Effects of a transmission line on the properties of a surface discharge based on a segmented ground electrode design

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Abstract. The paper deals with a new way of modifying the properties of a surface discharge. This method consists of influencing the surface potential distribution on the dielectric layer. For this, we used two configurations of plasma device. The first one is a standard surface discharge. While the second one is based on a surface discharge with a segmented ground electrode to which we added a transmission line. For these experiments, the surface discharge is supplied by an AC high voltage of a few kV with frequency ranging between 0.5 to 4.5 kHz, and operates in DBD mode. The velocity of the produced electric wind has been recorded using a pressure probe in a quiescent environment. From these measurements, the maximum velocity has been extracted and used to compare the performance of the different configurations. In addition, the voltage waveform and current-discharge, from which the power can be calculated, have also been recorded. The results highlight the capability to modify the topology of the electric wind produced by the new configuration of plasma device. The highest induced velocity achieved is 15% greater than the standard case with the same power consumed.

1. Introduction

The purpose of this study focuses on optimizing the electromechanical properties and/or increasing the size of the plasma sheet of a surface discharge. Indeed, the performance of these systems, as devices enabling active control of an aerodynamic airflow or reduction of air pollution, are related to the electric wind velocity induced by the discharge and/or by the extension of the plasma above the insulating barrier. Conventionally, the performance improvement of a surface discharge is obtained by modifying two parameters: 1) the shape of the device and 2) the input electric parameters [1-5]. In summary, these enhancements increase the injected power into the plasma.

In the present work, a new way of modifying the properties of surface discharge is proposed. This method consists of influencing the surface potential distribution on the dielectric layer. To achieve this, a surface discharge based on a design of segmented ground electrode is achieved. Then, we have connected a transmission line (i.e. an LC network) to the segmented ground electrode.

From the electrical power measurements and those of induced flow, a comparison of electromechanical behavior has been performed between the new setup and the standard discharge.

2. Experimental part

Figure 1 shows a schematic illustration of the setup of both discharges. The standard surface discharge (named SD # 1) that forms the baseline case for this study, consists of two electrodes asymmetrically flush mounted on each side of a dielectric plate, plus a counter-electrode placed on the top side of the insulating wall. This counter-electrode is separated relatively to the right edge of the electrode #1 by an air gap of 40 mm, named the SD gap. Each electrode is made of aluminium strip. The upper electrodes are 100 mm-long (in spanwise) for 20 mm in width. The lower electrode (electrode #2) is 25 mm wide for 100 mm in spanwise. The dielectric used is an alumina plate 150 × 150 mm² and 1.5 mm-thick.
The new design of surface discharge (named SD # 2) is similar to the baseline case, except the bottom electrode is substituted by a segmented electrode (electrode #2') to which we added a transmission line. This segmented electrode is composed of three 5 mm wide aluminium strips. Each strip is separated by an air gap of 5 mm. This keeps the total area of the combined width of strips and air gaps equal to electrode #2. The transmission line consists of an LC network composed of two coils and three capacitors. Depending on the inductance and capacitance values, several SD # 2 configurations have been investigated.

![Figure 1. Scheme of two plasma devices used: standard discharge (left) and new configuration (right).](image)

Surface discharges are powered by an AC high-voltage connected to the electrode #1 as shown in Figure 2. The AC high voltage is obtained with the help of a transformer supplied by a power amplifier (NF Corporation, model 4510). The transformer can supply a maximum peak voltage of 20 kV at driving frequencies up to 5 kHz. The two other electrodes are grounded. In this case, the surface discharges operate in DBD mode [4, 5].

The applied voltage is measured by using an HV probe (Tektronix, model P6015A). The current, $i$, is deduced from the voltage across a non-inductive resistor ($R = 100 \, \Omega$) connected in series between the electrode #2 (or the whole electrode #2' and transmission line) and the earth. Each electrical waveform was recorded using a fast digital oscilloscope (Tektronix, model DPO 2024). From both voltage and currents curves, the total electrical power consumption can be calculated as follows:

$$P = \frac{1}{nT} \int_{t=0}^{nT} v(t) i(t) \, dt$$

where $v(t)$ and $i(t)$ are the measured voltage and current versus time, respectively, $T$ is the waveform period, and $n$ is the number of periods. In practice, the time-averaged value computed with only one cycle would not allow a convergent value to be reached because it should vary from one cycle to another. Therefore approximately 10 cycles have been recorded.

![Figure 2. Surface discharge](image)

Measurements of the induced velocity above the plasma devices are realized with a total pressure probe made in glass connected to a low differential pressure manometer (Manostar, model W081). The probe is located at $x = 10 \, \text{mm}$ (horizontal axis) and $y = 0.2 \, \text{mm}$ (vertical axis) above the dielectric. The origin of the coordinates corresponds to the right edge of electrode #1 as shown in Figure 2. This setup allows the time-averaged velocity component $U$ to be determined by using the following expression:

$$U = \sqrt{\frac{2(\Delta p)}{\rho}}$$

where $\Delta p$ is the pressure difference between the measured pressure $p$ and the atmospheric pressure $p_{\text{atm}}$, and $\rho$ is the air density.
3. Results

3.1. Capacitor value of the LC network
In this section, the influence of capacitance variation of the transmission line on the electromechanical behavior of the surface discharge has been analyzed. In this experiment, the coil value of the LC network is fixed with \( L = 1 \) mH. Only the capacitance varies. The capacitor \( C \) ranges from 0.1 to 100 \( \mu \)F. A sinusoidal waveform is applied, with the peak voltage fixed at 9 kV.

Figure 3 displays the power consumed as a function of frequency between the SD # 1 and the SD # 2 with several configurations of \( LC \) network. Compared to the baseline case, it appears that the SD # 2 device, without and with the transmission line, has no significant effect on electrical power consumption.

Evolution of the induced electric wind versus power consumed is presented in Figure 4. Several significant results are highlighted:

1. Without the \( LC \) network, it appears that the plasma device with the segmented ground electrode generates higher electric wind compared to the baseline case. The velocity gain reaches about 10% at a given power consumed.

   As shown by other authors [6] for another range of voltage-frequency and a different electrode arrangement, this result confirms that the use of a segmented ground electrode increases the induced flow by the surface discharge.

2. Depending on capacitance value, the electric wind velocity is either decreased or increased. For the capacitors of 10 and 100 \( \mu \)F, we can see that the measured velocity is constantly reduced. This reduction is of the order of 12% on average with \( C = 10 \) \( \mu \)F. In the case where \( C < 10 \) \( \mu \)F, the flow produced by SD # 2 is initially reduced. But from a power threshold, a velocity gain is achieved. The highest induced velocity reached 15% greater than the standard case with the same power consumed.

   It seems that the electric wind is higher with a low capacitor value, here \( C = 0.1 \) \( \mu \)F.

   These results are interesting because they highlight the capability of modifying the electric wind topology by influencing the surface potential distribution on the dielectric barrier.

3.2. Inductance variation of the LC network
In a second set of experiments, the effect of inductance variation of the transmission line on the properties of the plasma device is investigated. To achieve this, the capacitor value of the \( LC \) network is fixed with \( C = 0.1 \) \( \mu \)F, deduced from previous results (see Figure 4). Here, three values of coil are tested, i.e. 1, 10 and 100 mH. The waveform applied is sinusoidal, with the peak voltage fixed at 9 kV.

Electrical power consumption versus frequency between the SD # 1 and the SD # 2 with several configurations of \( LC \) network is shown in Figure 5. As in the previous section, one can remark that the plasma device with a segmented ground electrode, in the presence or absence of the transmission line, has no effect on the power consumed for the range of voltage-frequency used in this study.

![Figure 3](image3.png)  
**Figure 3.** Evolution of the electrical power versus frequency for every configuration.

![Figure 4](image4.png)  
**Figure 4.** Electric wind velocity versus power consumed for every configuration.
Whatever configuration of the SD # 2 used, the induced flow is constantly reduced up to a power threshold. Beyond this threshold, the velocity is higher compared to the electric wind generated by the baseline case. Moreover, it appears that the coil effect on the electromechanical behavior is better with a low inductance value, i.e. with $L = 1 \text{ mH}$.

4. Conclusion
In this paper, the results show the capability of modifying the properties of a surface discharge by using a segmented ground electrode to which we connected a transmission line. Firstly, it appears that this electrode arrangement, without or with an $LC$ network, has no effect on the power consumed by the discharge. Secondly, the SD # 2 plasma device (in presence or absence of $LC$ network) produces an effect upon the induced electric wind velocity. Depending on the values of inductance and capacitance, the electric wind velocity can be reduced or accelerated. This can be explained by the fact that the transmission line modifies the distribution of surface potential by varying the propagation and the shape of the sinusoidal waveform, resulting a variation of the propagation velocity of streamers above the dielectric barrier. From these results, it seems that low values of capacitance ($C = 0.1 \mu \text{F}$) and inductance ($L = 1 \text{ mH}$) allow the most significant velocity gains to be achieved from a threshold power consumed. It means that the propagation velocity of the sinusoidal waveform into the $LC$ network is proportional to the velocity of streamers (about $10^6 \text{ m/s}$).

This study should be completed by future investigations to better point out the physical mechanisms that occur at the surface discharge. First, by highlighting the spatial and time variation of potential at the dielectric surface by adapting the method described in [7] to our setup. And finally, by performing electric wind velocity mapping according to the coordinates $x$ and $y$.

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