Miniaturized laser-Dopler-anemometer for space applications

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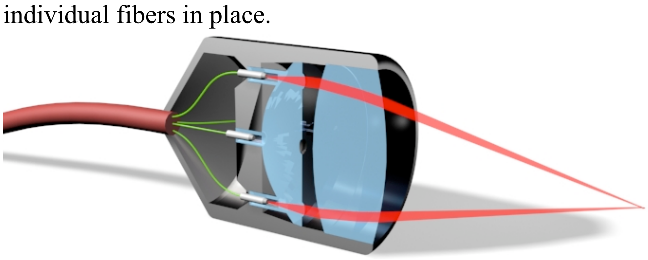
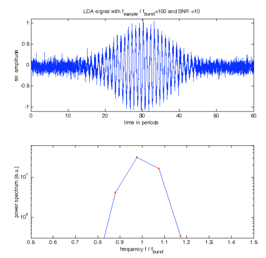
We present promising and versatile new technologies for realizing highly miniaturized LDV system for two component velocity measurements with direction detection, together with a novel optical design for the LDV probe and a new method for autonomous frequency estimation.
In general, LDV measurements are complementary to flow mapping techniques. Compared with these, the LDV technique produces highly resolved data in time as well as in location over a wide range of velocities without requiring much data storage. However, the use of the laser Doppler velocimeter technique for measuring flow velocities in dynamic flow experiments under microgravity does not only have to take the size, weight and power requirements (and especially the heat removal constraints) into account, but has to deal with lack of access, higher reliability and the necessity for autonomous operation with high precision over all possibly occurring velocities under investigation. None of these are usually a concern for LDV systems used in a 'normal' laboratory or test facility situation.
Due to the limited available space – not only for the LDV – geometries for microgravity experiments tend to be smaller and more compact than commercially available systems and even measurement heads are usually built for.
This affects the minimal and maximal values of the access range of any LDV measurement head, which usually lies in between 30 to 120 mm, depending on facility and experiment. Any LDV probe for space applications should be able to accommodate – possibly with different front lenses – said range without too much of a compromise in the size of the measurement volume or the signal-to-noise-ratio, since accuracy in velocity determination as well as position are of prime concern.
To accomplish this, an innovative design for measuring two velocity components was realized by ZARM. A highly integrated multi-functional optical element was developed, that consists of 4 aspheric lenses for collimating the light from the single mode fibers, which will create the measuring volume, as well as two aspheric mirror surfaces for redirecting the back-scattered light from the particles in the measuring volume into the multi-mode fiber and towards the detector. Additionally, this monolithic optical element also incorporates the mechanical structures for holding the individual fibers in place.

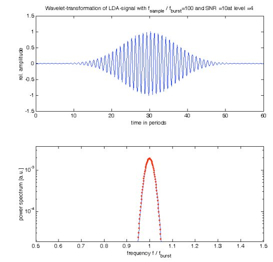


2d-LDV-measurement head with integrated optical element

By using one fiber coupled laser diode for each LDV beam, the optical frequency difference of the laser diodes can be used for the directional discrimination and additionally the laser power in the measuring volume can be increased. This concept for velocity direction detection has already been verified at the PTB where different 2d-LDV systems have been realized using set ups based upon discrete optoelectronic components as well as fiber coupled components. Especially the readily available optoelectronic components for telecommunication applications allow us to optimize and miniaturize such systems. Here, the channel separation is based on a novel method of using the coherence properties of different semiconductor lasers, one for each LDV beam. Instead of requiring, for example, bulky multi-wavelength lasers and additional expensive and fragile opto-mechanic components, the compact size of the system results by using three semiconductor lasers whose different optical frequencies are controlled very accurately by a microcontroller-based frequency stabilization system. In this way, the difference frequencies between the laser diodes, which act as carrier frequencies for the measuring information, can be tailored to the measuring task. Thus the signal to noise ratio can be optimized and the required bandwidth of the detection system may be kept moderately small. The LDV measuring signal – which contains the beat signals of the three Doppler shifted laser frequencies – is determined with the help of these two reference signals, given by the beat signals of the two laser beam pairs, one for each velocity component. Thus two LDV signals are obtained in the baseband and independently of frequency drift. These signals can then be analyzed with the help of a combination of discrete wavelet (DWT) and fast Fourier transformation (FFT), which achieves optimal frequency estimation over the whole frequency range.



Signal analyzed only by FFT



Signal analyzed by DWT+FFT

Given its small size, low power consumption, its simpler and more robust realization, this 2d-LDV system, together with the newly developed algorithms for autonomous frequency estimation, is likely to open up completely new fields for precise flow velocity measurements in space as well as on earth.