Time resolved PIV in a rotating diverging channel

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This paper deals with the development of a PIV system to measure the time evolution of the velocity fields in a rotating diverging channel. The light sheet is produced by means of a continuous laser diode and the images are taken with a high speed camera, both rotating with the channel. In this way a direct and hence more accurate measurement of the time variation of the relative velocity is performed. The Laser Diode module has 25 Watts maximum Power at 806 nm. It is coupled in a N.A.= 0.22, 200 µm core diameter fiber cable. The laser sheet created by a compact optics module has 16° total aperture and 1 mm maximum thickness. The High Speed Camera has an internal memory of 1 GB that allows to store images during rotation. Exposure time can be set to a minimum of 2 µs. In this way it is possible to set the correct amount of light for each acquisition.

The facility consists of a divergent channel of 0.7 m length and .079 m inlet hydraulic diameter and is mounted on a 2.5 m rotating vertical disk. It reproduces the impeller passage of a Micro Gasturbine while respecting the main scaling parameters. The facility allows an independent variation of the Reynolds number $\mathrm{Re} = \dfrac{u_m d_h}{\nu}$ from $2.9 \cdot 10^3$ to $3 \cdot 10^4$, and Rotation number $\mathrm{Ro} = \dfrac{2\omega d_h}{u_m}$ from 0. to 0.55. Mass flow is set by a centrifugal blower at the inlet or by a throttling valve, and measured with a Venturi tube. The seeding is vaporized oil produced by a VKI built smoke generator. It consists of a heated plate at 180 C and it is fed with air compressed at 1.8 bars. Particles have a typical diameter in the range 1- 3 µm.

Flow in micro Gasturbines is characterized by low Reynolds number, large Coriolis forces and a considerable heat transfer. Accurate performance prediction and optimization of those devices are possible only if the Navier-Stokes solvers correctly account for those phenomena.

Time Resolved PIV measurements were taken in an area at midway between channel inlet and outlet, at mid height. The area between wall and midsection was covered by two slightly overlapping measurement zones of 53x 40 mm² each.

Changing the sense of rotation allows measuring on pressure and on suction side by acquiring data in the some zone. Camera resolution was set at 640x 480 pixels². Two Reynolds number: 11285 and 16900 were investigated at three Rotation number values: stationary, 0.13 and 0.33. In the present measurement campaign a maximum velocity of 3.2 m/s is measured at 3 kHz and 130 µs exposure time settings of the camera and a maximum rotation speed of 60 RPM. Images were processed with WI.D.I.M., a software developed at VKI. It performs a cross- correlation with windows displacement according to a predictor vector, followed by an iterative grid refinement and windows distortion. The code also uses a Gaussian sub- pixel interpolation to compute the displacements. Following parameters settings are used: 48x 48 pixels initial windows size, 2 refinement steps, and 50% overlapping. 8295 vectors are obtained in each zone, with a vector separation of 6x 6 pixels. Quality of the measurements is proved by signal to noise ratio maps and an example histogram of displacements. Non valid vectors, calculated comparing each vector with the neighboring ones, were kept under 1%. The Uncertainty on the bulk flow velocity, based on the method of Kline and McClintock, was also limited to a maximum of 1%. Mean flow fields were computed using 1000 couples to have statistically correct results. Instantaneous flow fields give us information about vorticity and turbulence structures.

The facility proved to give accurate results both in non rotating and in rotating case. Detailed measurements in space and time domain highlighted the increasing influence of Ro on the boundary layer behavior. The suction side flow is stabilized by rotation and the boundary layer thickness increases. At Ro= 0.33, recorded movies and time resolved flow fields show intermittent backflow. Flow is destabilized on the pressure side. It is more turbulent and less likely to separate. The vorticity is confined to a small area close to the wall resulting in a reduced boundary layer thickness.

The system provided accurate data that can be used to quantify the effects of rotation on turbulence and to validate turbulence models in the Navier- Stokes solvers.