VORTEX STRUCTURES GENERATED BY DBD PLASMA ACTUATOR

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This article deals with the research of vortex structures generated by a plasma actuator. Plasma actuators belong to devices that can be used for active flow control. However, one can find only a limited amount of information dealing with the physical principal of this phenomenon. The conclusion of this article is formulated to give an simple explanation of physical laws acting during generating, evaluating and decay of vortex structures to ensure that results could be apply in the future for more applicable research.

The dielectric barrier discharge (DBD) actuator consists of two electrodes which one is powered by high-voltage high-frequency waveform and second electrode is grounded. Both electrodes are separated by a dielectric layer [1]. This kind of device can generate so-called electric wind (plasma-induced wall-jet-like flow) in steady regime. After the application of amplitude modulation to the waveform, the unsteady regime occurs which is characterized by present of series of vortices. The vortex behaviour is determined by driven parameter of modulation (modulation frequency, duty cycle DC). However, other parameters (even geometrical) influence the generated flow patterns.

The investigation of this kind of flow field is not an easy task. Quite extended area, the presence of plasma discharge and strong electrostatic field and the demand to sufficient spatial and temporal resolution are a big challenge to velocity measurement technique. Since the plasma-induce flow is investigated without the influence of free flow, the actuator is placed at the bottom of the closed plexi-glass chamber. This chamber is adjusted to be able to guarantee the measurement by TR-PIV and HW anemometry inside it. The measurements were performed in the Institute of Thermomechanics by procedures adjusted to this unconventional condition.

The vortex street is pseudo-periodical process. To be able to study only periodical essence of that phenomenon, phase-averaging has to be implemented into sampled data. Then random component (the variance of vortex core location etc.) is averaged which allows us to determine the generally valid physical principles. Phase-averaging is performed when every period given by modulation frequency is divided into twenty phases. The investigation of vortex structures is then carried out by vortex identification schemes based on velocity gradient tensor and then by various computations (e.g. vortex circulation, trajectory, diameter etc.).

The results could be divided into two groups. First one is flow field around plasma actuator in steady regime. The wall jet generated by plasma is very tightly held to the surface which means that position of maximal velocities are up to two millimeters from the wall. The maximal velocity depends on various parameters as electrode gap, electrode width, voltage magnitude and frequency magnitude. In the case of amplitude modulation, there is a strong dependency on duty cycle and modulation frequency.

The shape of wall jet was evaluated both for steady regime and unsteady regime. The thickness development and the decrease of maximal local velocities in the velocity profiles were observed how they go against each other almost symmetrically. The shape factor (the rate between the position of local maximal velocity and the contractual boundaries of the wall jet) was evaluated for different configurations in order to determine the total wall jet behaviour.

The most important part of that research was the dynamics of coherent structures present in the unsteady regime. The trajectory, the convective velocity, the changing radius of the vortex and the circulation were utilized to describe the dynamic behaviour and based on that a simple physical model was introduced. The vortex cores were identified for every configuration and consequently the vortex core trajectory was reconstructed. The convective velocity was computed as an average of individual increments of trajectory. This drift velocity is increasing with applied modulation frequency and it is decreasing with a higher duty cycle (see the Fig. 1). The equivalent radius of vortex was calculated from only the upper half of vortex (to eliminate the influence of wall jet) and the boundary of vortex was set considering to actual value in the core. The radius is increasing in time for all configurations and it reaches a higher magnitude for lower frequencies. The circulation was determined from the vorticity field by integration which means that it is not so affected by such uncertainty. As it was shown in previous study [2], the circulation is rising during the entire working cycle of actuator and even is still in progress after the end which implies that there is some inertia in vortex feeding.

The question was if the convective velocity is related with self-induced velocity of the vortex given by Biot-Savart law. It was found out that self-induced velocity is multiplicatively smaller then measured induced velocity. The induced velocity was then found as quadratic function of duty cycle and modulation frequency. This model of vortex generated by DBD actuator can help by future implementation of plasma actuators and by CFD simulations.

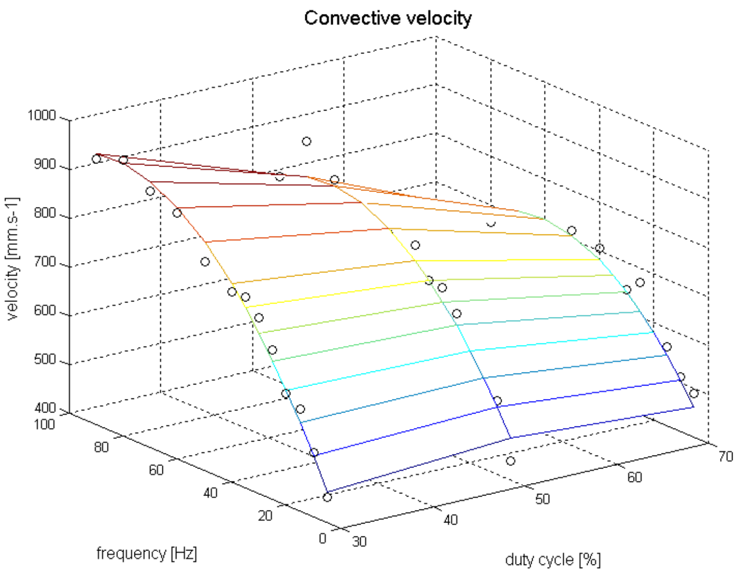

Fig. 1 – Measured convective velocity of the vortex core

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References:

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[2] Procházka, P. & Uruba, V.; Parametric study of vortex train generated by plasma in dependency on input voltage waveform; *Experimental Fluid Mechanics*, 2012, pp. 594-598