TEMPORAL DEVELOPMENT OF RELATIVE ABLATION OF PLASTICS IN MINIATURE CIRCUIT BREAKER DURING SWITCHING PROCESS

David Simek

Doctoral Degree Programme (5), FEEC BUT

E-mail: xsimek18@stud.feec.vutbr.cz

Abstract: The paper is focused on an ablation of plastic materials in contact with an electric arc inside the electrical apparatus during the switching process. It is possible to obtain temporal development using method based on optical emission spectroscopy. The emission spectra were taken during the switching process. The hydrogen alpha spectral line of Balmer series was used as an indicator for evaluating of plastics ablation. Complications connected with the measurements are discussed. The main part of the paper deals with a temporal development of relative concentration of a hydrogen in plasma inside the miniature circuit breaker. Atomic spectral lines database of National Institute of Standards and Technology was used as a spectral data source for evaluation.

Keywords: optical emission spectroscopy, plasma, miniature circuit breaker, electric arc

1 INTRODUCTION

A great increase in electrical devices in households, as well as in companies has been noticed over the last few decades. Market supply is growing, with increasing customer demand [1]. The price for each product decreases with an increasing series of each product manufactured in serial production because the costs for research and design are divided between more and more pieces of goods. Thus, products become more accessible and sales quantity increases, and the cycle is repeated.

The demand for electric power distribution increases with an increasing number of installed devices. A probability of fault also increasing. Faults may be sorted into a lot of groups according to different criteria. The main four groups are overvoltages, series arcs, and dangerous leakage currents and overcurrents. There are some devices designed for discovering these faults as fast as possible and protection against dangerous consequences of them.

The protection devices have a wide variety of principles and constructions. However, most of them have one common construction task, they must break the electrical circuit in case of a fault. Nowadays some companies are trying to use constructions with semiconductors for this purpose [2], but this solution has a few limitations [3]. The most significant limitations are the losses and a price. Problems with losses are typically solved using a hybrid solution. Principle scheme of hybrid solution is shown in the figure 1.

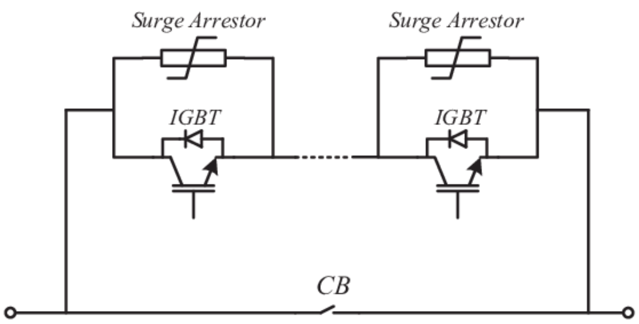


Figure 1: Principle scheme of hybrid circuit breaker [4].

The hybrid solution combines classical switching devices with contacts and semiconductor devices [5]. On the other hand, it is still not possible to use these devices for low-cost applications due to their high price, for example in assemblies for households.

However, despite the low price, these applications must be safe. Thus, the most crucial parameter is the rating between price and reliability.

Many companies focusing on increasing reliability and decreasing the expenses connected with the manufacturing of the devices. This paper is focused on this aim.

Classical devices using an electric arc for releasing energy accumulated in the electrical circuit during the switching off process. The arc has a high temperature, typically a few thousand Kelvins [6]. Thus, the reliability of these devices is mostly affected by the dynamic and thermal effects of the arc. This article is focused on the thermal stress on plastic materials in a miniature circuit breaker (MCB) construction. Damaged plastic materials are the second most common problem leads to MCB malfunction (note: the first one is a degradation of contact material).

Damage rate of plastics depending on their behavior during the contact with the arc. This behavior is mostly affected by the arc temperature, type of the material and duration of the contact. The plastics are being melted and ablated during the contact with the arc. Melting and ablating rate decreasing plastics lifetime.

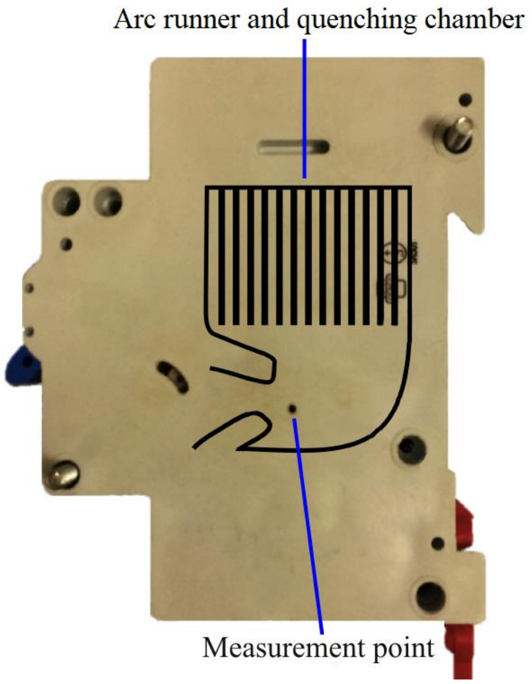
There are several methods for evaluating of the ablation of plastics.

The most common method is based on placing small pieces of plastics with defined weight into contact with an electric arc for a defined period. The mass loss is typically measured after each period using sensitive scales. The biggest disadvantage of the mass loss method is that the result is mass loss during the one whole procedure without any temporal resolution. The second disadvantage of this method is the impossibility of application on a real series device because the parts have weights over the range of most scales with a sensitivity suitable for ablation study. On the other hand, the advantage is that the result is the absolute mass loss of the examined material. This method is not the topic of the article, because the aim was temporal development of relative ablation rate.

The optical emission spectroscopy was chosen as a suitable method for the study of the temporal development of the relative ablation rate. This method is a powerful tool for non-affective experimental research on radiative objects. Optical emission spectroscopy is based on the measurement of radiation of the arc plasma. Radiation of the arc is mostly caused by self-deexcitation of atoms excited during inflexible collisions.

2 EXPERIMENTAL SETUP

The experiment was performed in High current laboratory of Centre for research and utilization of renewable energy at Brno university of technology. The power source was a synchronous generator with a maximum power of 16 MVA, rated speed of rotation is of 1000 RPM/50 Hz. An examined electrical device is a miniature circuit breaker with B type characteristic. Rated current of the breaker is 10 A and tripping capacity of 10 kA. Optical measurement was shoot in the measurement point close to the contact area, see figure 2. This area is the most stressed by the arc.



Optical emission measurement was performed using monochromator Andor Shamrock 500i in the Czerny-Turner configuration. CCD Camera Newton 940 was used as a detector. The resolution of the monochromator is given mostly by used dispersion grating. Dispersion grating with a groove density of 1200 l/mm was used. Order of the devices was according to figure 2.

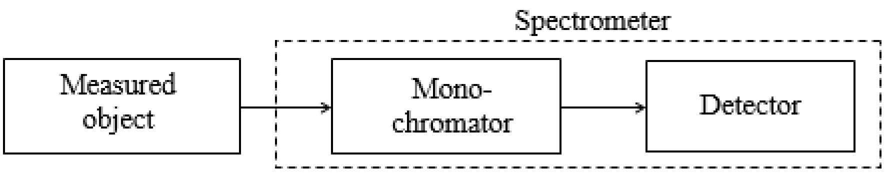


Figure 2: Block diagram of spectra measurement.

Test circuit parameters were adjusted according to table 1.

parameter	value
effective voltage	42 V
current	2800 A
frequency	50 Hz
power factor	0.5

Table 1: Experimental circuit parameters.

The breaker was placed on the testbench and connected to the circuit with presumed current according to the voltage and loads combination. The lever was turned into on position. The voltage was applied. The breaker magnetic tripping unit tripped the breaker and the breaker interrupted the circuit. Radiation spectra were taken during breaking process.

3 RESULT AND DISCUSSION

Emission spectra were taken with a focus on the hydrogen alpha line. Stored data were corrected using correction on wavelength and intensity. Corrected spectra were normalized, see figure 3.

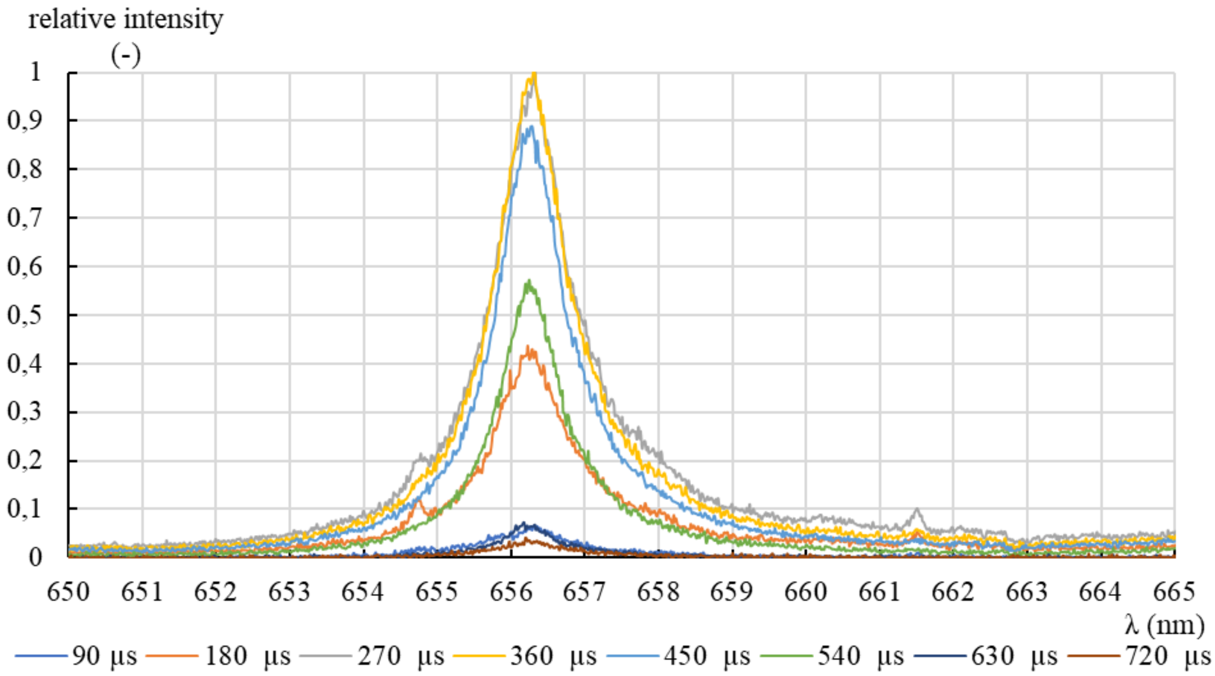


Figure 3: Temporal development of a hydrogen alpha line in the examined point.

Figure 3 contains the temporal development of a hydrogen-alpha line in the examined point. The whole switching procedure takes about 2.5 ms. Hydrogen spectra are presented only in the duration of 720 µs. This is caused by the position of an arc.

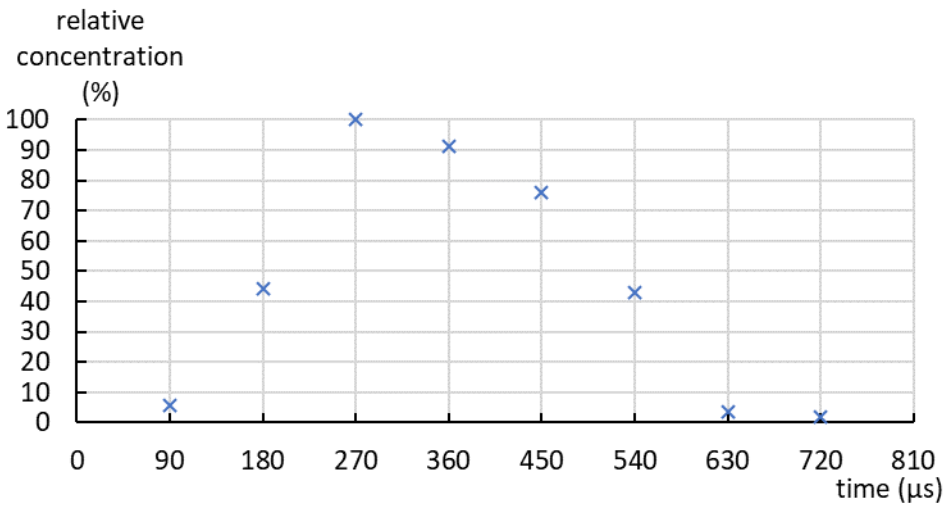


Figure 4: Temporal development of a hydrogen concentration inside the breaker.

Figure 4 shows the temporal development of a hydrogen concentration in the breaker. There is almost no ablation of plastics at the very beginning of the switching. This is caused by the dynamics of contacts. Thus, the arc burning only in evaporated contact material. There is a sharp increase in concentration from 90 to 270 µs. This section is critical for the damage of the plastics around the critical point. The concentration slowly decreasing from this point similar to the cooling curve. This indicates almost no ablation of the examined material.

There were some complications that had to be solved before experiments.

The first complication was a pressure leak through the measuring hole. Changed pressure can affect the switching process. Also, the particles may damage the optical fiber. We solved this using a piece of plexiglass.

The second problem was plexiglass used for the solution of the first complication because this plexiglass also emitting particles into the plasma and distorts results. The best solution is silicate glass for this purpose. Silicate glass has almost no attenuation around the whole visible spectrum and it has good temperature resistance. Bohr-silicate glass was used because of its properties close to pure silicate glass and series production for microscopes.

4 CONCLUSION

The aim of the experiments was to find out the relative ablation rate of the plastics in the critical point of the miniature circuit breaker during the switching process. The optical emission spectroscopy method was used for this purpose. This method is suitable for relative ablation rate findings. Ablation is represented by the hydrogen alpha relative concentration inside the breaker. Relative concentration is presented, see results in figure 4. The main result of the measurement is that the hydrogen concentration was significantly decreased after 600 µs of the experiment. That's mean that the damages on the material are being caused during this time and there is almost no hydrogen concentration when the arc is in the quenching chamber. A solution to decrease damages on the plastics is innovated arc runner leads to faster movement of the arc to the quenching chamber.

The next step is going to be devoted to the absolute ablation rate using a combination of optical emission spectroscopy and precise mass loss measurement.

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