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Characteristics of Plasma Synthetic Jet Actuator in Repetitive Working Mode

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Abstract : Plasma synthetic jet actuator (PSJA) is a new concept of zero net mass flow actuator which utilizes pulsed arc/spark discharge to rapidly pressurize gas in a small cavity under constant-volume conditions. The unique combination of high exit jet velocity (>400 m/s) and high actuation frequency (>5 kHz) provides a promising solution for high-speed high-Reynolds-number flow control. This paper focuses on the performance of PSJA in repetitive working mode which is more relevant to future flow control applications. A two-electrodes PSJA (cavity volume: 424 mm3, orifice diameter: 2 mm) together with a capacitive discharge circuit (discharge energy: 50 mJ-110 mJ) is designed to enable repetitive operation. Time-Resolved Particle Imaging Velocimetry (TR-PIV) system working at 10 kHz is exploited to investigate the influence of discharge frequency on performance of PSJA. In total, seven cases are tested, covering a wide range of discharge frequencies (20 Hz-560 Hz). The pertinent flow features (shock wave, vortex ring and jet) remain the same for single shot mode and repetitive working mode. Shock wave is issued prior to jet eruption. Two distinct vortex rings are formed in one cycle. The first one is produced by the starting jet whereas the second one is related with the shock wave reflection in cavity. A sudden pressure rise is induced at the throat inlet by the reflection of primary shock wave, promoting the shedding of second vortex ring. In one cycle, jet exit velocity first increases sharply, then decreases almost linearly. Afterwards, an alternate occurrence of multiple jet stages and refresh stages is observed. By monitoring the dynamic evolution of exit velocity in one cycle, some integral performance parameters of PSJA can be deduced. As frequency increases, the jet intensity in steady phase decreases monotonically. In the investigated frequency range, jet duration time drops from 250 µs to 210 µs and peak jet velocity decreases from 53 m/s to approximately 39 m/s. The jet impulse and the expelled gas mass (0.69 µN•s and 0.027 mg at 20 Hz) decline by 48% and 40%, respectively. However, the electro-mechanical efficiency of PSJA defined by the ratio of jet mechanical energy to capacitor energy doesn’t show significant difference (o(0.01%)). Fourier transformation of the temporal exit velocity signal indicates two dominant frequencies. One corresponds to the discharge frequency, while the other accounts for the alternation frequency of jet stage and refresh stage in one cycle. The alternation period (300 µs approximately) is independent of discharge frequency, and possibly determined intrinsically by the actuator geometry. A simple analytical model is established to interpret the alternation of jet stage and refresh stage. Results show that the dynamic response of exit velocity to a small-scale disturbance (jump in cavity pressure) can be treated as a second-order under-damping system. Oscillation frequency of the exit velocity, namely alternation frequency, is positively proportional to exit area, but inversely proportional to cavity volume and throat length. Theoretical value of alternation period (305 µs) agrees well with the experimental value.
Keywords : plasma, synthetic jet, actuator, frequency effect
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