Influence of SDBD plasma aerodynamic actuation on flow control by AC power supply and AC-DC power supply

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Abstract. In this paper, the excitation effect of single dielectric barrier discharge plasma actuator (SDBD) is compared by using AC power supply and AC-DC power supply. AC-DC power supply is based on the AC power supply, just adding DC component. The flow measurement is carried out by PIV technique. Results show that the excitation effect of AC power supply and AC-DC power supply increases by the increase of voltage, the range of speed field excited by AC power is greater than that of AC-DC power supply. For x direction maximum speed, excited by AC power supply is close to AC-DC, and for y direction maximum speed, AC power supply is greater than AC-DC power supply. So the excitation effect of AC power supply is better than that of AC-DC power supply for SDBD.

1. Introduction
Plasma flow control technology which is a new active control technology has become the focus of current research that can control flow separation effectively [1]. It can increase lift, reduce resistance, shock absorption and noise reduction [2, 3], so it has a wide application prospect in the field of Aeronautics and Astronautics [4]. Also plasma flow control technology has no moving parts, short response time, excitation frequency bandwidth and other excellent features [5, 6].

The experimental excitation power supply is mainly based on AC power supply and nanosecond power supply, AC power supply provides sinusoidal alternating current, and the direction of the voltage varies periodically with time. The AC-DC power supply adds DC component to the AC power supply, the magnitude of the DC voltage is peak value of the alternating current and the direction is negative, so that the sinusoidal voltage of the AC output moves downward to a peak value, the output voltage of the power supply is in one direction. For the same SDBD plasma actuator, when the peak voltage of the AC power supply is same with the AC-DC power supply and the output frequency is the optimum frequency, then the excitation effect of the two power supplies is comparable. The flow field measurement is carried out by PIV technology. The experiment can find that in a certain range, the excitation effect of AC power supply and AC-DC power supply increases with the increase of voltage. At the same voltage, the excitation effect of AC power supply is better than AC-DC power supply.
2. Experimental Method

2.1. Plasma actuator
In the experiment, SDBD plasma actuator consists upper electrode and lower electrode. Each electrode is 0.02mm thickness, the upper electrode is exposed on the dielectric plate and the lower electrode is covered on the dielectric plate. Both have 400mm length, the upper electrode is 2mm width and the lower electrode is 20mm. There is no gap between upper electrode and lower electrode, the dielectric plate made of FR-4 Epoxy Glass Cloth which has a 440mm chord, a 200mm span and a 1.5mm thickness. The upper electrode is connected to the high voltage of power supply by a wire, the lower electrode is connected to the low voltage of power supply, seen Figure 1.

![Figure 1. Sketch of the plasma actuator](image)

2.2. Power supply and PIV
The AC power supply provides a sinusoidal alternating current, the direction of voltage changes sinusoidal periodically with time, AC-DC power supply is based on the AC power supply, adding DC components. We make the DC voltage is same with the AC peak-peak voltage, the direction is negative, when AC is combined with DC, the sinusoidal output voltage moves downward a peak-peak voltage, so the output of power supply is in one direction. The Figure 2 is the waveform of AC power supply and AC-DC power supply under the sinusoidal output voltage.

The PIV system (Figure 3) is made by the DantecDynamic Company. The Nd:YAG Laser, produced by the Beamtech Optronics Co., emits single pulse of energy ≤ 200 mJ and produces double pulses with a time interval of 60 μs. The laser sheet is 1 mm thickness, and is set at the position of 50% span-wise length of electrodes to make sure the induced flow is two dimensional. The sampling number for ensemble averages is 100. A CCD camera of 2048 × 2048 pixels is used to capture the field-of-view of 30 mm × 30 mm.
3. The Experimental Results

3.1. X direction velocity field
From the Figure 4, we could know that when use AC power supply and AC-DC power supply, with the increase of voltage, the velocity in the direction of x increases. The position of the maximum velocity is gradually delayed as the voltage rises, the large speed range of the excitation by AC power is better than AC-DC power supply.
Figure 4. X direction of velocity field driven by AC power supply (a) and AC-DC power supply (b)

The variation of wake velocity distribution caused by plasma excitation along x coordinate is analyzed. The maximum velocity is from y=0.95 mm and extracted along the direction of x. The velocity distribution in the y=0.95 mm line is shown below:

Figure 5. X directional velocity distribution driven by AC power supply (a) and AC-DC power supply (b) (y=0.95 mm)
From the Figure 5, we could know that when use AC power supply and AC-DC power supply, the plasma is generated and move to the right, the air near the electrode is adsorbed, so the air on the left of upper electrode has a speed, as a result of the reverse flow in the discharge, the air close to the top electrode has a deceleration, then plasma produced between the upper electrode and the lower electrode, so the air accelerates again, after reaching the maximum speed, the plasma has a limited area, the air speed slows down. The maximum speed excited by the AC power supply and the AC-DC power supply is basically the same. As the large speed range of the excitation by AC power is better than AC-DC power supply, so the excitation effect of AC power supply is better than AC-DC power supply for SDBD.

3.2. Y direction velocity field
From the Fig.6, we could know that when use AC power supply and AC-DC power supply, the velocity of the downward direction increases gradually, it’s because the plasma excitation effect becomes stronger with the increase of voltage, the capacity of air adsorption increases, thus the y direction velocity increases, the maximum speed appears near the upper electrode and creates a suction peak. At the same voltage, the AC power supply has better adsorption capacity, and the air downward speed is greater than the AC-DC excitation.

Figure 6. Y direction of velocity field driven by AC power supply (a) and AC-DC power supply (b)
The variation of wake velocity distribution caused by plasma excitation along x coordinate is analyzed. The maximum velocity is from y=0.95 mm and extracted along the direction of x. The velocity distribution in the y=0.95 mm line is shown below:

![Figure 7. Y directional velocity distribution driven by AC power supply (a) and AC-DC power supply (b) (y=0.95 mm)](image)

From the Figure 7, we could know the maximum y speed increases from -0.32 m/s to -0.55 m/s with voltage increasing excited by AC power supply, when using AC-DC, y direction of the speed change is small, the maximum speed increased from -0.2 m/s to -0.5 m/s. So the excitation effect of AC power supply is better than AC-DC power supply for SDBD.

4. Conclusion
In this paper, the effect of AC power supply and AC-DC power supply on the actuation of SDBD is studied by PIV technology, and the following conclusions are obtained:

1) In a certain voltage range, the excitation effect of AC power supply and AC-DC power supply on SDBD increases with the increase of voltage.

2) The range of speed field excited by AC power is greater than that of AC-DC power supply. For x direction maximum speed, excited by AC power supply is close to AC-DC, and for y direction maximum speed, AC power supply is greater than AC-DC power supply. So the excitation effect of AC power supply is better than that of AC-DC power supply for SDBD.

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