Application of Background Oriented Schlieren method for diagnostics of surface discharge

I Korotkikh\(^1\), Yu Malakhov\(^2\) and N Skornyakova\(^3\)

\(^1\) Physics Department, National Research University “Moscow Power Engineering Institute”, Moscow, 111250, Russian Federation
\(^2\) Physics Department, National Research University “Moscow Power Engineering Institute”, Moscow, 111250, Russian Federation
\(^3\) Physics Department, National Research University “Moscow Power Engineering Institute”, Moscow, 111250, Russian Federation

Abstract. The results of visualization of an electrical discharge arising on the surface of glass or plastic are presented. This type of discharge is used for formation, research, control the parameters of ozonizers; as a source of ultraviolet radiation; in the study of the parameters around surfaces of gas or plasma flows. The possibility of using the background oriented schlieren method for determining the temperature field of a surface discharge is shown in paper.

1. Introduction
The object of research in this paper is an electric discharge arising on the surface of glass or plastic, the work was performed using a high-speed digital video camera. Discharges of this type are often used in the formation, research and control the parameters of ozonizers to ensure their stable operation. Highly efficient ozone generators are increasingly being used for water purification. Practical interest to this discharge is also related to the problem of the insulation preservation (increasing its electrical strength breakdown by superficiality) and elimination of fuss discharge plasma on the skin of aircraft devices, and with solving the problem of obtaining the discharge in multichannel and diffuse form. In addition, these discharges are used as a source of ultraviolet radiation, as well as in the study of gas or plasma flows around surfaces.

2. Object of study
In this research the special experimental cell was constructed. This cell consists of a glass plane-parallel plate and copper electrodes. Breakdown occurs in air media at atmospheric pressure at the frequency of 12.5 kHz, the amplitude of breakdown voltage can be varied in the range of 10-15 kV. The discharge current is up to 10 A, and the alternating current frequency is 10-15 kHz. Ionization and air glow take place between two flat electrodes, forming a plasma “sheet”.

The surface discharge in experimental cell is formed as a result of breakdown between the cathode and anode in air at atmospheric pressure. The discharge occurs on the surface of glass or plastic cells located vertically, perpendicular to the main optical axis of the system. High-speed video recording of the formation and evolution of a surface discharge is carried out using a Fastec HiSpec-1 digital video camera and a CMOS lens with a focal length \(F = 50\) mm, that is necessary to create an image of surface discharge on the matrix plane [1]. The resulting images are sent to a personal computer. A rectangular hole is cut in the surface of the cathode of the discharge cell, it is used for recording and further determination of the temperature field using the background oriented schlieren method.
The schematic diagram of the discharge cell for studying of the surface discharge is shown in Fig. 1.

![Schematic diagram of a discharge cell for studying the surface discharge.](image)

**Figure 1.** Schematic diagram of a discharge cell for studying the surface discharge.

1 - black matte background screen, 2 - cathode of discharge cell (DC component), 3 - high-voltage power supply, 4 - anode of discharge cell (DC component), 5 - anode of discharge cell (AC component), 6 - laboratory transformer, 7 - high-speed digital video camera with interference filter, 8 - personal computer with software.

3. High-speed visualization of surface discharge

The high-speed registration of the surface discharge was carried out at a frequency of 3000 frames per second. The image is a matrix, the number of its rows and columns corresponds to the shooting mode. The cells of the image matrix contain the values of the radiation intensities for a given row and column.

The minimum brightness in the absence of radiation corresponds to the value 0 (black) in the image matrix, and the maximum brightness corresponds to the value 255 (white). The rest of the values correspond to shades of gray.

The optical axis of the high-speed camera is oriented along the normal to the plane of the discharge cell. The scale factor of transfer of the surface discharge image to the matrix plane is determined before shooting. Then, the images of the investigated object (surface discharge) are recorded, the possible shooting modes are with frequencies of 1000, 2000 and 3000 frames per second for 2-3 s. This time is sufficient to obtain an array of experimental data required for further research of the surface discharge parameters.

Shooting is performed in depth of brightness with a dynamic range of 8 bits. The maximum resolution of a digital video camera is $1280 \times 1024$ pixels per inch, the frame duration is $1.98 \cdot 10^{-3}$ s. The pixel size is $14 \, \mu m$.

The shooting was carried out with violet, red and green interference filters in order to avoid the flare during registration.

A photograph of experimental cell for studying a surface discharge is shown in Fig. 2.
4. Application of the background oriented shlieren method to determine the temperature field at the dielectric surface of the discharge cell

The essence of the background oriented shlieren method is as follows [2]. A high-speed digital video camera records screen images without and with the investigated object. Images are the random patterns on dark blue background. One image is recorded in the absence of a disturbed medium in the image transmission channel. In another photo the medium is disturbed by surface discharge streamers that leads to the change in optical properties of medium. In the presence of a disturbed medium (surface discharge streamers) the position of the points images on the background screen changes, and also the image structure of the background screen changes.

The displacements of object points are recorded. Cross-correlation processing analyzes the changes in the position of points on the structured screen image. Further processing is reduced to the study of changes in the coordinates of the background screen points that is associated with a change in refractive index of the medium that depends on temperature. By analyzing the obtained images, one can trace the dynamics of the surface discharge evolution.

The background screen is a number of chaotic structures on the dark blue background. Randomness is necessary because the displacement of structures inside and outside the investigated object is different. If the arrangement of structures is ordered, then the situation may arise when it is impossible to see the displacement of structures inside the investigated stream.

The obtained patterns of visualization of the surface discharge were used to study the temperature distribution over the dielectric and electrodes surfaces using background oriented shlieren method. This distribution must be well known in order to optimize the operating mode of ozonizer that is based on surface discharge cells, and also to predict its service life.

In addition, when the certain temperature is reached on the substrate surface, a sharp decrease in the ozone concentration occurs. Constant monitoring of the temperature field is required for efficiency of ozonizers work. The use of conventional thermocouples to determine the temperature near the electrodes is impossible, because breakdowns can occur to the thermocouples themselves, the discharge can go to them. In order to avoid breakdown to thermocouples, as well as to ensure temperature control in the discharge region, background oriented shlieren method was used.

An infrared camera or thermal imager that could also be used to determine temperature does not provide the required spatial and temporal resolution, and the shadow background method can solve this problem.

In order to obtain the temperature field it is necessary to determine the normalization factor connecting the values of the displacements of the background screen points and the temperature at the reference point. Temperature values are recorded using two thermocouples: reference (determining the
temperature outside the investigated object) and probe, located in the immediate vicinity of the investigated object. Standardizing thermocouples are located so as to avoid breakdown on them.

Continuous temperature recording is carried out using an analog-to-digital converter. A sequence of temperature values is formed at the investigated point at successive times with a step of 0.1 s. A normalization factor is determined that connects the value of the correlation coefficient and temperature at the investigated point of the field. All elements of the matrix of correlation coefficients obtained during image processing are multiplied by the normalization coefficient, and thereby the temperature field at different points of the investigated area of the surface discharge is determined.

The results obtained indicate that the temperature field of the surface discharge has a sharp inhomogeneity near the electrodes. The lowest temperature is close to room temperature, this is the temperature away from the electrodes. The highest surface discharge temperature is 65 °C that is confirmed by theoretical studies. In the obtained temperature field the individual bright points are observed, where local heating occurs that is associated with the evaporation of electrode materials.

5. Conclusion

The obtained results show that the temperature values of the investigated region of the surface discharge are in the range from 23 to 65 °C. The obtained temperature values indicate that both excited atoms and positive and negative ions are present in the surface discharge radiation. This study confirms the possibility of using the contactless background oriented shlieren method [3] to determine the temperature field in the surface discharge region that is necessary to control the operation of ozonizers and predict their service life.

References

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