

Initial Flow Structure Control of Jet Diffusion Using a Coaxial DBD Plasma Actuator

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Abstract The dielectric barrier discharge plasma actuator (DBD PA) is applied to diffusion control of the jet flow issued at Reynolds numbers (based on a nozzle diameter) of $Re = 1.0 \times 10^3$ and 2.0×10^3 from a nozzle of 10 mm in diameter. The detailed flow structure is documented using particle image velocimetry, hot-wire anemometry, and laser flow visualization. In the experiment of the present study, the jet flow was controlled using a coaxial DBD PA, which generates an induced flow in the same direction as the jet direction. We investigated the difference in the influence of the flow induced by DBD PA on the main jet flow while varying the voltage, frequency, and intermittency. The induced flow was found to become stronger as the frequency and voltage increased. The diffusion of the jet flow was controlled.

1 Introduction

A number of jet diffusion control techniques, such as coaxial flow, sound excitation, and the use of a flap, have been proposed. In recent years, the dielectric barrier discharge plasma actuator (DBD PA), which is an atmospheric pressure plasma actuator, has been applied to wing separation control and cylinder wake control (Corke et al. 2010). However, a vortex ring of Kelvin–Helmholtz (K–H) instability is formed near the nozzle exit with a specific cycle. Since the characteristics of a jet are governed by the vortex ring at the early jet region, jet diffusion

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control can be carried out through a vortex ring generation and growth process. In the present study, the flow induced by a DBD PA made the main jet instability to increase. Diffusive mixing was controlled when the instability at the early jet region was generated by the induced flow. The influence of continuation DBD PA or intermittent DBD PA on a jet diffusion is investigated herein.

2 Experiment

Figure 1 shows a cross section of the coaxial-type DBD PA setup at the round nozzle exit, the main jet, and the overall view of the induced flow. The DBD PA consists of an exposed electrode, an insulated electrode, and a dielectric layer. In a convergent round nozzle having an exit inner diameter of $d = 10$ mm, the electrode was arranged coaxially with the nozzle. Plasma was generated by adding the alternating voltage of the impressed voltage of 2–6 kV, a frequency of 4–15 kHz, and the intermittency frequency from the power supply. The jet is at $Re = 1.0 \times 10^3$ and 2.0×10^3 (based on a nozzle diameter). The laser light sheet method was used. A photograph of the jet flow was visualized with a high-speed camera at 6,000 fps within the range of $x/d = 6$, where x is the distance from the nozzle exit. Finally, the visualization picture was analyzed by PIV.

3 Results and Discussion

3.1 Change in Velocity Distribution by DBD PA

Figure 2 shows the velocity distribution chart for the case in which a plasma at $x/d = 1$ is not generated, and the velocity distribution chart for frequencies from 4 to 14 kHz for voltages of approximately 5.5 kV in case of continuous mode and a

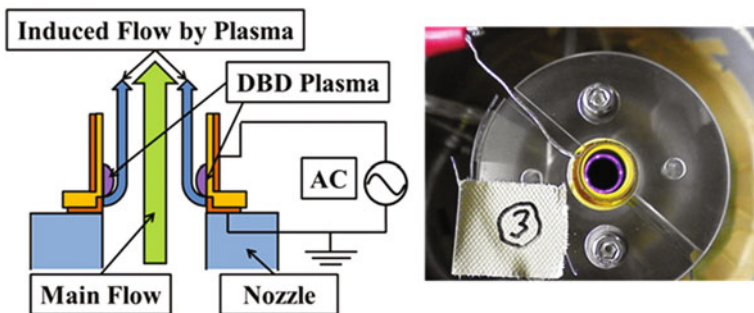


Fig. 1 Cross section of the DBD PA and photograph of the nozzle

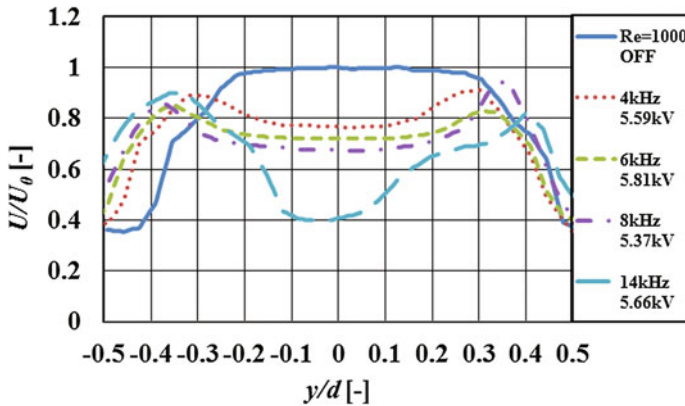


Fig. 2 Velocity distribution around the nozzle at $x/d = 1$ ($Re = 1.0 \times 10^3$)

Re of 1.0×10^3 . Here, U_0 is the center velocity of $x/d = 1$ when DBD PA is not generated. The velocity distribution in the free boundary layer is maximal at approximately $y/d = \pm 0.4$, and the velocity distribution at the center decreases as the frequency increases. This is because the flow in the vicinity of approximately $y/d = \pm 0.4$ was accelerated by the induced flow generated by the DBD PA. Since the supplied air mass flow rate is constant, if the velocity distribution is expanded radially, the law of conservation of mass indicates that the central velocity decreases.

3.2 Intermittency Frequency and Duty Ratio

Figure 3 shows photographs of typical flow structures at DBD PA for a frequency of 15 kHz, a voltage of approximately 4.9 kV, an intermittency frequency of 320 Hz, a duty ratio of 0 to 90 % (The duty ratio is defined as B/A , where A is the

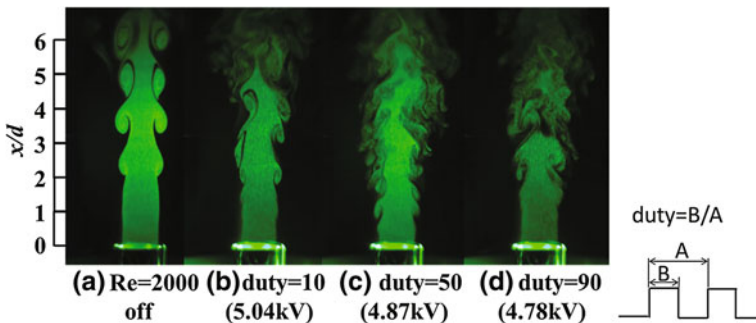


Fig. 3 Typical flow visualizations at **a** off, **b** 10 %, **c** 50 %, and **d** 90 % ($Re = 2.0 \times 10^3$)

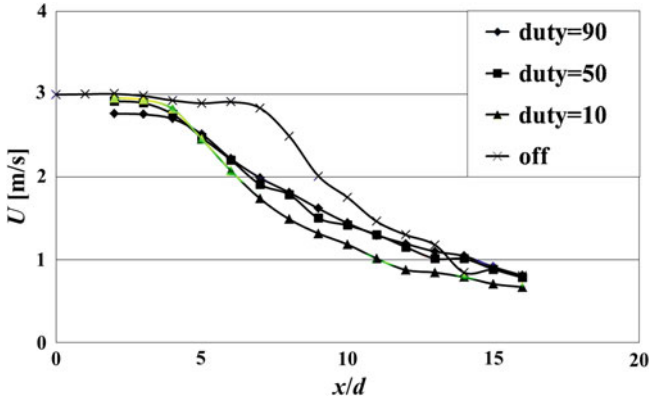


Fig. 4 Velocity distribution on the jet axis ($Re = 2.0 \times 10^3$)

intermittency period and B is the plasma impression time. The duty ratio is 0 % when the DBD PA is in the off condition and 100 % when the DBD PA is operating in continuous mode.), and a Re of 2.0×10^3 . The intermittency frequency is twice the preferred frequency (approximately, 160 Hz at $Re = 2.0 \times 10^3$) of the jet stream. For the case in which the DBD PA is off, due to K–H instability, a vortex ring is generated in the neighborhood of $x/d = 2$, and a vortex ring sequence is formed. At $B/A = 50$ %, the instability approaches the nozzle, and the vortex ring has collapsed at an early stage. As B/A increases, the position at which the vortex ring is generated approaches the nozzle, and the interval of the vortex ring narrows.

3.3 Velocity Distribution on the Jet Axis

Figure 4 shows the distribution of the mean velocity, U , along the jet axis for various duty ratios. For the case in which the DBD PA is off, the velocity potential core length is $x/d = 7$. For the case in which the DBD PA is on, the velocity potential core length is $x/d = 4$. This is thought to occur because the velocity at the surface of the nozzle wall increases as a result of the DBD PA, as discussed in Sect. 3.1. The potential core length is decreased sharply by turning on the DBD PA. K–H instability is enhanced by the DBD PA near the nozzle, and the application of intermittent plasma is believed to generate vortex rings near the nozzle that collapse at an early stage.

4 Conclusions

The flow velocity distribution in the vicinity of $y/d = \pm 0.4$ around the nozzle increases due to the flow induced by DBD PA, and the velocity at the center of the nozzle decreases in case of continuous mode. For the DBD PA at $B/A = 50\%$ in case of intermittent mode, the instability approaches the nozzle, and the vortex ring collapses at an early stage. The potential core length is decreased sharply by the use of DBD PA at an early stage. K-H instability is enhanced by the DBD PA near the nozzle. Intermittent plasma is considered to generate vortex rings near the nozzle, and these vortex rings collapse at an early stage.

References

Corke TC, Enloe CL, Wilkinson SP (2010) Dielectric barrier discharge plasma actuators for flow control. *Ann Rev Fluid Mech* 42:505–529