A Thesis for the Degree of Ph.D. in Engineering

Numerical investigation on the discharge process of a nanosecond-pulsed surface dielectric-barrier-discharge plasma actuator

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Thesis Abstract

Surface dielectric-barrier-discharge plasma actuator (SDBD-PA) has shown its promising prospects in aerodynamic applications. Due to the complexity in discharge plasmas, numerical modelling of plasma actuators is important to understand its physics and improve the intensity of plasma actuation.

Two-dimensional fluid-model simulation of an SDBD-PA, driven by a nanosecond voltage pulse, is conducted. We first focus on the influence of grid resolution on the computational result. It is found that the result is not sensitive to the streamwise grid spacing, whereas the wall-normal grid spacing has a critical influence. The computed propagation velocity of discharge streamer changes discontinuously around the wall-normal grid spacing about 2 µm due to a qualitative change of discharge structure. The present result suggests that a computational grid finer than that was used in most of previous studies is required to correctly capture the structure and dynamics of streamer: under positive nanosecond voltage pulse, a streamer forms in the vicinity of upper electrode and propagates along the dielectric surface with a maximum propagation velocity of $2 \times 10^8$ cm/s, and plasma sheath layer with low electron density exists between the streamer and dielectric surface.

Based on the grid convergence study, a systematic numerical investigation of the nanosecond-pulsed SDBD evolution under positive (PEP) and negative electrode polarity (NEP) is performed. Under both PEP and NEP, two discharge strokes take place corresponding to the leading edge and trailing edge of the nanosecond voltage pulse. During the first stroke, the positive streamer propagates along the dielectric surface accompanying a thin sheath layer, while the negative streamer stays attached to the dielectric surface. The positive streamer propagates faster than the negative streamer. During the second stroke, a sheath layer forms between the negative streamer and the dielectric surface due to the electrons drifting away from the near-surface region, while the sheath layer between the positive streamer and the dielectric surface fades away due to the electrons drifting toward the dielectric surface. For both PEP and NEP, it is revealed that a strong downstream body force is generated when the sheath layer exists, due to the high net charge density and strong electric field in the near-surface sheath layer.

Parametric study is conducted to investigate the influence of voltage amplitude, dielectric permittivity and thickness on the discharge propagation, generated body force and heat source under both PEP and NEP. It is found that the discharge current, generated body force and heat source increase with increasing the dielectric permittivity or decreasing the dielectric thickness. The improvement of body force is mainly due to the increase of net charge density in the sheath layer.

The series of the present numerical simulations reveal the plasma discharge in detail, which is important to understand the physics of SDBD-PA and to help improving its flow control ability.