CAUSE-EFFECT RELATIONS BETWEEN DISCHARGE CAPACITANCE AND VOLUME FORCES OF DBD PLASMA ACTUATORS

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INTRODUCTION

Dielectric barrier discharge (DBD) plasma actuators are used for flow control in gas flows. Besides time-averaged investigations of the resulting volume force distribution [5] the determination of the time- and phase-averaged volume force information became more important in the past years [1, 2, 7, 9]. Although there are several publications about the development of the volume, force there is no obvious agreement about the exact behaviour. It is widely accepted that the contribution of the high voltage driving the plasma discharge is different in the positive and negative half-cycles, as shown by Enloe et al. [3] and Orlov et al. [8], for instance. The investigations mentioned above use a sinusoidal driving signal to identify the phase relation of the measured volume force. The work presented in this abstract deals with the measurement of phase-averaged volume force distribution $f(x, y, \Phi)$ at very high frequencies $f$ of the operating voltage $V$, pushing the measurement technique particle image velocimetry (PIV) to its limits. For the first time the measured volume forces are assigned to the instantaneous capacity of the plasma actuator using the Lissajous figure (cyclogram), rather than the commonly used voltage signal; see Figure 1. As such, a deeper insight into the interrelation of the discharge and the resulting momentum transfer is provided.

SETUP AND RESULTS

The velocity information was obtained by means of particle image velocimetry. The measurements were performed in quiescent air to eliminate the influence of an external flow on the wall jet generated by the plasma actuator. A single plasma actuator was driven by a high voltage sinusoidal signal with $V_{pp} = 12$ kV and a frequency of $f = 10$ kHz. The operating voltage was generated using a Minipuls 6 and di-ethyl-hexyl-sebacat (DEHS) was used for tracing. With the experimental equipment it is allowed to record up to eight phase positions at arbitrary phase angles for the chosen parameter settings of the actuator. The measured operating voltage $V$ and charge values $Q$ are plotted against each other in Q-V-cyclograms, also known as Lissajous figures [6]. Within the Lissajous figure the instantaneous capacitance of the actuator can be identified by calculating its slope according to

$$C(t) = \frac{dQ(t)}{dV(t)} \quad (1)$$

Figure 1 shows the Lissajous figure of a DBD with the characteristic capacitances $C_0$ and $C_{eff}$. $C_0$ represents the electrical pure passive component (cold) capacitance and $C_{eff}$ the effective capacitance, consisting of a combination of the passive component $C_0$ and the contribution of the plasma itself to the capacitance [4]. The measurement points for the PIV images and the resulting position of the correlated values are also shown in Figure 1. The positions were deliberately chosen to make sure that noisy areas (e.g. quenching of the plasma) are omitted.

Figure 2 shows the evolution of the actuator capacitance over phase and the determined integral value of the volume

![Figure 1: Typical Q-V-cyclogram (Lissajous figure) of a DBD with characteristic capacitances $C_0$ and $C_{eff}$](image)

![Figure 2: Evolution of the capacitance of the plasma actuator and the volume force over the measured phase positions. The characteristic capacitances $C_0$ and $C_{eff}$ are highlighted. The positive volume force is generated during the negative half-cycle of the sinusoidal operating voltage.](image)
force per phase. The positive volume force is generated in
the negative half-cycle, during the appearance of a glow type
discharge [3]. The existence of areas with almost zero volume
force for two phases is remarkable (Φ = 3π/4 and Φ = 7π/4).
In both cases the volume force is zero for the dark periods [6]
with a pure passive capacitance $C_0$ in the cyclogram, where
positive and negative parts of the volume force compensate
each other. The quenching of the plasma induces the deceler-
ation of the flow and simultaneously the capacitance changes
from $C_{eff}$ to $C_0$, as can be identified from the shark kinks in
the Lissajous figure. The spatial distribution of the volume
force $f_x$ at different phase angles is shown in Figure 3. Fig-
ures 3a and 3c correspond to the effective capacitance $C_{eff}$
while Figures 3b and 3d refer to the passive component ca-
pacitance $C_0$. The positive and negative contributions to the
volume force in Figure 3b and 3d compensate each other, such
that the resulting volume force is approximately zero.

The resulting volume force is in good agreement with
previous publications (see Figure 4). The findings of
Neumann et al. [7] show the same development, even
though measured with laser doppler anemometry (LDA). The
results presented in this abstract and the results of Neumann
et al. [7] show a slightly shifted behaviour due to the fact that
the operating frequency is higher compared to the measure-
ments of Benard et al. [1], Debien et al. [2] and Wilke [9]. It
is hypothesized that - despite reasonable Stokes number - the
higher frequencies imply a slight phase lack between the flow
and the tracers.

**CONCLUSION**

The temporal evolution and spatial distribution of the
volume force at a high frequency operating voltage shows
a similar behaviour compared to previous publications. In
agreement with literature the results show that the positive
volume force is generated in the negative half-cycle during
the glow-discharge and the negative volume force is formed
in the positive half-cycle during the streamer-discharge. Ad-
ditional consideration of the Lissajous figure clearly uncovers
the dependency of the generated volume force to rely on the
instantaneous capacity of the plasma actuator rather than the
operating voltage. During the dark periods, thus passive ca-
pacitance $C_0$, the overall volume force is counterbalanced to
approximately zero. The main part of the plasma discharge
at $C_{eff}$ shows the major contribution to the resulting volume
force. The streamer type discharge in the positive half-cycle is
not able to compensate the dominant negative volume force,
which in turn leads to a negative volume force at the respective
phase. In conclusion, this new insight into the capacitance-
volume force-interrelation might serve as the basis for novel
control concepts in discharge-based closed-loop control appli-
cations in aerodynamics.

**REFERENCES**


