INVESTIGATIONS ON THE INTERACTION BETWEEN SWITCHING ARC AND QUENCHING GAS IN INSULATING NOZZLES BY OPTICAL MEASUREMENTS

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ABSTRACT

The optimization of today's switching technologies as well as the development of new switching technologies require a deep understanding of the physical processes during the current interruption process. Optical measurement methods – in this contribution the background-oriented schlieren method (BOS) – allow a quantitative determination of the physical properties gas density and temperature around current zero. By this method optical measurements of the switching arc in a circuit breaker model are performed with current amplitudes of $I_{peak} = 3.5$ kA in air at ambient pressure with exposure times down to 200 ns. Recordings are taken either from one or from two viewing directions and density profiles are reconstructed by filtered back-projection. Characteristic changes in the flow structure, e.g., the position of the Mach disc before and after current zero are, identified. The results of CFD-simulations (computational fluid dynamics) are found to be in agreement with the measurements.

1. INTRODUCTION

The optimization of the established SF_6-based (sulphur hexafluoride) switching technologies, as well as the investigation of possible future substitutes for SF_6, both require a deep understanding of the physical processes associated with the interruption process in high voltage circuit breakers. Up to now these processes can be only accessed by the measurement of current and arc voltage. The arc resistance distribution can also be measured [1]. By these methods no spatially resolved measurement of gas density and temperature inside the nozzle system is possible. In order to get access to these physical properties inside the nozzle system of a gas circuit breaker, an optical investigation method, based on the background-oriented schlieren method (BOS), was developed in previous investigations [2]. In this contribution this method is applied to an axially blown switching arc in a circuit breaker model.

2. PRINCIPLE OF THE BOS-METHOD

The background-oriented schlieren method is a modification of the schlieren method. In contrast to the conventional schlieren method, here the experimental setup only consists of a structured background pattern, a light source for illuminating the pattern and a camera (see figure 1) [2, 3].

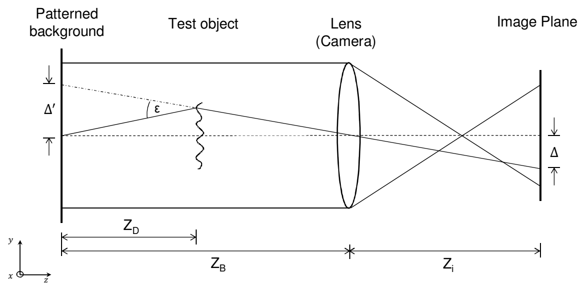

Fig. 1 Schematic drawing of the setup for the background-oriented schlieren method

Due to light refraction by the test object the background pattern seems to be virtually shifted compared to a reference recording of the background pattern [2, 4]. From this shift the deflection angles ε can be determined and a reconstruction of the three-dimensional distribution of the refractive index of the test object is possible by filtered back-projection. Based on the refractive index distribution, gas density and temperature profiles are deduced by material data tables [2].

3. EXPERIMENTAL SETUP

The BOS method is applied to the switching arc inside a circuit breaker model (see figure 2). The circuit breaker model is equipped with two plug electrodes made of tungsten-copper (WCu) and a PTFE (polytetrafluorethylene) nozzle system. Furthermore, a mixing volume is attached to the nozzle system. Gas is supplied from two external vessels with a volume of V = 20 l each. For the generation of the switching arc the high current part of a synthetic test circuit is used. The experiments are performed with $I_{peak} = 3.5$ kA in air at ambient pressure. The blow gas system is adjusted to achieve a blow gas pressure of approximately $\Delta p = 0.7$ MPa in the mixing volume.

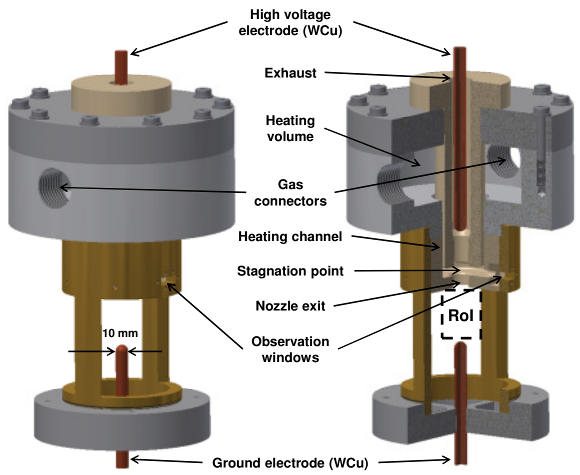

Fig. 2 Cross-sectional view of the circuit breaker model. The region of interest (RoI) for the evaluation of the measurements is indicated by the dashed square.

Optical measurements are performed at the area between nozzle exit and ground electrode using a PCO SensiCam 370 LF with exposure times down to 200 ns. For measurements from one viewing direction the optical setup is arranged according to previous investigations [2].

A mirror system M1 to M4 is added to the optical setup to allow measurements from two viewing directions with one camera according to figure 3. This approach results in a reduction of the image resolution, as a coarse background-pattern – increase of the dot size by a factor of approximately three compared to the one perspective setup – has to be used to ensure the interpretability of the measurement results.

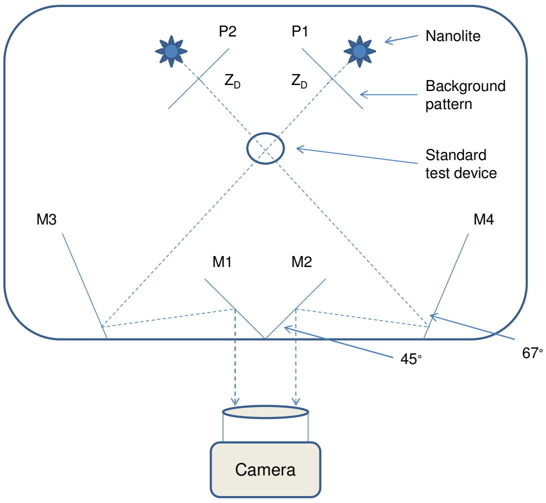

Fig. 3 Schematic drawing of the experimental setup for two viewing directions

4. DENSITY RECONSTRUCTION

From the recordings of the SensiCam, information about the test object, i.e. the switching arc surrounded by the quenching gas flow, is obtained in one image plane in case of the measurement from one viewing direction. In case of measurements from two viewing directions, this information is obtained in two perpendicular image planes as shown in figure 3. The principle behind the reconstruction is illustrated in figures 4 and 5. The reconstruction is based on the inverse Radon transformation [2]. The information recorded in the image plane, the so-called projection ("1-3-5"), is used for the reconstruction of the three-dimensional density field. The reconstruction is performed over 180° in angular steps of $\Delta\theta_i = 0.25°$. For these discrete angular steps the values, which result from the corresponding projection ("1-3-5") at the angle θ_i, are added to each grid point or square-shaped subsection, respectively in the line of sight. The reconstruction grid presented in figures 4 and 5 as an example consists of nine square-shaped subsections. The physical values are obtained by normalizing the obtained sum in each square-shaped subsection to the number of projections.

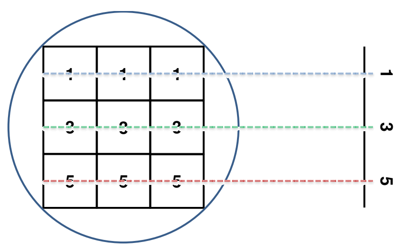

Fig. 4 First back-projection with $\theta_1 = 0°$

For the setup with one viewing direction the same projection is used for each back projection step under the assumption of ideal rotational symmetry in a first approach. In case of the arrangement with two viewing directions one projection is used for the first half of the angular steps, while the other projection is used for the second half.

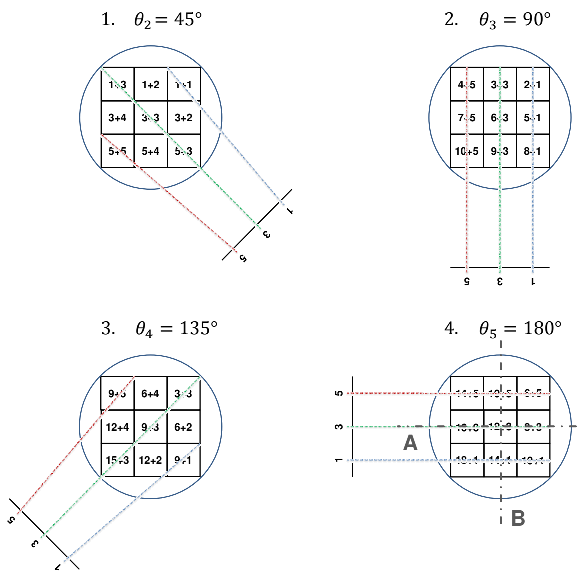

Fig. 5 Principle of the reconstruction from projection data

Two cross-sectional views A and B of the reconstruction are used for the analysis as indicated in figure 5. Strong asymmetries in the reconstruction can be identified by comparing view A and B.

5. RESULTS AND DISCUSSION

The results of the reconstruction of an arc measurement at $t_{beforeCZ} = 33.3$ µs before current zero from one viewing direction are depicted in figure 6. From these, increased density values in the range of $\rho = 4$ kg/m^3 at $z = 0$ mm and $x = \pm 3$ mm at the nozzle exit are observed due to the high pressure of the expanding gas at the nozzle exit. Moreover, a turbulent cooling due to the mixing of hot and cold gas is noticeable at the free jet boundary located at $x = \pm 7$ mm for all z positions in both cross sectional views. In addition to the determination of the three-dimensional density distribution, the calculation of a shadowgram from the measurement data is possible. Two arc measurements, one before and one after current zero, are compared in figure 7. Before current zero an upstream shift of the Mach disc is observed with respect to the after current zero measurement. After current zero a shift of the Mach disc back towards the cold flow position, i.e. the position detected during a measurement without electric arc, is found.

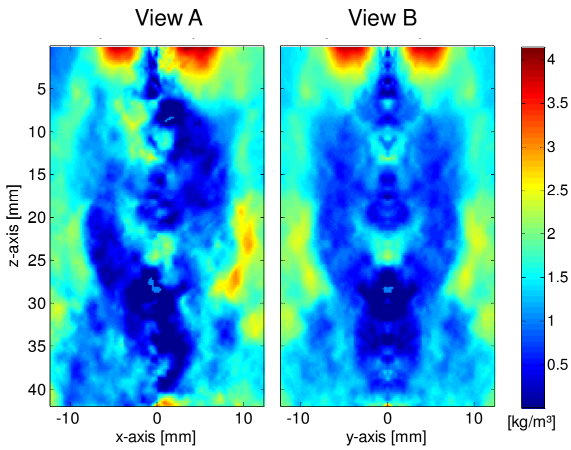

Fig. 6 Reconstruction of the density distribution of an arc measurement recorded at $t_{beforeCZ} = 33.3$ µs (one viewing direction). The position z = 0 mm is located near the nozzle exit (see figure 2).

This transition of the Mach disc is in agreement with previous investigations [5], and results from the changed mass flow through the nozzle exit during the high current phase. Here further investigations are necessary in order to determine the influence of the arc diameter on the flow structure. Additionally, turbulent mixing at the free jet boundary between hot gas and cold blow gas flow can also be identified from the shadowgrams.

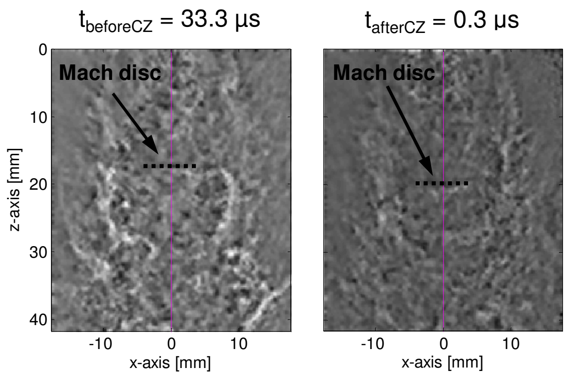

Fig. 7 Comparison of the Mach disc position for two measurements before and after current zero. The position z = 0 mm is located near the nozzle exit (see figure 2).

In addition to the results obtained from one viewing direction an exemplary density reconstruction with two viewing directions recorded at $t_{afterCZ} = 14.3$ µs after current zero is depicted in figure 8. In comparison with the recordings from one viewing direction a loss of resolution is observed in the density reconstruction resulting from the use of a coarse background pattern as described in section 3. An improved localization of the decaying plasma channel is possible from cross-sectional view A and B compared to the measurements with one viewing direction. Nevertheless the position of the Mach disc and the turbulent mixing at the free jet boundary can be identified more clearly from the measurements with one perspective. Thus in future investigations an increase of the resolution is necessary for the setup with two viewing directions.

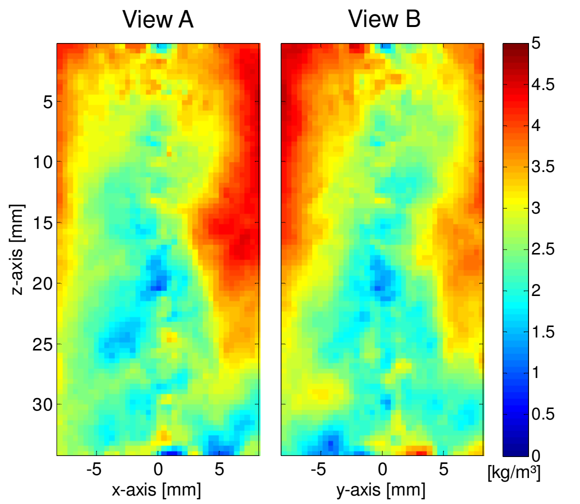

Fig. 8 Reconstruction of the density distribution of an arc measurement recorded at $t_{afterCZ}$ = 14.3 µs (two viewing directions). The position z = 0 mm is located near the nozzle exit (see figure 2).

Finally, the results of CFD-simulations of the circuit breaker model agree with the density values obtained from the reconstruction. The characteristic shift of the Mach disc as well as the position of the free jet boundary can be identified from the simulation results as shown in figure 9.

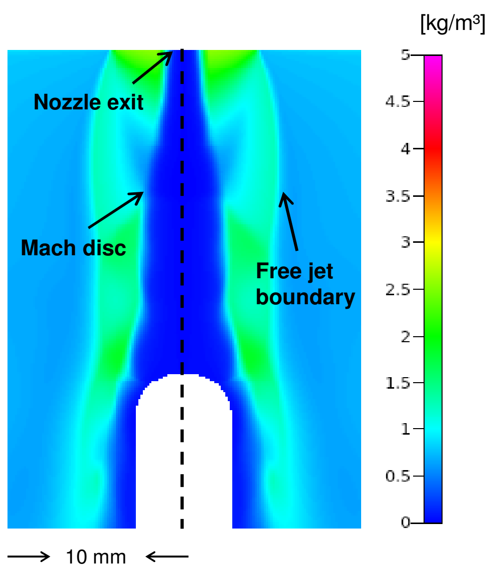

Fig. 9 CFD-simulation of the investigated circuit breaker model at $t_{beforeCZ}$ = 16 µs

6. SUMMARY AND OUTLOOK

In this contribution the interaction between switching arc and quenching gas was investigated, applying the BOS method for measurements with one and two viewing directions. From the results a characteristic upstream shift of the Mach disc was observed before current zero as well as turbulent mixing at the boundary layer between arc plasma and blow gas flow. The extension of the experimental setup to measurements with two viewing directions results in an improved localization of the hot gas remaining around current zero from the high current phase. However, an increase of the image resolution is required in future investigations and can be achieved by using two cameras. The technique could also be expanded to more than two viewing directions.

ACKNOWLEDGEMENT

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