contacts operating at Kozloduy NPP

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Abstract

Selected electrical equipment of different monitoring systems operating at Kozloduy NPP has been studied for identification of the changes occurring during its long use under the conditions of monitored radiation background. As a part of a complex research program, pre- and post-service microhardness measurements of Ag and Ag–Cd electrical contacts were undertaken. The interpretation of the experimental results led to formulas describing adequately the microhardness–depth profiles. The changes of material characteristics varied in the different types of the electrical components.

Keywords: Nuclear Power Plant (NPP); Electrical contacts; Microhardness

1. Introduction

Degradation processes of the electronic equipment for control and monitoring of different systems on Units 5 and 6 of Kozloduy NPP were studied in a previous paper [1]. A combined investigation of the electrical equipment has also been carried out and the present work represents a part of it.

Electrical contacts must meet strict criteria concerning their current conduction and wear resistance through the design operation time. Heating, repeated dynamic loading, corrosion and erosion result in degradation of surface morphology, structure, chemical composition and electrical and mechanical properties. Studies on microindentation hardness are widely used to assess the effect of the upper degradation processes. As shown by Blau, post-service comparison of surface and bulk properties of Cu and Cu alloys help to do wear–hardness correlations [2]. The combination of pre- and post-service tests results in even more valuable information [3].

The same approach has been used to the study on the distribution of microhardness with depth in Ag and Ag–Cd electrical contacts: along with used samples, their unused analogues have been tested. The aim of the work was to reveal the peculiarities of microhardness–depth profiles in the various types of electrical components.

2. Experimental details

2.1. Samples

The electrical equipment was exploited for about 10 years under the conditions of monitored radiation background. A selection of contactors was made, from which about 70 contacts, operating in continuous load mode with operation ratio close to 1 were dismounted and tested. Along with these used (s-) contacts, each sample series contained one or two unused (n-) contacts that had not been in operation at all before the experiment. While all the n-contacts were low Ohmic and had linear *I–V* characteristics, most of the s-ones exhibited considerably greater electrical resistance and deviations in the linearity of the *I–V* characteristics. A detailed study on electrical parameters degradation is to be presented in a forthcoming paper.

In Table 1, some basic characteristics of the studied contacts are given.

The impurities in the samples were detected using the X-ray microprobe of a Philips electron microscope.

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Table 1
Characteristics of the contacts

Sample series	Contactor	Type	Basic composition of the contact	Exploitation current (A)	Typical post-service contact resistance (mO)
II.1, IV.1, IV.3	Two-position relays	Low-duty	Ag	≤1	5–30
I.2, I.4, II.2	Auxiliary relays	Medium-duty	Ag–Cd	≤5	10–50
III.2	Time relay	Medium-duty	Ag–Cd	≤5	10–50
II.3	Auxiliary relay	Heavy-duty	Ag–Cd	≥10	10–30
V.1	Blocking relay	Heavy-duty	Ag–Cd	≥10	10–30

2.2. Microhardness measurements

The samples were of planar or hemispherical geometry. Their surface was fairly smooth and no additional mechanical or chemical treatment was needed. When necessary, the s-ones were carefully cleaned with ethanol.

Microhardness measurements were carried out at room temperature with a PMT-3 microhardness tester. A Vickers diamond indenter was used. Compared to that of Knoop, it is of a bigger penetration depth into the tested material at the same load.

The Vickers microhardness Hv is related to the load P according to the formula:

$$\mathrm{Hv}(\mathrm{kg/mm}^2) = 1.854\, P(\mathrm{kg})/d^2(\mu\mathrm{m}^2),$$

where d is the imprint diagonal. Hv was plotted as a function of the penetration depth h (μm) = $d/7$.

The flat contacts were indented at about 10 different loads of the interval $P = 2$–50 g in order to study the dependence Hv = f (h). At least five indentations were produced at each load and the mean arithmetic value of h was taken. The available for indentation surface of the spherical samples was too small and they were measured only at $P = 20$ g.

3. Results and discussion

3.1. Ag contacts

Flat Ag contacts were dismounted from three different low-duty relays. The n-samples were of bright optically homogeneous surface with rare dark stains containing S. The surface of the s-samples was mat with embedded particles in which the impurities S, Fe, Ca, Si, Cl, Sn, In and Cu were detected. Being too small, these particles were not separately indented.

The dependences Hv (h) obtained are shown with points in Fig. 1. The data on n-samples is given in the left-hand part of the figure. The first dependence summarizes the data on two n-samples of identical behavior. Similar 'collective' dependences are observed in the s-samples as well, regardless of the localization of the latter in the contactor. These profiles are given in the right-hand part of the figure.

In Fig. 1, it can be seen that Hv tends to saturate at greater h, i.e. to become load-independent reaching the bulk value Hv_∞. In the subsurface layer of the s-samples greater than Hv_∞ (series II.1 and IV.3) or smaller than Hv_∞ (series IV.1) values were measured.

We succeeded in fitting the experimentally measured microhardness dependence on the indenter penetration depth with an exponential function of the type

$$y = +b\exp\left(-\frac{x}{c}\right), \tag{1}$$

as it was done for PbSe, CN_x and $\mathrm{Mg_2Sn}$ [4–6]. The fitting of our data by means of Eq. (1) is shown in Fig. 1 (middle curve, the upper and lower ones being the 99% confidence limits).

The variables x and y correspond to h and Hv and a is the load-independent microhardness Hv_∞ of the contact material at $h \to \infty$; b is a positive or negative constant for every specific sample; c is a quantity with the meaning of deformation penetration depth, depending on the surface state, the material elastic constant and microstructure [4].

The parameters of Eq. (1) are given in Table 2.

It can be seen that the computed values are consistent with the experimentally measured ones and are in agreement with literature data [7]. The mean arithmetic value is ~63 kg/mm^2 for the n-samples and ~55 ± 2 kg/mm^2 for the s-samples. Such a decreased Hv_∞ is characteristic for thermally annealed samples. Hence it may be concluded that the heating of the samples during operation caused by the electric current flow through them possesses the effect of thermal annealing in situ. It affects not only the contacting surface zone but the bulk of the samples as well.

The course of the microhardness–depth profiles in the subsurface region is of a greater interest. It influences the other parameters of Eq. (1). While the values of c are almost identical, those of b are greater for the s-samples. It can be seen that the profiles are steeper—the difference between the bulk and the contacting zone microhardness values increases as a result of operation.

Table 2
Parameters of Eq. (1) for the Ag contacts

Series	Figure	Type of the sample	a	b	c
II.1	Fig. 1a	n	62.62	1.93	1.00
	Fig. 1a	s	54.91	123.30	0.74
IV.1	Fig. 1b	n	61.84	−56.98	1.00
	Fig. 1b	s	55.31	−80.75	1.00
IV.3	Fig. 1c	n	64.89	−26.58	1.00
	Fig. 1c	s	54.83	51.73	0.85