Comparison of airflow patterns produced by DBD actuators with smooth or saw-like discharge electrode

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Abstract. In this paper we compare the performance of DBD actuators when either a smooth or saw-like electrode is employed. Two electrode arrangements of DBD actuators are investigated. The first is the classic DBD actuator and the second is a DBD actuator with floating electrode. The usefulness of the saw-like electrode in these two types of DBD actuators is studied.

1. Introduction
The plasma generated by the surface dielectric barrier discharge (DBD) is capable of inducing electrohydrodynamic (EHD) flow for modifying airflow around aerodynamic elements [1-3]. Devices using the DBD for flow control are called DBD actuators. DBD actuators can improve the properties of aerodynamic elements modifying airflow around them and are useful to control flow separation and laminar-turbulent flow transition, to reduce drag and improve the lift of airfoils.

In the past decade many DBD actuator configurations were investigated [3]. The results obtained showed that DBD actuator properties, such as size of the plasma region and generated airflow velocity depend on electrode configuration, dielectric material properties and applied voltage. Usually, a smooth plane electrode was used as the HV electrode. However, other shapes of electrodes were also used to improve airflow generated by DBD actuators e.g. a wire electrode.

In this paper we compare the performance of DBD actuators when either a smooth or saw-like electrode is employed. Two electrode arrangements of DBD actuators are investigated. The first is the classic DBD actuator and the second is a DBD actuator with floating electrode. The usefulness of the saw-like electrode in these two types of DBD actuators is studied.

Also the influence of the floating electrode position on the airflow produced and the discharge current was studied for the DBD actuator with the saw-like floating electrode.

2. Experimental set-up
2.1. Classic DBD actuators
The classic DBD actuator consisted of two electrodes mounted on opposite sides of a 2 mm-thick glass plate. The HV electrode (on the upper side of the actuator) was exposed to ambient air when the grounded electrode was insulated with a polyimide tape to eliminate discharges on the bottom side of the actuator. Two types of classic DBD actuators were studied. The first, without any displacement between the HV electrode and grounded electrode (25 mm wide) (Fig. 1a) and the second in which the displacement between the HV electrode and the grounded electrode (10 mm wide) was 20 mm
(Fig. 1b). Both types of classic DBD actuators were made in two variants, with either a smooth HV electrode or a saw-like HV electrode. Both types of HV electrodes, made of a 50 µm-thick copper tape, were 6 mm wide (Fig. 2).

**Figure 1.** Side view of the classic DBD actuator with an electrode displacement of 20 mm (a) and the classic DBD actuator without electrode displacement (b)

![Fig. 1](image)

**Figure 2.** Photo of a smooth (a) and a saw-like (b) electrode used in the classic DBD actuators

### 2.2. DBD actuators with floating electrode

The first DBD actuator with floating electrode consisted of a HV electrode and a grounded electrode, both fixed on the one side of the 2 mm-thick glass plate and both insulated, and a third electrode at floating potential placed on the opposite side of the glass plate (Fig. 4). The floating electrode was exposed to ambient air. Either the smooth or saw-like electrode was used as the floating electrode. The floating electrode and the HV electrode were 6 mm wide while the grounded electrode was 10 mm wide. The displacement between the HV electrode and the floating electrode was 1 mm, and between the floating electrode and the grounded electrode was 15 mm.

**Figure 4.** Side view of the DBD actuator with floating electrode

![Fig. 4](image)

To optimise the floating electrode position, a second DBD actuator with saw-like floating electrode was used (Fig. 5) (floating electrode in x = + 6 position). It consisted of two 2 mm-thick glass plates and three 50 µm-thick copper electrodes. The HV electrode, the grounded electrode and the floating electrode were 20 mm, 10 mm and 6 mm wide, respectively. The length of HV and grounded smooth electrodes was 100 mm. The saw-like floating electrode was 50 mm long (Fig. 3). The first glass plate with the HV electrode was fixed. The second glass plate with the saw-like floating electrode and the grounded electrode, placed on the first one, could be shifted along the x direction. The HV and grounded electrodes were insulated with polyimide tape. The saw-like floating electrode was exposed to ambient air. The distance between the grounded electrode and the saw-like floating electrode was 10 mm, whereas the displacement between the HV electrode and the saw-like floating electrode could be varied.

**Figure 5.** Side view of the DBD actuator used for optimisation of the saw-like floating electrode position

![Fig. 5](image)
2.3. Experimental apparatus
The experimental set-up consisted of an AC power supply, an oscilloscope, a discharge current probe, a flow channel in which the DBD actuators were placed, and a particle image velocimetry (PIV) [3] equipment for two-dimensional (2D) measurements of airflow velocity fields generated above the DBD actuator.

A sinusoidal high voltage (frequency 1.5 kHz) applied to the DBD actuators was generated by the power amplifier (TREK, model 40/15, $U_{pp}$ – up to 80 kV) which amplified the signal from the function generator METEX MS9150. Discharge current was measured by a Pearson current probe (Rogowski coil). The voltage signal was delivered to the oscilloscope from a high-voltage probe in which the HV power amplifier was fitted.

The experiments were carried out in ambient air at atmospheric pressure in an open-ended flow channel. During the experiment there was no externally forced airflow in the flow channel.

3. Results

3.1. Classic DBD actuators
In Fig. 6 an example of the time-averaged flow velocity vector field of the airflow generated by the classic DBD actuator without electrode displacement (saw-like HV electrode).

![Image of time-averaged flow velocity vector field](image)

**Figure 6.** The time-averaged flow velocity vector field of the airflow generated by the DBD actuator (saw–like HV electrode) without electrode displacement. The applied sine-wave voltage was $32 \text{ kV}_{pp}$, the frequency - 1.5 kHz.

Fig. 7 shows flow velocity profiles obtained for the classic DBD actuators without electrode displacement (saw-like HV electrode) at different applied voltages. The profiles were determined 12 mm downstream of the active edge of the HV electrode. The profiles clearly show that at the same applied voltage the velocities of the airflow generated by the DBD actuator with the saw-like HV electrode are higher than those for the DBD actuator with the smooth HV electrode. The most remarkable difference in airflow velocities occurs at the lower applied voltages. Similarly, the airflow velocity generated by the classic DBD actuator with 20 mm electrode displacement is higher when the saw-like HV electrode is used.

![Image of flow velocity profiles](image)

**Figure 7.** Flow velocity profiles measured for the classic DBD actuators without electrode displacement for smooth (a) or saw-like (b) HV electrode.

3.2. DBD with floating electrode
The time-averaged flow velocity fields of the airflow generated by the DBD actuator with smooth or saw-like floating electrode are presented in Figs. 8a and 8b, respectively. The vertical airflow velocity profiles measured for DBD actuators with the floating electrode (smooth or saw-like) were determined 20 mm downstream the active edge of the floating electrode (Fig. 9). The results show that velocities of the airflow generated by the DBD with saw-like floating electrode are higher than for the DBD with smooth floating electrode.

To find the optimal position of the floating electrode in the DBD actuator, measurements of the amplitude of DBD current pulses and the flow profiles were carried out for different positions of the floating electrode in respect to the HV electrode. The results obtained show that the maximum amplitude of the discharge current pulses and maximum airflow velocity were observed when the floating electrode was in $x = +1$ mm position (where the floating electrode saw teeth were 1 mm
downstream of the HV electrode edge). Thus, we concluded that position $x = +1 \, \text{mm}$ is the optimal position of the floating electrode in the investigated DBD actuator.

Figure 8. Time-averaged flow velocity vector fields of an airflow induced by the DBD actuator with smooth (a) and saw-like (b) floating electrodes. The applied sine-wave voltage was $60 \, \text{kV}_{\text{pp}}$, the frequency - 1.5 kHz.

Figure 9. Flow velocity profiles measured for the DBD actuator with smooth (a) and saw-like (b) floating electrodes.

4. Summary and conclusions
Using the 2D PIV method the influence of the HV electrode shape on the airflow generated by the classic DBD actuator and the DBD actuator with floating electrode was investigated.

The comparison of obtained velocity maps clearly showed that in all cases velocities of the airflow generated by the DBD actuators were higher when the saw-like electrode was used. The most significant differences in airflow velocities were observed when relatively low voltages were applied. Also, when the saw-like electrode is used the DBD starts at lower voltage.

In order to determine the optimal position of the saw-like floating electrode in the DBD actuator measurements of the DBD current pulses and of the generated airflow were made. The results obtained showed that the optimum position of the saw-like floating electrode was $x = +1 \, \text{mm}$ i.e. when nearly the whole saw-like floating electrode was above the HV electrode and only its saw teeth were 1 mm downstream of the HV electrode edge. The floating electrode can be useful for forming long surface DBD for actuators [4, 5].

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