Development of a Laser Velocimeter

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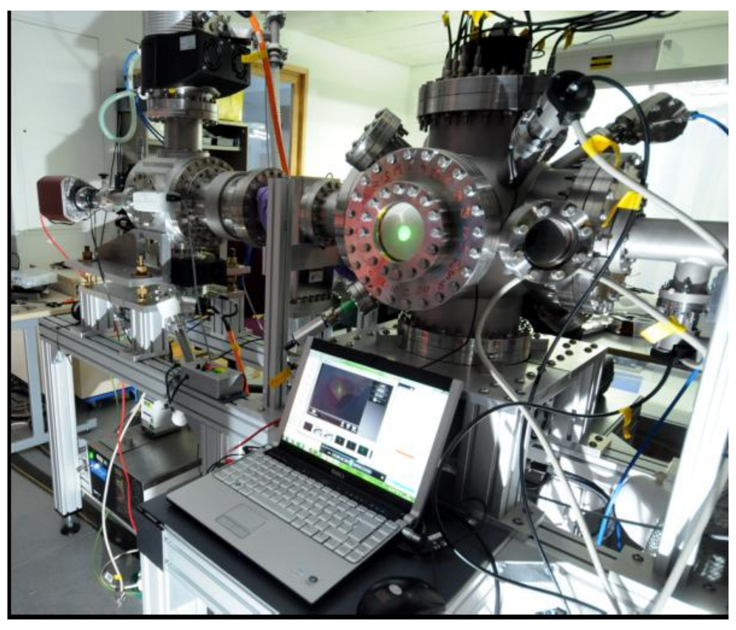
Abstract

A curtain-shaped beam profile monitor has been developed by the QUASAR Group as a least destructive monitor for various types of particle beams. The development of a laser velocimeter for an in-detail characterization of the gas jet, allowing for investigations into the jet dynamics itself, probing simultaneously its density, velocity, and temperature, is the aim of this project. For this purpose, laser self-mixing will be used for the jet analysis, providing unambiguous measurements from a single interferometric channel, realizable in a compact experimental setup that can be installed even in radiation-exposed environments. Investigations into jet seeding techniques will complement these studies.

Background

A laser velocimeter for the characterization of particle beams or gas jets will be developed at the Cockcroft Institute / University of Liverpool, UK. Such gas targets are important for a number of accelerator-based experiments, either as cold targets for collision experiments, but also for beam diagnostic purposes.



Curtain gas jet setup at the Cockcroft Institute, UK.

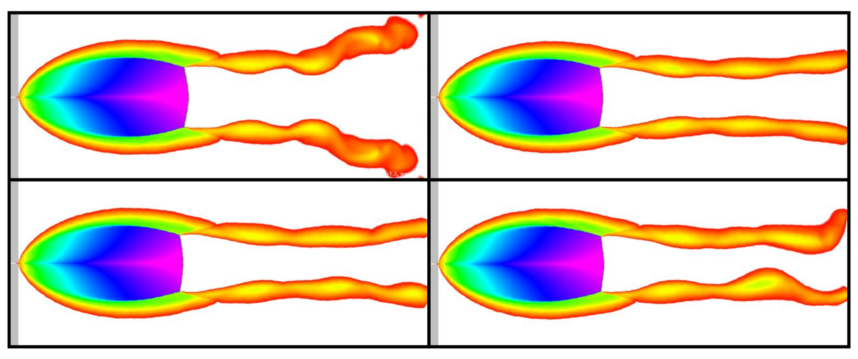
To date, very few studies have addressed the optimization of the application of a curtain shaped, supersonic gas jets. The development of a laser velocimeter for an in-detail characterization of the gas jet and investigations into the jet dynamics, probing simultaneously its density, velocity, and temperature will be all realized within this project.

For this purpose, laser self-mixing will be used for jet analysis, providing unambiguous measurements from a single interferometric channel, realizable in a compact experimental setup.

The task

The task is to measure density, temperature and velocity profile of a rarefied, supersonic gas jet expanding in vacuum. The type of jet could be differ.

As a result of the project the device should measure velocity in wide range, up to 2000 m/s. The laser velocimeter should provide the in-detail information not only about the **velocity,** but also about **density and temperature of any jet**.



Subsequent stages (5 ms, 10 ms, 300 ms, 650 ms) of the free expansion of an axissymmetric gas jet computed by CFD code

Possible Solutions

There are many measuring techniques for investigation of Supersonic flows in aerodynamics such as mechanical, acoustic, and optical ones.

For supersonic flows, ***mechanical techniques*** could cause major perturbation of the investigated system, hence leading to erroneous measurements.

Acoustic techniques provide only bad quality information on the flow, jeopardized by both the low resolution and the small number of observable phenomena.

The most popular and reliable technique for jet characterisation is ***the optical one***. There is still a broad spectrum of different methods, the most important of which we list in what follows.

- Schlieren photographs
- Particle Image Velocimetry
- Laser Doppler Velocimetry
- Spectrally resolved Rayleigh scattering
- Interferometry

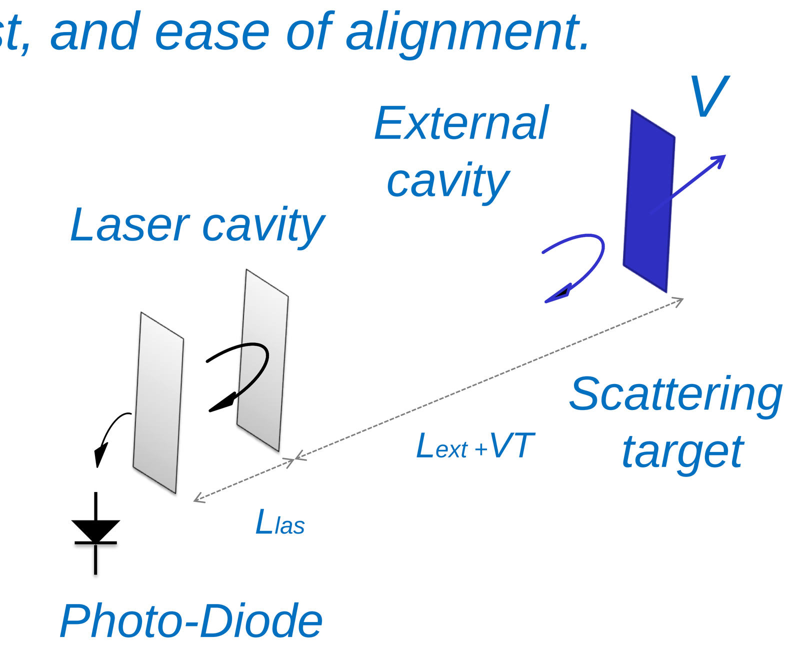
However, most of them require powerful laser systems or very precise system, which should be adjusted for each specific task or system.

Self-mixing Technique

Small portion of light is reflected from studying object and is returned into the laser cavity. Then it is mixed with the original wave inside the laser.

The main advantages of The self-mixing scheme with respect to traditional interferometry have such advantages as possibility of *unambiguous measures from a single interferometric channel, compactness of the setup, low cost, and ease of alignment.*

Laser plays rule of a coherent heterodyne receiver and the amplifier of the signal, and at the same time the quadratic detection of the registered signal is inside the laser. The signal produced in the both the power and frequency spectrum of laser. The signal forms inside the active laser medium, and the external influence cause the changing of power and the laser pumping.



the self-mixing system could be described as if the scattered target is an additional mirror and the whole system as a laser with external cavity with length L, which is depends on the velocity of the target.

$$P=Po[1+mF(wt')]$$

where t' =2Lext/c is the external time of flight, w is the frequency after feedback, Po and P are the optical power without and with feedback, m is a modulation parameter. Depends on the feedback and the distance to scattering target, there are *four possible signals*:

Weak feedback F is cosine	Weak feedback F has non-symmetrical shape	The moderate feedback Bistable system the sawtooth-like signal (three-value function F)	The strong feedback five-value function F the mode-hopping regime

Signal Detection

There are three ways to convert the optical signal into electrical signal in the case of self-mixing.

Traditional way: laser is a receiver of the light from the object. The signal from laser is an optical one, and photodiode converts it into the electrical signal.

Autodetection: the electric signal forms by detection of the variation of driving current of the laser itself (or of the terminal voltage)

Antenna registration: the registration of electric induction of active medium, which produced on the outside antenna

Short-term Goals

1. ***Be familiar with the technique in the whole***
   - ***literature studies***
   - ***first experimental set-up with mirror target as a scattering target. This mirror can have different scattering properties***
2. ***Studying things about self-mixing in fluids, because of close mechanism of interaction with the laser light***

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