Bistatic wind lidar system for traceable wind vector measurements with high spatial and temporal resolution

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Why wind lidar systems?

Lidar – Light detection and ranging

Wind energy sector:

Traceable wind speed measurements necessary for

• Wind potential analysis (site assessment)
• Power curve testing

Most precise wind speed measurements:
Wind met masts with cup anemometers

• High effort for mast heights > 100 m
• Expensive

Wind lidar (optical wind remote sensing devices)

• Technical and economical more reasonable
• Traceability?
Traceability of wind lidar systems

Objective: Reduction of m.u. of wind lidar systems

M.u. strongly depends on homogeneity of wind field

m.u. – measurement uncertainty

Lowest possible m.u. [%]

Wind speed [m/s]
Traceability of wind lidar systems

Prospective: 
PTB lidar as reference standard (for remote sensing dev.)

Prior: 
Validation required (Wind tunnel test facility)

m.u. – measurement uncertainty
Monostatic measurement principle

Conventional lidar systems

Determination of velocity vector by tilting the transmitting/receiving unit

→ High spatial and temporal averaging

Complex terrain (inhomogeneous wind field)

Measurement failure up to 10 % possible

Large measurement volume

One common transmitting and receiving unit

Conventional lidar systems

- Large measurement volume
- Complex terrain (inhomogeneous wind field)
- Measurement failure up to 10 % possible

Monostatic measurement principle
Bistatic measurement principle

PTB lidar

Advantages

• High spatial resolution / small meas. volume:
  • 100 m: length 0.6 m; Ø 6 mm
  • 200 m: length 2.4 m; Ø 12 mm

• Measurement of complete velocity vector by means of single aerosols („3C simultaneous“)

Challenges

• Adjustment very sensitive
• Little scattering light (low SNR)
• High frequency resolution necessary (acute angle)
Bistatic measurement principle

PTB lidar

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Comparison measurements with wind met mast (WMM):

Deviation within measurement uncertainty of cup anemometers of WMM

for homogeneous and inhomogeneous wind fields

One transmitting and three receiving units
Wind tunnel test facility for PTB lidar

Controllable and well-defined wind flow fields and precise flow speed reference traceable to SI units (LDA) for

• Analysis
• Validation

of the bistatic PTB lidar

Wind tunnel test facility (WTTF)
WTTF requirements

- Minimum working distance: 5 m between PTB lidar and wind tunnel test section
- High flow quality (low turbulence level ≤ 0.5 %, high homogeneity)
- Cross section (nozzle): 50 x 50 cm², test section length: 75 cm
- Flow velocity: 4 m/s to 20 m/s
- Flow velocity traceable with laser Doppler anemometer (m.u. ≈ 0.15 %)
- Accurate localization of lidar measurement volume within the test section

Buildup of the WTTF on intermediate level in EULER-Building I (Competence Center for Wind Energy)

Wind tunnel:
- Maximum dimensions: 3,50 m x 6,70 m
- Test section position: → Diffusor, settling chamber
Wind tunnel: Measurement platform:

- Height: 8 m
- Dimensions: 8 x 5 m²
- Hatch under test section
WTTF: Characterization

**Turbulence level**

- Flow velocity up to 30 m/s
- Turbulence level ≤ 0.35 %

**Flow velocity (along test section)**

- Open test section
2D flow profiles along the test section

- Cross section: 400 x 400 mm²
- 10 x 10 mm² steps

1st half of test section:

High homogeneity, 0.1 % per dm (r ≤ 100 mm)

\[ v_{av} (75 \text{ mm}) = 11.16 \text{ m/s} \]
\[ v_{av} (375 \text{ mm}) = 11.12 \text{ m/s} \]
\[ v_{av} (635 \text{ mm}) = 10.82 \text{ m/s} \]
First validation measurements I

PTB lidar vs. LDA

1. Averaging the acquired data over different time slots $\Delta t$

2. Calculation of standard deviation $\sigma$ for each $\Delta t$

- small $\Delta t$: $\to$ 0.04 m/s Turbulence of WT
- large $\Delta t$: $\to$ const. Long-term drift of WT
- Deviation of mean values (3 h) Lidar $\leftrightarrow$ LDA: 0.05 ‰

Oertel et al., “Validation of three-component wind lidar sensor for traceable highly resolved wind vector measurements”, *J. Sens. Sens. Syst.*, 8, 9-17, 2019
DOI: 10.5194/jsss-8-9-2019
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First validation measurements II

PTB lidar vs. LDA

- Measurement time: 1 h
- Averaging time $\Delta t$: 1 s
- 90° rotation
- Mean deviation: < 0.5 %
- Average mean deviation: $0.37\% \pm 0.06\%$

→ Measurement height
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Stand: 06/19