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An Experimental Study Of An Electroaerodynamic Actuator

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Abstract: The electroaerodynamic actuator or plasma actuator uses the characteristics of the non-thermal surface plasmas. These plasmas are created in atmospheric pressure by a DC electrical corona discharge at the surface of a dielectric material. The two electrodes are two conductive parallel wires. The applied voltage is of several kilovolts. The corona discharge creates a tangential electric wind that can modify the boundary layer flow properties. In this paper, we present the results found for two geometric configurations: the flat plate and the cylinder. In order to study the discharge specificity, we have found the current- voltage characteristics for different inter-electrode gaps, different dielectric materials and for different values of air relative humidity. Moreover, we present the curves of linear current density- electric field. All these measurements are carried out when the discharge is stable without any spark. We show some photos that illustrate the steady discharge types. At last, we quantify the aerodynamic aspect of the discharge by giving the ionic wind velocity profile of the discharge at the surface of the dielectric obstacle.

Keywords: Actuator, conductive wires, discharge, plasma, ionic wind.

1 Introduction

Many studies dealt with electroaerodynamic actuators. The most important application is the active airflow control (Léger *et al.*, 2001 and Léger *et al.*, 2002). The corona discharge may be used as an air-moving mechanism in order to modify the airflow around an obstacle (Artatna *et al.*, 1999; Desimone *et al.*, 1999 and Artana *et al.*, 2000). An important property of these actuators is the tangent energy injection to the surface, which justifies actuator efficiency. We don't need high ionic wind velocities to have a great effect on the airflow at the surface of an obstacle. The manipulation of a free airflow can affect three main phenomena: the laminar-to-turbulent transition, the separation and the turbulence (Moreau 2007).

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Delaying the laminar-to-turbulent transition has many advantages. Several experimental and numerical studies showed the effects of electroaerodynamic actuators, also called plasma actuators, on the airflow. Soetomo (1992) experimentally observed a drag reduction effect induced by AC (Alternative Current) and DC (Direct Current) corona discharges along a flat plate in the case of flow velocities up to 2 m/s. Considering the same experimental conditions, El khabiry *et al.* (1997) and Colver *et al.* (1999) numerically showed a consistent drag reduction. In ambient air, a corona is formed around the lowest diameter electrode (usually the positive one) and an electric wind is created tangentially to the wall. An experimental investigation of the dielectric-barrier-discharge conducted by Forte *et al.* (2006) showed that an optimization of some actuator parameters may produce an ionic wind with a velocity up to 7 m/s at 0.5 mm of the wall, for a single actuator and 8 m/s for many actuators.

Currently, a great deal of interest is devoted to airflow control around a plane wing. Corke *et al.* (2004) and Post (2006) used the plasma actuators to leading edge separation control and to trailing edge lift control. They experimentally showed that these actuators may increase the maximum lift coefficient and slightly decrease the minimum drag coefficient. Numerical and experimental studies are carried out by He *et al.* (2007) and confirm that the plasma actuator could be effective in controlling the turbulent flow separation. The experimental study of Patel *et al.* (2008) showed the effectiveness of the single–dielectric-barrier-discharge plasma actuators for leading edge separation control on airfoils.

Our study was based on some actuators placed at the surface on a dielectric stand. We used two geometries for the actuator support, a flat plate and a circular cylinder, to satisfy several applications. For each studied case, we have changed some parameters such as the inter-electrode gap, the dielectric material type and the air relative humidity. This parametric study allows for a comparison between actuators and to investigate the effect of the already mentioned parameters on the corona current values. Therefore, we could determine the configuration that gives a maximum of corona current. In the present work, the qualitative aspect of the DC corona discharge is presented and photos taken to highlight the discharge manifestation. This paper also contains results about the quantitative aspect of the corona discharge in the case of an actuator at the surface of a printed flat plate.

2 Experimental setup

The Direct Current (DC) surface corona discharge used in our experiments is obtained through applying a high positive potential at the anode (about 30-40 kV) and connecting the cathode to the ground. We use different dielectric materials and different geometrical forms of the surface (figure 1). The DC corona discharge is created at the surface of:

- Printed flat plate: the anode and the cathode are two printed tracks and they have diameters of 0.5 mm and 2 mm, respectively. The gap between the two electrodes is of 4 cm.

- Glass flat plate and Plexiglas plate: the anode and the cathode are two electrical conductor wires and they have diameters of 0.5 mm and 2 mm, respectively. The gap between the two electrodes is fixed at 2cm and 4cm.

- Polyamide (PA) Cylinder: the two electrodes are placed into two grooves at the surface of a Polyamide cylinder. They are opposed diametrically. The cylinder's internal diameter is 30 mm and the external diameter is 40 mm. The electrodes are two electrical conductor wires having respectively diameters of 0.4 mm and 2 mm.

- Glass Cylinder: the two electrodes are placed at the surface of a glass cylinder. The electrodes are two electrical conductor wires having respectively diameters of 0.4 mm and 2 mm. They are opposed diametrically.

The length of the electrodes is 20 cm. All our measurements were taken when the discharge is steady. The steady condition is defined as the measured current values corresponding to a stable discharge without any spark.

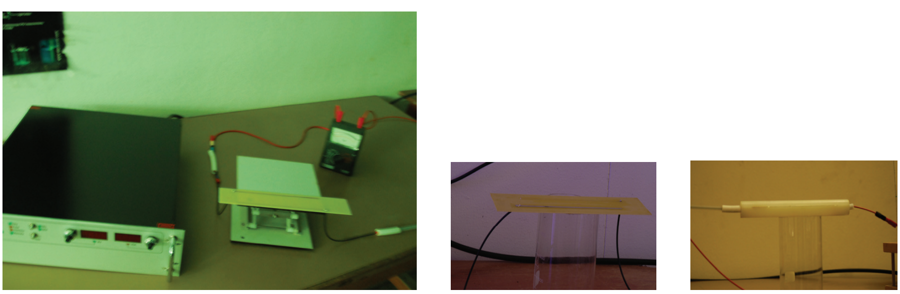


Figure 1: Experimental setup (a): two electrodes at the surface of a flat plate (b): two electrodes at the surface of a circular cylinder

3 Electric corona characteristics

3.1 Current-voltage characteristics

3.1.1 Effect of inter-electrode gap

The DC corona discharge is created at the surface of two glass cylinders with different external and internal diameters. The electrodes are opposed diametrically. Figure 2 shows the characteristics for cylinder1 having an external diameter of 8 cm and cylinder2 with an external diameter of 4 cm. We notice that the current values obtained at the surface of cylinder1 are lower because the electrodes are more distant, whereas for cylinder2 the current values are more important and the discharge is more stable.

3.1.2 Effect of air relative humidity

To study the effect of air relative humidity, we placed the actuator in a glass enclosure and used a hair dryer to change the ambient conditions inside the enclosure. We notice that the corona current values at the surface of a PA cylinder were less important when the relative humidity increases (figure 3). When the relative humidity increases, the lower currents are due to the lower mobility of the ions as a result of their combination with polar water molecules (Abdel-Salam 1985). Moreover, the discharge is no longer stable if the relative humidity exceeds 50%. This is due to the fact that the disruption voltage, the tension causing instabilities, decreases when the relative humidity increases (Fouad *et al.*, 1995 and Loeb 1965).

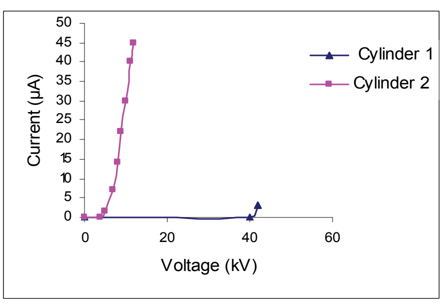


Figure 2: Current-voltage characteristic for different inter-electrode gap

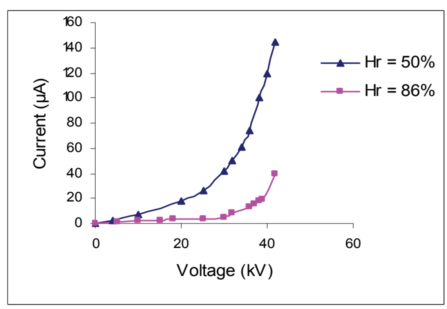
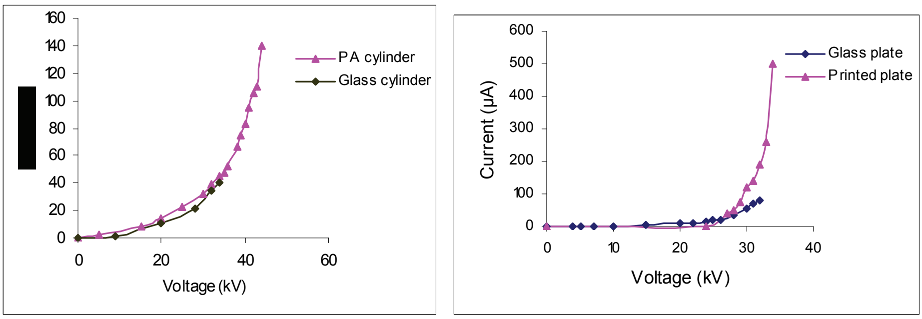


Figure 3: Current-voltage characteristic for different relative humidity values

3.1.3 Effect of the dielectric material

For an actuator based on two electrodes at the surface of a cylinder, figure 4.a presents the results obtained for the glass and PA cylinders, having internal and external diameters of 3 cm and 4 cm respectively. We notice that the current values obtained with the PA cylinder are more important than the values obtained with the glass cylinder. Figure 4.b shows that the current values are higher for the printed flat plate than for the glass flat plate.



(a) (b)

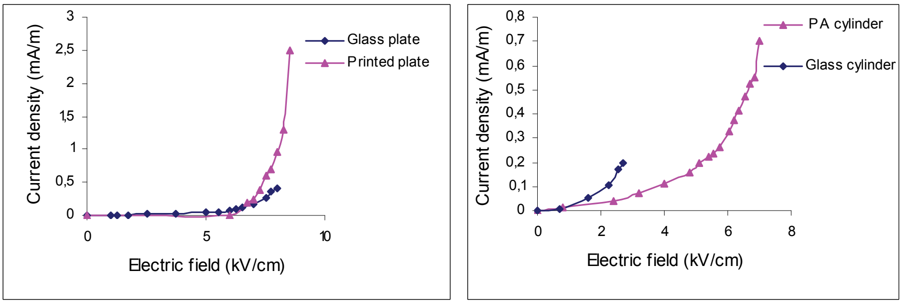
Figure 4: Current-voltage characteristic for two different dielectric materials (a) : case of a cylinder (The title of the y-axis is Current (μA)) (b) : case of a flat plate

3.2 Linear current density-electric field characteristics

These characteristics show up for the printed and the glass plates when the inter-electrode gap is 4cm. Results are shown for this gap length because it corresponds to the maximum corona current values, as it is indicated in a previous work (Mestiri *et al.* 2008). Then, we consider this case because it is the most interesting one. These characteristics are traced from those of figure 4. Figure 5.a shows that for the printed flat plate, the current density values reach 2.5 mA/m; so the discharge type is "Corona" or "high spot". This type is characterized by its important current values and it is the most stable type of the discharge (Moreau *et al.* 2002). Whereas for the glass plate, the current density does not exceed 0.5 mA/m and the discharge is less stable. For the case of a PA cylinder, we note that the discharge is of a "glow" type which is a stable discharge. But for the glass cylinder, the discharge is a "spot" one and is not stable (figure 5.b).

4 Photographic analysis

Discharge photos were taken with a digital Nikon D100 camera. These photos were taken almost at dark so that we can identify the luminous aspect of discharge regimes. This qualitative study justifies the existence of "glow" and "high spot" discharges. In the case of a discharge at the surface of a printed plate and a PA cylinder,



(a) (b)

Figure 5: Current density-electric field characteristic for two different dielectric materials (a) : case of a flat plate (b) : case of a cylinder

we could observe a blue to purple sheet in the inter-electrode gap, which characterizes the "glow" regime (figure 6 and figure 7). In figure 8, and for a discharge at the surface of a Plexiglas flat plate, we could notice that the two electrodes became two luminous lines, characterizing the "Corona" or "High spot" regime which is the most stable regime.

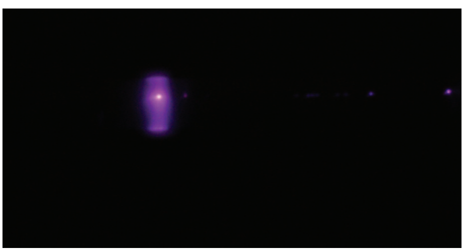


Figure 6: "Glow" discharge at the surface of a PA cylinder

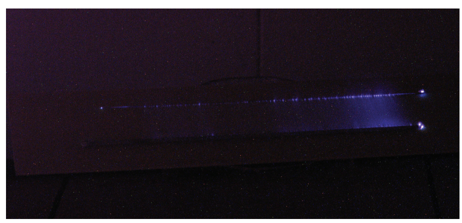


Figure 7: "Glow" discharge at the surface of a printed plate

5 Aerodynamic aspect of the discharge

In this section we present the results of the quantitative study carried out for the actuator based on two electrodes printed at the surface of a flat plate. The dynamic effect of the discharge is due to the ionic wind. The ionic wind measurements are made with a Furness Controls (FCO12) micromanometer connected to a glass Pitot tube. We present the ionic wind velocity profiles for two x values (x is the distance to the downstream of the cathode), the applied voltage is 29,5 kV. Figure 9 shows

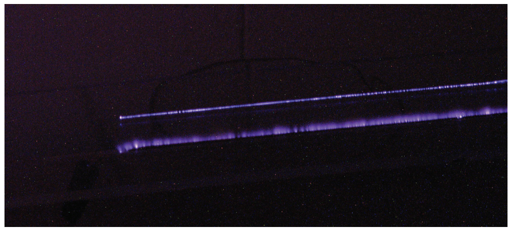


Figure 8: "Corona" or "High spot" discharge at the surface of a Plexiglas plate

that the ionic wind is more important at the vicinity of the cathode (x = 5mm) and we obtain tangent velocities of 2,2 m/s close to the plate surface. The aim of this aerodynamic study is to show that the ionic wind is weakened with the distance downstream of the cathode. Since it is important to link the discharge regimes to the ionic wind velocity, we can look at figure 4.b when the voltage is equal to 29.5kV. Then, we draw a correspondence with figure 5.a to determine the relative current density value which indicates the discharge regime. Indeed, when the voltage is of 29.5kV, we can deduce from figures 4 and 5 that the linear current density is approximately 0.6mA/m, which corresponds to the "High spot" discharge.

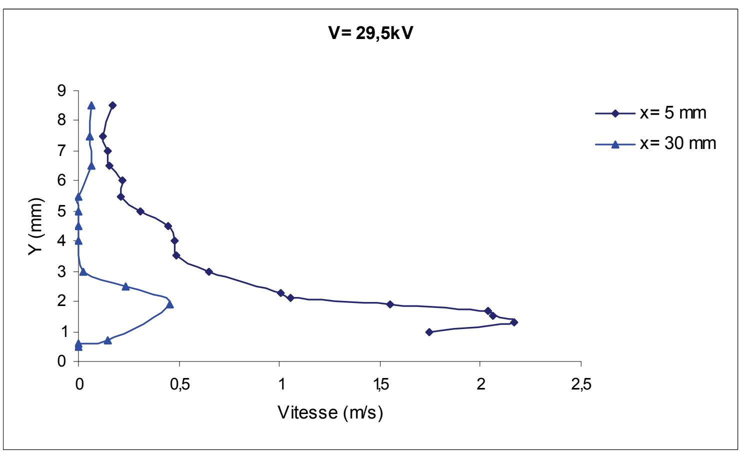


Figure 9: Velocity profile for two x values (x: distance to the downstream of the cathode)

6 Conclusion

In our electric study of the electroaerodynamic actuator, we have varied the inter-electrode gap, the dielectric material and the ambient air relative humidity. We observed that the corona currents are higher with the printed plate and the PA cylinder and that we have obtained the current densities corresponding to the “corona” and “glow” regimes which are the most stable. However, for the glass plate and glass cylinder, the discharge is less stable and the current values are lower. Also, the discharge is no longer stable when the humidity is greater than 50%. The qualitative study of the corona discharge shows that the obtained discharge regimes are the most stable, which corresponds to effective current values. In fact, current values are proportional to the ionic wind velocity (Mestiri *et al.* 2008). The obtained tangentially ionic wind velocity is of 2.2 m/s which is efficient for the airflow control, therefore validating the efficiency of our electroaerodynamic actuator. We will complete this work by PIV (Particle Image Velocimetry) measurements. Currently, we are working on the corona discharge at the surface of another geometrical form which is a plane wing of NACA0015 type.

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References

Abdel-Salam, M. (1985): Positive wire-to-plane coronas as influenced by atmospheric humidity. *IEEE Trans. Ind. Appl.,* Vol. IA-21, No. 1, pp.35-40.

Artana, G.; Dadamo J.; Desimone, G.; Diprimio, G. (2000): Air fow control with electrohydrodynamic actuators. *Proceedings of the second International Workshop on Conduction Convection and Brakdown in Fluids*, Grenoble, May 2000, 190-194.

Artana, G.; Desimone, G.; Touchard, G. (1999): Study of the changes in the fow around a cylinder caused by electroconvection. *Inst. Phys. Conf. Ser.*, Vol. 163, Proc. Electrostatics’99, pp. 147-151.

Colver, G.; El Khabiry, S. (1999): Modeling of the corona discharge along an electrically conductive flat with gas flow. *IEEE Trans. Ind. Appl.*, Vol. 5. No. 2, pp. 387- 394.

Corke, T. C.; He, C.; Patel, M. P. (2004): Plasma Flaps and Slats: an application of weakly-ionized Plasma actuators. *American Institute of Aeronautics and*

Astronautics, Portland, Oregon, 28 June- 1 July 2004, Paper 2004-2127.

Desimone, G.; Diprimio, G.; Artana, G. (1999): Modifications to the fow field around a cylinder by means of electrodes placed on its surface. *Proc. SFE 99*, Poitiers, France, July 1999, pp. 80-84.

El Khabiry, S.; Colver, G. (1997): Drag Reduction by D.C Corona Discharge Along Electrically Conductive Flat Plate for Small Reynolds Number Flows. *Physics of fluids*, Vol. 9. No. 3, pp. 587-599.

Forte, M.; Jolibois, J.; Moreau, E.; Touchard, G. (2006): Optimization of a Dielectric Barrier Discharge actuator stationary and non-stationary measurements of the induced flow velocity- Application to airflow control. 3^{rd} *AIAA Flow Control Conference*, San Francisco, California, June 2006, AIAA 2006-2863.

Fouad, L.; Elhazek, S. (1995): Effect of humidity on positive corona discharge in a three electrode system. *Journal of Electrostatics*, Vol. 35, pp. 21-30.

He, C.; Corke, T. C.; Patel, M. P. (2007): Numerical and experimental analysis of plasma flow control over a hump model. 45^{th} *Aerospace Sciences Meeting*, January 8-11, 2007, Reno, Nevada, paper 2007-0935.

Léger, L.; Moreau, E., Artana. G.; Touchard, G. (2001): Influence of a DC corona discharge on the airflow along an inclined flat plat. *J. Electrostatics*, Vol. 51- 52, pp. 300- 306.

Léger, L.; Moreau, E.; Touchard, G. (2002): Electrohydrodynamic airflow control along a flat plate by a DC surface corona discharge- Velocity profile and wall pressure measurements. *American Institute of Aeronautics and Astronautic*, St. Louis, Missouri, 24-26 June 2002, Paper 2002-2833.

Loeb, L. B. (1965): Electrical Coronas, Their Basic Physical Mechanism. *University of California Press, Berkeley*.

Mestiri, R.; Hadaji, R.; Ben Nasrallah, S. (2008): The electrical discharge as a source of mechanical energy. *Desalination*, Vol. 220, pp. 468-475.

Moreau, E. (2007): Airflow control by non-thermal plasma actuators. *J. Phys. D: Appl. Phys.*, Vol. 40, pp. 605-636.

Moreau, E.; Léger, L.; Touchard, G. (2002): Contrôle de l'écoulement d'air autour d'un obstacle à l'aide d'une décharge électrique ou plasma- Application à l'aéronautique. *GEVIQ*, Laboratory of Aerodynamic Studies, University of Poitiers.

Patel, M. P.; Ng, T. T.; Vasudevan, S.; Corke Corke, T. C.; Post, M. L.; Mc Laughlin, T. E.; Suchomel, C. F. (2008): Scaling effects of an aerodynamic plasma actuator. *Journal of Aircraft*, Vol. 45, No. 1, pp. 223- 236.

Post, M. L.; Corke, T. C. (2006): Separation Control Plasma Actuators, Dynamic Stall Vortex Control on Oscillating Airfoil. *AIAA Journal*, Vol. 44, no.12.

Soetomo, F. (1992): *The influence of high voltage discharge on flat plate drag at low Reynolds number air flow*. M. S. Thesis, Iowa State University, Ames, Iowa.