Experimental Study of Kinematic Structure of Ionic Wind in Needle-Torus Electrode System in Air

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Abstract—The paper presents the results of experimental study of the ionic wind that emerges at a corona discharge in the needle-torus electrode system. In the experiment, we measured the current-voltage characteristic (CVC) and kinetic structure using the Particle Image Velocimetry (PIV) method for different polarities of the applied voltage in the range from the ignition of corona discharge up to pre-breakdown. We obtained velocity distributions along the symmetry axis and velocity profiles at different voltages. The electric wind at the negative polarity was found to emerge in the form of pulsed gas flows brought about by the current pulses (Trichel pulses). Snapshots of alternating charged gas clumps accelerating in interelectrode gap were taken.

Keywords—Ionic wind, PIV, corona discharge

I. INTRODUCTION

It is well-known that the ignition of a corona discharge in the air is accompanied not only by ionization processes, but also the motion of the neutral medium in the interelectrode gap (IEG), which is called the ionic wind. The phenomenon finds its use in a variety of technologies and devices, such as electric filters, EHD actuators, ion engines, heat transfer enhancement, etc [1]. Experimental study of the ionic wind kinetics is a rather complicated task, since the corona discharge leads to the formation of space charge and it occurs only in high electric fields. Therefore, until recently [2, 3], it was possible to measure the speed of the ionic wind only outside the sheath of the corona discharge. The paper presents the results of the velocity field measurements in the needle-torus electrode system for different polarities of the applied voltage.

II. METHODOLOGY

As mentioned, the experiments were performed in the needle-torus electrode system (Fig. 1). The distance from the tip of the needle to the upper plane of the torus is 24 mm, the diameter of the generating circle of the torus is 8 mm, and diameter of the rotation circle is 40 mm. High voltages of different polarities were applied to the electrode needle. The resistor for measuring the current in the system is connected between the ground and the torus. Measurements of velocity field were made using PIV-method on FlowMaster installation provided by LaVision Inc. The installation consists of a double-pulse Nd-YAG laser with line excitation in the visible range of 532 nm, 4 ns time flash, flash energy being chosen about 50 mJ. To reduce the reflected light, the needle electrodes were blackened. The cylindrical lenses were arranged at the laser head to make thin light sheet for visualization of the EHD flow between the electrodes. The resulting light sheet is estimated to be about 0.5-1 mm wide. The resulting image was shot with CCD camera Image proX2M (dynamic range 14 bits, resolution 1200×1600 pixels) and processed later with the DaVis software. The time between laser flashes was chosen so that the displacement of particles between frames is in the range from half pixel to a quarter of interrogation window size. The data were processed using the adaptive algorithm for multiple iterations. Interrogation window size on the first iteration was set equal to 48×48 pixels, 50% overlap; on the second pass, the window size is equal to 24×24 pixels, 50% overlap. Thereafter, the obtained data were filtered to remove speed values, if the cross-correlation function was less than 0.3. The data obtained for each measurement in the series were averaged. Separate measurements in the series were used to estimate the measurement accuracy.

One of important issues in the study of the ionic wind using PIV-method is the choice of particles for visualization. The paper [4] reports a comparison of different tracer particles for PIV measurement in the EHD airflow. The authors have tested various materials for visualization, such as cigarette smoke, oil, EMS (Expancel microspheres), TiO2 and concluded that to achieve consistent results, the tracer particles should not change the current. For example, they showed that EMS and oil tracers can increase the current several-fold, so it is not suitable for visualization. Besides controlling

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current value, it is important to choose tracers with diameter as small as possible, so that it does not affect the mechanical properties of the fluid. The reliable results can be obtained using tracers with average diameter about one micrometer.

In the paper, we used bis(2-ethylhexyl) sebacate (DEHS) to visualize the flow. The same substance was tested for the air flow visualization from DBD in the paper [5]. In our work, DEHS was sprayed using an aerosol generator, supplied with the setup. The average diameter (as claimed by the manufacturer) of individual tracers is 500 nm, the generation rate was about 100 million drops per second.

To assess the impact of aerosol in our system, current-voltage characteristics (CVC) were measured in the air before and after starting aerosol supply for different polarities (Figs. 2 and 3).

From Fig. 2, we can conclude that there is a negative polarity aerosol effect on the order of 10-20%. Similar current deviation values were recorded in [4], and the authors have carried out the verification of the velocity field, showing that at these values of deviation current measured velocity remains within the accuracy. CVC for positive polarity graph is shown in Fig. 3. We see here that there is practically no change in the current running in the system.

Thus, we can conclude that the distortions introduced by visualizing DEHS particles into our system can be neglected. The error associated with a standard deviation when averaging in one series of measurements is in the range of 5-15%.

III. RESULTS

Let us consider the velocity field in the system, resulting from different polarities of applied voltage that change from the ignition threshold up to 15 kV.

A. Negative Polarity

Richer in terms of diversity of observed phenomena is the negative polarity. It is known that the corona discharge ignition at the polarity produces Trichel pulses of frequency that increases rapidly with increasing voltage, and then, at higher voltages, corona remains stable. If we apply the voltage where they just emerge, a video camera can take pictures of the following shape of the imaging particle distribution (Fig. 4):

Fig. 4 shows the distribution of tracer particles recorded by the camera. Light points correspond to individual visualizing particles. At the top of the image, we can see a bright area (X = 6 mm, Y = 1 mm) that corresponds to the reflection from a needle. Under the needle, there is an area without particles. The area appears with a single pulse of the current and apparently contains a portion of the space charge, because it moves downward at a speed of about 30 cm/s (Fig. 5).
The number of areas without particles increases linearly with increasing of voltage. Appearance of the areas also corresponds to the pulses of the current at current-time characteristic. Thus, we can conclude that the obtained image corresponds to the movement of the charged media from a single Trichel pulse. A further increase in voltage leads to the air flow becoming uniform. A typical pattern of distribution of the ionic wind velocity is shown in Fig. 6. Velocity distributions at other voltages are similar to this one.

The typical velocity distribution in the system of electrodes reveals that the acceleration zone spreads as far as about 1 mm from the needle. Farther on, there is a uniform laminar flow about 1 mm wide. Thickness of the plume approximately corresponds to the size of the negative corona discharge sheath.

B. Positive Polarity

In contrast to the negative polarity, the positive corona discharge has close-fitting shape and retains it until the streamers appear. So, there is no such variety of phenomena here. Fig. 7 shows the pattern of distribution of the velocity field for the polarity.

It should be noted that the width of the ionic wind plume at the positive corona is less than at the negative one. The sheath of the positive corona discharge is determined by radius of the electrode. This leads to the fact that the widths of the hydrodynamic jets in these two cases are different.

It should also be noted that the maximum speed value at the positive polarity is almost twice higher.

IV. DISCUSSION

Now we shall consider the velocity profiles at a distance of 5 mm from the tip of the needle for different polarities and different voltages (Fig. 8).

Based on the plot (Fig. 8), we can evaluate the width of the hydrodynamic plume as the difference between the two extreme values of the distance variable (x) at which the velocity variable is equal to half of the sum between maximum and minimum values of velocity.
For negative polarity the width is equal to 2.8±0.3 mm, while the width of positive polarity one is 1.5±0.3 mm. Thus, we have confirmed the conclusion, drawn from the qualitative analysis of contour plots above.

It should also be noted that the profiles of velocity at the negative polarity exhibit a stable position of the speed maximum, whereas at the positive polarity the maximum shifts depending on the voltage; that is, one can observe the lack of stability in the spatial position of the ionic wind jet.

Compare the axial velocity distributions (Fig. 9). We see that the acceleration zones for the two polarities are roughly the same, their size being smaller than 1 mm, which corresponds to the characteristic size of the corona discharge sheath. Beyond the acceleration zone, the velocity along the axis is almost constant for negative polarity. At the positive polarity, there is considerable decrease of the velocity at higher voltages. This happens because the thickness of the positive plume is about that of the laser sheet, so a little shift of the former can lead to moving plume out of sight.

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It is known from other authors’ studies that after the ignition of corona discharge there is a linear dependency of the velocity maximum on the applied voltage, as well as the magnitude of the maximum is proportional to the square root of the current.

Fig. 10 shows that there a good agreement between the obtained data and those from literature.

We see in Fig. 11 that there is a square root dependence of the maximum speed on the current. Thus, the data follow the known empirical relationships [6].

V. CONCLUSION

The experiments have yielded the following results:

- The emergence of Trichel pulses can be seen as the lack of seed particles in the interelectrode gap. The typical velocity of pulse propagation is about 30 cm/s.
- The width of the hydrodynamic jet at the negative
polarity was found to be twice that at the positive one.

- A good agreement with previous results is obtained.

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REFERENCES


