07 - 10 September 2009

PROCEEDINGS

54. IWK

Internationales Wissenschaftliches Kolloquium

International Scientific Colloquium

Information Technology and Electrical Engineering - Devices and Systems, Materials and Technologies for the Future

Faculty of Electrical Engineering and Information Technology

Startseite / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=14089

TECHNISCHE UNIVERSITÄT
ILMENAU

Impressum

Herausgeber: Der Rektor der Technischen Universität Ilmenau
Univ.-Prof. Dr. rer. nat. habil. Dr. h. c. Prof. h. c.
Peter Scharff

Redaktion: Referat Marketing
Andrea Schneider

Fakultät für Elektrotechnik und Informationstechnik
Univ.-Prof. Dr.-Ing. Frank Berger

Redaktionsschluss: 17. August 2009

Technische Realisierung (USB-Flash-Ausgabe):
Institut für Medientechnik an der TU Ilmenau
Dipl.-Ing. Christian Weigel
Dipl.-Ing. Helge Drumm

Technische Realisierung (Online-Ausgabe):
Universitätsbibliothek Ilmenau
ilmedia
Postfach 10 05 65
98684 Ilmenau

Verlag: isle

Verlag ISLE, Betriebsstätte des ISLE e.V.
Werner-von-Siemens-Str. 16
98693 Ilmenau

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ISBN (USB-Flash-Ausgabe): 978-3-938843-45-1
ISBN (Druckausgabe der Kurzfassungen): 978-3-938843-44-4

Startseite / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=14089

OPTICAL METHODS TO EVALUATE SURFACE MODIFICATIONS AT SWITCHING ELECTRICAL CONTACTS

Martin Reichart

Austrian Center of Competence for Tribology, AC²T research GmbH, Wiener Neustadt, Austria,
E-mail: reichart@ac2t.at

ABSTRACT

In general, contact erosion of electrical switchgears is analysed ex-situ by microscopic methods and quantified by measuring the mass change of the electrical contacts.

However, for the investigation of switching failures, the modifications of the electrodes' topographies between single switching operations are important. Besides mechanical wear, especially arcing may cause precarious surface manipulations due to melting, vaporisation and material transfer which lower the reliability and the life of electrical contacts.

Therefore, a novel method to evaluate the modifications of the electrodes' shapes was developed. First experiments demonstrate the applicability for detecting modified surfaces in-situ during the lifetime.

Index Terms - Electrical switching contacts, topography, arc root, material transfer, interlocking

1. INTRODUCTION

The reliability and the lifetime of low-power electrical contacts are strongly influenced by erosion phenomena. For example each single arc process results in a topography change at the arc roots due to melting and vaporisation, which influences the following switching operation. Contacts switching DC loads can even create material transfer pip and crater formations which may cause non-opening faults due to interlocking or bridging [1].

In general, contact erosion is quantified by measuring the mass change of the electrical contacts. However for the investigation of switching failures, the modifications of the electrodes' topographies are important. Even a small net-amount of transferred material per switching operation may result in precarious material transfer shapes which lower the reliability and the life of electrical contacts [2].

Therefore, the analysis of contact erosion has recently been improved by evaluating the volume change ex-situ using three-dimensional (3D) non-contact surface scanning systems [3], [4]. To visualise modifications of the electrodes' shapes in-situ during lifetime (in particular the pip growth due to material transfer), the observation of two-dimensional photographs proved to be of value [5]. By further development of this in-situ and non-touching method, a continuous characterisation of pip changes (pip height or the ratio of pip height and pip base diameter) throughout test runs was made possible. Additionally the recorded pip modifications could then be compared to other important measured physical parameters such as the separation force by composing time-lapse movies. However, this method has so far only been used to record global topography changes between multiple switching operations.

2. EVALUATION METHOD

To reveal and analyse topography modifications of the contact surface due to single switching operations, enhancements of the recording system as well as of the post-processing analysis was needed.

In order to achieve evaluable pictures, the stability of the brightness and thus the illumination of the samples is essential. By taking pictures with a CCD-camera at constant illumination between successive switching cycles and by evaluating the changes of the brightness between the consecutive pictures, the altered surface regions can be detected and visualised.

In Fig. 1 to Fig. 3 an exemplarily evaluation is demonstrated. Fig. 1 shows a brand new contact rivet, while in Fig. 2 the same contact after one single switching operation is displayed. These two pictures are then evaluated by automatic Matlab®-based computer software: changes of the brightness between the consecutive pictures, which are calculated by point-wise subtraction of greyscale-values, represent altered surface regions. In Fig. 3, brighter pixels in the subsequent picture (Fig. 2) are indicated by red-coloured areas, darker ones by blue-coloured regions. The greater the brightness-difference, the darker the colour is set (dark red pixels in the contact area in Fig. 3).

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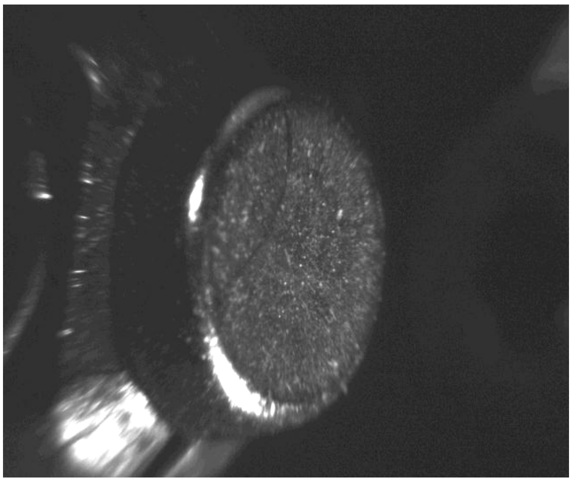

Figure 1   New contact rivet

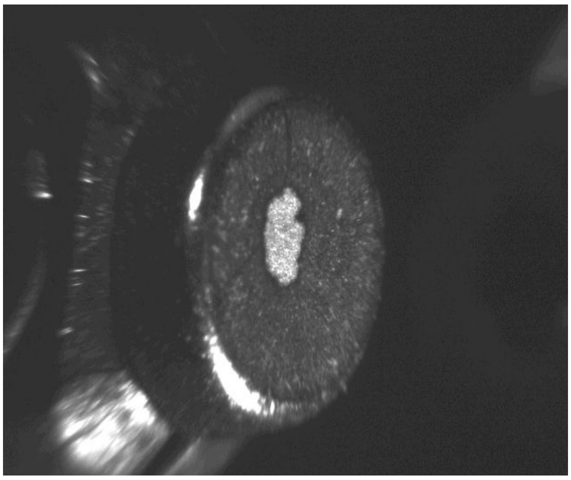

Figure 2   Contact after 1 switching operation

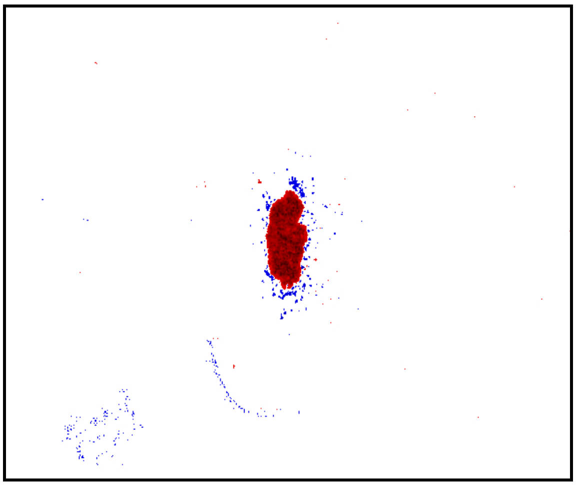

Figure 3   Calculated brightness change

The final picture (Fig. 4) is obtained by overlaying the latter photography (Fig. 2) of the contact with the calculated picture (Fig. 3). Furthermore, additional information about the switching conditions can also be inserted into the picture, like in this case at the upper right corner the voltage trace at make which illustrates the arcing condition during the occurring long bounce.

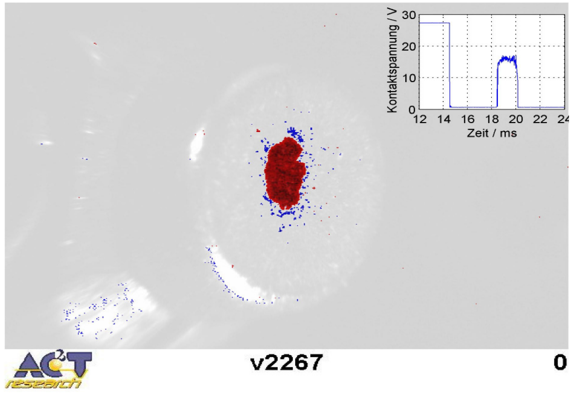

Figure 4   Resulting superimposed image

This example is rather obvious and could also be evaluated without the computer-assisted image comparison. However, when investigating surface topographies after multiple switching operations, the surface differences are not as evident between consecutive switching cycles as in this example after the first switching operation.

Using this method, a continuous characterisation of small surface modifications between single switching operations throughout complete test runs was made possible.

3. EXPERIMENTAL

Multiple experiments have been performed to evaluate the application areas of this novel method, especially with regard to characterising the arc roots and the material transfer.

3.1. Experiment 1 – Evaluation of the arc root

The first experiment was carried out with a model switch which is a one axis linear motion switch with axially aligned closing and opening directions [6]. After make, the current was switched off using an auxiliary relay. Break operations were performed without electrical load. Therefore the surface modification on the cathode due to arcing at make and the resulting fracturing at break can be investigated. Under the selected switching conditions, given in Table I, short and long bounces [7] evolved. The aim of this work was to investigate the surface modifications due to these two different bounce behaviours.

TABLE I.   EXPERIMENTAL CONDITIONS

Switch:	1-axis model switch
Load voltage :	27 VDC
Load current :	23 A, ohmic, make-only
Bounce pattern:	Short bounce & long bounce
Contact distance:	300 – 320 µm
Static contact force :	25 – 35 cN
Contact material :	Ag1000
Fixed contact side: Movable contact side:	Cathode, flat rivet Anode, spherical rivet
Number of operations:	2,000

3.2. Experiment 2 - Evaluation of the material transfer

The second experiment was conducted with a model switch using mass-produced relay leaf springs. Therefore a multidimensional motion of the movable contact is implemented while adjustments of the contact distance and the contact force are allowed. Again, after make, the current was switched off using an auxiliary relay. Break operations were performed without electrical load. Under the selected switching conditions, summarised in Table II, a material transfer pip and crater were formed on the cathode and the anode, respectively. Due to multidimensional contact motion, an asymmetrical material transfer shape evolved and interlocking occurred during the experiment. Therefore the surface modification due to material transfer at make can be investigated.

TABLE II. EXPERIMENTAL CONDITIONS

Switch:	Relay model switch
Load voltage :	14 VDC
Load current :	12 A, ohmic, make-only
Bounce pattern:	Long bounces
Spring length	8 mm
Contact distance:	500 µm
Static contact force :	25 – 35 cN
Contact material :	Ag/CdO-90/10
Fixed contact side: Movable contact side:	Cathode, flat rivet (Material transfer shape: PIP) Anode, spherical rivet (Material transfer shape: CRATER)
Number of operations:	3,000

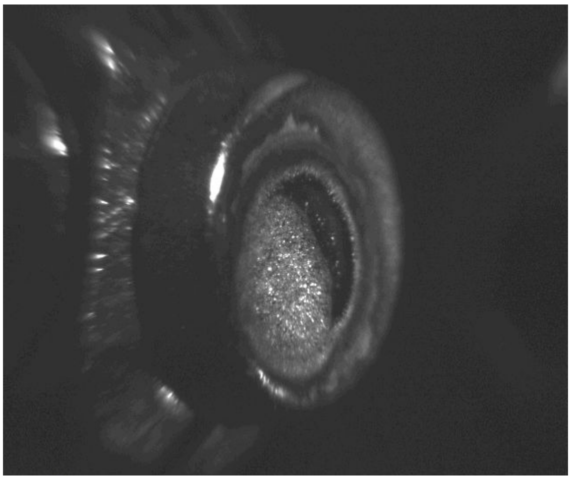

Figure 5 Cathode after 1,199 switching operations

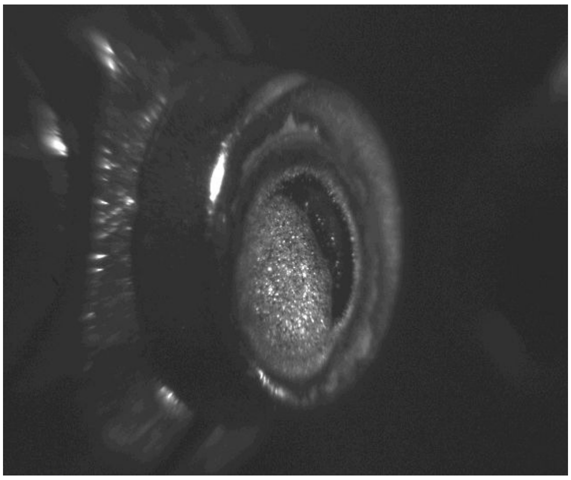

Figure 6 Cathode after 1,200 switching operations

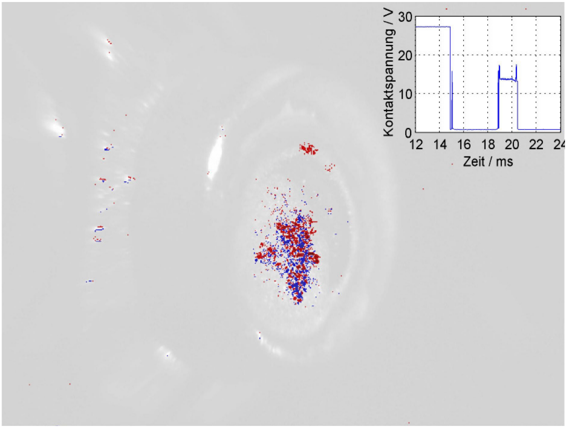

Figure 7 Calculated brightness change after a long bounce

4. RESULTS

4.1. Experiment 1 - Evaluation of the arc root

In Fig. 5 and Fig 6 the Ag1000 cathode after 1,199 and after 1,200 switching cycles is displayed, respectively. Fig. 7 shows the resulting brightness change after this single switching operation.

Additionally, in the upper right corner of Fig. 7, the contact voltage vs. time curve of the 1,200th make operation, i.e. the closing process between the two images of Fig. 5 and Fig. 6, is plotted. During this closing process, a long bounce arc (arc duration of about 1 ms) occurred. This long-lasting arc caused a wide spread modification of the contact surface, as the broad coloured region in Fig. 7 suggests. Therefore it can be assumed, according to [7], that the arc mode changed from an anode- to a cathode-dominated arc during the long bounce.

Fig. 8 and Fig. 9 show the same cathode after 999 and 1,000 switching operations, respectively. Fig. 10 displays the resulting point-wise subtraction of the grey-scale pixel values between Fig. 8 and Fig. 9.

The small coloured area in Fig. 10 indicates a concentrated arc root caused by a short bounce arc. This corresponds to the recorded contact voltage vs. time curve of the make process at switching operation 1,000 (see graph in the upper right corner of Fig. 10). These two observations suggest that the short arc was an anodic arc, which also correlates with [7].

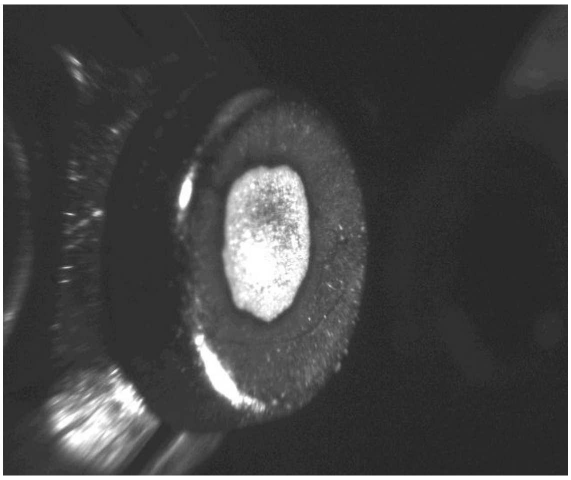

Figure 8 Cathode after 999 switching operations

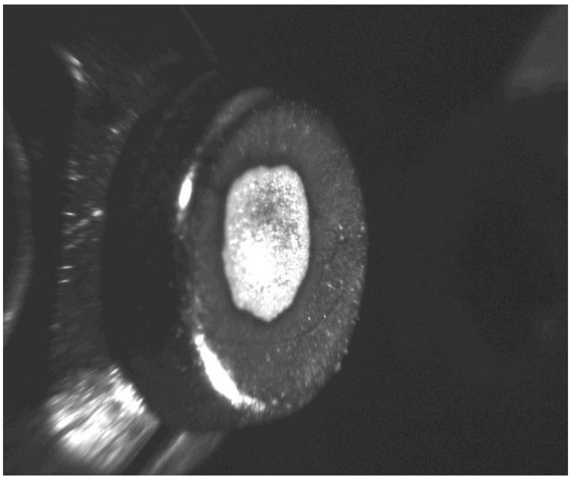

Figure 9 Cathode after 1,000 switching operations

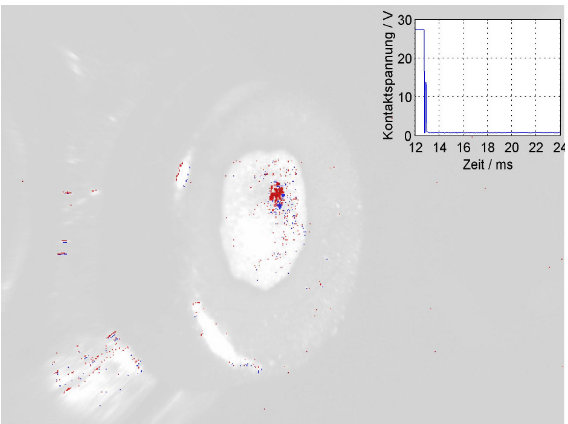

Figure 10 Calculated brightness change after a short bounce

4.2. Experiment 2 - Evaluation of the material transfer

The developed evaluation method need not always calculate the brightness difference between successive switching operations.

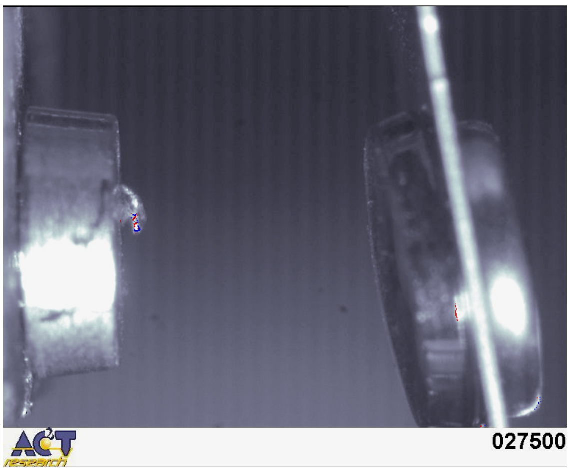

Figure 11 Cathode after 27,500 operations

Figure 12 Brightness change on top of the material transfer pip

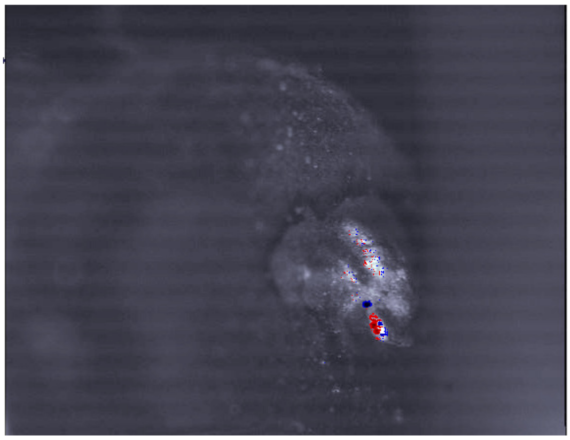

Figure 13 Head-on view of the material transfer pip after 29,932 switching operations

In this example, the step size of operations between two pictures under evaluation was set to 50 cycles. Fig. 11 shows the calculated brightness change and thus the surface modification of the cathode between switching cycles 27,450 and 27500. In the left part of the picture, the cathode with a material transfer pip, and in the right part the anode on the leaf spring are visible.

Fig. 12 shows an enlarged image of the material transfer pip on the cathode. As coloured regions are only superimposed on top of the pip, the material transfer during these investigated 50 switching operations only took place on the displayed overhang nose of the material transfer shape.

Fig. 13 displays the surface modification between two successive switching operations after 29,932 switching cycles. It shows the same contact system from a different angle of view. To see the cathode nearly head-on, the camera position was rotated about 45° counter clockwise. Due to the rotation, the leaf spring of the movable part already moved into the field of view. As the spring was situated out of the focus region it is only visible as blurred region in the right part of Fig. 13. Additionally, a blurred region is visible in the left part of Fig. 13. This is an effect of the high magnification and the resulting small obtainable depth of field, which inhibits focusing on the whole contact rivet when the contact surface and the CCD-chip are skewed. Again, material transfer took place on top of the material transfer pip.

5. CONCLUSION

A new computer-assisted in-situ method was developed to detect qualitative surface changes during a running test series. The only limitations of this method are the resolution of the optical system and the depth of field, especially for material transfer investigations. First experiments showed the capability to visualise changes of the surface topography due to material transfer and arcing phenomena, e.g. anode-dominated and cathode-dominated arcs.

6. ACKNOWLEDGEMENTS

This work was funded by the "Austrian K*plus*-Program" and was carried out at the "Austrian Center of Competence for Tribology" in Wiener Neustadt, Austria.

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8. BIOGRAPHY

Martin Reichart was born in Mödling, Austria. In 2004 he received the academic degree Diplomingenieur für Präzisions-, System- und Informationstechnik (FH) from the University of Applied Sciences Wiener Neustadt, Austria. Since 2004 he has been with the Austrian Center of Competence for Tribology (AC²T research).