Application of a Fabry-Pérot interferometer for multi-point flow measurements

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Common spectroscopic flow velocity measurement systems use absorption cells for the frequency-intensity conversion. The following article shows a proof-of-principle to realise this task interferometrically via a Fabry-Pérot interferometer. This setup has several advantages, but a complementarity between stray light power and edge steepness was found.

1 Introduction

Using atomic or molecular absorption cells for evaluating the Doppler shift by frequency to intensity conversion in common spectroscopic flow velocity measurement systems leads to several drawbacks [1]:

1. The applied laser frequency is bound to the spectral lines of the used absorption medium, which restricts the choice of lasertypes.
2. The achievable edge steepness of the transmission function is limited, which also limits the minimum measurement uncercainty.
3. For high light powers the measurement uncertainty can suffer from optical saturation effects in the absorption medium.

In an interferometrical system none of those effects can arise, therefore an Fabry-Pérot-Interferometer (FPI) is intended to be used instead of the molecular absorption cell.

2 Experimental Setup

Due to the strong angle dependence of the transmission τ_{FPI} through the FPI, the main challenge on realising such an interferometric measurement system for multiple measurement points is to achieve the same spectral transmission function for all measurement channels. Depending on the position of the FPI in the optical setup, there are different solutions for this problem.

Using the telecentric setup, where the FPI is arranged in the intermediate image plane, this demand is fulfilled per se for all points within the field of view. But in order to maintain a high edge steepness, the numerical aperture *NA* has to be in the range of less than 10^{-3} [2]. This leads to a very low amount of collected scattered light power, which makes the telecentric setup inapplicaple for technical flows.

Arranging the FPI in the fourier plane of the optical path leads to the collimated setup, which sets no limitiations to the *NA* . To gain the same spectral transmission for all measurement channels, the idea presented here is to use optical fibres for beam guidance and to arrange the fibre ends annularly around the optical axis. Thereby all measurment channels are equally regarding the angle of incidence in the FPI and the particular transmission functions are the same. Hence this solution is used below.

3 Estimation of the Measurement Uncertainty

To estimate the achievable measurement uncertainty the concept of the Cramér-Rao bound (CRB) is applied. Therefor the effective transmission function τ_{eff} of the measurement channels has to be known. Because of the spatial dependency of the angle of incidence φ a spatial averaging over the fibre end face S is necessary and leads to

$$\tau_{\mathrm{eff}}(f) = \frac{\int\limits_S \tau_{\mathrm{FPI}}(\varphi, f) \cdot I(r,\varphi)\,\mathrm{d}S}{\int\limits_S I(r,\varphi)\,\mathrm{d}S}, \qquad (1)$$

with $I(r,\varphi)$ as the intensity depending on the radius r from the optical axis [3].

By means of a numerical evaluation of the CRB for the given parameters of the FPI and the optical components using equation (1), a complementarity between the achievable scattered light power and the

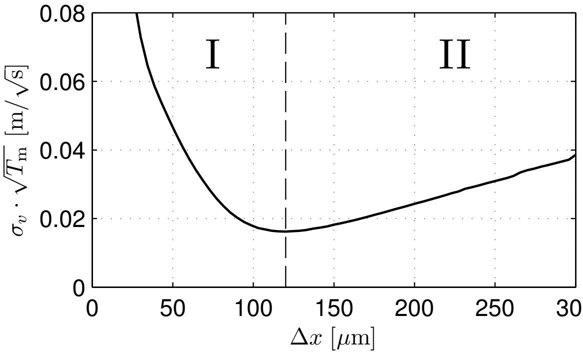

Fig. 1 *Minimal achievable measurement uncertainty σ_v of the velocity v according to the spatial resolution Δx*

edge steepness depending on the spatial resolution Δx was found. Lower values of Δx mean, that the detector area is smaller, which leads to a lower amount of scattered light power. Higher values of Δx increase the effect of the spatial averaging in equation (1) and the edge steepness decreases.

The influence of the scattered light power and the edge steepness on the measurement uncertainty can be seen in figure 1. In region I the uncertainty is limited by the scattered light power, in region II by the edge steepness. This leads to an optimum of the measurement uncertainty according to the spatial resolution. The position of the optimum depends on the parameters of the setup such as the quality of the interferometer mirrors or the used laser power.

4 Measurement system

A scheme of the complete measurement system is depicted in figure 2. The system consists of a temperature and frequency stabilised Master Oscillator Power Amplifier laser (MOPA) with 600 mW output power. The light is guided by a single mode fibre into the measurement volume. A reference beam is coupled out with a glass plate and imaged through the FPI onto a avalance photo diode (APD). The output signal is used for the frequency stabilisation of the laser. Thus potential frequency drifts of the FPI are compensated by laser frequency control. The measurement volume is seeded with Di-Ethyl-Hexyl-Sebacat (DEHS). The scattered light is collected with a linearly arranged fibre array and transformed to the annulary array at the interferometer. Thereby the field of view is independend of the effective transmission of the measurement channels. The light is then imaged through the same FPI as the reference beam and detected with an APD array. The detector signals are recorded with a digital data acquisition system and evaluated via a standard PC.

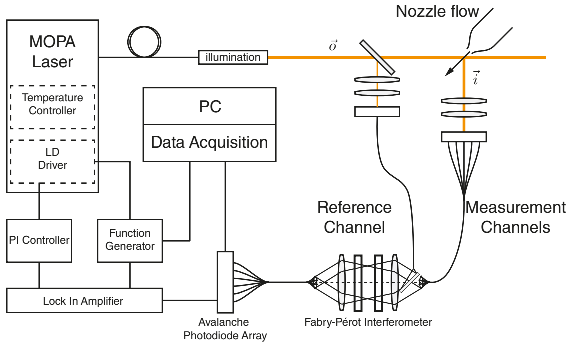

Fig. 2 *Schematic set-up of the measurement system with Fabry-Pérot interferometer.*

5 Result

The capability of the measurement system to measure the velocity of a technical flow for multiple points was demonstrated at a nozzle flow.

The measurement volume was located 25 mm in front of the nozzle exit and the flow profile was resolved by traversing the 4 measurement channels. Due to instabilities of the mechanical setup a systematic error up to 13 m/s appeared. This error was compensated by normalizing the flow profiles and could be reduced by a more stable mechanical construction. The mean standard deviation was 0.5 m/s for 10 s measurement duration. The measurement values in the boundary area show a slightly higher uncercainty because of the lower seeding concentration, thus lower scattered light power. Yet the measured velocity values show a good agreement with a flow profile acquired by Laser Doppler Anemometry.

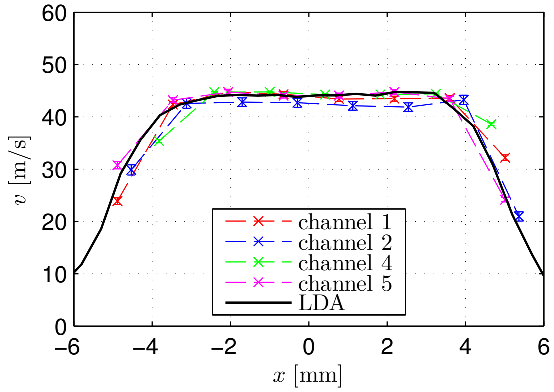

Fig. 3 *Measured profile of the flow velocity v for a nozzle flow compared to an Laser-Doppler Anemometer (LDA) measurement.*

6 Summary & Outlook

A proof of principle for a spectroscopic flow velocity measurement system for multiple measurement points using a Fabry-Pérot interferometer was realised and a complementarity between achievable scattered light power and edge steepness was found. Perspectively the measurement uncertainty of the system can be reduced further by using a higher output power laser and higher finesse mirrors.

References

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