

# Time-resolved PIV measurements with CAVILUX<sup>®</sup> HF diode laser

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## 1 Introduction

Particle Image Velocimetry (PIV) is a non-intrusive optical technique to measure instantaneous 2D velocity fields in fluid flows. As a state-of-the-art measurement technique in fluid dynamics R&D, PIV provides several advantages over traditional measurement techniques such as Laser Doppler and Hot Wire Anemometry. PIV is a whole-field technique which is able to capture instantaneous velocity fields over a 2D domain. This kind of data reveals flow topology, i.e. coherent flow structures such as vortices. Thus, besides providing accurate quantitative information of the flow field, PIV is also a very effective tool for studying physical phenomena contributing to the turbulence kinetic energy and other statistical measures of turbulent flows. Especially, PIV performed with high-speed imaging system creates new insight into the dynamics of turbulent motions.

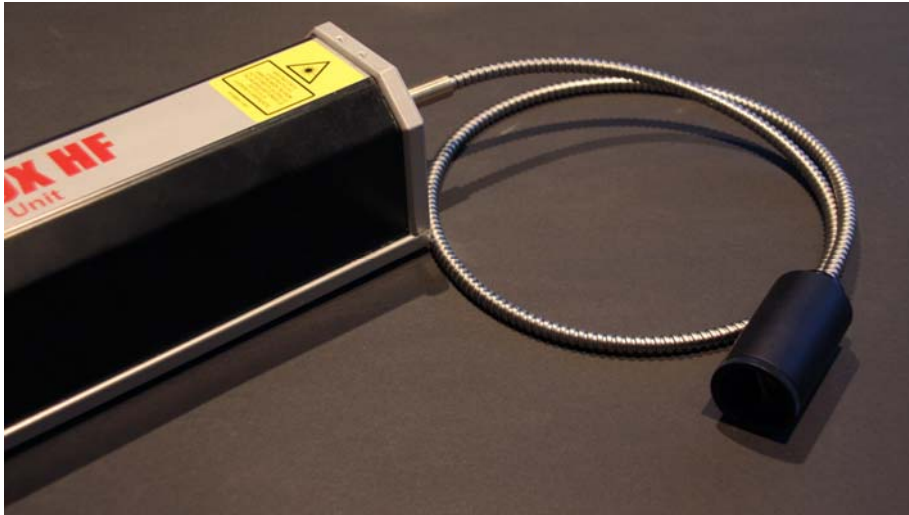
This paper presents time-resolved PIV experiments utilizing a high-speed camera and CAVILUX HF diode laser. CAVILUX diode lasers provide many attractive properties for PIV. Desired pulse sequences with accurate control of pulse energy and temporal spacing of consecutive pulses can be obtained easily. Furthermore, the laser unit is coupled to fiber optics, which allows a robust and flexible guidance of light to the measurement volume. The laser unit is very compact, which allows easy installation and mobility also in challenging industrial environment.

## 2 The measurement equipment

Tracer particles are illuminated by CAVILUX HF diode laser equipped with a special light sheet generating fiber optics. The wavelength of the laser is 808 nm and the pulse energy ~0.5mJ at 20 kHz. The pulse energy can be increased linearly as the pulse frequency is decreased. For example, at 1 kHz pulsing rate the pulse energy can be about 10 mJ. CAVILUX control unit can be programmed to produce single pulses or bursts of pulses at desired frequency and duration. However, in these measurements the laser is used as a slave, which delivers pulses with user defined duration according to external synchronization signals provided by the camera.

The light sheet is created by using a fiber optic light guide with individual fibers arranged to a line at the output end. The width of the light sheet is determined by the width of the line in which the fibers are laid. Also the beam divergence affects the sheet width at the measurement plane. The thickness of the light sheet as well as the focus distance can be changed by adjusting the position of the fiber output with respect to a cylindrical lens, which is the only lens in the setup. With present design, a light sheet with a thickness of less than 1 mm is obtained at the distance of 100 mm from the lens. It is estimated that approx. 50 % of light provided by the laser is transmitted through the optics in the present design. Figure 1 presents the laser head and the light sheet optics.

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*Figure 1. Laser head and light sheet optics.*

Particle images are recorded with a Photron FASTCAM SA1.1 high-speed camera equipped with a Nikon 105mm f/# 2.8 lens and a narrow optical band-pass filter to block ambient illumination. Originally 12bit images are stored as 8bit grayscale bitmaps with 2bit shift. Details of the image recording parameters are given in Section 3.

The PIV data analysis exploits a rather standard procedure. Since there is no need for image preprocessing, the recorded images are directly sent to the cross-correlation analysis. This analysis utilizes a multi-pass correlation technique with an interrogation area refinement from 64 pix to 32 pix. The data is smoothed with a 3x3 unit filter after the first pass. The final pass is not filtered. After the PIV computation, a post-processing algorithm is used to detect spurious vectors. This algorithm utilizes two criteria to detect erroneous velocity vectors. The first criterion is based on setting predefined physical limits for the allowed velocities. Actually, the pixel displacements are limited to a user defined window. The other criterion is based on the local median filtering and the comparison of each velocity vector with the median of its 3x3 neighborhood. In the case that a vector is identified as a spurious one, it is removed and the hole is filled by a Gaussian weighted interpolation from the 3x3 neighborhood.

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### 3 Experiments

Air flow from a circular slit nozzle is measured to study vortex generation in the shear layers. These vortices are expected to result in noise at high flow rates. A schematic drawing of the experimental setup is presented in Fig. 2. The PIV measurement plane is adjusted to extend over both shear layers.

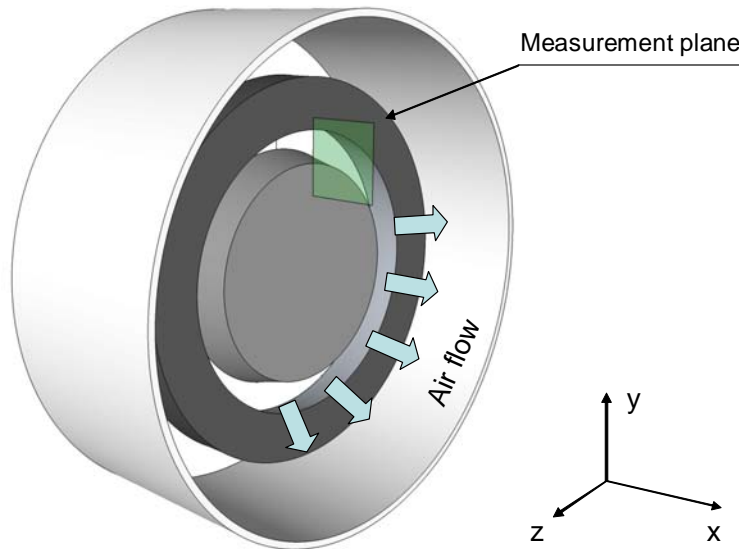


Figure 2. A schematic drawing of the measurement setup.

The nozzle is installed to a closed air circulation which is driven by a centrifugal fan. The maximum velocity of the air leaving the nozzle is about 20 m/s and the slit height is about 8 mm. With these experimental parameters, the imaging area is selected as 15x15 mm<sup>2</sup> and the imaging frequency as 20 kHz. This combination allows sequential PIV correlation to be computed, i.e. two consecutive frames are correlated to obtain a velocity map. Thus, the sampling rate for the velocity data is 20 kHz as well. This high imaging rate limits the camera resolution to 512x512 pix<sup>2</sup>. Also the laser pulse duration is limited to 1 μs as a result of the maximum duty cycle of 2 %.

The seeding is generated with an ultrasound droplet generator which is immersed in a dedicated seeding water tank. Before entering the measurement section, the air is circulated through the seeding tank. Small water droplets (<20μm) are mixed in the air flow and carried to the measurement plane where they are used as flow tracers. At high velocities the droplets are expected to follow the flow adequately.

In total 20'000 images are collected for PIV processing. Examples of images captured in the measurement plane are presented in Fig. 3. The image quality is very good; only a few large particles are over exposed and the gray scale distribution of the image occupies the full dynamic range of the image.

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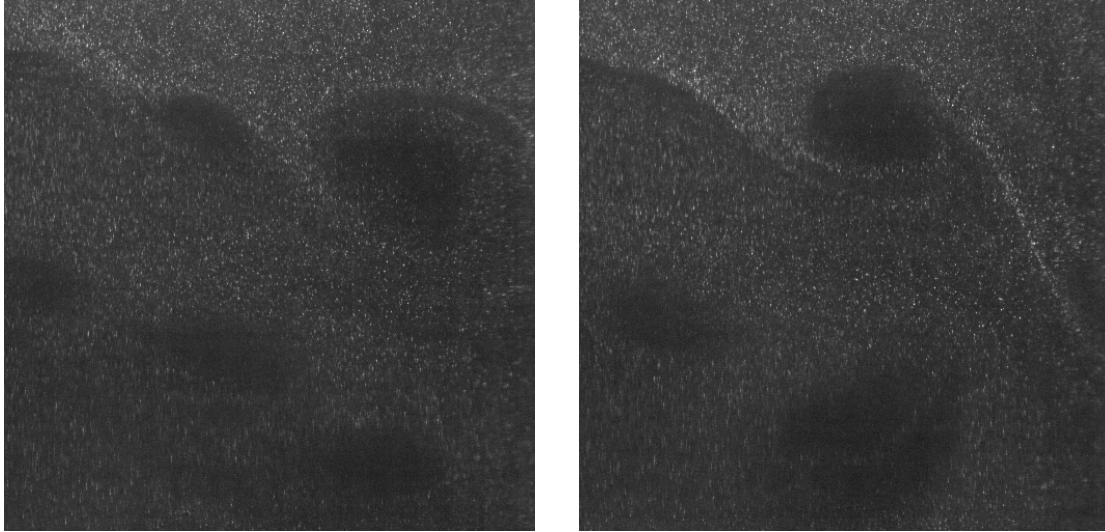


Figure 3. Examples of particle images.

## 4 Results

Figure 4 portrays an example of velocity field obtained from the PIV computation. The lack of seeding particles in the middle of the vortices causes some additional uncertainty in the velocity estimates. In general, the PIV interrogation successfully predicts the velocities also in the high-gradient regions. The flow field is characterized by the high-speed jet out of the slit and vortices developing in the shear layers. Figure 5 presents the mean velocity field and the velocity RMS field indicating active shear layers. The data is further analyzed by computing spectral estimates in various locations in the flow field. This is done by establishing point-wise velocity time-traces at desired locations over the set of 20'000 velocity fields. A short piece of such a time-trace is given in Figure 6 as an example. This data is sent to the 1D spectral estimation yielding the traditional PSD estimate presented in Fig. 7. There are two dominant peaks below 1 kHz, which are clearly related to the vortex dynamics.

The salient feature of the HS-PIV data is the inherently dense spatial grid of data which allows detailed analysis of the bulk flow, shear layers and the jet without any a priori information of their actual location.

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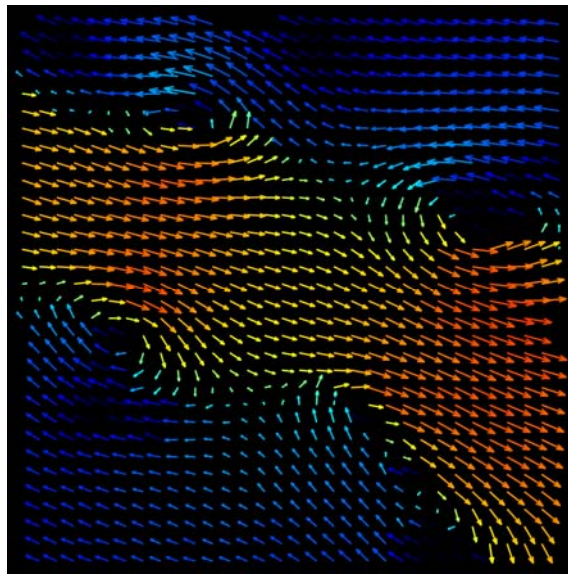


Figure 4. An instantaneous flow field.

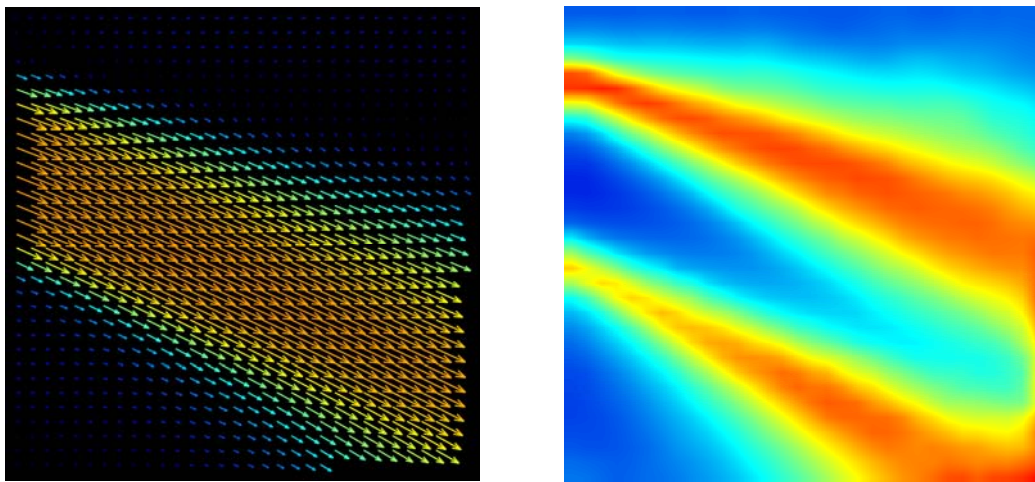


Figure 5. Mean and RMS fields of the flow.

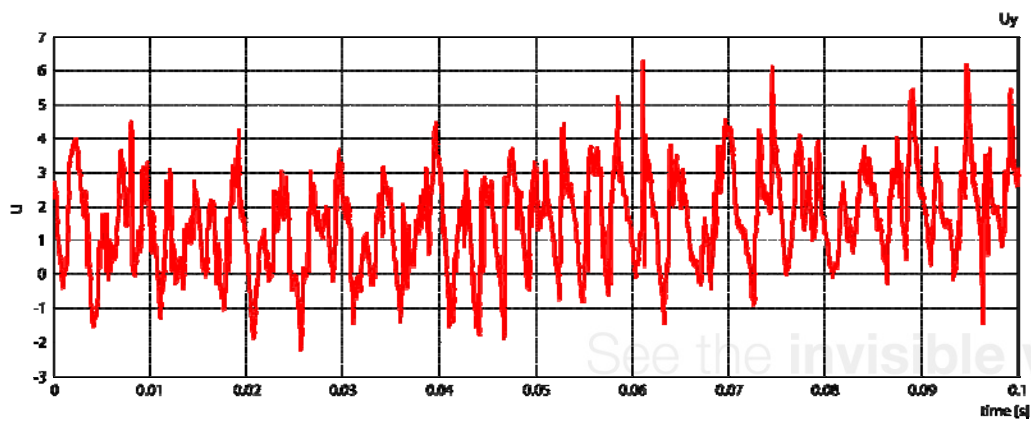


Figure 6. Time-trace of the velocity y-component in the lower shear layer.

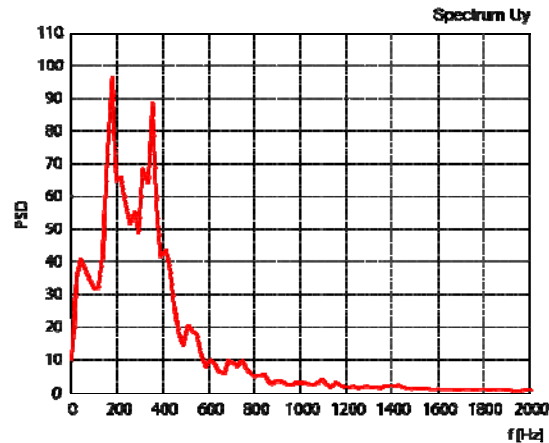


Figure 7. Spectrum estimated for the velocity  $y$ -component in the lower shear layer.

## 5 Conclusions

The application of diode lasers to PIV measurements offers very attractive possibilities. Compact and robust equipment, freely programmable bursts of pulses, flexible guidance of light to the measurement volume and affordability are the most important features of diode lasers. This work demonstrated that although the power provided by a diode laser does not match the power provided by pulsed solid-state lasers, the diode lasers present an adequate choice even for high-speed PIV.

## About the author



*Hannu Eloranta* (Dr.Tech.) has been working as a researcher in the Group of Experimental Fluid Dynamics at Tampere University of Technology. His research topics include several aspects of flow dynamics, such as turbulence, fluid-structure interactions and flow control. In addition he has been developing optical measurement techniques and analysis methods for fluid mechanics. Currently he is working in Pixact Ltd - a company specialized in developing optical measurement techniques.



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