Test and calibration methods of laser Doppler anemometers

Peter Mahnke, Oliver Kliebisch, Gerhard Geyer, Raoul-A. Lorbeer
DLR Stuttgart, Institute of Technical Physics
Pfaffenwaldring 38-40, 70569 Stuttgart
peter.mahnke@dlr.de

Abstract: We present test and calibration methods designed to assess and compare the electro-optical performance and sensitivity of fiber-coupled laser Doppler anemometers (LDAs). For sensitivity analysis and comparison of different LDAs a fiber-coupled test setup that generates precisely frequency-shifted laser pulses, which are fed back into the fiber LDA, is introduced. The efficiency of the optical transceiver system is evaluated by determining the coupling efficiency of the back-reflected beam at the beam waist location into the fiber, employing a flat mirror. This dual approach facilitates a precise characterization of the electro-optical performance and the imaging optics of an LDA.

1. Introduction

Fiber-coupled Laser Doppler anemometers (LDA), especially in airborne applications [1], need to be reliable and reproducible measurement devices. Well defined optical defects in glass can be used as reproducible scattering targets [2] for performance characterization of LDAs. For the generation of optical test signals for LDAs the previously introduced method has the following drawbacks:

1. The moving target must be positioned and moved exactly within the laser beam.

2. Transceiver optics and the fiber-coupled LDA cannot be qualified and tested independently.

Therefore, we present a fiber coupled test and calibration setup to assess the electro optical sensitivity of a fiber coupled LDA independent from the transceiver optics and a separate setup to characterize the performance of the transceiver optics.

2. Description of the Laser Doppler Anemometer

Figure 1 depicts the general setup of a fiber-coupled LDA. All components in a fiber-coupled LDA are polarization maintaining to preserve the capability of the light to interfere under changing environmental conditions (vibrations, shocks, temperature). In the LDA a small bandwidth laser oscillator, e.g. a DFB fiber or diode laser, is split into two fiber-optical channels. One channel serves as a homodyne, or, if frequency shifted by an AOM, as heterodyne local oscillator for the detector. The other channel is amplified in an EDFA and guided through a fiber-optic circulator to the transceiver optics. The transceiver optics images the fiber facet into the air and receives the light, which is backscattered and Doppler shifted by moving aerosol particles. The backscattered light is separated in the circulator and interferes with the local oscillator light using a 50:50 fiber coupler. The resulting hetero-/homodyne signals are then detected on balanced photodiodes. The resulting electrical signals are digitized by a fast analog-to-digital converter (ADC) and processed in real-time on a field programmable gate array (FPGA) [3-4].

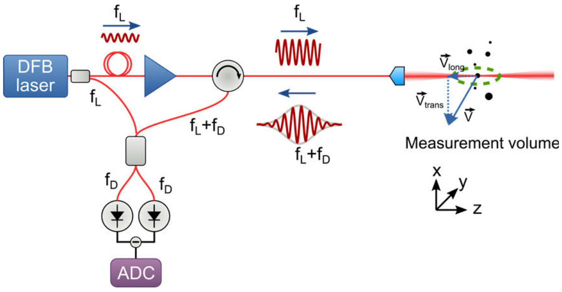

Figure 1. Schematic of a fiber-coupled reference beam laser Doppler anemometer (modified from [2]).

3. Setup to characterize the electro-optical performance of the fiber-coupled LDA

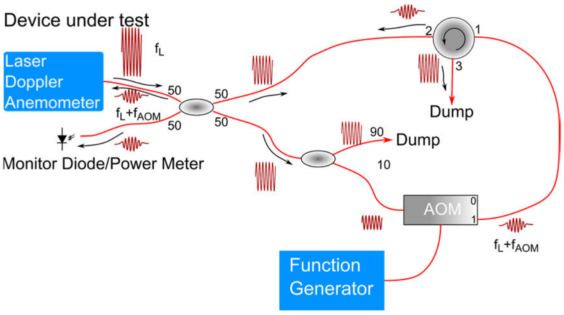

Figure 2. Schematic of a laser test pulse generator for the laser Doppler anemometer.

The fiber-coupled test setup is shown in figure 2. The LDA under test is directly fiber-coupled to the test setup. In the test setup a 50:50 coupler splits the laser output of the anemometer into two channels. One channel is dumped, using a fiber-optic circulator, the other channel is attenuated by another 90:10 coupler to minimize the power entering the acousto-optic frequency shifter (AOM). The AOM further attenuates, pulse forms and introduces a frequency shift of 80 MHz the light from the device under test. The obtained laser pulse is fed back to the laser Doppler anemometer passing through the optical circulator and the 50:50 coupler.

The optical circulator is used to prevent the light passing backwards trough the fiber-coupled optical setup. To measure the power of the frequency shifted light, including the circulator induced losses, the 50:50 coupler is placed directly to the device under test. In this way a similar power is measured by the power meter/calibrated photo diode and the device under test.

The peak power and length of the laser pulse is controlled by a programmable function generator and is measured by using a calibrated monitor diode or power meter on the second “input” of the 50:50 fiber-optic coupler. Power calibration of the back reflected frequency shifted light is performed by driving the AOM with a continuous 80 MHz signal and optical power measurement of the monitor channel. This calibration measurement can be done for various electrical driving powers.

Using a defined output pulse generated by this setup, the LDA sensitivity, including its fiber dependent losses and the LDA noise sources (shot noise, Johnson noise and RIN), can be characterized.

A full bandwidth characterization of the detector is currently not possible with this setup, since the bandwidth shift variation of a fiber coupled AOM is limited due to the fiber coupling of the device. This limits the frequency variation to approximately 10% of the operational frequency of the AOM. By adding an electro optic phase modulator behind the AOM, which is driven by a linear saw-tooth signal, will enable to generate signals with other frequency shifts [5]. This requires a saw-tooth signal generator with a high bandwidth to address the full frequency bandwidth of an LDA. On the other hand, this is not necessary to characterize, if it is done before the detector is integrated.

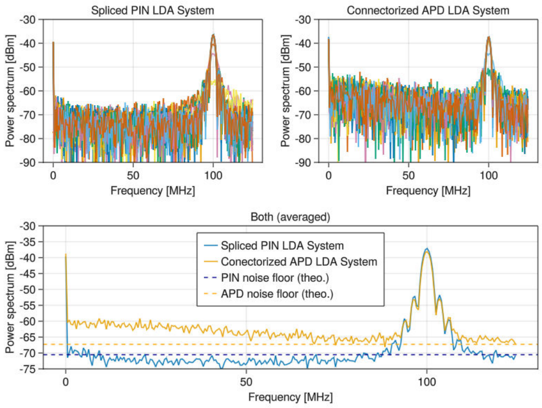

Figure 3. Comparison of two LDA systems using the test setup.

Figure 3 depicts a comparison of two fiber-couple LDA systems. One of the systems “Connectorized APD LDA System” is described in [1]. It has an avalanche photo diode (APD) balanced detector with approximately 0.1 mW of power in the reference arm of the detection interferometer. The other system has a similar output power and approximately 0.2 mW of local oscillator power in the reference arm of the fiber interferometer. It uses a Thorlabs PDB770C p-i-n photo diode balanced detector module (PIN) and a Lumibird M104 as laser source with no additional EDFA.

Another noteworthy difference between the two systems is, that the first system consists of connectorized components and the other system is spliced. Therefore, the system with sliced components has no fiber connector losses and due to the use of a PIN detector no APD excess noise. For the comparison measurement both systems were operated at 20 mW output power and the same data acquisition system was used (for details see [1]). The AOM was operated with a 40 cycles pulse train at 100 MHz with 5 Hz repetition rate, resulting in a sinc² power spectrum.

In the two upper plots of the figure multiple measured power spectra of the generated pulses are displayed for the two systems. The observed amplitude variation in the measured signal is due to clipping of the generated laser pulse by the individual fast Fourier transform (FFT) window. A 512-bin FFT with sampling rate of 250 MSa/s was used.

In the lower plot of the figure the averaged signals for both systems are displayed. Also, the theoretical noise levels derived from local oscillator shot noise, detector Johnson noise and APD excess noise are displayed for the two systems. The theoretical noise levels resemble the measured noise levels quite well for the spliced LDA system. The APD LDA system shows more noise due to the excess noise of the APD and 1/f noise. The signals are amplified by both systems to a similar level. The spliced system has lower component losses than the connectorized system and shows an overall significant better SNR.

4. Setup to characterize the diffraction and transmission losses of the transceiver optics

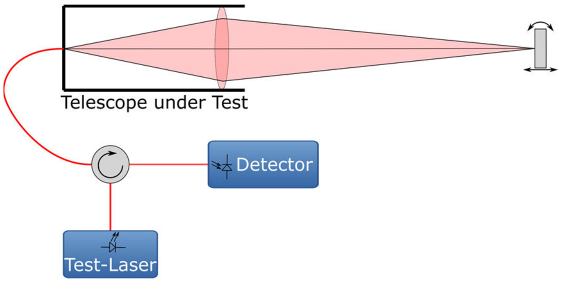

Figure 4. Characterization setup for the transceiver optics.

Figure 4 shows the setup, which is used to characterize the transceiver optics performance. It is designed to measure the diffraction and transmission related losses of the transceiver optics.

The setup uses a fiber-coupled test laser with a defined optical output power which is fed to the transceiver optics through a fiber optic circulator. In the focus of the transceiver optics a flat silver is placed which passes the emitted laser power back into the fiber through the circulator to the detector. The mirror is mounted on a kinematic mount which can be adjusted to the optimal position in the focus where the received power reaches its maximum.

The ratio of the maximum received power and emitted laser power describes the diffraction (quadratic Strehl ratio) and transmission related losses. Although this setup does not characterize the magnification of the imaging, which should be known by design, it is suitable to characterize the component-induced insertion losses as well as the loss of signal due to optical aberrations.

5. Conclusions

In this short outline we presented measurement setups which are suitable to assess the electro optical performance of an LDA.

The fiber-coupled test pulse setup can be used to compare fiber-coupled LDA systems SNR. It is also suitable to measure the LDA systems sensitivity. The test setup could be improved by adding a phase modulator to assess the LDA detector bandwidth.

For the characterization of the optics we presented a simple setup suitable to measure the transmission and diffraction losses of a transceiver optics.

6. References

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