The Effect of the Dielectric Material Thickness to Induced Velocity in Plasma Actuator

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Abstract

Plasma actuator is an active flow control method which very promising because it has many advantages, like simple, light, involves no moving components, responses quickly, uses a little electrical power, easily formed, and doesn't form any induced drag. However, besides from its many advantages, plasma actuator is still in its research and development phase. One of the variable which greatly impacts the performance of plasma actuator is the thickness of the dielectric material, and for that reason, the thickness of the dielectric material test was conducted in this research by measuring the flow profile which formed with a sensor thermistor. The thickness variations of the dielectric material which were used are 2, 3, 4, and 6 mm. From the result of the measurement, shown that a thin dielectric material will form a high induced velocity, up to 1.2 m/s in 3 mm-thick dielectric material and decreases by 0.2 m/s in every 1 mm increase of the thickness of dielectric material. Meanwhile the damage of dielectric material occurred in the 2 mm-thick dielectric material, which caused by the failure of electrical insulation that the material suffered.

Keywords: Plasma Actuator, induced velocity, dielectric material thickness.

Introduction

Flow control, according to Flat (1961), is a technique to manipulate flow from its usual condition. Flow control itself can be divided into two kinds, active and passive. What's make these two methods different is their source of energy. Where in the active method a source of external energy is needed, the passive method doesn't require such thing. However, even though the active flow control needs more energy in its application, this method is more preferred in flow modification. [1] This because, even the passive flow control conserves more energy, passive flow control can only affect as much as 10% to the flow.

Plasma actuator is a method to actively controlling method, which uses electrical energy in its operation. The principle of plasma actuator happens where high voltage current ionizes air to become ions, which can be controlled with electrical field. This ion will interact with air to form such ion wind [3].

Plasma Actuator has several advantages compared to other active flow control: simple [4-6], light [7-9], involves no moving components [10], responses quickly [11-12], uses a little electrical power [13-14], easily formed [15-16], and doesn't form any induced drag [17]. These advantages simply make Plasma Actuator to be a very promising flow control device.

Although there are many advantages that a plasma actuator could have, this method is known to be still in research and development phase. This happens, because there's still so many things remain unknown about plasma actuator, so that the existing components of plasma actuator are still far from being optimal. Speaking of this optimization, the thickness of dielectric material is one of the main factors to influence the performance of Plasma Actuator [18]. That way, we were trying to discuss about the thickness variation effect to the performance of Plasma Actuator in controlling flow.

Plasma Actuator

Plasma actuator consists of two electrodes which divided by a dielectric material. Electrode in this context is a conductive material which being passed by electrical current, while dielectric is an insulative material. Other than being highly electrical-resistive, having a high breakdown voltage (E_B) value is also one of the important thing a dielectric to have. Furthermore, this value is a parameter to indicate the resistance of a material to high-voltage electrical current.

A high-voltage and high-frequency alternative current (AC) transmitted through an electrode. Its electrons, which could ionize air, shifted and formed electrical-charged particles called Plasma. The plasma would have some forces due to electrical field, then those forces in a form of body force would be given to the surrounding air. This transfer of forces would change the surrounding air contour, and if used correctly, Plasma Actuator could form some effects, like: drag force reducing and lift force enhancing.

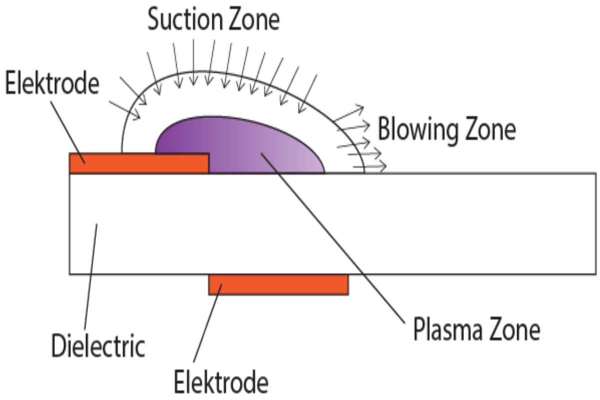

Figure 1. Plasma Actuator scheme

Plasma actuator would form two kinds of flow manipulation: blow and suction effect. Blow effect formed at the downstream area of the plasma actuator, while the suction effect formed at the upstream area. Both effects formed continuously as long as the plasma actuator is active.


Figure 2. Flow visualization with plasma actuator (white) and with plasma actuator (red).

Methodology

In order to understand the effect of the dielectric material thickness variation to the performance of plasma actuator, an experiment about measuring the air flow velocity which formed by plasma actuator was conducted. In this experiment, plasma actuator was placed on a dielectric material which made of flat plate-shaped epoxy resins. The variations of the thickness itself are: 2, 3, 4, and 6 mm. The electrode which used made from copper sheets with a length of 10 mm and a thickness of 50 µm. Meanwhile for the electrical setting, the triangle waves with 8000 V of V_{rms} and 10 kHz frequency, was used.

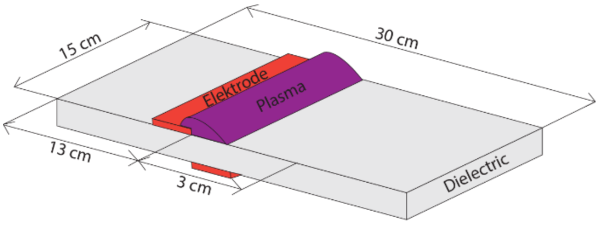

Figure 3. Plasma Actuator model

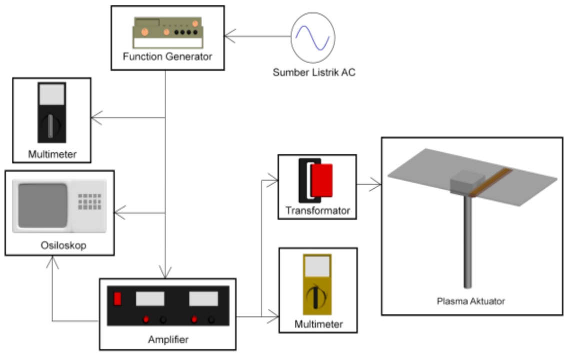

Figure 4. Plasma actuator electrial scheme

The usage of a triangle wave in this experiment was based on the result of the measurement in electrical wave variation. In this measurement, showed that a triangle wave formed the highest effect on induced velocity. This was important, as in a high induction of velocity, the variated parameter effects would show clearly.

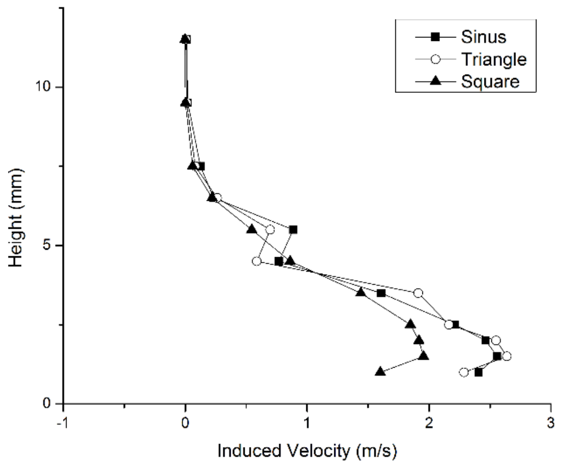

Figure 5. Graph of waves effect to induced velocity

Figure 6. *Wind sensor*

The experiment was conducted in a wind tunnel which set with a velocity of 1 m/s. Meanwhile the measurement device which used was a wind sensor from modern device, where the sensor itself was a thermistor, a resistor which its resistance value changes as the variation of temperature. This wind sensor would work just like a hot wire, where the value of resistance would change due to the temperature. This wind sensor was also connected with an Arduino Uno, so that the data could be acquired by the computer in real time.

Before this setup was used in the measurement, this measuring setup was calibrated with a DANTEC hot wire, which also was calibrated with a CTA. This calibration result is shown in Figure 6 and Table 1. The uncertainty of this measuring setup turned out to be less than 5%, making this setup was valid for measurement.

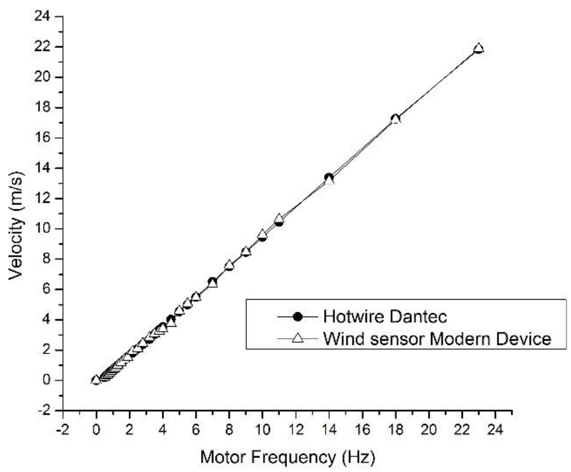

Figure 7. Calibration result

Table 1. Measurement Parameter

No.	Parameter	Value
1	Error	2.13%
2	Resolution	0.03 m/s
3	Sampling Rate	196 Hz

Data acquisition in this experiment was conducted in the range of 16 cm from the leading edge of the plate or 3 cm from plasma actuator location. From this location a flow velocity profile was obtained with the effect of plasma actuator.

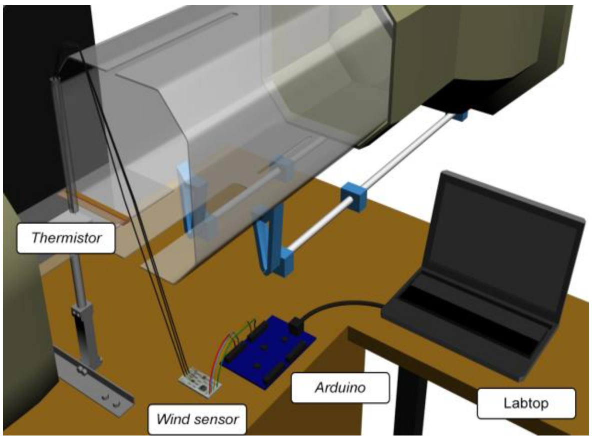

Figure 8. Experimental Setup

Result & Discussion

In this experiment, the result showed that a plasma actuator could give a blowing effect to the air, changing the air flow contour as shown in figure 9. The biggest effect was happened to be near the surface of the dielectric, while in the area far from the surface, the flow velocity was almost the same as the free stream velocity. As showed by the maximum velocities which formed by every velocity profiles, the relation between the velocity induction effect which formed by plasma actuator and the thickness variation of the dielectric happened to be linear, with the highest velocity induction was formed by the thinnest dielectric material. With this 3 mm dielectric material and free stream velocity of 1 m/s, the velocity induction could be formed up to 1.2 m/s.

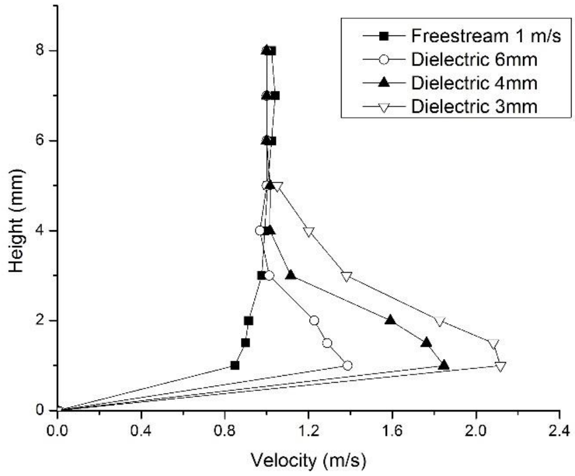

Figure 9. Graph of induced velocity to dielectric thickness

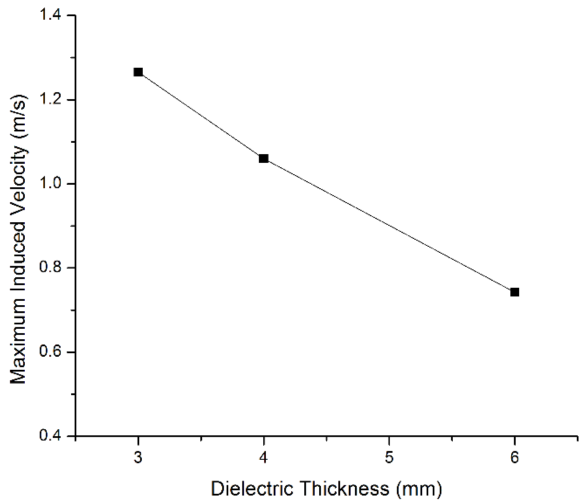

Figure 10. Graph of maximum induced velocity to dielectric thickness

Figure 10 shows that the thicker the dielectric material, the less the effect of plasma actuator to the flow. On the other hand, the thinnest dielectric material gave the best performance. However, there is a limit of this thin dielectric material. The decrease induced velocity due to dielectric thickness directly affects the quality of plasma production.

When a dielectric material is far too thin, the dielectric material will suffer from damage as suffered by a 2 mm-thick dielectric material. This damage was caused by a breakdown that would be suffered by a far too thin dielectric material, which caused when the electric load that was transmitted to the material had already exceeded the breakdown voltage of the material. This phenomenon caused the dielectric material to loss its function as an insulator and triggered a high value of electrical current, resulted in material damage.

Figure 11. Dielectric failure

Conclusion

The thickness variation of the dielectric material will affect the performance of plasma actuator. A thick dielectric material will reduce the velocity induction effect which formed by plasma actuator. Every increase of the thickness by 1 mm results in the decrease of velocity induction by 0.2 m/s. However the breakdown voltage of the material itself limits the thickness of the material to not be far too thin.

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