ENVIRONMENTAL IMPACTS ON LONG-TERM RELIABILITY OF WIRING TERMINALS

Miroslav Kopča, Peter Poljovka

Institute of Power and Applied Electrical Engineering, Faculty of Electrical Engineering and Information Technology SUT Bratislava, 812 19 Bratislava, Slovak Republic
E-mail: miroslav.kopca@stuba.sk

Received 23 May; accepted 28 May 2014

Abstract

Electrical installation clamps provide a long term conductive connection. During their operation in power distribution systems these contact components are exposed to the influence of a wide spectrum of internal and external degradation factors. The objective of the paper is the verification of the features of progressive contact components with a cage clamp (WAGO system) in various conditions. Experimental results and evaluation methodology of degradation of contact components are a part of the designed controlled ageing system for nuclear power plants.

1. Introduction

Electric terminals are exposed to a number of external and internal interferences during operation. Among the determinants that affect the terminal transfer characteristics most significantly are external environment factors, current load in the respective circuit and changes in contact force. Negative effects of the determinants mainly comprise changes in surface characteristics of the materials in conductive connection. The changes are the primary cause of contact member failures in real-life applications.

2. R_K Contact Resistance

When establishing dismountable contact of two conductive elements in the contact member, an additional resistance applies to combined resistances of the remaining circuit elements, with the resistance referred to as R_K *contact resistance* or R_{PR} *transition resistance***.**

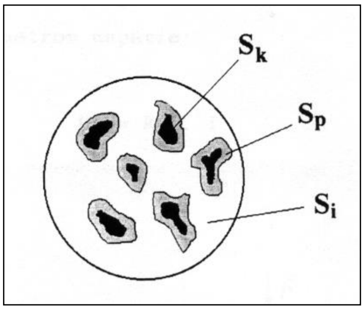

Fig.1 *Contact surface*

1. Surface with *metal contact* $S_k = \Sigma S_{Ki}$
2. Surface with *metal-like (semiconductive) contact* $S_p, = \Sigma S_{Pi}$

3. *Insulation surface S_i*, consisting of various types of multimolecular layers that mainly contain oxides, polymers and mechanic impurities, but also areas without any mechanical contact (air gaps).

Contact Surface

In real-life applications, the contact surfaces are deformed through acting force F, with the deformation being either temporal (elastic) or irreversible (plastic). For plastic deformation, there is an increase in actual contact surface. The total surface S_c through which mechanical force F_K is transferred then comprises e.g. three partial contact surfaces (Fig.1).

Necking Resistance R_Z

One of the key transition resistance factors at contact R_{PR} is the fact that currently, it is not technically feasible to manufacture a perfectly smooth metal surface (Fig. 1). Consequently where in closed position, two 'irregular' contact surfaces are subjected to acting force, there is no current transfer through the entire **apparent contact surface** created by overlay of the elements in contact but through small sections of the surface instead the total of which constitutes **actual contact surface.** The idea of **necking** is a key element in the modern electric contact theory. According to some sources [1], actual contact surface in any given contact only constitutes about 1/1000 of apparent contact surface. The reduced contact cross-section with **purely metallic contact** (S_k in Fig. 1) applicable according to theory constitutes a contact transition resistance component, sc. **necking resistance R_Z.** For calculating necking resistance, (fictitious) diameter is employed of the round cross-section of the actual contact surface $S_k = \Sigma S_{Ki}$, also referred to as a.

$$R_z = \rho / 2a \tag{1}$$

However, the contact surface shape cannot be precisely determined in real-life circumstances while the actual contact resistance is subject to changes on each circuit closure and opening. This means statistically random variations in the contact transition resistance as evidenced e.g. by *contact noise.*

Contact surface layers

Layers that are formed on contacts due to environmental effects feature:

- High resistivity;
- Usually negative thermal resistance factor

In the emergence of surface layers on contacts, three main types of contamination apply:

a) **Contamination through organic substances** as a result of presence of organic vapours and gases. With the contacts being hot due to current transfer, the substances polymerise. High dielectric strength and high transition resistance usually characterise the layers.
b) **Contamination through inorganic substances.** Mainly caused by contact material corrosion due to environmental effects. In inorganic layer growth, also electric discharge plays a complementary role.
c) **Mechanic contamination** mainly applies to naked contacts, being caused by non-conductive particles that settle on the contacts.

Where a surface layer is present with thickness h_p and resistivity ρ_p, additional transition resistance applies on the surface layer R_v..

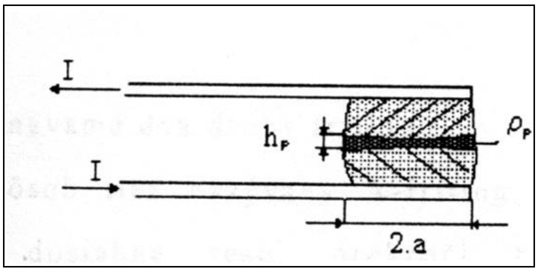

Fig.2 *Contact surface layers*

In reference to Fig. 2, resistance R_v may be calculated using formula

$$R_v = \frac{\rho_p \, h_p}{\pi \, a^2} \tag{2}$$

The total contact transition resistance value then equals

$$R_{pr} = R_z + R_v = \frac{\rho}{2a} + \frac{\rho_p \, h_p}{\pi \, a^2} \tag{3}$$

For very thin surface layers of up to approx. 2 nm width, sc. tunnel resistivity ρ_T applies in Formula (2) instead of ρ_p as on current transfer through the layers, particularly tunnelling effects apply with respect to charge carriers.

For thicker surface layers (above 2 nm) resistivity of which exceeds tunnel resistivity values by approx. two decimal places, current transfer may be completely prevented. Current transfer is reestablished only by disrupting the layer surface through external interference (electric or mechanical). Electric disruption of the layer through electrochemical breakdown is referred to as *friting*.

3. Sample Selection and Preparation

The electric components subject to assessment are used for dismountable electric contact assemblies acting force in which is generated through cage extension spring (Fig. 3). Credit to its shape and materials employed, the spring establishes perfect electric contact in complex operational modes and for a broad range of conductor effective cross-sections.

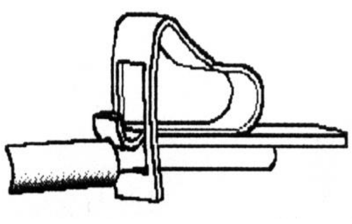

Fig. 3 *Cage extension spring*

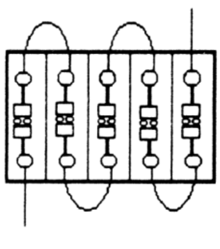

Fig.4 *Terminal block assembly*

- **Sample selection**

For measurement purposes, assembly terminals with the following characteristics have been selected and prepared:

- Applicable conductor cross-sections: 0.08 – 1.5 mm^2
- Nominal current: 18 A
- Maximum voltage load at terminal: 400 V.

- **Test Block Assembly**

Test blocks have been assembled compliant with provisions of *VDE 0607*. The standard requires assembling test blocks using 5 terminals in serial connection. The block scheme is shown in Fig. 4.

For measurement purposes, eight identical blocks have been prepared, with two blocks placed in each test environment (Chart 1). In each pair, terminals in one block have been connected through solid and in the second through coiled copper conductors.

- **Test Environments**

Test Environment Description Chart 1

Environment No.	Environment characteristic
1	**Laboratory** –insignificant temperature changes in laboratory conditions
2	**Light chemical stress** – temperature and moisture changes, light chemical contamination
3	**Heavy chemical stress** – temperature and moisture changes, heavy chemical contamination

4. Measurement

- **Measurement Technique Selection**

For measuring low resistances, techniques should always be selected that minimize negative effects to measurement accuracy. The main causes of measurement inaccuracies are transition resistances at terminals and connection line resistances. For this reason, the scheme applicable under the volt-ampere technique for measuring low resistances has been used, with the resistance subject to measurement added to the circuit in four-conductor connection. If using digital measuring devices with $I_x >> I_V$, the volt-ampere technique selected is precise enough for purposes of measuring terminal contact resistances, with no further correction needed to values recorded.

- **Measurement Conditions**

All measurements have been conducted at 1 A direct current. Ambient temperature of 30 °C has been selected.

During actual measurement with 1 A test current, it was necessary to wait until the characteristics at the point of tested transition resistances have stabilised *'forming'* the contacts, and sc. *friting* effects fade away. As stabilized, the condition was referred to when the decrease stopped in voltage value (indication in mV).

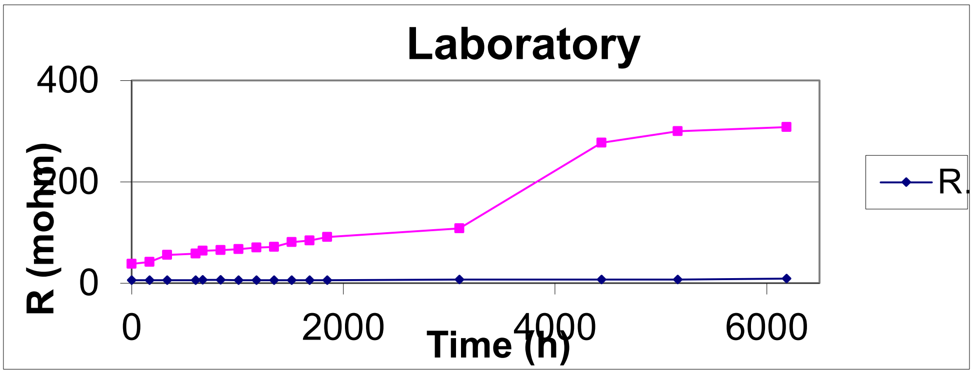

Fig. 5 *Laboratory environment*

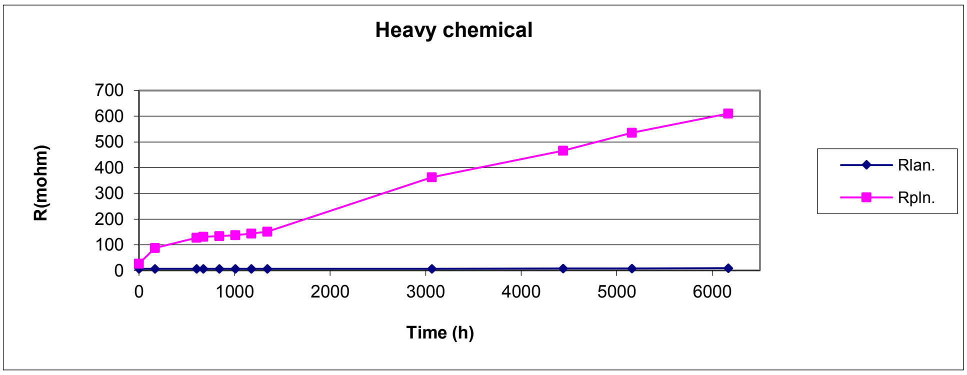

Fig. 6 *Heavy chemical stress environment*

- **Measurement Results, Correction and Visualization**

Results Correction. Material resistance for the conductors used at 30 °C was determined using a simple calculation formula as R_v = 4,576 mΩ. The value was then subtracted from the values recorded.

Results visualization is shown in Figures 5 and 6, with the R_L curve representing temporal changes in transition resistances for coiled conductor block and R_p for solid conductor block. The visualizations refer to environment in which the blocks were placed and measurements conducted in time intervals indicated on the *x*-axis.

- **Discussion of Results**

The dependences identified (Fig. 5 and 6) indicate that the increase in transition resistance values was significant only for terminals connected by means have **coiled conductors**. The increase in transition resistance was evident already for initial measurements at point $t = 0$. When using **coiled conductor**, obviously no reliable and gastight connection has been established through clamp pressure.

5. Conclusion

Based on the test results and analysis, the following practical recommendations apply for electric installation providers and operators when using electric terminals with cage extension spring:

- In terms of long-term stability and environmental resistance, solid conductors are the preferable solution;

- When using coiled conductors for any specific reason, minimize where possible negative environmental effects e.g. by hermetically enclosing the assembly;
- Do not exceed nominal voltage values, particularly in heavy stress environments as at current overload and high contact temperatures, thermostimulated electrochemical degradation may emerge.

Acknowledgement
This contribution is the result of the project implementation: Industrial Research Centre for operating lifetime of selected components of power plants (ITMS: 26240220081), supported by the Research & Development Operational Programme funded by the ERDF.

References

[1] KEITHLEY Instruments, Inc.: Low level measurements. Copyright: Keithley Instruments 1992.
[2] WAGO GmbH: Hauptkatalog HK 1 – 4, 1992
[3] CABÚK, P – PIETRIKOVÁ, A. – BUJALOBOKOVÁ, M.: Zariadenie pre skúšky spoľahlivosti v rôznych klimatických podmienkach. In. DIAGNOSTIKA`05, 7-th. International Scientific Conference, Nečtiny 6. – 8. September 2005, Czech Republic, pp. 247-250.