Phase-locked 3D3C-MRV measurements in a bi-stable fluidic oscillator

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In this work the phase-resolved internal flow of a bi-stable fluidic oscillator was measured using phase-locked 3D3C-MRV, also termed as 4D-MRV [1]. A bi-stable fluidic oscillator converts a continuous inlet-mass flow into a jet alternating between two outlet channels and, as a consequence provides an unsteady, periodic flow. Since data acquisition of a single time step in a 3D volume can take up to several minutes, only a small portion of data is acquired per period cycle, i.e. the acquisition of the entire data set is segmented over many cycles of the periodic process. By this technique a phase-resolved velocity field is created. However, the procedure requires triggering to the periodic nature of the flow. Therefore, triggering the MR scanner precisely on each flow cycle is one of the key issues discussed in this manuscript.

A triggering system was developed, based on a piezo-element pressure transducer, providing a reliable signal despite the harsh magnetic and electro-magnetic environment inside an MR scanner. The obtained 4D-MRV data are compared to data measured using Laser-Doppler anemometry and good agreement between the results is found.

Subsequently, the validated 4D-MRV data is analyzed and the fluid-mechanic features and processes inside the fluidic oscillator are investigated and described in detail.

The design of the fluidic oscillator was taken from Arwatz et al. [2] and the geometry was kindly provided by Prof. Avi Seifert. The actuator was scaled in order to suit the experimental limitations. For the 4D-MRV measurements it is necessary to trigger the MRI scanner precisely on the periodic flow. The scanner can process an electrocardiogram signal or a TTL signal. In this work unsteady pressure measurements seemed most appropriate for this purpose. Several types of pressure transducers and installation positions were considered and tested and a pressure sensor based on a piezo-electric foil was chosen. The pressure signal has to be filtered and analyzed in real time to generate the triggering signal for each flow cycle individually. The filtered pressure signal is then sampled by a National Instruments Real-Time PCI-1031 DC system, equipped with a NI PXI-8106 embedded controller card and a NI PXI-6259 multifunctional DAQ card, running under the LabVIEW Realtime operating system. The signal is sampled every 10ms and a high-pulse of 15ms duration is generated when the pressure signal crosses the zero Volt threshold on a negative slope. The TTL triggering signal is fed into the MRI scanner through a RCA jack.

The 4D-MRV sequence is an advanced 3D3C-method, which subdivides the 3D-velocity encoding into equidistant time steps for an underlying cycle. A Siemens Trio Tim System with a 3 Tesla strong main magnetic field was used. In preliminary experiments the oscillation frequencies of the fluidic oscillator were determined from unsteady pressure measurements for three different feed-back tubes as a function of the Reynolds number. The feed-back tubes had different lengths l and different inner diameters d.

For validating the MRV data Laser-Doppler-Anemometry (LDA) measurements have been conducted. The data of the 4D-MRV measurements and of the LDA measurements are in good agreement concerning the development of the velocity data in time and space and concerning the magnitudes of the velocity. Both techniques precisely capture the periodic oscillation of the exiting jet with all details.

In this investigation the jet switching mechanism is defined to be a composition of three different phases: At first a stay phase occurs, during which the jet is attached to one wall and is staying locally fixed. Subsequently a detachment phase from the wall can be observed. The detachment starts with a slow and slight movement of the jet away from one Coanda wall and ends with the advancement of the jet to the center of the interaction cavity pointing directly on the leading edge of the splitter. Then the influence of the opposing Coanda wall prevails and, hence, the jet moves towards this wall. This phase can be termed attachment phase.

Essential contributions to the understanding of the fluidic-oscillator flow could be made and new insights into the processes composing the flow cycle in such devices were obtained. The flow cycle could be divided into three phases: the stay phase, the detachment phase and the attachment phase. Further analysis and interpretation of the data are currently conducted and will complete the here described experimental procedure and results.
