5th Micro and Nano Flows Conference
Milan, Italy, 11-14 September 2016

Velocity measurements in an Omega-micromixer using Stereo-MicroPIV

F. Gökhan ERGİN [1,*]

* Corresponding author: Tel.: +45 4457 8173; Fax: +45 4457 8001; Email: gokhan.ergin@dantecdynamics.com
1 Product Manager, Dantec Dynamics, Skovlunde, DK

Keywords: MicroPIV, Stereo MicroPIV, Image calibration, omega micromixer

Mixing is often enhanced in the presence of three-dimensional (3D) flow structures such as vortices. In micro scales the initiation of such 3D microstructures is often suppressed because of the low Reynolds number inherent to micro scale flows. Passive, omega-shaped serpentine micromixers have the potential to induce three- dimensional rotating flow structures around sharp corners and thereby enhance mixing efficiency.

Experiments are performed on the flow through an omega micromixer in order to check the presence of micro scale vortices. The microchannel features a simple Omega shape with several 90-degree corners (Fig. 1). The channel height and width is 1mm, which is rather large compared to what can be achieved with current micro-manufacturing techniques. This is intentional in order to perform measurements at different channel depths and construct the time-averaged 3D flow field in the future campaigns. In the current study results from a single measurement plane (center-plane) is reported.

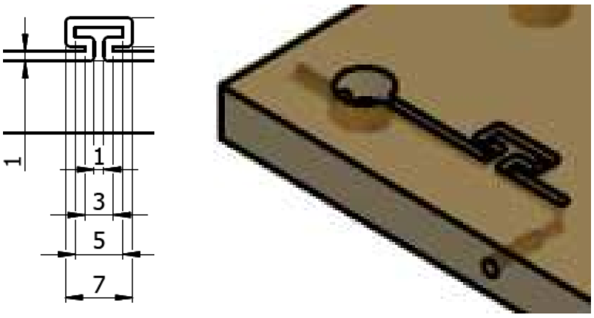

Figure 1 Omega-micromixer and its dimensions in mm

Stereoscopic MicroPIV technique [1,2] has received increased attention recently, as it can provide the necessary multiple-component velocity information in micromixers in micron scale resolution. Experiments are performed to measure all three velocity components in the middle plane of the microchannel, at the sharp corners. The experimental setup includes a Leica fluorescence stereomicroscope, 2x PlanApochromatic common main objective, a custom-built micro image calibration kit (Fig. 2), laser and LED illumination, and a checkerboard calibration plate (Fig. 3). The selected microscope and objective configuration can produce a stereoscopic half-angle of ~23 degrees in water (full angles 46 degrees), and this means that the uncertainty of the off-axis velocity component is expected as 2.4 times that of the in axis velocity components [3].

Figure 2 Stereoscopic image calibration kit

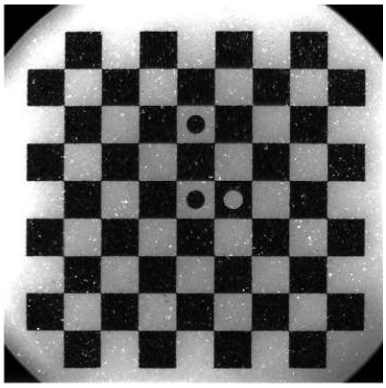

Figure 3 View of the checkerboard calibration target. Each square edge dimension is 100µm.

Stereoscopic image calibration in a microchannel is simply difficult, if not impossible. In order to achieve an accurate representation of the object space in 3D, a dedicated image calibration kit is used, which consists of a checkerboard calibration target, a calibration pool and a microstage to traverse the target in the calibration pool. The cover glass of the calibration pool and of the microchannel are the same material simulating similar optical conditions during calibration and measurements. The calibration target includes two checkerboard patterns for 1mm and 0.5mm object size. The larger pattern is used to match the channel dimension. Carefully placed circular markers allow an unambiguous definition of the planar coordinate axes. During calibration, a pulsed mono- chromatic LED device is used for illumination, which proves useful in obtaining calibration images with good contrast. The calibration is performed (i) by imaging the checkerboard pattern in known positions within the depth of field (ii) by computing mapping function for the 3D space using a 3rd order polynomial function used by Soloff et al [4] and (iii) by performing calibration refinement. The depth of field is adjusted by closing the aperture of the zoom optics of the stereomicroscope.

A depth calibration is also performed for accurate positioning of the measurement plane in the microchannel. The depth calibration, stereoscopic calibration and experiments are performed at 5x system magnification, which resulted in a Field of View of 3mm x 3mm. During depth calibration and measurements the aperture was fully open producing a 16µm field depth (important for depth calibration) and 99µm correlation depth (important for experiments). During calibration the iris diaphragm was only 2/3 open, producing a field depth of 32µm. Five calibration images were used at h=400µm, 450µm, 500µm, 550µm and 600µm. The average reprojection error for left and right cameras were found as <0.2pixels.

A high precision syringe pump with a linear step resolution of 12 nm is used to deliver the distilled water seeded with 1µm-diameter Nile-red fluorescent particles. The flow rate accuracy and reproducibility are given as ±0.35% and ±0.05% respectively. The syringe pump can drive two syringes simultaneously and the flow rate is adjustable between 1.6 pl/min to 300 ml/min using different syringe sizes. High quality airtight glass syringes are used to generate a smooth flow during the measurements. A flow rate of 15ml/min produced an expected average velocity of 250mm/s. (Re = 250)

During measurements, pulsed illumination at 532nm from a 60mJ/pulse dual-cavity Nd:YAG laser is delivered to the microscope using a liquid light guide and imaging is performed using two FlowSenseEO 4Mpix PIV cameras. Planar three component velocity measurements are computed by combining the 2D2C velocity field information from each camera, and refined image calibration information. Contrast of raw particle images was enhanced by performing a background subtraction using minimum pixel value found in the ensemble. An ensemble masking technique is also applied.

It was challenging to find intricate flow details when the complicated flow field was observed using the 2D viewer. 3D views of the results indicate that micro-vortex systems are present close to the corners of the omega-micromixer (Fig. 4). These small-scale vortices are only recognizable using a 3D viewer and from a particular angle.

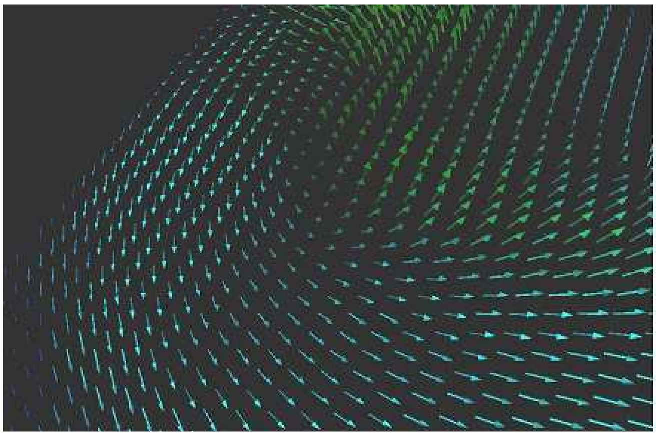

Figure 4 A vortex observed close to one of the sharp corners in the simple omega-micromixer. Colors indicate the magnitude of the velocity vector.

REFERENCES

[1] Lindken, R., Westerweel, J., & Wieneke, B. (2006). Stereoscopic micro particle image velocimetry. *Experiments in Fluids*, 41(2), 161-171.

[2] Brede, M., Witte, M., & Leder, A. (2006) Stereo-Micro PIV measurements of the three-dimensional separated flow in the wake of a backward facing step. Proc. 13th Int Symp on Applications of Laser Techniques to Fluid Mechanics.

[3] Prasad, A.K., Stereoscopic Particle Image Velocimetry. (2000) *Experiments in Fluids*, 29, 103-116.

[4] Soloff, S.M., Adrian R.J., & Liu Z.-C. (1997) Distortion compensation for generalized stereoscopic particle image velocimetry. *Meas. Sci. Tech. in Fluids*, 8, 1441-1454.