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Effects of magnetic field intensity on ionic wind characteristics

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ABSTRACT

The characteristics of ionic wind under the magnetic field are studied by using a needle-to-mesh electrode. With the increasing of magnetic field intensity, the amplitude of Trichel pulse decreases and the pulse frequency increases significantly; the ionic wind speed clouds in the *yOz* plane shift from concentric circle to eccentric ellipse, and the ionic wind profiles along *y*-axis gradually transfer from a symmetrical distribution to a biased state; the maximum wind speed value and the corresponding electrical-to-kinetic energy conversion efficiency are also increased. These results illustrate that the magnetic field could adjust the ionic wind.

1. Introduction

The ionic winds have widely applications in the following areas, such as thermal management [1–3], airflow control [4–6], propulsion [7–9] and so on. Ionic wind is sourced by the movement of large numbers of particles in an electric field. In essence, it is a comprehensive process of interaction between charged and neutral particles in the corona discharge space.

Different field effects, such as electrical field, flow field and so on, could adjust the spatial distribution and movement of the particles, and the characteristics of ionic wind are improved. J. D. Moon et al. utilize a needle-ring-net structure to make the distributions of electric field, charged particles and ionic wind more uniform [10]. D. F. Colas et al., Y. T. Birhane et al. and Zhang et al. propose that using auxiliary electrodes or multi-electrode array configuration could generate a multi-level electric field, which could increase the velocities of charged particles and improve the characteristics of ionic wind [11–13]. E. Moreau et al.‘s and Wang et al. illustrate that the flow field of ionic wind are improved by adjusting the electrode arrangement or the ratio between electrode spacing and flow path size [14,15].

The charged particles and the corresponding discharge characteristics can also be influenced by the magnetic field. S. Peka´rek et al. [16,17] and K. Elabbas et al. [18] and Xu et al. [19] observe that the ionization and diffusion process are enhanced by the magnetic field, the intensity and the uniform of discharge are increased. He et al. and Zhou et al. [20,21] find that the distribution of the charged particles would be deflected under the effect of magnetic field, and the corresponding discharge mode would be transferred. Besides, the plasma density is increased and the input energy are decreased under the effect of the magnetic field, and these results are discussed by Park et al. [22]. Industrial patent [23] also describes a system in which the direction of ionized air moving through a computing device is deflected under either an electric or a magnetic field. Therefore, it is reasonable to propose that the magnetic field with a strong intensity have a definite influence on the ionic wind at atmospheric pressure. In this paper, the characteristics of ionic wind under different magnetic field intensities are demonstrated in detail, and the corresponding mechanism is also discussed.

2. Experimental setup

The schematic diagram is shown in Fig. 1, which include a discharge system, a magnetic field system, and a measurement system. The discharge system consists of a stainless-steel needle as an emitter and a copper mesh as a collector, and the emitter and collector are also named as cathode and anode in some papers. The electrodes are separated by $L = 10\,\mathrm{mm}$. The radius of the needle tip is $\sigma = 120\,\mu\mathrm{m}$. The copper mesh electrode is a plain type mesh, the size is $60\mathrm{mm} \times 60\,\mathrm{mm}$, the aperture is 5.0 mm, and the diameter of the wire is 0.2 mm. The located plane of the mesh electrode is as the *yOz* plane, the projection position of needle onto the *yOz* plane is as the origin of the coordinate system. A DC high voltage negative source is applied to the needle emitter, the collector is grounded through a sampling non-inductive resistor $R = 1\,\mathrm{k}\Omega$. A pointer micro ammeter is connected in series with the collector to measure the averaged discharge current. The input voltage U is measured by a high voltage probe (Tektronix P6015A) and the

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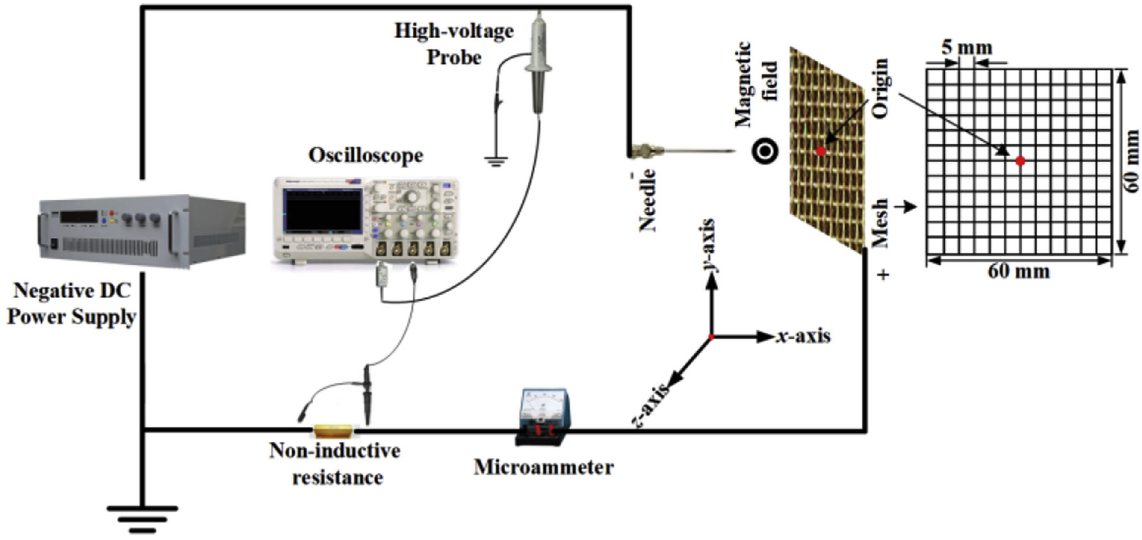

Fig. 1. Schematic of the experimental setup.

discharge current is detected by the voltage drop across measuring resistor *R*. A digital storage oscilloscope (Tektronix 3024) is applied to record the discharge signals. The temperature is 15 °C, and the relative humidity is 40%.

The uniform strong magnetic field is generated by an electromagnet, the size of each magnet is 60 mm × 120 mm in the *xOy* plane. The magnets are magnetized vertically along their axes, and the direction of the magnetic field is along the *z*-axis. The distribution of magnetic field intensity is performed by using Hall's probe and a tesla-meter. The maximum value of magnetic field intensity is $B = 1.2$ T for the spacing of 60 mm, and the non-uniformity of magnetic field intensity $\Delta B/B$ is less than 1%, the direction of the magnetic field along the positive *z*-axis is as positive.

A telescopic perpendicular probe hot-wire anemometer (with the precision of 0.01 m/s) is applied to measure the ionic wind velocity. The distance between the anemometer and the collector electrode is 10 mm. The hot-wire anemometer is fixed in the high precision optical lift stand, and it could move in the *yOz* plane (with the precision of 0.1 mm/scale).

3. Results and discussion

3.1. Influence of magnetic field intensities on the discharge characteristics of ionic wind

The discharge currents under the different magnetic field intensities are shown in Fig. 2. The discharge currents maintain a typical Trichel pulse waveform: a series of pulses are superimposed on the DC component (-0.1 mA), and the pulses are consisted with a faster-falling edge and a slower-rising edge. The Trichel pulse is transferred from large amplitude, low frequency pulse to small amplitude, high frequency pulse under the effect of magnetic field intensity with 1T order.

The influence of magnetic field intensities on Trichel pulse parameters are further illustrated in detail by the statistical analysis. The amplitude and interval time of Trichel pulse in 200 ms are selected as the statistical parameters, and the statistic results under different magnetic field intensities are shown in Fig. 3. With the increasing of magnetic field intensity, the peak value of the probability density curve is gradually reduced, and the half-width of the probability density curve is extended. Compared with the condition of $B = 0$ T, the peak value with $B = 1.2$ T is about three fourths (from -0.63 mA to -0.47 mA), and the pulse interval time with $B = 1.2$ T is decreased to two thirds (from 2.2 μs to 1.5 μs).

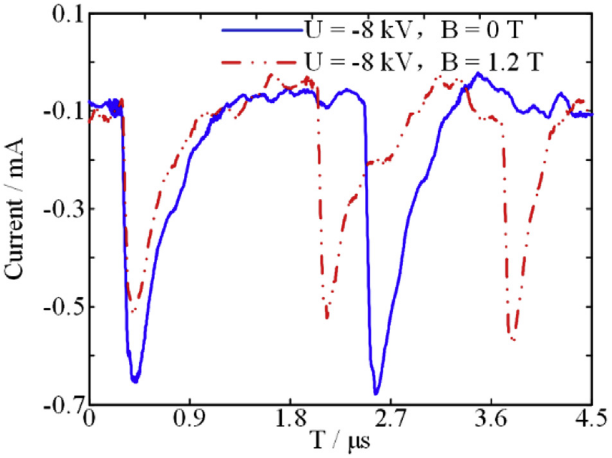

Fig. 2. Current waveform of Trichel pulses.

3.2. Influence of magnetic field intensities on the velocity distribution of ionic wind

The velocity distributions of ionic wind under different magnetic field intensities are demonstrated. The experimental results are shown in Fig. 4. The closer to the center, the higher the velocity is, and the less the corresponding area is. For $B = 0$T, the velocity distribution of ionic wind exhibits a concentric arrangement, the maximum ionic wind velocity is 1.6 m/s, and the concentric ring area is 1200 mm^2. For $B = 1.2$T, the velocity distribution of ionic wind is deflected along the negative *y*-axis, the maximum ionic wind velocity is 2.2 m/s, and the corresponding area is 680 mm^2.

Furthermore, the velocity profiles of ionic wind along the *y*-axis under different magnetic field intensities are shown in Fig. 5. For $B = 0$T, the ionic wind velocity profile curve approximates a symmetrical distribution along the *y*-axis. The center position is at the origin of the *y*-axis, and the maximum velocity is about 1.95 m/s. For $B = 1.2$ T, the ionic wind velocity profile curve is deflected along the negative *y*-axis, and the shape approximates the positive skewness distribution curve. The maximum ionic wind velocity is about 2.2 m/s and the corresponding position is shifted to $y = -6$ (mm). The ionic wind velocity profile curves for $B = 1.2$T and $B = -1.2$T are vertical symmetry along the line of $y = 0$ (mm).

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