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# DIAGNOSTICS OF VARIOUS PHENOMENA IN LV DEVICES UNDER REAL SWITCHING CONDITIONS

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**Abstract.** The article deals with issues to be tackled when performing experiments with low voltage devices under real switching conditions and subsequently discusses various phenomena in an experimental device. The first part describes optimum setting of diagnostic equipment - mainly for optical diagnostic methods. The second part describes some phenomena encountered during switching process under real switching conditions – arc roots movement (cathode and anode spots). These phenomena are not only important for experimental study itself but also form necessary input data for numerical models and their validation.

**Keywords:** electric arc, optical diagnostics, high speed video, arc root movement.

## 1. Introduction

When performing experiments in low voltage devices to study various phenomena under real switching devices, one has to get over effects affecting considerably quality of information gained. One of the most widespread method of arc study is based on optical diagnostics with the usage of high-speed camera. Here, the extreme light intensity accompanying arc burning at short-circuit currents and its variation plays a crucial role. Usually special filters like neutral density filters and bandpass filters are combined to get optimum result. The question is how to choose combination of camera setting (lenses, shutter time, iris) and filters close to the optimum from the very beginning for various phenomena to be studied and large scale of testing parameters (currents ranging from A to several tens of kA). The paper provides partly an answer to this question at the first part.

Arc extinguishing process in low voltage devices is usually connected with magnetic field influence on arc moving towards quenching chamber. The arc movement is also significantly influenced by arc root behavior - both on contacts and possibly various types of arc runners. This phenomenon is quite a complex one and very difficult to be accurately modeled in numerical models [1, 2]. To verify the models, a lot of experiments (statistical values) have to be carried out. To shorten the time necessary to evaluate a lot of data, a special code in Matlab software was prepared.

To take into account this phenomenon in the numerical model, a lot of experimental data are needed. Some of the experimental results are presented in this paper.

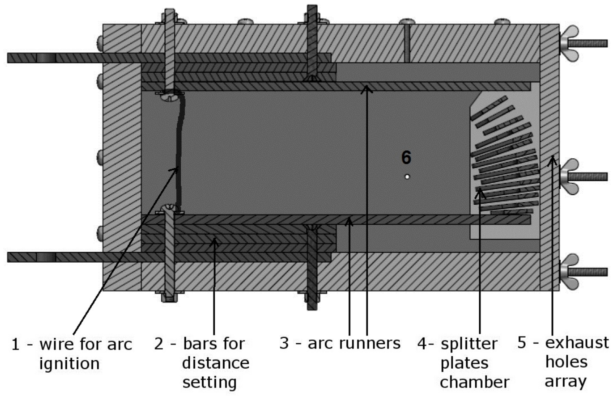


*Figure 1. CAD model of the device used for experiments.*

## 2. Experiment setting

### 2.1. Experimental model

Fig. 1 shows the model used for both optimal diagnostic equipment setting and arc root movement study. The model enables to perform experiments with currents up to 10 kA, measure pressure at three points (6), change exhaust array (5) (number and diameter of the holes on the right side of the model) behind the chamber, change space between arc runners (3) by adding auxiliary bars (2). The arc is ignited on the left side of the model by a small wire (1) and moves towards the chamber (splitter plates) (4) on the right side by the action of magnetic forces created by the loop of the current path. For optical diagnostics, front side and possibly left side is formed by PC transparent material. One has to consider that this type of material absorbs UV part of arc spectra!

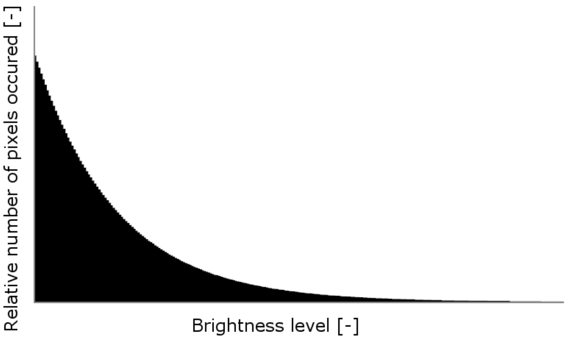


*Figure 2. Optimal histogram for switching arc.*

### 2.2. Optimal setting of the diagnostics equipment

When using high speed video for switching arc diagnostics, one has to set properly not only e.g. field of view, depth of field and sharpness, but also the right exposition. The preliminary right exposition could be easily checked by the histogram of the data obtained. For each situation, a different type of histogram is optimal. Regarding switching arc, it was found that optimal histogram should be close to the Fig. 2 – decaying exponential function.

Due to the high intensity of switching arc radiation, various filters have to be used. To estimate their setting (in $EV$) the following procedure was found to be useful [3]. From several experiments performed, with currents ranging from 3000 to 7600 A, the useful formulas for preliminary setting of the camera exposition was found. As it results from the experiments, the expected switching arc exposition could be estimated from the following formula (exposition expressed in $EV$):

$$EV_{\text{arc}} = 37.33 + 1.33 \cdot \Delta I + \Delta EV_{\text{reflection}} \quad (1)$$

In eq. (1) $\Delta I$ stands for the difference between the maximum current tested and 5000 A. $\Delta EV_{\text{reflection}}$ stands for influence of background material other than matt black – e.g. a gray middle reflective material could be considered to be equal to 4. Eq. (1) is valid for spectrally neutral transparent viewing window. Thus, for example for test current of 10 kA and gray middle reflective material we have $EV_{\text{arc}} = 42.66$.

The exposition of the camera itself can be expressed by the following equation:

$$EV_{\text{cam}} = \log_2 \frac{100 \cdot f^2}{\text{ISO} \cdot t} \quad (2)$$

In eq. (2) $f$ stands for focal ratio of the lens used (including iris), ISO sensitivity of the camera sensor and $t$ time of the electronic shutter used. E.g. for the camera used: ISO equates to 25 000, $t$ is set to 293 ns, and $f = 16$, gives $EV_{\text{cam}} = 21.74$. The required exposition shift of the filters can be then estimated from the simple formula:

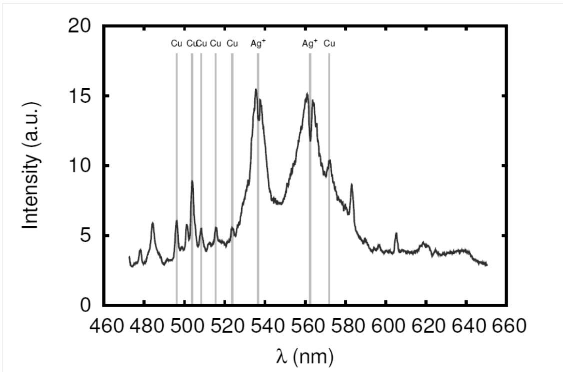


*Figure 3. Arc spectrum measured in the experimental model.*

$$EV_{\text{filter}} = EV_{\text{arc}} - EV_{\text{cam}} \quad (3)$$

Using (3), we obtain the required filter shift $EV_{\text{filter}} = 20.92$

This can be simply done by neutral density filters only. However, when the particular phenomena like arc roots want to be studied, a combination of bandpass filters and neutral density filters is more convenient. Fig. 3 shows the spectrum of the arc done with the model above in CVVOZE Power Laboratories. One can notice significant line of $Ag^{+}$ resulting from the contacts. If we want to enhance arc root tracking, usage of bandpass filter like 540/10 nm is of great advantage – see section 3. Furthermore, bandpass filters are often used together with laser light for background illumination of mainly mechanical events [4].

## 3. Arc root movement

### 3.1. Arc root movement automatic evaluation

Due to a lot of experiments performed and a lot of data (individual pictures) within an experiment, it is necessary to evaluate automatically arc roots movement. The program for this purpose was prepared in MATLAB code [5]. The principle of arc root evaluation is briefly explained in Fig. 4 - 6. Fig. 4 shows the original picture extracted from high speed video. By special algorithm, this pictured is converted into black-and-white (binary) regime and for each spot the centre is being found - Fig. 5. Subsequently by another part of algorithm, the individual cathode and anode spots are identified - Fig. 6.

### 3.2. Arc root movement example

Fig. 7 shows an example of arc root movement along the arc runners from the ignition point towards the quenching chamber. The high speed camera was set to 50000 fps. The distance between arc runners was 65 mm, behind the chamber 3 openings of 9 mm in diameters were used to set up the pressure. Maximum tested current value is 6 kA. It is evident that cathode spot is moving towards the chamber by the action of

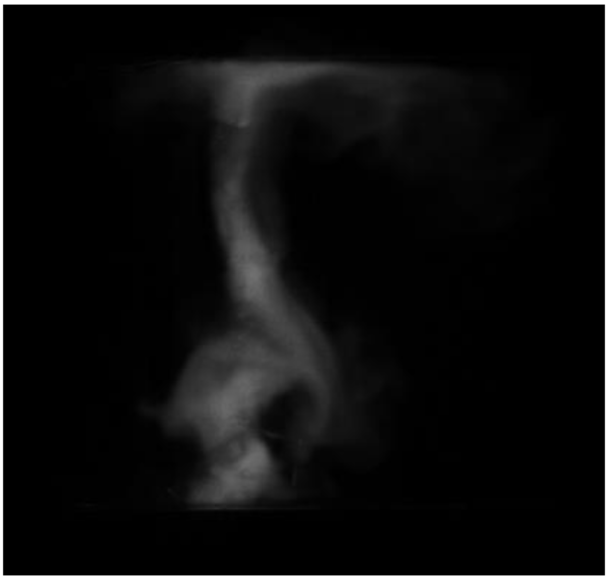

*Figure 4. Single picture extracted from high speed video - raw data.*

magnetic field with several jumps (marked by cycles), which corresponds to the theory of thermoemission principle of cathode spot creation. The anode spot, on the other hand, moves quite smoothly, which is also expected. There is only one step (marked by a cycle), which is caused by pressure (reflection from the side cover behind the chamber). The position of the anode spot runs ahead of the cathode spot most of the time.

### 3.3. Influence of parameters on arc root movement

Several influences on arc roots movement were studied. Fig. 8 shows the influence of pressure conditions on average velocity $v_{\mathrm{avg}}$ of arc spots. The pressure conditions were changed by changing the array of exhausts on the right side cover (behind the chamber) - change of the holes number and their diameter. The distance between arc runners was 65 mm. The general trend is that with the higher pressure both the spots have lower velocity - it corresponds to the fact, that with higher pressure the aerodynamic resistance against arc movement is higher while the electromagnetic force acting on the arc (it has opposite direction) could be considered constant. The exceptions can be seen for very small pressure (the higher local pressure accelerates the arc) and high pressure (reflections from the side cover causes rapid backward movement mainly of the anode spot which moves more easily). Fig. 9 shows the influence of arc runner distance on arc movement. Both the cathode and anode spots move slower as the distance increases. The main reason is the increase of aerodynamic resistance (higher cross section of the arc from the side point of view). This influence overcomes the small increase of the overall arc force due to electrodynamic forces with increase of the distance.

*Figure 5. Binary transformed picture.*

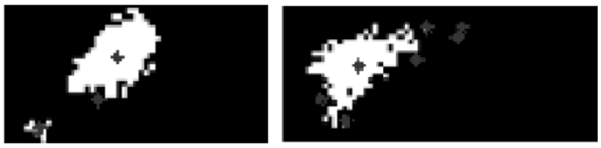

*Figure 6. Identification of the center of cathode (left) and anode (right) spot.*

## 4. Conclusions

The paper describes optimal setting of various parameters for high speed video usage to study switching arc under real switching conditions. Special attention was paid to proper selection of combination of neutral density filters and band pass filters to study arc root movement. Based on this setting, the study of arc roots movement and influences affecting the arc root movement were evaluated. For automatic arc root movement evaluation, a special program in Matlab code was prepared. The paper shows the influence of pressure in the chamber and distance between electrodes on arc root velocities. The figures of velocities

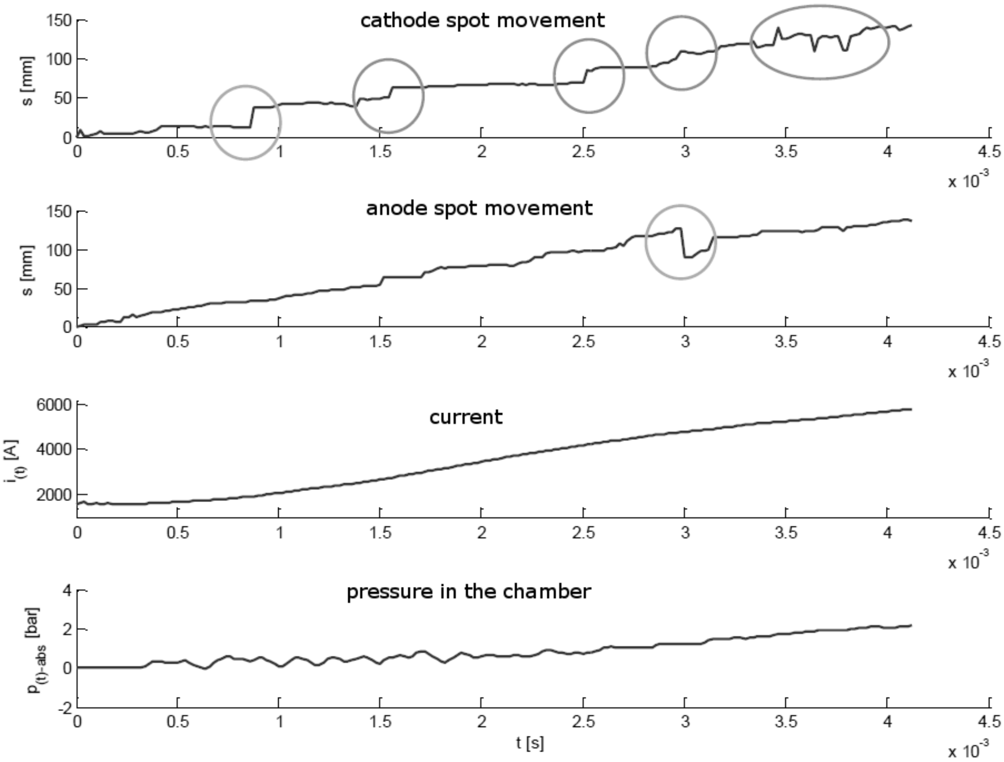


*Figure 7. Arc root movement evaluation.*

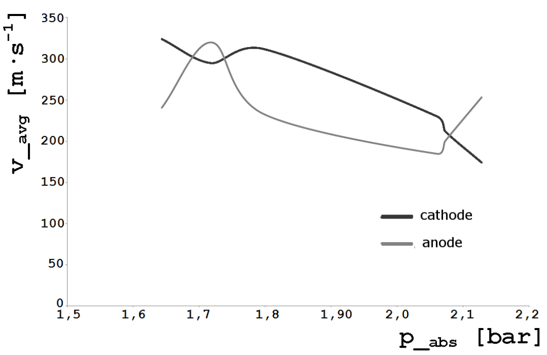


*Figure 8. Influence of pressure on arc root movement.*

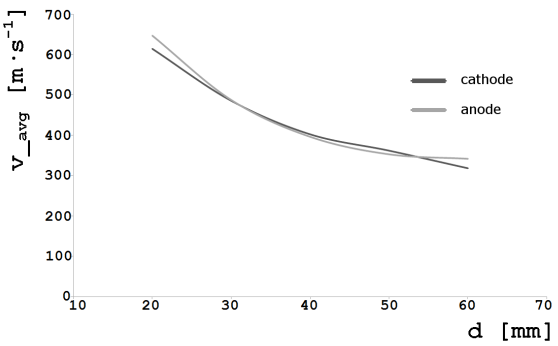


*Figure 9. Influence of distance on arc root movement.*

and several jumps in characteristics are valid for the experimental model only, but the general trends can be expanded to any other geometry and volume of the quenching chamber.

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