

Global Doppler frequency shift detection with near-resonant interferometry

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A feasibility study about measuring global Doppler frequency shifts with near-resonant interferometry is presented. In an imaging interferometer with unequal optical path lengths, changes in frequency will result in a phase shift and hence in a local distortion of the interference fringe pattern. By adding a dispersive element to one leg of the interferometer, the optical path length difference becomes strongly frequency dependent.

In the vicinity of a resonant transition, both absorption and refractive index of a medium are functions of the wavelength and molecular or atomic absorption filters become strongly dispersive. In the present study iodine vapor, for which theoretical and experimental spectroscopy data is available, is investigated. The refractive index of iodine is derived from calculated absorption data through optical data inversion using the Kramers-Kronig relationships. With this data, the system characteristics for the setup shown in Fig. 1 are predicted. Compared to a glass block of the same length and a refractive index of 1.5, the iodine cell theoretically enhances the sensitivity by a factor of five and adds an apparent non-linearity to the system. Sensitivity and non-linearity of the method can be adjusted by the choice and condition of the medium and by the geometrical path length difference in the interferometer. From the variation of vapor pressure and temperature in the calculations, conditions for improved system sensitivity are derived.

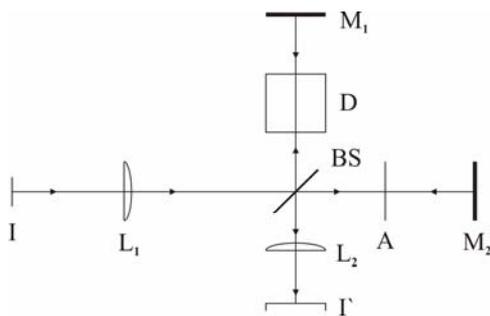


Fig 1 Michelson interferometer with a dispersive element D used for the measurements. M_1 and M_2 are mirrors, BS the beam splitter and A a neutral density filter. The lenses L_1 and L_2 form an image of the object plane I on both mirrors and in the image plane Γ .

Rotating disc and free jet experiments with a pulsed frequency-doubled Nd:YAG laser light source and a Doppler Global Velocimetry (DGV) iodine vapor cell show the applicability of the proposed method for planar Doppler velocimetry. From the local distortion of the interference pattern due to the phase shift, the frequency shift is calculated. The phase of a recorded fringe pattern is retrieved by quadrature filtering the image and subsequently solving the phase-unwrapping problem in a least-squares sense. By

subtracting the zero-velocity phase from the measured phase distribution, the local phase shift due to the Doppler effect is computed (Fig. 2).

The theoretical data is compared to the rotating disc experiments with good qualitative agreement. Quantitatively, the system sensitivity is overestimated in the theory by a factor of 1.5. A possible reason for this disagreement is the assumption of a Gaussian line shape for the calculation of the absorption data. Due to the comparatively poor frequency stabilization of pulsed Nd:YAG systems, the accuracy of direct system calibrations is limited and only an estimate for the measurement errors can be given. For the present setup, a spatial resolution of 10 pixels and a measurement error of a few m/s seems probable.

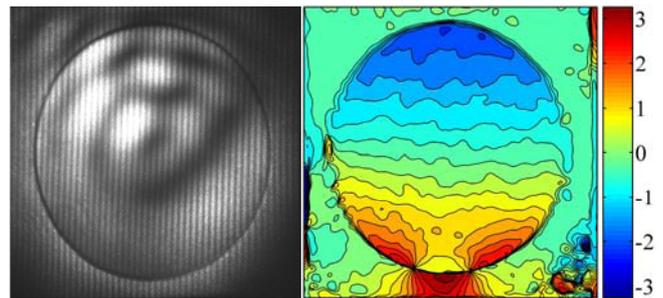


Fig 2 Fringe pattern and net unwrapped phase shift for the rotating disc experiment.

The proposed method is inherently a single camera technique without image alignment and camera calibration issues. Because only the position of interference fringes needs to be determined in the post processing step, image intensity noise affects accuracy only in a minor way. The measurement range is much larger than for transmission based techniques, where it is limited to the shoulder of one absorption line.

As in other global Doppler techniques, laser frequency stabilization and system calibration needs to be considered carefully. The interferometric setup, susceptible to changes of the optical path length difference due to vibrations or density variations, poses its own challenges.

Using theoretical models and experimental data from a test setup the present study shows that near-resonant interferometry is capable of measuring global Doppler frequency shifts. The choice between numerous dispersive media such as molecular and atomic gas cells or Stark and Faraday effect filters, and the many ways to influence their dispersive properties, creates a highly adaptable technique.