doi:10.14311/ppt.2017.3.265
Plasma Physics and Technology **4**(3):265–268, 2017

EXPERIMENTAL TEMPERATURE MEASUREMENTS IN MINIATURE CIRCUIT BREAKER

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Abstract. Low voltage switching apparatuses efficiency depends on the speed of movement of the switching arc from the contacts to the quenching chamber. The paper is focused on investigation of this movement of an arc. Measurement of radiation spectra of the electric arc burning inside miniature circuit breaker and moving to quenching chamber are presented. Measured radiation spectra contain suitable atomic spectra lines for calculation purposes. The problems connected with the measurements are discussed. The main part of the paper deals with a calculation of temperature of the investigated plasma of the arc. Atomic lines database of National Institute of Standards and Technology was used as a spectral data source for the calculations.

Keywords: switching arc, miniature circuit breaker, atomic emission spectroscopy, temperature measurement.

1. Introduction

Low voltage circuit breakers are electrical apparatuses widely used for breaking of short-circuit currents and overloads. Those devices are divided into three main groups: miniature circuit breakers (MCB), molded case circuit breakers (MCCB) and air circuit breakers (ACB). Miniature circuit breakers are the smallest breakers of those groups. These devices are the most common devices in the standard switchboards.

One of the crucial parameters of circuit breaker is a breaking capacity, which depends on arcing time of MCB. Long arcing time may cause damages due to a very high temperature of an arc. On the other hand, short arcing time may create overvoltage across the insulation. Arcing time is affected by movement speed of contacts, arc movement from contact area to the quenching chamber and quenching chamber efficiency. Arc movement between the moving contacts of MCB were experimentally observed recently using laser arc imaging technology [1]. Another approach of an analysis of this phenomenon are computer simulations. Some interesting simulations of the contact opening process were presented in [2]. Simulation of arc movement to the quenching chamber including temperature calculation inside MCB under specific conditions was performed [3]. Temperature maximum was found at about 20 000 K in this simulation.

The temperature of an arc is significant parameter of quenching. The main goal of our measurement was to find out the development of the arc temperature during switching off process because of its effects to the speed of quenching. Optical emission spectroscopy was used as a mean of obtaining the arc temperature inside the MCB. MCBs are usually made of plastic, silver plated copper and ferromagnetic materials which are all affected by the arc. Parts whose are in direct contact with an arc are generally made of copper. Therefore, plasma inside miniature circuit breaker often contains copper vapour, which is clearly visible in its radiation spectrum. It allows calculation of the temperature and other important physical properties using atomic lines of copper.

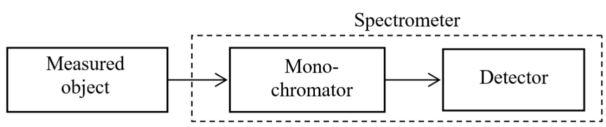

Figure 1. Block diagram of emission spectra measurement.

Block diagram of measuring circuit is shown in Figure 1. Spectrometer was used as measuring instrument. CCD chip is commonly used as a detector.

2. Experimental setup

Measurements were performed in the High current laboratory of the Centre for Research and Utilization of Renewable Energy. 16 MVA three phase asynchronous generator was used as a power supply. Excitation of generator were 13 %. Series of special resistors and coils were used for the current and power factor adjustment. Current flew to the test bench 1 through the 16 MVA high current transformer with conversion rate 4800 V/250 V. Investigated device was miniature circuit breaker with B characteristic, nominal current of 10 A and tripping capacity of 10 kA. Optical fiber was used for necessary separation of measuring devices from the power circuit and transmission of light from a specific position to the input slit of the spectrometer. The Avantes Avaspec ULS-3648TEC was used as spectrometer. Data were stored and processed in laptop using AvaSoft 8.0 software.

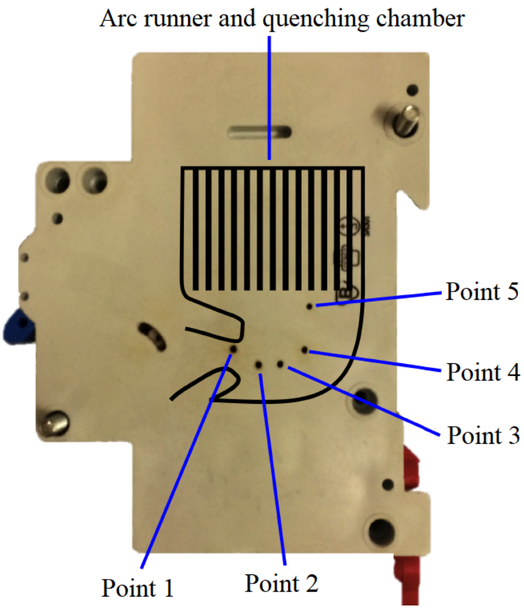

Figure 2. Diagnostic holes positions (investigated points).

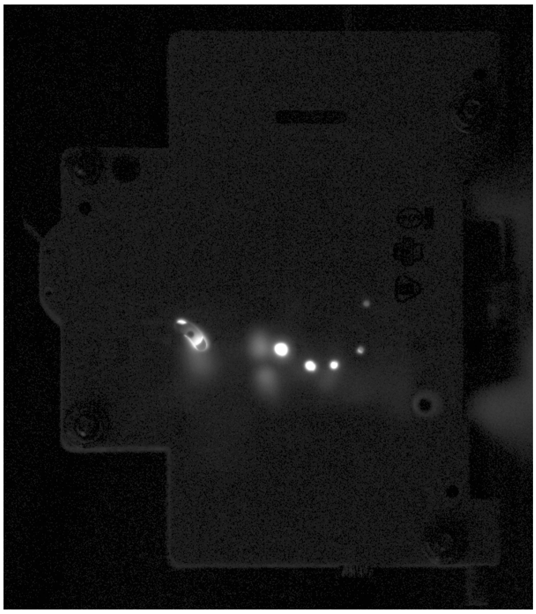

Figure 3. Picture cut out of high-speed video.

The arc was burning inside the circuit breaker, thus small holes were drilled for diagnostic purposes along the arc runner, see Figure 2.

3. Measurement procedure

1. Test circuit were calibrated to these parameters: $U_{\mathrm{ef}} = 42\,\mathrm{V}$, $I_{\mathrm{ef}} = 2.8\,\mathrm{kA}$, $\cos\varphi = 0.5$, $f = 50\mathrm{Hz}$.
2. Calibration of spectral sensitivity of the spectrometer was carried out.
3. Optical fiber was adjusted to the investigated point 1.
4. Test circuit was switched on and the overload was interrpted by the tested sample.
5. Radiation spectrum was saved into the laptop.
6. Procedure from 3 to 4 was repeated several times.
7. Optical fiber was shifted to next point and spectra were saved.
8. Radiation spectra lines were identified.
9. Relative radiation intensities of suitable lines were calculated.
10. Boltzmann plot was created for each point and the temperature was calculated.
11. Temperatures for each point were plotted into the graph ordered from the nearest to the fearthest distance from the contact pair of the breaker.
12. High speed videos of investigated points were taken in second part of measurements.

4. Results and discussion

The high-speed video were taken by a Photron SA-X2 high-speed camera. One picture of the high-speed video is shown in the Figure 3.

In this case, voltage and current were measured by data acquisition system of the laboratory during the test. Waveforms of voltage and current during the one of tests are presented in the Figure 4.

High-speed video in combination with waveforms allow evaluation of important parameters of the test. Evaluated parameters are presented in the Table 1.

Parameter	**Units**	**Value**
Voltage switching peak	(V)	100
Maximum current	(A)	880
Switching off time	(ms)	2.5
Reaction time	(ms)	close to zero
Lever movement delay	(ms)	0.8
Lever movement duration	(ms)	4.2

Table 1. Important parameters of the test.

Example of radiation spectrum can be seen in the Figure 5. Radiation spectrum of copper is suitable for calculation purposes, because it contains appropriate lines. The spectral lines are intensive and have appropriate distance between each other. Copper was probably evaporated from the arc-runner or contacts.

λ measured	**λ database**	**Element**
510.2 nm	510.6 nm	copper
514.9 nm	515.3 nm	copper
520.5 nm	520.9 nm	silver
521.4 nm	521.8 nm	copper
546.2 nm	546.5 nm	silver
577.9 nm	578.2 nm	copper

Table 2. Assignment of elements.

Measured spectral lines were assigned to elements

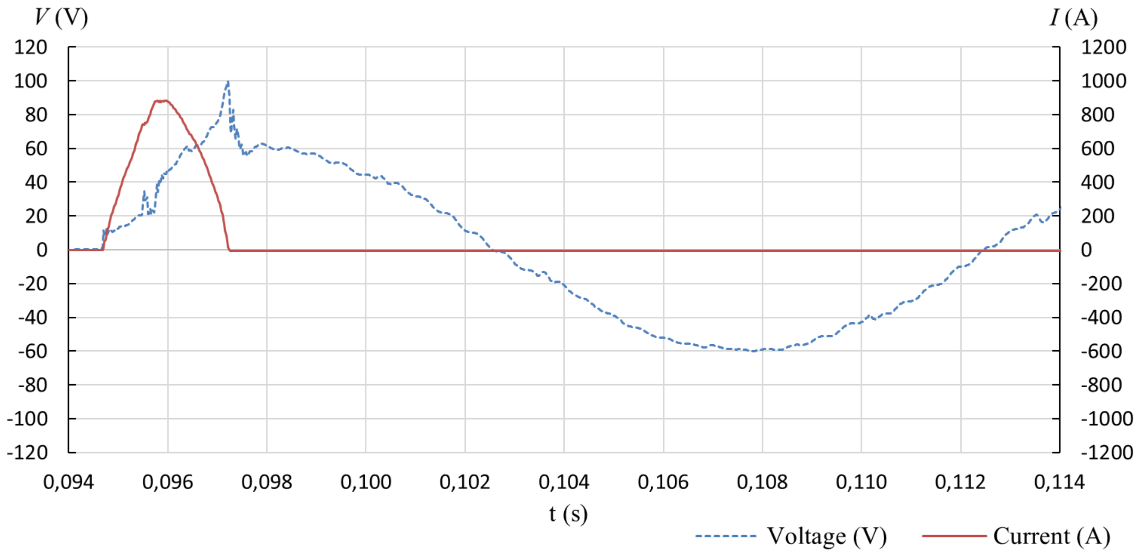

Figure 4. Waveforms of voltage and current during the test.

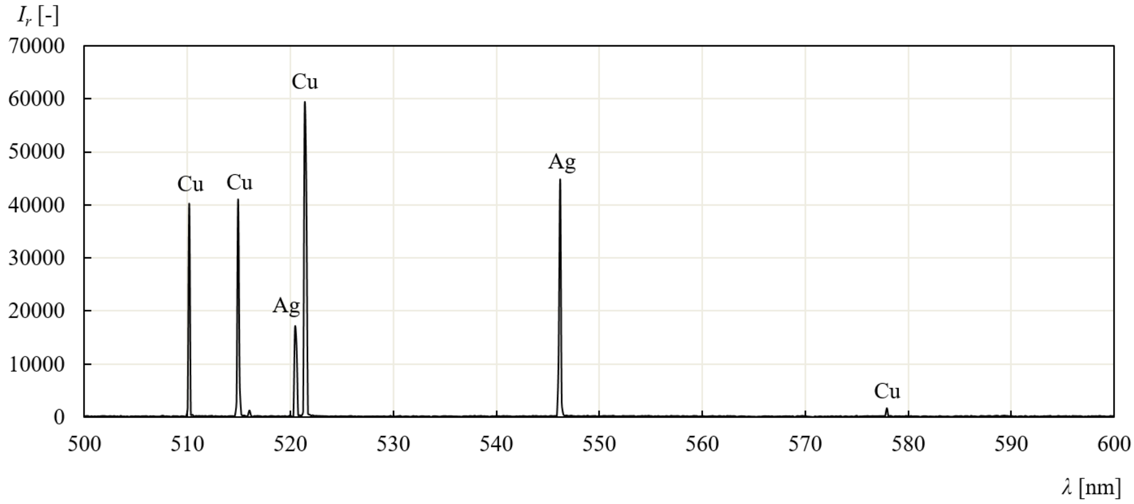

Figure 5. Example of the spectrum measured at the point 5.

using NIST database [4], see table 2 .

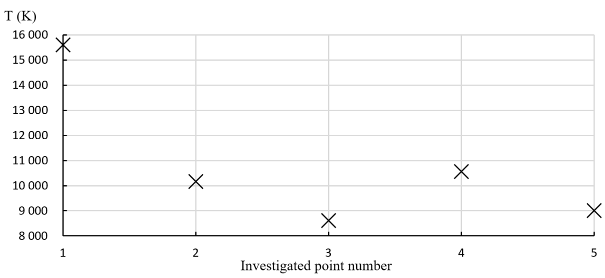

Figure 6. Temperatures measured at investigated points.

Temperatures measured at investigated points are presented in the Figure 6.

The arc temperature was calculated about 15 600 K as maximum temperature near the contact system of the breaker. The temperature sharply decreases with decreasing distance from the contact system to 8 600 K at the point 3. At the point 4, there is an increase of temperature to 10 600 K. At the point 5 temperature decreases to 9 000 K because of splitter plates cooling.

It is important to mention that the temperature calculation may be affected by a few complications. The first one is a spectral lines shape deviation. It depends on spectrometer resolution and measurement conditions. The second problem corresponds with database using. The transition strength and the transition probability, or Einstein coefficient were taken from the NIST database. The NIST database states that the values used for calculations has accuracy of C+ class. That means accuracy more than 82 %.

Another problem is related to the database using again. NIST database cannot cover all experiment conditions of the spectral line measurement. That means that the database contains lines measured under different pressures, humidity, ambient temperatures etc.

5. Conclusions

The aim of the measurement was to find out the temperature of the arc inside miniature circuit breaker during the switching off proccess. Temperatures measured at investigated points are presented in Figure 6.

Atomic emission spectroscopy was used for spectra measurement. High-speed videos helped to find out important times for diagnostic of the breaker behaviour under this conditions. Temperature was calculated from the relative intensity of spectral lines of copper. Calculated values correspond to realistic assumptions, although the calculation contains simplifying assumptions.

Acknowledgements

Authors gratefully acknowledge financial supports from the Ministry of Education, Youth and Sports of the Czech Republic (NPU I programme, project No. LO1210 and faculty project No. FEKT-S-17-4374) and from the Czech Science Foundation under project No. GA 15-14829S.

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