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Sliding discharge in air at atmospheric pressure: electrical properties

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Abstract

Several studies have shown that a surface non-thermal plasma may be used as an electrofluidodynamic actuator for airflow control. For few years, we has been working on this subject, especially in the case of DC corona discharges and AC barrier discharges established at the wall of profiles. The present paper deals with a new type of surface plasma using a sliding discharge. This discharge, excited here by a negative AC voltage with a positive DC component, is created in a three-electrode geometry: one DC positive electrode and two negative AC electrodes at the same voltage. Then a barrier discharge is established between the positive electrode and the first negative one when a surface corona discharge or *sliding discharge* is generated between the positive electrode and the second negative one. In this preliminary study, the goal is to obtain a stable sliding discharge. Then the electrical properties of this discharge are observed and briefly discussed.

Keywords: Plasma actuator; Surface discharge; Sliding discharge

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1. Introduction

The possibility of using plasma actuators for airflow control has been studying for several years. The goal of such actuators is to modify the airflow profile within the boundary layer. The main plasma effect is the ionic wind of several m/s produced at the surface of the profile. This promising application of ''Electrostatics'' might be used by aeronautic industry to reduce the drag of a plane or to stabilize the flow in order to avoid unsteadiness which generate unwanted vibrations, noise and losses.

In previous works [1,2], a great number of experiments such as visualizations, particle imaging velocimetry (PIV) measurements, velocity and wall pressure measurements with different types of profiles for velocities up to 30 m/s allowed us to show that the ionic wind induced by the surface corona discharge may increase the velocity at close vicinity of the wall, resulting in a modification of the airflow properties inside the boundary layer.

Although this process might be promising, the main disadvantage of the DC corona discharge is that it is unstable (glow-to-arc transition) in many conditions (high humidity, presence of dust …). A first way to reduce these hazards is to use a AC barrier discharge. A second possibility is to utilize another type of more stable surface discharge, usually applied for HF laser pump in laser gas such as nitrogen and argon [3,4]: the *sliding* discharge. Consequently, the purpose of the present paper is to study and to describe the electrical behaviour of this discharge when it is established in air at atmospheric pressure. No mechanical measurements have been performed.

2. Types of plasma actuator

2.1. DC surface corona discharge

The first plasma actuator studied consists in a DC surface corona discharge established between two wire electrodes flush mounted on the surface of a dielectric profile. Usually we use polymethyl-methacrylate (PMMA or Plexiglas). Typically, the anode is a 0.7–1.2 mm-diameter wire and the cathode has a greater diameter, from 1.2 to 2 mm (Fig. 1a). They are placed inside grooves. The distance between both electrodes is typically 4 cm. A negative potential of -10 kV is applied at the cathode and a variable positive potential at the anode. To obtain a stable and efficient discharge, a reduced electric field of about 8 kV/cm is needed, that is to say a potential difference of 32 kV for a gap of 4 cm. Thus to establish the discharge, $+22$ kV are needed at the anode. In such conditions, the time-averaged discharge current for 20 cm-long-electrodes is ≈ 0.2 mA and the discharge-induced-velocity is about 3 m/s at 1 mm above the wall, from the anode to the cathode. In these conditions, as a function of several atmospheric and geometrical parameters, several discharge regimes may be obtained. Two regimes may be used for ionic wind production. In the first one, the corona regime, a thin sheet of blue ionized air is visible to naked eye at the surface of the dielectric, between both electrodes. Here,

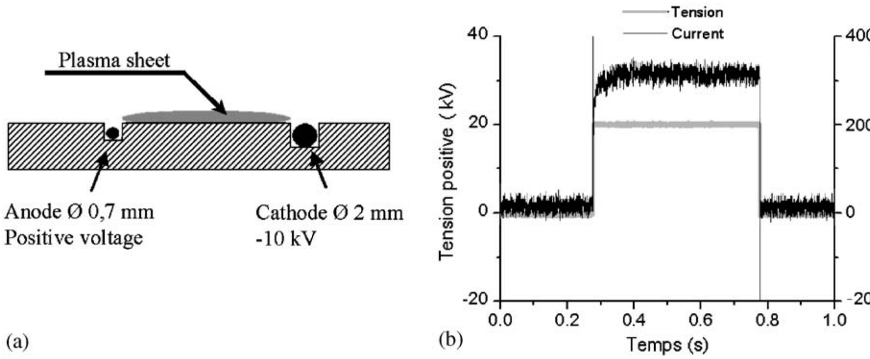

Fig. 1. (a) Schematic side view of the DC surface corona discharge set-up; (b) typical behaviour of the discharge current with a square wave excitation.

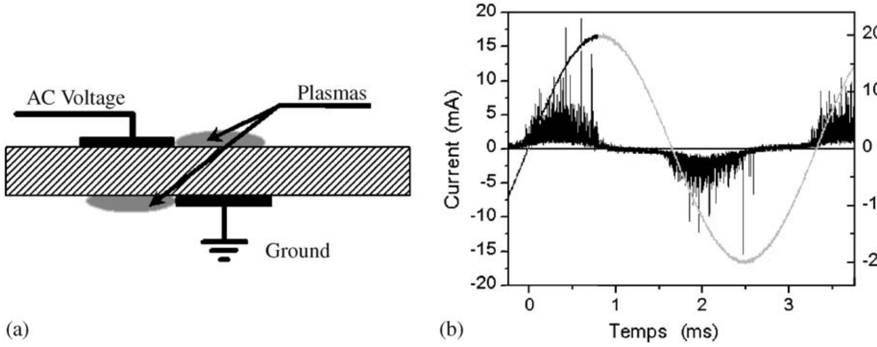

Fig. 2. (a) Schematic side view of the AC surface barrier discharge set-up; (b) typical behaviour of the barrier discharge current.

the discharge current versus time is composed of peaks: the discharge is a "streamer" discharge. In the second one, there is no peak and the discharge is more stable.

To obtain a pulse ionic wind, one can use a square wave excitation at the anode. For instance, Fig. 1b presents the voltage applied at the anode and the discharge current versus time. It shows that when there is a voltage step (20 kV in 60 µs), a capacitive current peak appears, and then the current reaches a stable value, 300 µA here, in some ms.

2.2. AC surface dielectric barrier discharge (DBD)

Another type of discharge may be used to limite the glow-to-arc transition: the barrier discharge (DBD), perfected by Roth in 1998 [5]. This plasma actuator is composed by two flat electrodes flush mounted on both sides of a dielectric, as shown in Fig. 2a. One electrode is grounded and the other one is connected to a sine high voltage of several kV rms and a frequency between 100 Hz and several kHz. In these conditions, a plasma sheet of blue ionized air is visible on each side of the dielectric as shown in Fig. 2a. It looks like a quasi-uniform glow, but in fact it is constituted of microdischarges distributed uniformly in time and space along the electrode length. For example, Fig. 2b presents a typical behaviour of the applied voltage and the associated discharge current versus time, for an electrode length of 20 cm. It shows that the current is composed by a capacitive component due to the dielectric between both electrodes, plus the plasma current. This one consists in current pulses of some μs, corresponding to microdischarges or streamers.

2.3. Sliding discharge

These two types of plasma have some disadvantages: the DC corona is sometimes very unstable and the barrier discharge produces very high power peaks which may induce problems of electromagnetic hazards. It is the reason why our goal is to perfect a stable discharge without the inconvenient of the barrier discharge. For that, we have used a configuration described in the literature and usually used in pure gas for laser applications [3,4]. It consists of stabilizing a surface corona with the help of a DBD. It is explained in the next section.

3. Experimental setup and results

The electrode geometry is given in Fig. 3a. Usually, the electrode placed below the dielectric flat plate is grounded and the other one is excited by a positive pulse high voltage. In our case, the positive electrode is connected to a DC positive potential of 11 kV obtained with a DC power supply DEL (40 kV, 3.75 mA). An AC potential (square or sine wave) is applied at the negative electrode with the help of a HV power amplifier TREK 20/20C (20 mA, 20 kHz). This AC voltage varies from zero to -18 kV. Then its time-averaged value is -9 kV. Both electrodes are aluminium foils (≈ 15 μm thick) flush mounted on the surface of a PMMA flat plate with a thickness

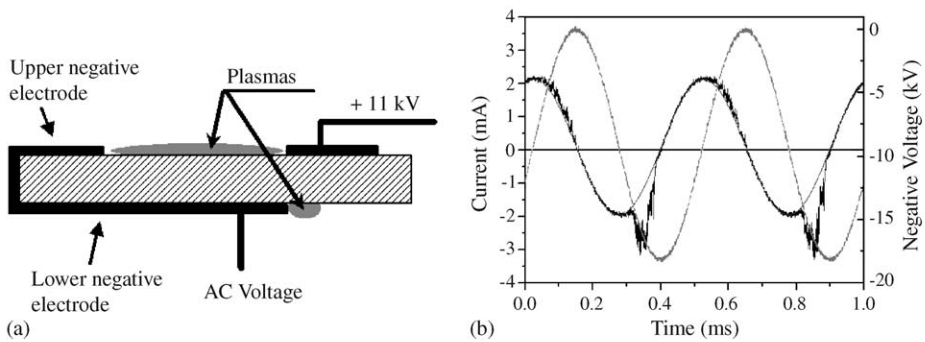

Fig. 3. (a) Schematic side view of the sliding discharge set-up; (b) typical behaviour of current in black and associated voltage in grey for a frequency = 1 kHz.

of 6 mm. The current is observed with a low current transformer ACCT Bergoz (accuracy of some μA and bandwidth of 300 kHz).

In these conditions, two plasmas are produced. One is visible on the lower side of the insulating flat plate, around the right edge of the lower negative electrode (Fig. 3a). The second one covers the plate wall between both electrodes, on the upper side of the dielectric. Fig. 3b presents a typical behaviour of the discharge current versus time. This current wave shows 3 components:

- A sine component with a phase shift of $\pi/2$ compared to the voltage. It corresponds to a capacitive effect due to the dielectric between the upper electrode and the lower one, and the gas gap between both upper electrodes.
- A DBD component, appearing when the AC voltage reaches its time-averaged value. This component is more visible in Fig. 4a, where we have plotted the total discharge current minus a theoretical fitting of the capacitive component. The DBD current, corresponding to the discharge DBD between the right edge of the lower electrode and the left edge of the positive electrode, is weak because the flat plate is thick (6 mm here). It has been experimentally verified with a thinner plate that this component increases when the flat plate thickness decreases.
- A sliding discharge component corresponding to the plasma between both upper electrodes. This plasma is ignited just before the potential difference between the positive and the negative electrode reaches its maximum. Then the negative part of the current in Fig. 4a is composed mainly by the sliding discharge current and by the DBD current.

To confirm the 3 component hypothesis, the upper negative electrode is now removed. This induces the suppression of the sliding discharge current component. The current measured in this case corresponds to the capacitive current minus the DBD current. If the capacitive component is numerically removed by a theoretical fitting, we observe only the DBD component which is represented in Fig. 4b. This shows that the symmetrical shape of the DBD current remains low. This confirms

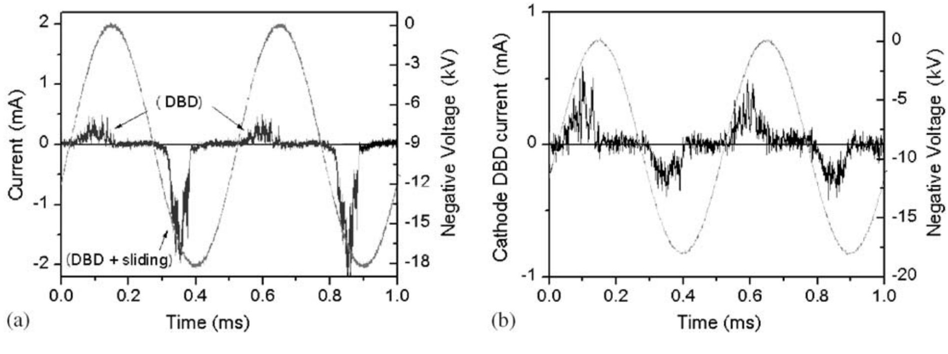

Fig. 4. (a) Typical behaviour of the sliding discharge current when the capacitive component is removed; (b) typical behaviour of the current when the upper negative electrode is removed.

that the negative part of the discharge current in Fig. 4a in this 3 electrode set-up is mainly the sliding discharge current.

4. Conclusion

This study has presented an experimental set-up using a three-electrode configuration. With this set-up, a large stable homogenous and luminous plasma sheet could be obtained in air at atmospheric pressure. But the general behaviour of this discharge is complex. Its seems that 3 phenomena occur: a capacitive effect mainly due to the dielectric, a DBD discharge between 2 electrodes placed on both side of the dielectric, and a sliding discharge between 2 electrodes placed on the same side of the dielectric.

This preliminary study has shown that the DBD discharge could be limited by using a thick insulating flat plate. However a great number of experiments will be needed to well-understand the electrical and mechanical properties of the sliding discharge in air.

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