CALIBRATION REPORT OF LIDAR UNIT "WLS7-436"

PREPARED FOR:
MASSACHUSETTS CLEAN ENERGY CENTER

Report No.: CalibrationReport_WLS7-436

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Texas
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18 October 2019

CLASSIFICATION

CLIENT'S DISCRETION

VERSION

A

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Contact	Anthony Kirincich

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AUTHOR(S)	REVIEWER(S)	APPROVED BY
		
Imane Meznoudi (Wind Measurement)	Onur Damar (Wind Measurement)	Edward Burin des Roziers (Subject Matter Expert)

DOCUMENT HISTORY

VERSION	DATE	SUMMARY
A	18 October 2019	Initial Report

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α	Shear factor	[-]
v	Wind speed	[m/s]
z	Height of the sensor	[m]
TI	Turbulence intensity	[-]
σ_v	Standard deviation of the wind speed	[m/s]
T	Air temperature	[K]
RH	Relative humidity	[%]
k	Class number of the anemometer	[-]
K_p	Coverage factor	[-]
U_i	Wind speed in bin i	[m/s]
N	Number of data set by bin	[-]

DEFINITIONS

Turbulence intensity

$$\mathrm{TI} = \frac{\sigma_v}{v} \quad (1)$$

Shear factor

$$\alpha = \frac{\ln(v_1/v_2)}{\ln(z_1/z_2)} \quad (2)$$

Uncertainty contribution from anemometer behaviour

$$U_{FS\,2,i} = (0.05\,{}^{m}/_{s} + 0.005 \cdot U_i) \cdot \frac{k}{\sqrt{3}} \quad (3)$$

1. INTRODUCTION

Following an order of Massachusetts Clean Energy Center a calibration of a LiDAR of the type WindCube V2 by Leosphere (WLS7-436) against a met mast has been performed at a test site in the US.

In this report the measurement results of the LiDAR device are compared to those from calibrated cup anemometers mounted on a met mast. The aim of this comparative assessment is to convey traceability to international standards of this particular LiDAR unit. The evaluation process is based on the IEC 61400-12-1 Ed. 2 Annex L [2]. This standard describes the calibration procedure of remote sensing devices in the frame of power curve measurements on wind turbines. However, this approach generally also applies in the field of wind resource assessment, under the recommendations of MEASNET [4].

The data of the LiDAR measurement (130 m, 125 m, 95 m and 60 m) have been compared with the measured met mast data at 4 different heights (130 m, 125 m, 94 m and 58 m) during a period of 36 days (2019.08.20 – 2019.09.25) for wind speed bins between 4 – 16 m/s and for the wind direction sector 67 – 354°. In addition, measurement results of the met mast and LiDAR unit have been compared in terms of turbulence intensity, wind direction and wind shear.

UL was not involved in the installation of the instruments on the mast but has gathered all relevant information. However, UL was responsible for the installation of the LiDAR unit close to the mast.

It is ensured that the results presented in this report have been measured in an unbiased manner, following the best practices and to the best knowledge of the participating persons.

2. MEASUREMENT SITE

2.1 Description

The test site is located in the state of Texas in the US. The LiDAR unit was located in a distance of about 44 m South-West from the met mast. The altitude of the LiDAR unit was approximately 1100 m above sea level. The mast and LiDAR unit are located at the edge of an open field. The further vicinity of the test site remains flat and consists of open fields and woods.

As far as obstacles are concerned, a turbine is located approximately 300m NNE of tower and a 80m NRG tilt up tower at approximately 500m N of the tower.

The coordinates of the reference mast and the LiDAR are given in Tab. 2.1 Coordinates of the LiDAR and the reference mast (Geographic [deg,min,sec], WGS84).

These coordinates were measured by UL within the accuracy of the GPS measuring device.

Tab. 2.1 Coordinates of the LiDAR and the reference mast (Geographic [deg,min,sec], WGS84)

Location	Coordinates	
	West	North
LiDAR	101°47'30.36"	34°57'52.44"
Reference Mast	101°47'29.66"	34°57'53.75"

The test site is suitable for RSD calibration. It is considered as flat terrain according to IEC 61400-12-1 Ed.2 [2]. Topographic data was acquired from the publicly available Shuttle Radar Topography Mission (SRTM) [8]. The site topographical variations and requirements are summarized in the following table.

Tab. 2.2 Topographical conditions at the test site. L: defined as 250 m. Measurement sector considered as full 360°.

Distance	Sector	Allowed maximum slope	Observed maximum slope	Allowed maximum terrain variation from plane	Observed maximum terrain variation from plane	Remark
< 2L	360 degrees	< 3 %	0.9 %	< 16.7 m	3.6 m	pass
≥ 2L and < 4L	Measurement sector	< 5 %	0.6 %	< 33.3 m	6 m	pass
≥ 2L and < 4L	Outside measurement sector	< 10 %	0.7 %	Not applicable	Not applicable	pass
≥ 4L and < 8L	Measurement sector	< 10 %	0.5 %	< 50.0 m	8.6 m	pass
≥ 8L and < 16L	Measurement sector	< 10 %	1.4 %	Not applicable	Not applicable	pass

The maximum slope observed within a range of 500 m (2 L) from the met mast is 0.9%.

The maximum terrain variation from plane within a range of 1 km (4 L) from the met mast is 6 m.

There is a remarkable magnetic declination present at the site: 6.04°E ± 0.34° changing by 0.10°W per year.

2.2 Overview

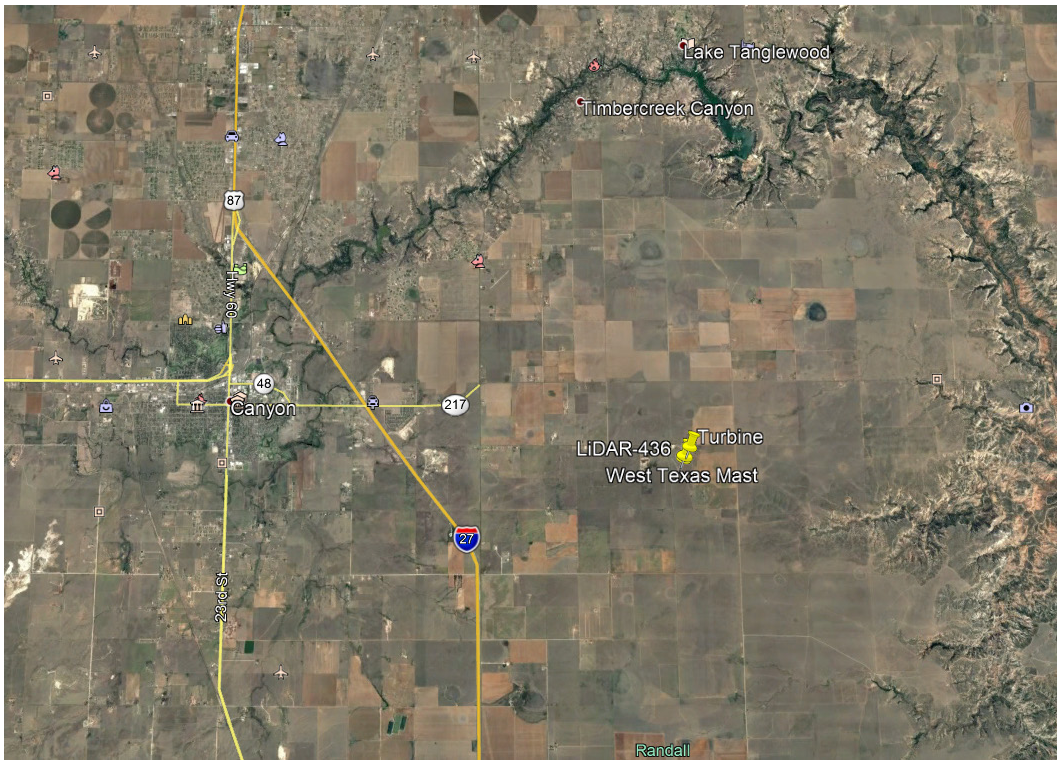

Fig. 2.1 The online resource “Google Earth” provides a good impression of the location [7].

Fig. 2.2 Close-up map of the mast and LiDAR positions.

2.3 Panoramic view of the test site

Fig. 2.3 View towards north.

Fig. 2.4 View towards northeast.

Fig. 2.5 View towards east.

Fig. 2.6 View towards southeast.

Fig. 2.7 View towards south.

Fig. 2.8 View towards southwest.

Fig. 2.9 View towards west.

Fig. 2.10 View towards northwest.

2.4 Determination of the measurement sector

Around the reference mast and the LiDAR, a wind turbine is located which was considered for the determination of the measurement sector.

Tab. 2.3 Measurement sector for power curve measurements according to the IEC 61400-12-1 0. The reference mast has been used as a reference (x=0; y=0) in the x;y coordinates.

Object	X[1]	Y[2]	D[3]	Distance to object	Direction from object	Wake	
	[m]	[m]	[m]	[D]	[degrees]	[degrees]	[degrees]
Reference mast disturbed							
WT 1 (Gold wind 3S)	154	261	140	2.17	29	354	67
Met mast undisturbed						67	354
RSD disturbed							
WT 1 (Gold wind 3S)	154	261	140	2.48	28	356	64
LiDAR undisturbed						64	356
Final Measurement sector according to IEC 61400-12-1 0						**67**	**354**

3. WIND MEASUREMENT

A complete overview of the measuring equipment of the met mast including serial numbers and calibration values is given in Tab. 10.1.

3.1 Description of the met mast

The meteorological mast consists of a Lattice Triangular construction. It has been erected at an altitude of about 1100 m above sea level. The measurement mast is still in use.

The mast layout presents some deviations with respect to IEC 61400-12-1 Ed. 2 [2]. The top anemometer is attached above one corner of the triangular mast; therefore, it should be mounted at a height of at least 11 times the mast section above the mast, this was not respected in this mast layout. Furthermore, the exact orientation of the lightning catcher with respect to the top anemometer could not be fully verified in the documentation. The effect of the lighting catcher however is most likely filtered out by the turbine wake filter presented in section 2.4. In addition, the mast disturbance filter on section 4.4 was also applied to the top anemometer since the top arrangement is not compliant with the IEC. As a result, additional mounting uncertainty has been applied to the top anemometer.

The measured data are recorded by a data logger of type Campbell Scientific CR1000X/2438 with a sampling rate of 1 Hz. The time zone of the logger is set to UTC-6.

The orientation of the booms was measured by UL with a GPS during the site inspection and has been verified.

A visual check of the mast has been performed during the site inspection and the condition of the measurement mast was good.

Only the sensors that were used for the calibration evaluations have been considered here. A complete overview of the sensors mounted on the mast can be found in Fig. 3.1.

[1] Coordinates in east direction (seen from the measured turbine)

[2] Coordinates in north direction (seen from the measured turbine)

[3] Rotor diameter of the WT resp. equivalent rotor diameter of obstacle according to IEC

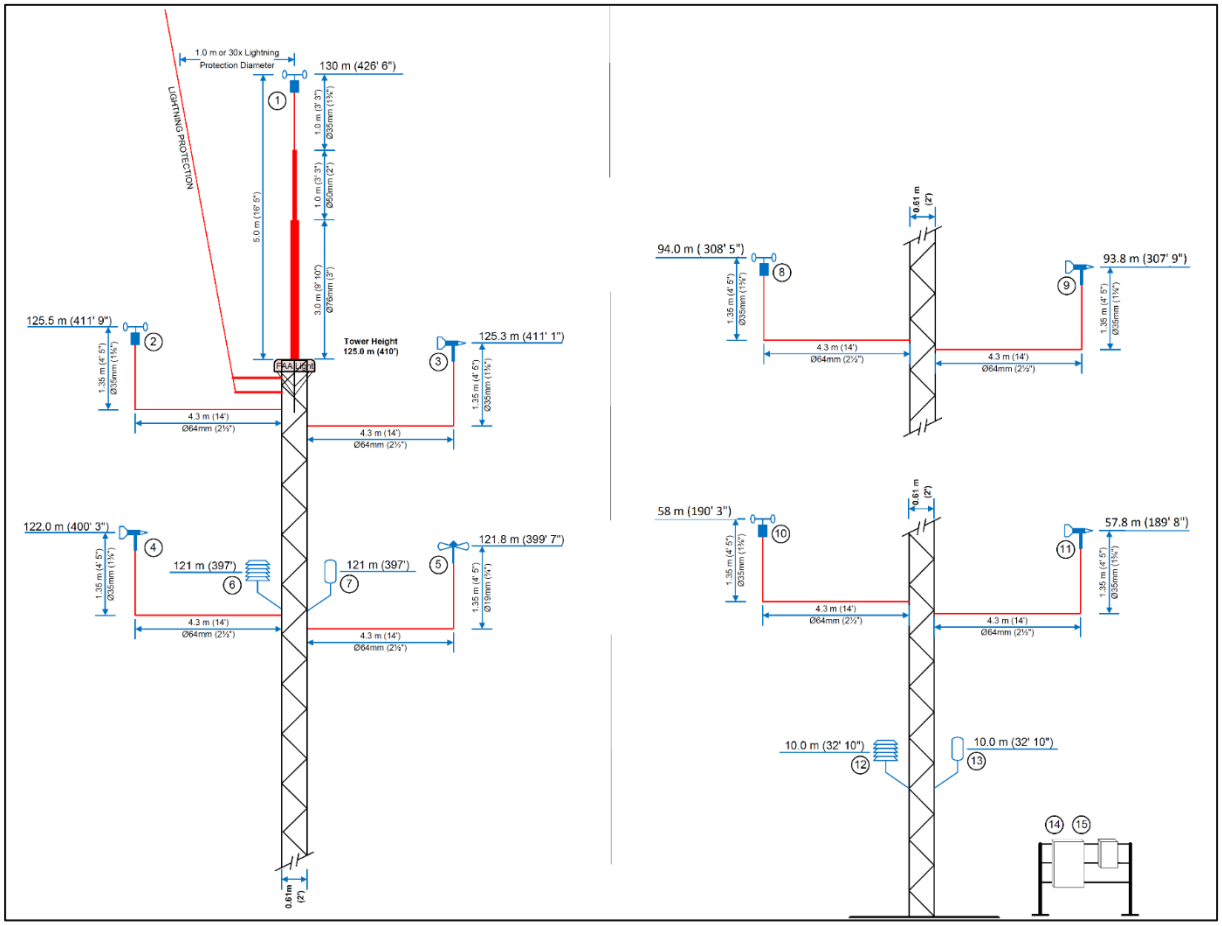

Fig. 3.1 Sketch of the met mast and its dimensions. Not to scale.

3.1.1 Wind speed

The measurement of wind speed was performed at 4 heights.

At the top of the tower, at 130 m, one cup anemometer of type Thies Clima (v1) have been mounted on an L-shaped boom pointing towards 0°.

A second anemometer (v2) of type Thies Clima was mounted at 125 m on an L-shaped boom pointing towards 294°.

A third anemometer (v3) of type Thies Clima was mounted at 94 m on an L-shaped boom pointing towards 294°.

A fourth anemometer (v4) of type Thies Clima was mounted at 58 m on an L-shaped boom pointing towards 294°.

All the anemometers are classified following IEC 61400-12-1 Ed. 2 [2], Annex I [2] as 0.9A or 1.8A class sensors [6].

All anemometers have been calibrated by the client in a wind tunnel (MEASNET [5], DAkkS/DKD accreditation) before the wind measurement period. The respective calibration certificates are given in the appendices (see section 10.2).

3.1.2 Wind direction

The main wind direction (Dir_1) was measured at a height of 125 m on the met mast with a wind vane of type Thies Clima, mounted on an L-shaped boom. This wind vane is orientated towards 112° and is used as a reference for direction filtering for the calibration evaluations.

3.1.3 Air temperature, relative humidity and air pressure sensors

The temperature was measured at a height of 121 m and the air pressure sensor was measured at a height of 121 m.

3.2 Photo documentation of met mast

Fig. 3.2 Top section. Top mounted anemometer Thies Clima on top boom at 130 m. Anemometer Thies Clima on L-shaped boom at 125 m and wind vane Thies Clima mounted on an L-shaped boom at 125 m. Anemometer Young on L-shaped boom at 122 m and wind vane Thies Clima mounted on an L-shaped boom at 122.

Fig. 3.3 Anemometer Thies Clima on L-shaped boom at 94 m and wind vane Thies on an L-shaped boom at 94 m.

Fig. 3.4 Anemometer Thies Clima on L-shaped boom at 58 m and wind vane Thies on an L-shaped boom at 58 m.

Fig. 3.5 Complete mast overview.

3.3 Description of LiDAR unit

The LiDAR device is of type WindCube V2 by Leosphere. The unit ID is “WLS7-436”. The unit was located at an elevation of 1100 m above sea level. The measuring range is 40-200 m. At each height measurements of horizontal and vertical wind speed as well as wind direction are performed. For each time step and measuring height a signal quality is supplied in addition.

LiDAR data was synchronized to UTC+0.

The measurement period of the LiDAR device was 2019.08.20 – 2019.09.25 (36 days).

The measurement data are supplied as 10-min statistics values.

According to the information received from the manufacturer, there is no indication of a technical problem or fixed echoes.

3.4 Configuration of the LiDAR

HeaderSize=40
Version=2.1.9
ID System=WLS7-436
ID Client=MassCEC
Location=MVCO ASIT
GPS Location=Lat:34.964570N, Long:101.791760W
Comments=Lense height is 1 m above agl;
FCR Option=OFF
timezone=UTC+0
****
Windcube Parameters (internal use only)
****
Sampling Frequency (Hz)=250000000.000
Ref Frequency (Hz)=67800000.000
Pulses / Line of Sight=20000
Samples / Pulse=1024
Reflected Pulse Start=61
Reflected Pulse End=135
Ref pulse samples nb=1
Nb High Pass Filter Points=5
FFT Window Width=50
Laser Diode Current (mA)=1900
LOS=
Init Drive Position (°)=90
Pulse Repetition Rate (Hz)=30000.000
Pulse Duration (s)=0.000000175
Trigger Delay Time=0.000000020
Wavelength (nm)=1543.000
ScanAngle (°)=28.000
DirectionOffset (°)=0.000
Declination (°)=-2.500
PitchAngle (°)=0.200
RollAngle (°)=0.100
CNRThreshold=-23.000
VrThreshold (m/s)=NaN
SigmaFreqThreshold (m/s)=NaN
WiperCNRThreshold=-19.000
WiperAltitude (m)=100
WiperDuration (ms)=5000
Altitudes (m)= 49 59 79 94 99 124 129 139 159 179 199

3.5 Photo documentation of LiDAR unit

Fig. 3.6 LiDAR in its final position.

4. INPUT DATA PREPARATION

4.1 Initial data sets

The data set of the met mast and the LiDAR were provided to UL from the client. The LiDAR data were available in the “.sta” format. The met mast data were provided to UL in their correct physical quantity. The correct application of the calibration values and wind direction offsets was checked to prove consistency by UL.

The measurement period for this calibration is 2019.08.20 – 2019.09.25 (UTC-6).

The availability of the met mast data set amounts to 100% (5293 out of 5293 possible data samples) and the availability of the LiDAR data set amounts to 97.27% (5149 out of 5293 possible data samples).

The availability of the combined met mast and LiDAR data set amounts to 97.27% (5149 out of 5293 possible data samples).

For the calibration evaluation a filtering of the data set is necessary in order to exclude influences that affect the measurement of the met mast’s sensors and the measurement of the LiDAR unit. The discussed filter criteria are applied to the original data set. The filtering procedure is performed for each evaluated measuring height separately. On the resulting data set a further visual inspection is performed. The following filters have been applied:

4.2 Signal quality

The LiDAR unit WindCube V2 by Leosphere determines for each 10-min mean value a signal quality value. The quality values relates to the signal to noise ratio detected by the LiDAR and lie generally in the range between 0 – 100. For the calibration evaluation a minimum signal to noise ratio of 80 is recommended by UL. This value has been determined from the user manual of the LiDAR.

4.3 Wind speed

For all evaluations, wind speed has been filtered between 4 and 16 m/s as requested by the IEC 61400-12-1 Ed. 2 Annex L [2]. The wind speed signal recorded at the met tower has been used as a reference. Subsets of the data base have been filtered for studying the relations of wind direction, wind shear and turbulence intensity.

4.4 Wind direction

Wind direction filters have to free the meteorological mast and RSD from wakes from neighbouring wind turbines and other obstacles. Therefore, a wind direction filter has been applied and the resulting measurement sector (see section 2.4) is from 67° to 354°.

Additional wind direction filters in order to avoid any disturbance effects from the met mast structure on the reference cup anemometers should be applied. A standard sector of +/- 45° away from the mast should be excluded from anemometer data. For the top anemometer at height 130 m, the excluded measurement sector is [335°-65°] since the lightening catcher is oriented at 20°. It is to be noted that the orientation for the lightening catcher could not be fully verified with the available documentation as explained in section 3.1.

For the side boom mounted anemometers, the excluded measurement sector is [69°-159°]. The evaluated anemometers at height 125 m, 94 and 58 m are mounted on horizontal booms pointing towards 294°, the remaining measurement sector is from **159° to 335°**. This approach is conservative with the mast disturbance effects observed, see below.

The diagram in Fig 4.2 shows the ratio V_{Mast1}/V_{Mast2} over all directions. It is expected to show a spike around 114° in the wind speed ratio as an indication of the mast wake around this direction. Another spike is expected around 20° to denote the lightening catcher effect on the top anemometer. The latter is not clearly detectable in the diagram as the corresponding sector coincides with the one affected by the turbine’s wake.

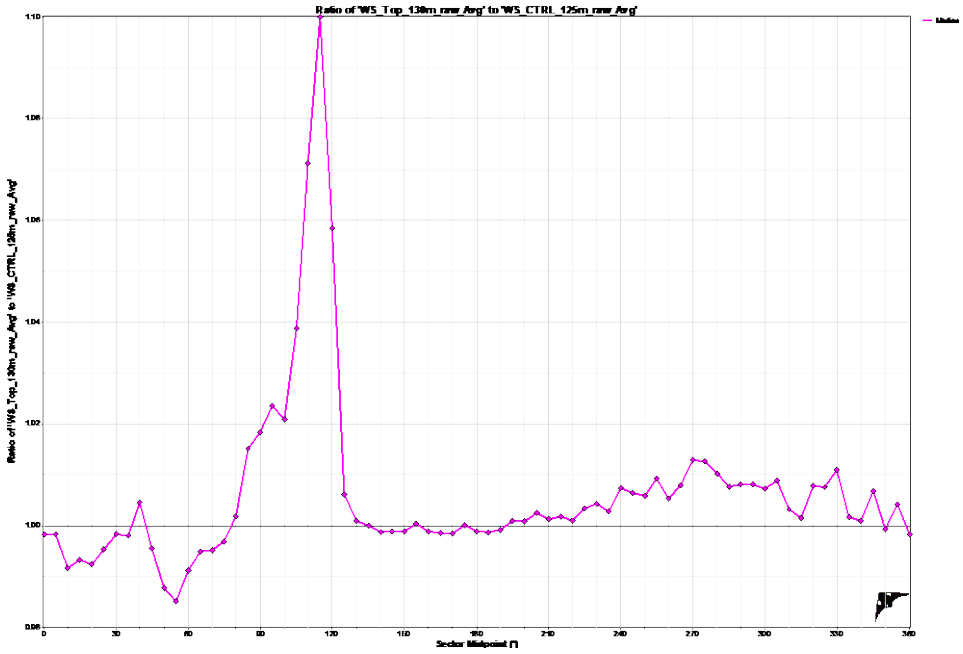

Fig. 4.2 Wind speed ratio v_{Mast1}/v_{Mast2} over wind direction measurement dir_1. The impact shown is a combination of mast effects.

4.5 Specific filters

For the subset of the turbulence intensity related evaluations, the data base has been filtered as to keep the values for turbulence values between **0.03 and 0.24** as recommended by [2] in table L3. The TI filter is applied only for the evaluation presented in Section 6.2.

For the wind direction evaluation, an additional filtering has been applied. To avoid statistical artefacts caused by angles close to north, reference wind direction between **352.5° and 7.5°** have been excluded as recommended by [3]. The northing filter is applied only for the evaluation presented in Section 6.3.

For wind shear evaluation, the evaluated subset has been filtered as to keep the values for wind shear between **-0.4 and 0.8** as recommended by [2] in table L3. The shear filter is applied only for the evaluation presented in §6.4.

All the filters described previously in 4.2, 4.3, 4.4 and 4.5 are applied to all data, for each bin at every height. The specific filters are additional filters which apply respectively to turbulence intensity, wind direction and wind shear.

4.6 Filtering statistics

The original data set consists of 5149 data samples.

4.6.1 General filters

The table below presents the amount of data samples excluded from the original data set by the different filters. They are applied to all evaluations. A single time step could be flagged by several filters, the union of this filtering is excluded in the final dataset.

Tab. 4.1 Filter statistics for additional filters applied for wind speed evaluations.

Evaluated height	Wind speed filter		Wind direction filter		Signal quality filter		Icing filter	
	Number	%	Number	%	Number	%	Number	%
130 m	479	9.3	1512	29.36	182	3.53	0	0.00
125 m	464	9.01	1512	29.36	174	3.38	0	0.00
94 m	457	8.88	1512	29.36	118	2.29	0	0.00
58 m	478	9.28	1512	29.36	251	4.87	0	0.00

4.6.2 Specific filter for turbulence intensity evaluation

The table below presents the amount of data samples excluded from the original data set by filtering turbulence intensity between 0.03 and 0.24.

Tab. 4.2 Filter statistics for additional filters applied for turbulence intensity evaluations.

Evaluated height	Turbulence intensity filter	
	Number	%
130 m	1492	28.98
125 m	1455	28.26
94 m	1282	24.9
58 m	1070	20.78

4.6.3 Specific filter for wind direction evaluation

The table below presents the amount of data samples excluded from the original data set by filtering wind direction over North between 352.5 and 7.5.

Tab. 4.3 Filter statistics for additional filters applied for wind direction evaluations.

Evaluated height	Wind direction filter over North	
	Number	%
130 m	72	1.4
125 m	72	1.4
94 m	72	1.4
58 m	72	1.4

4.6.4 Specific filter for wind shear evaluation

The table below presents the amount of data samples excluded from the original data set by filtering wind shear exponent between -0.4 and 0.8 as well as filtering RSD measurements for low signal quality.

Tab. 4.4 Filter statistics for additional filters applied for wind shear evaluations.

Evaluated height	Wind shear filter		Quality filter	
	Number	%	Number	%
125 m 58 m	106	2.06	251	4.87

5. UNCERTAINTY CALCULATION

The main output of a RSD calibration report as described by [2] is to evaluate the uncertainty resulting from the RSD performance verification test. One should take this uncertainty into account while using the RSD data as primary input for a power curve calibration as requested by [2] or for a bankable energy yield assessment as recommended by [4].

The wind speed measurement uncertainty is calculated for every evaluated height. The considered uncertainty sources are the following [2]:

- The standard uncertainty of the reference sensor (**v_Cup uncertainty**) with the following components (calculated with formula (3), page 8)
  - Calibration uncertainty at k_p=1: 0.05 m/s
  - Class number k of anemometer: Class A 0.9
- The uncertainty due to the mounting effects: 1.2% (top mounted, hub height anemometer), 1.5% (all other cup anemometers evaluated in this report were side boom mounted).
- The wind speed data acquisition system uncertainty: 0.1%
- The standard uncertainty of calibrations between different laboratories: 0.4%
- The mean deviation of the RSD measurements and the reference sensor (**Mean deviation**)
- The standard uncertainty of the measurement of the RSD ($\frac{V_{RSD\,std}}{\sqrt{N}}$, N representing the number of data per bin)
- The uncertainty of the RSD due to mounting effects has been assumed with 0.1 % in wind speed (**Mounting uncertainty RSD**)
- The uncertainty of the RSD due to non-homogenous flow within the measurement volume has been assumed to be 0 % in wind speed since the terrain is flat and simple.
- The uncertainty due to the distance between the RSD and the reference sensor calculated as 1 % times the separation distance divided by the measurement height. These uncertainties are 0.33% for 130 m, 0.35% for 125 m, 0.46% for 94 m and 0.75% for 58 m.

The resulting uncertainty (**v_RSD uncertainty**) is the root of the quadratic summation of the previous sources.

In order to assess its performance, the mean deviations of the RSD measurements against reference measurements shall be compared to the standard uncertainty of the calibration reduced by the mean deviation. This **uncertainty reduced by mean deviation** is the root of the quadratic summation of all uncertainty sources except the **mean deviation**.

It is recommended by [2] to correct the RSD measurements with the derived correction function $\mathbf{V_{cup}(V_{RSD})}$ presented in this report **if** the **mean deviation** exceeds the **uncertainty reduced by mean deviation** in at least one bin.

6. RESULTS OF CALIBRATION

6.1 Calibration of horizontal wind speed measurement

6.1.1 Calibration of horizontal wind speed measurement at 130 m

Total number of used data sets: 3315
Average of v_{cup} of all used data sets: 10.005 m/s
Average of v_{RSD} of all used data sets: 10.124 m/s

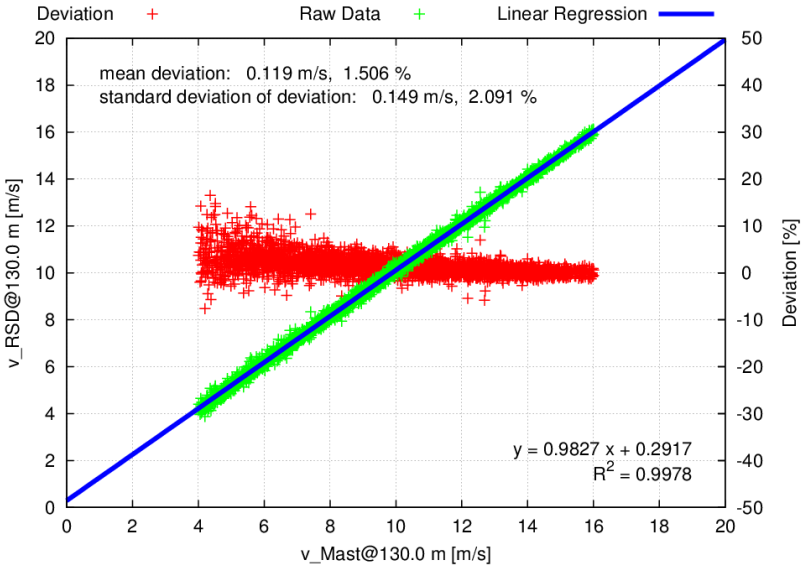

Fig. 6.1 Scatter plot of horizontal wind speed and deviation at 130 m for the data set prior to binning.

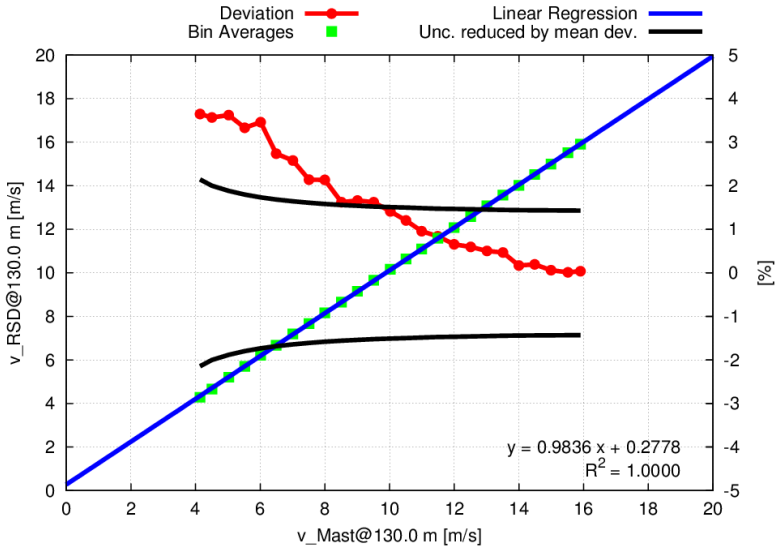

Fig. 6.2 Plot of bin analysis of horizontal wind speed and deviation at 130 m for the complete bins.

Tab. 6.1 Correction functions from bin linear regression for complete bins at 130 m.

Correction Function	Slope	Offset	R^2
Fit $V_{RSD} = V_{cup}$ * Slope + Offset	0.9836	0.2778	1.0000
Inverse fit $V_{cup} = V_{RSD}$ * Slope + Offset	1.0167	-0.2820	1.0000

Tab. 6.2 Bin analysis of horizontal wind speed and uncertainty calculation at 130 m.

v_Mast	v_RSD	N	v_RSD max	v_RSD min	v_RSD std	v_RSD std/sqrt(N)	Mean deviation	v_Cup uncertainty	Mounting uncertainty RSD	v_RSD uncertainty	Uncertainty reduced by mean deviation
[m/s]	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[%]	[%]	[%]	[%]	[%]
4.14	4.29	34	4.65	3.88	0.168	0.029	3.63	2.00	0.10	4.21	2.15
4.50	4.66	80	5.19	4.10	0.232	0.026	3.55	1.88	0.10	4.08	2.00
5.02	5.21	101	5.78	4.65	0.227	0.023	3.62	1.79	0.10	4.08	1.88
5.52	5.70	115	6.38	5.14	0.218	0.020	3.33	1.72	0.10	3.79	1.80
6.01	6.22	123	6.73	5.74	0.204	0.018	3.46	1.67	0.10	3.87	1.73
6.50	6.67	128	7.17	6.09	0.200	0.018	2.73	1.62	0.10	3.20	1.68
7.01	7.19	134	7.62	6.70	0.192	0.017	2.57	1.59	0.10	3.05	1.64
7.51	7.67	163	8.34	7.17	0.199	0.016	2.14	1.56	0.10	2.68	1.61
8.00	8.17	175	8.58	7.68	0.185	0.014	2.14	1.53	0.10	2.66	1.58
8.51	8.65	177	9.23	7.94	0.202	0.015	1.63	1.51	0.10	2.26	1.56
9.01	9.16	150	9.56	8.69	0.189	0.015	1.65	1.49	0.10	2.26	1.54
9.51	9.67	176	10.18	9.19	0.189	0.014	1.62	1.47	0.10	2.22	1.52
10.02	10.17	166	10.58	9.64	0.197	0.015	1.42	1.46	0.10	2.07	1.51
10.51	10.63	160	11.15	10.09	0.213	0.017	1.20	1.45	0.10	1.92	1.50
10.99	11.10	170	11.82	10.64	0.204	0.016	0.96	1.44	0.10	1.77	1.49
11.49	11.59	169	11.94	11.13	0.171	0.013	0.84	1.43	0.10	1.69	1.47
12.00	12.08	163	12.52	11.52	0.202	0.016	0.65	1.42	0.10	1.60	1.47
12.51	12.58	164	13.44	11.95	0.210	0.016	0.59	1.41	0.10	1.57	1.46
13.01	13.08	198	13.67	12.53	0.188	0.013	0.50	1.40	0.10	1.53	1.45
13.51	13.57	182	13.92	13.17	0.162	0.012	0.47	1.40	0.10	1.52	1.44
14.00	14.02	135	14.45	13.46	0.185	0.016	0.17	1.39	0.10	1.45	1.44
14.49	14.51	102	14.90	14.05	0.190	0.019	0.19	1.39	0.10	1.45	1.44
14.99	15.00	81	15.42	14.59	0.186	0.021	0.06	1.38	0.10	1.43	1.43
15.51	15.52	46	16.00	15.17	0.184	0.027	0.01	1.38	0.10	1.43	1.43
15.90	15.91	23	16.14	15.65	0.139	0.029	0.04	1.37	0.10	1.43	1.43

6.1.2 Calibration of horizontal wind speed measurement at 125 m

Total number of used data sets: 3331
Average of v_{cup} of all used data sets: 9.991 m/s
Average of v_{RSD} of all used data sets: 10.057 m/s

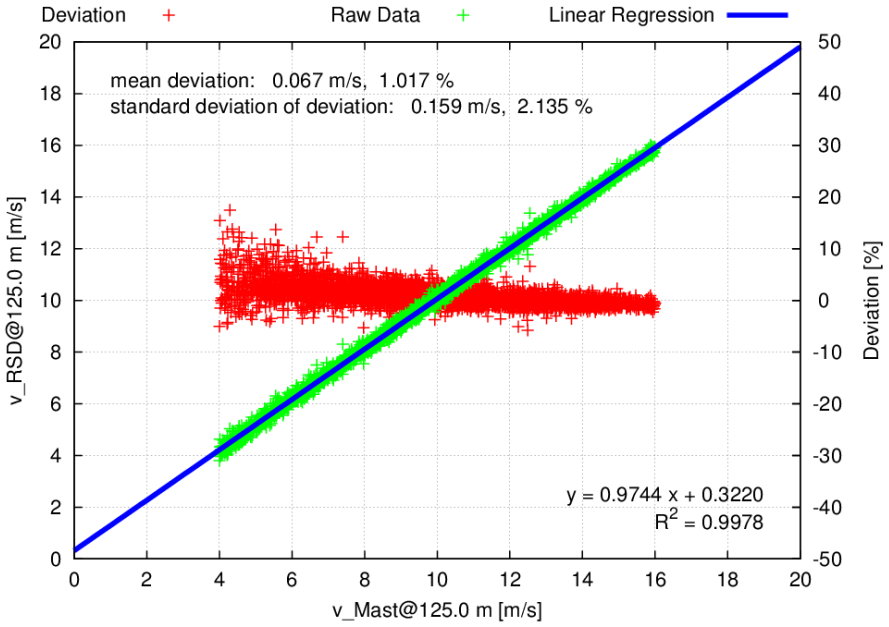

Fig. 6.3 Scatter plot of horizontal wind speed and deviation at 125 m for the data set prior to binning.

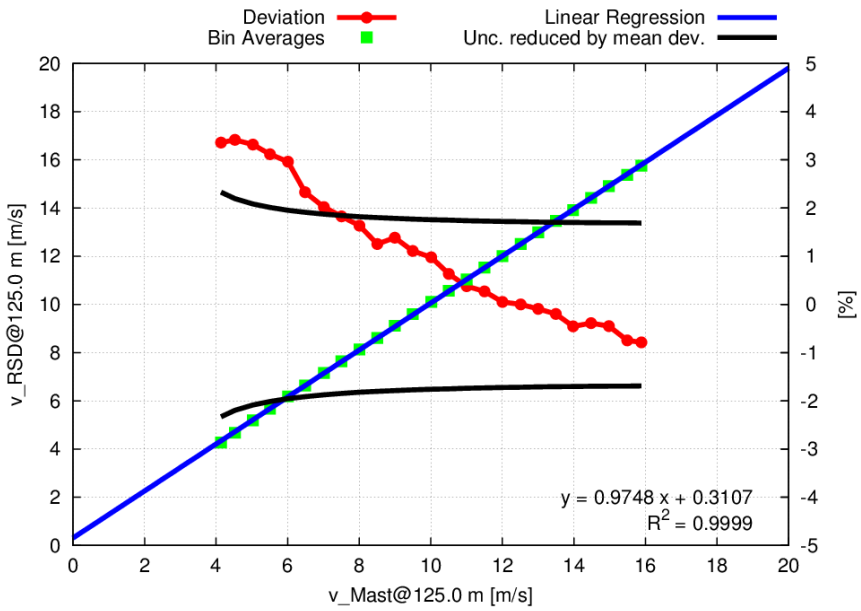

Fig. 6.4 Plot of bin analysis of horizontal wind speed and deviation at 125 m for the complete bins.

Tab. 6.3 Correction functions from bin linear regression for complete bins at 125 m.

Correction Function	Slope	Offset	R^2
Fit $V_{RSD} = V_{cup}$ * Slope + Offset	0.9748	0.3107	0.9999
Inverse fit $V_{cup} = V_{RSD}$ * Slope + Offset	1.0257	-0.3182	0.9999

Tab. 6.4 Bin analysis of horizontal wind speed and uncertainty calculation at 125 m.

v_Mast	v_RSD	N	v_RSD max	v_RSD min	v_RSD std	v_RSD std/sqrt(N)	Mean deviation	v_Cup uncertainty	Mounting uncertainty RSD	v_RSD uncertainty	Uncertainty reduced by mean deviation
[m/s]	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[%]	[%]	[%]	[%]	[%]
4.14	4.28	44	4.78	3.80	0.192	0.029	3.33	2.19	0.10	4.07	2.33
4.53	4.68	76	5.17	4.22	0.226	0.026	3.40	2.09	0.10	4.05	2.19
5.03	5.19	93	5.81	4.71	0.207	0.021	3.30	2.01	0.10	3.90	2.08
5.51	5.68	117	6.31	5.09	0.222	0.021	3.11	1.94	0.10	3.70	2.01
6.01	6.19	120	6.71	5.67	0.195	0.018	2.96	1.90	0.10	3.55	1.95
6.49	6.64	133	7.50	6.06	0.215	0.019	2.33	1.86	0.10	3.01	1.91
7.01	7.16	136	7.61	6.72	0.184	0.016	2.01	1.82	0.10	2.75	1.87
7.51	7.64	169	8.31	7.15	0.198	0.015	1.83	1.80	0.10	2.60	1.85
8.01	8.14	175	8.51	7.55	0.180	0.014	1.64	1.78	0.10	2.45	1.82
8.50	8.61	176	9.08	8.19	0.185	0.014	1.25	1.76	0.10	2.19	1.80
8.99	9.12	152	9.55	8.66	0.191	0.015	1.39	1.74	0.10	2.26	1.79
9.50	9.60	167	9.96	9.14	0.189	0.015	1.12	1.73	0.10	2.09	1.77
10.01	10.11	172	10.48	9.56	0.193	0.015	0.98	1.71	0.10	2.01	1.76
10.50	10.57	169	11.15	10.07	0.211	0.016	0.63	1.70	0.10	1.86	1.75
11.00	11.04	173	11.57	10.65	0.196	0.015	0.38	1.69	0.10	1.78	1.74
11.50	11.53	176	11.93	11.04	0.175	0.013	0.27	1.69	0.10	1.75	1.73
12.00	12.01	153	12.52	11.61	0.186	0.015	0.05	1.68	0.10	1.72	1.72
12.51	12.51	169	13.38	11.77	0.221	0.017	0.00	1.67	0.10	1.72	1.72
13.00	12.99	185	13.63	12.54	0.192	0.014	-0.08	1.67	0.10	1.71	1.71
13.50	13.47	199	13.89	12.87	0.177	0.013	-0.20	1.66	0.10	1.72	1.70
13.98	13.92	122	14.41	13.49	0.181	0.016	-0.46	1.66	0.10	1.76	1.70
14.48	14.42	110	14.89	14.03	0.176	0.017	-0.39	1.65	0.10	1.74	1.70
14.98	14.91	74	15.29	14.54	0.180	0.021	-0.45	1.65	0.10	1.75	1.69
15.49	15.38	43	15.76	15.07	0.167	0.025	-0.75	1.65	0.10	1.85	1.69
15.89	15.76	28	16.02	15.57	0.125	0.024	-0.79	1.64	0.10	1.86	1.69

6.1.3 Calibration of horizontal wind speed measurement at 94 m

Total number of used data sets: 3357
Average of v_{cup} of all used data sets: 9.479 m/s
Average of v_{RSD} of all used data sets: 9.584 m/s

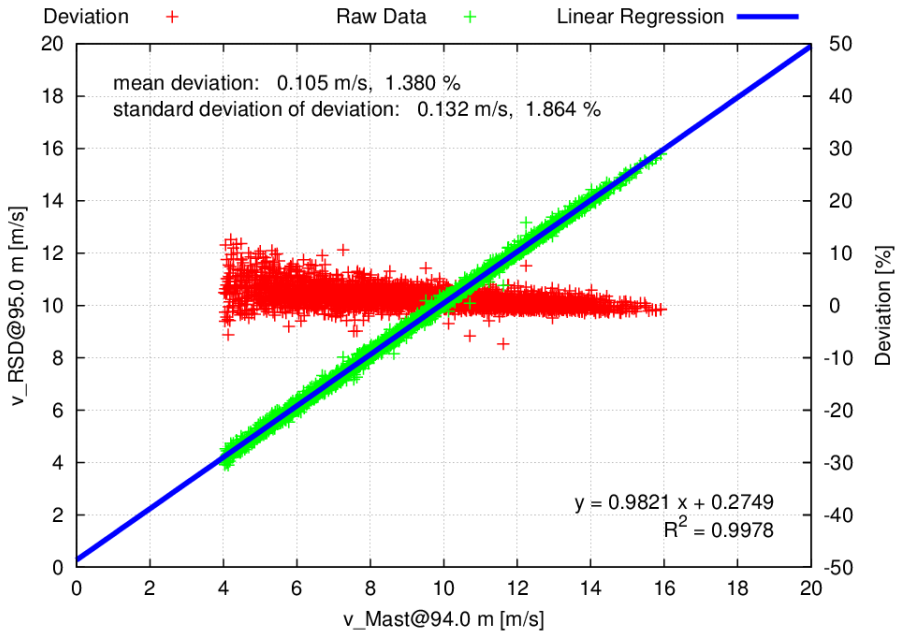

Fig. 6.5 Scatter plot of horizontal wind speed and deviation at 94 m for the data set prior to binning.

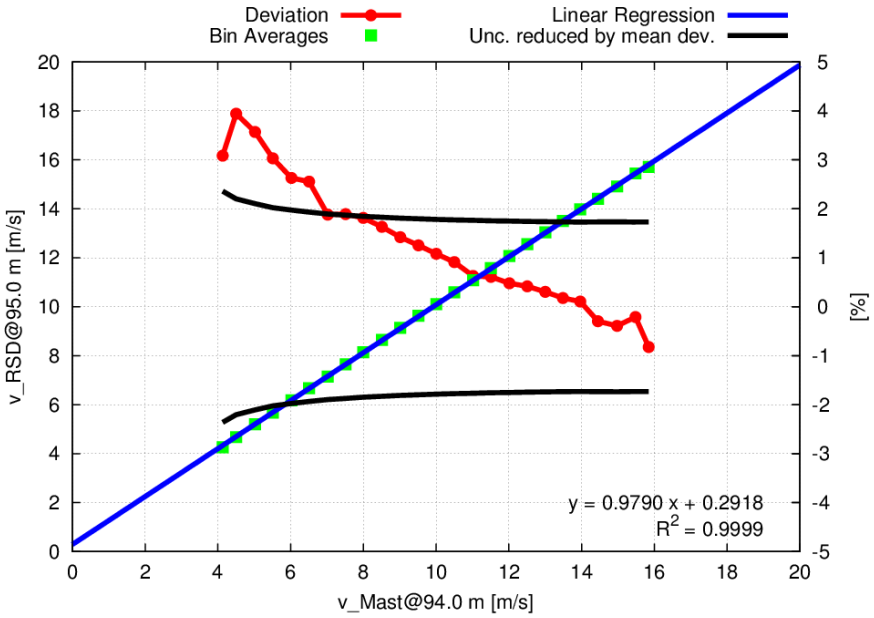

Fig. 6.6 Plot of bin analysis of horizontal wind speed and deviation at 94 m for the complete bins.

Tab. 6.5 Correction functions from bin linear regression for complete bins at 94 m.

Correction Function	Slope	Offset	R^2
Fit V_{RSD} = V_{cup} * Slope + Offset	0.9790	0.2918	0.9999
Inverse fit V_{cup} = V_{RSD} * Slope + Offset	1.0214	-0.2973	0.9999

Tab. 6.6 Bin analysis of horizontal wind speed and deviation at 94 m.

v_Mast	v_RSD	N	v_RSD max	v_RSD min	v_RSD std	v_RSD std/sqrt(N)	Mean deviation	v_Cup uncertainty	Mounting uncertainty RSD	v_RSD uncertainty	Uncertainty reduced by mean deviation
[m/s]	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[%]	[%]	[%]	[%]	[%]
4.13	4.26	37	4.73	3.90	0.186	0.031	3.10	2.19	0.10	3.89	2.36
4.50	4.68	77	5.18	4.25	0.206	0.023	3.95	2.09	0.10	4.53	2.20
5.02	5.20	90	5.62	4.70	0.201	0.021	3.58	2.01	0.10	4.16	2.11
5.51	5.68	130	6.03	5.28	0.183	0.016	3.01	1.94	0.10	3.63	2.02
6.02	6.18	145	6.72	5.55	0.201	0.017	2.64	1.90	0.10	3.30	1.97
6.51	6.68	145	7.33	6.24	0.198	0.016	2.57	1.86	0.10	3.21	1.93
7.02	7.15	176	7.58	6.66	0.182	0.014	1.87	1.82	0.10	2.66	1.90
7.51	7.65	183	8.18	7.14	0.208	0.015	1.89	1.80	0.10	2.66	1.87
8.00	8.14	215	8.62	7.59	0.189	0.013	1.83	1.78	0.10	2.60	1.85
8.51	8.65	175	9.09	8.16	0.199	0.015	1.63	1.76	0.10	2.45	1.83
9.02	9.14	178	9.52	8.64	0.175	0.013	1.42	1.74	0.10	2.30	1.81
9.51	9.63	193	10.19	9.24	0.182	0.013	1.25	1.73	0.10	2.19	1.80
10.00	10.11	226	10.51	9.57	0.175	0.012	1.08	1.71	0.10	2.09	1.78
10.50	10.60	221	11.10	10.09	0.189	0.013	0.90	1.70	0.10	1.99	1.77
11.02	11.09	177	11.56	10.69	0.185	0.014	0.64	1.69	0.10	1.88	1.77
11.51	11.58	173	12.20	10.77	0.184	0.014	0.61	1.69	0.10	1.86	1.76
12.01	12.07	196	13.17	11.67	0.187	0.013	0.47	1.68	0.10	1.81	1.75
12.51	12.56	208	12.98	12.18	0.180	0.012	0.42	1.67	0.10	1.79	1.74
13.00	13.04	157	13.51	12.64	0.174	0.014	0.31	1.67	0.10	1.76	1.74
13.48	13.51	117	13.99	13.15	0.166	0.015	0.18	1.66	0.10	1.74	1.73
13.97	13.98	75	14.43	13.60	0.170	0.020	0.11	1.66	0.10	1.73	1.73
14.45	14.41	31	14.70	14.10	0.159	0.029	-0.30	1.65	0.10	1.76	1.73
14.97	14.92	21	15.18	14.59	0.174	0.038	-0.39	1.65	0.10	1.78	1.74
15.48	15.45	7	15.56	15.24	0.098	0.037	-0.21	1.65	0.10	1.74	1.73
15.84	15.71	4	15.80	15.63	0.083	0.042	-0.82	1.64	0.10	1.92	1.73

6.1.4 Calibration of horizontal wind speed measurement at 58 m

Total number of used data sets: 3301
Average of v_{cup} of all used data sets: 8.563 m/s
Average of v_{RSD} of all used data sets: 8.625 m/s

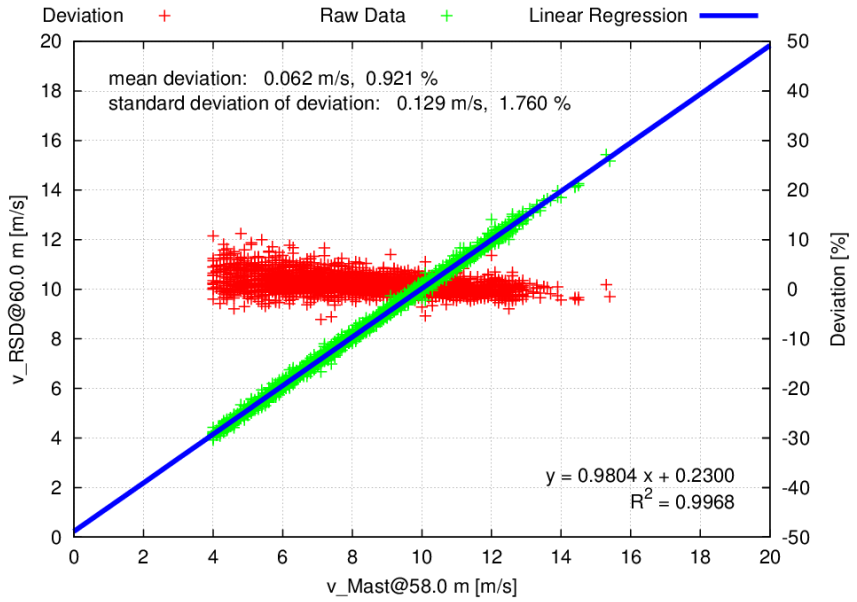

Fig. 6.7 Scatter plot of horizontal wind speed and deviation at 58 m for the data set prior to binning.

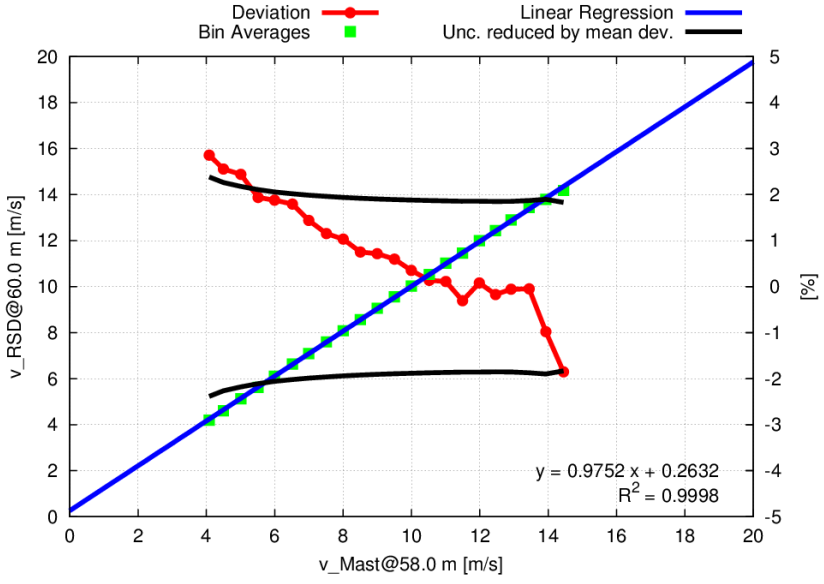

Fig. 6.8 Plot of bin analysis of horizontal wind speed and deviation at 58 m for the complete bins.

Tab. 6.7 Correction functions from bin linear regression for complete bins at 58 m.

Correction Function	Slope	Offset	R^2
Fit $V_{RSD} = V_{cup}$ * Slope + Offset	0.9752	0.2632	0.9998
Inverse fit $V_{cup} = V_{RSD}$ * Slope + Offset	1.0252	-0.2677	0.9998

Tab. 6.8 Bin analysis of horizontal wind speed and deviation at 58 m. Bins over 15 m/s are incomplete.

v_Mast	v_RSD	N	v_RSD max	v_RSD min	v_RSD std	v_RSD std/sqrt(N)	Mean deviation	v_Cup uncertainty	Mounting uncertainty RSD	v_RSD uncertainty	Uncertainty reduced by mean deviation
[m/s]	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[%]	[%]	[%]	[%]	[%]
4.08	4.20	34	4.49	3.92	0.133	0.023	2.87	2.19	0.10	3.73	2.38
4.50	4.61	93	4.98	4.23	0.182	0.019	2.53	2.09	0.10	3.40	2.26
5.01	5.13	116	5.58	4.73	0.201	0.019	2.44	2.01	0.10	3.27	2.18
5.51	5.62	150	6.19	5.17	0.187	0.015	1.94	1.94	0.10	2.87	2.11
5.99	6.11	186	6.75	5.65	0.190	0.014	1.87	1.90	0.10	2.78	2.06
6.52	6.64	179	7.11	6.17	0.183	0.014	1.80	1.86	0.10	2.70	2.02
6.99	7.09	217	7.80	6.62	0.197	0.013	1.43	1.82	0.10	2.45	1.99
7.51	7.60	231	8.18	6.99	0.197	0.013	1.16	1.80	0.10	2.28	1.96
8.00	8.09	260	8.64	7.68	0.182	0.011	1.02	1.78	0.10	2.19	1.94
8.51	8.57	240	8.97	8.22	0.174	0.011	0.74	1.76	0.10	2.06	1.92
9.00	9.06	260	9.74	8.68	0.182	0.011	0.71	1.74	0.10	2.03	1.91
9.50	9.56	275	9.99	9.15	0.168	0.010	0.60	1.73	0.10	1.98	1.89
9.99	10.03	257	10.66	9.56	0.182	0.011	0.35	1.71	0.10	1.91	1.88
10.52	10.53	218	10.99	9.96	0.182	0.012	0.13	1.70	0.10	1.88	1.87
11.01	11.02	210	11.67	10.65	0.189	0.013	0.12	1.69	0.10	1.87	1.86
11.50	11.46	148	11.89	11.08	0.181	0.015	-0.30	1.69	0.10	1.88	1.86
11.99	12.00	103	12.82	11.58	0.221	0.022	0.08	1.68	0.10	1.86	1.85
12.46	12.44	82	13.03	12.01	0.207	0.023	-0.18	1.67	0.10	1.86	1.85
12.91	12.91	24	13.25	12.63	0.161	0.033	-0.06	1.67	0.10	1.86	1.85
13.44	13.44	9	13.65	13.17	0.156	0.052	-0.04	1.66	0.10	1.87	1.87
13.93	13.80	3	13.97	13.70	0.123	0.071	-0.98	1.66	0.10	2.13	1.90
14.45	14.18	4	14.26	14.12	0.051	0.026	-1.85	1.65	0.10	2.61	1.83
15.35	15.31	2	15.44	15.17	0.135	NA	NA	NA	NA	NA	NA

6.2 Calibration of turbulence intensity

6.2.1 Calibration of turbulence intensity at 130 m

Total number of used data sets:	2374
Average turbulence intensity based on v_mast of all used data sets:	0.097
Average turbulence intensity based on v_RSD of all used data sets:	0.125

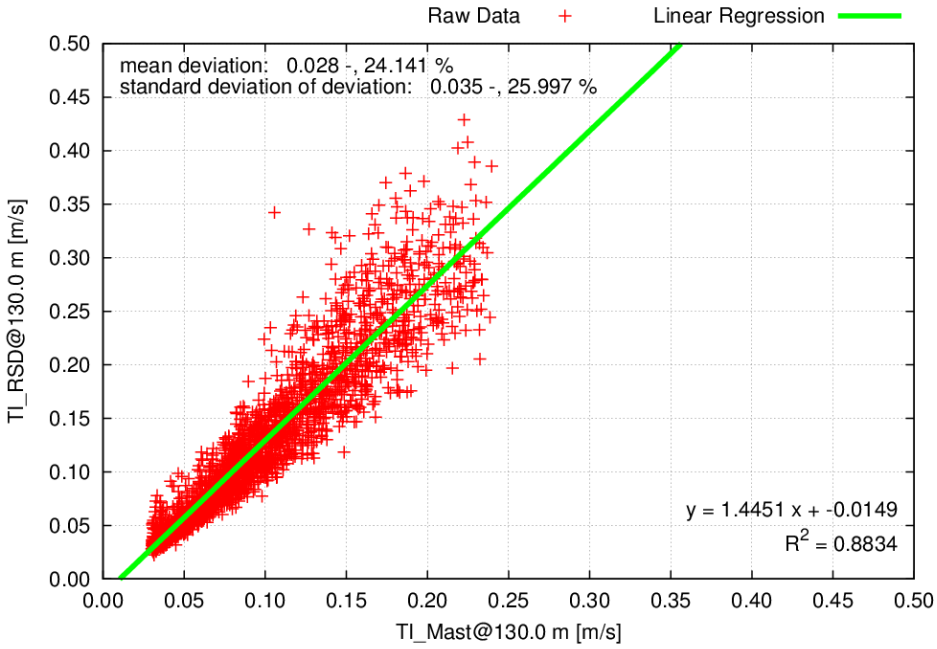

Fig. 6.9 Scatter plot of turbulence intensity and deviation at 130 m.

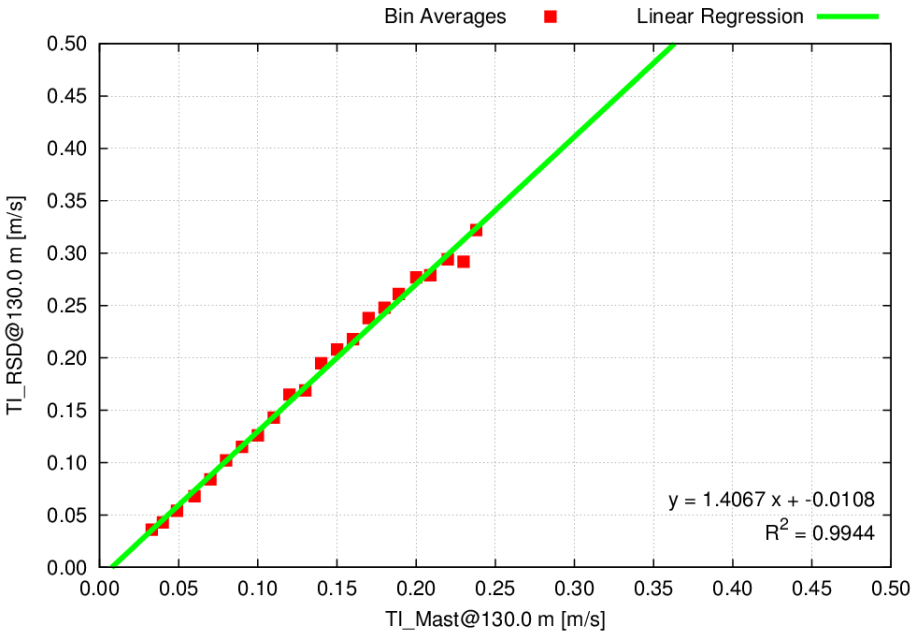

Fig. 6.10 Plot of bin analysis of turbulence intensity and deviation at 130 m.

6.2.2 Calibration of turbulence intensity at 125 m

Total number of used data sets:	2411
Average turbulence intensity based on v_mast of all used data sets:	0.097
Average turbulence intensity based on v_RSD of all used data sets:	0.124

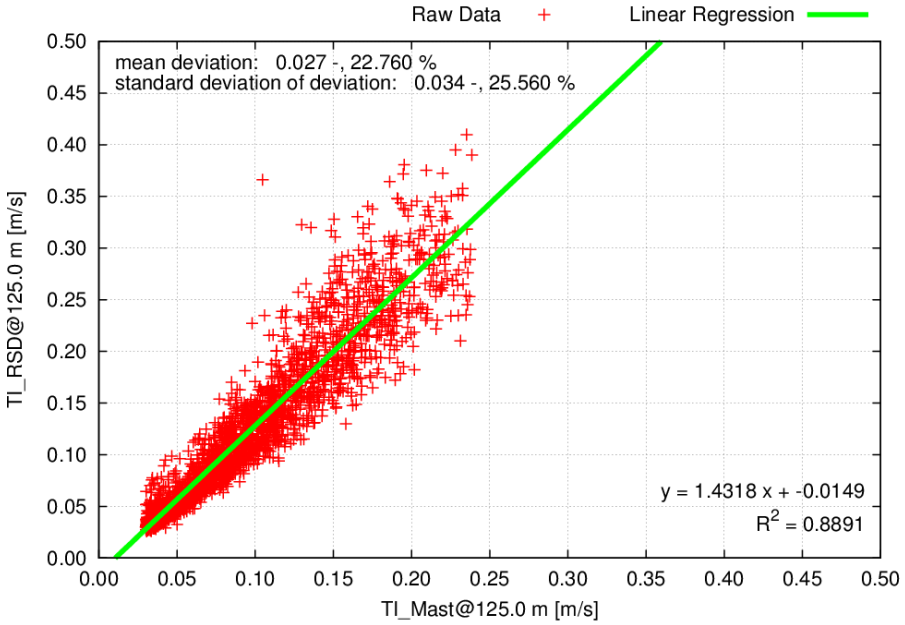

Fig. 6.11 Scatter plot of turbulence intensity and deviation at 125 m.

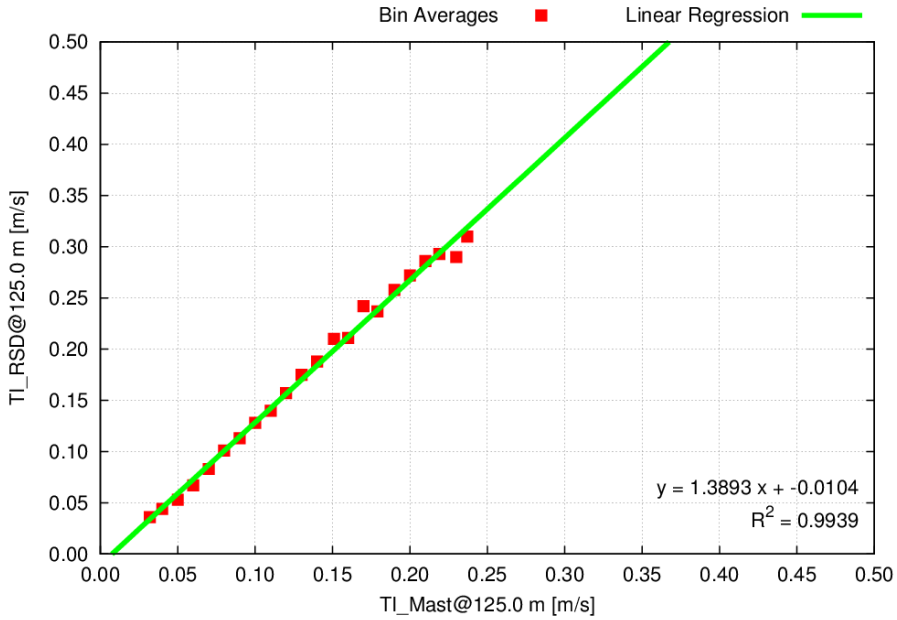

Fig. 6.12 Plot of bin analysis of turbulence intensity and deviation at 125 m.

6.2.3 Calibration of turbulence intensity at 94 m

Total number of used data sets:	2548
Average turbulence intensity based on v_mast all used data sets:	0.097
Average turbulence intensity based on v_RSD all used data sets:	0.117

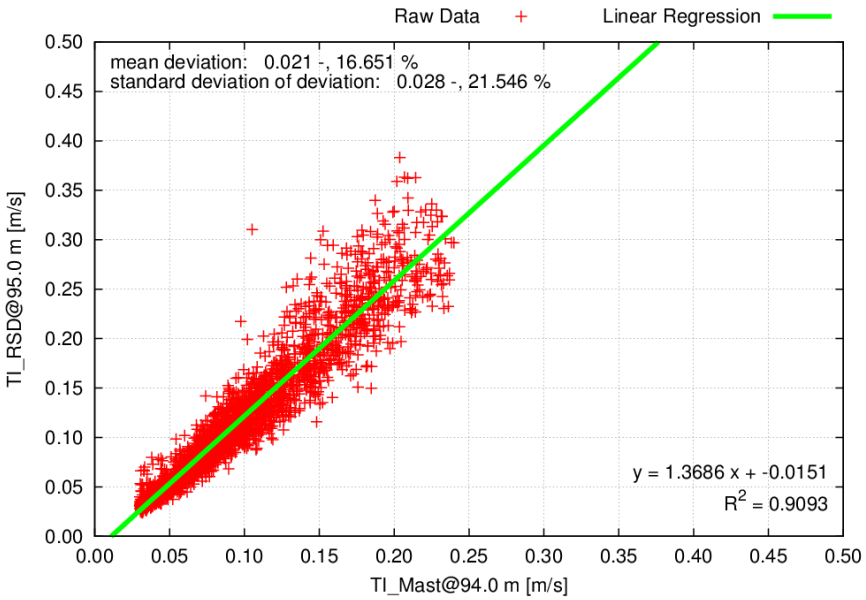

Fig. 6.13 Scatter plot of turbulence intensity and deviation at 94 m.

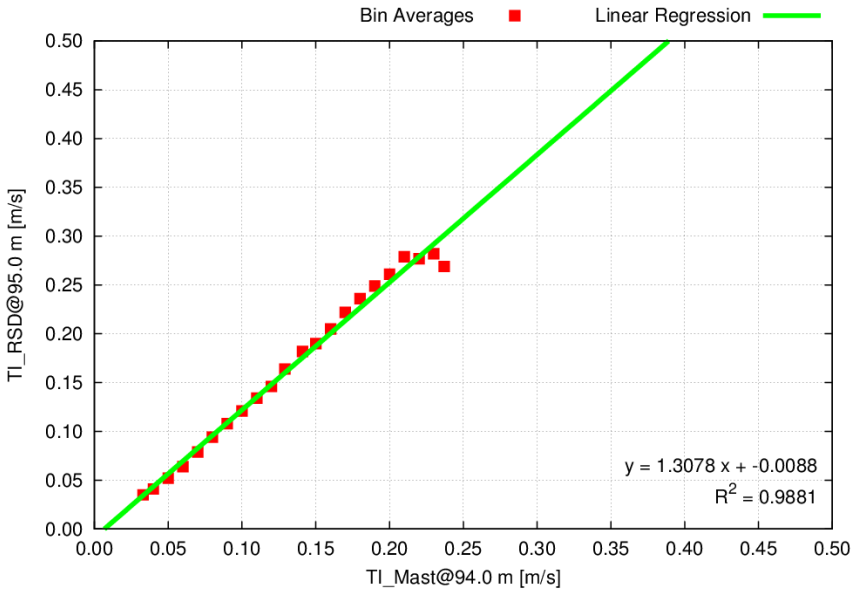

Fig. 6.14 Plot of bin analysis of turbulence intensity and deviation at 94 m.

6.2.4 Calibration of turbulence intensity at 58 m

Total number of used data sets:	2687
Average turbulence intensity based on v_mast all used data sets:	0.100
Average turbulence intensity based on v_RSD all used data sets:	0.113

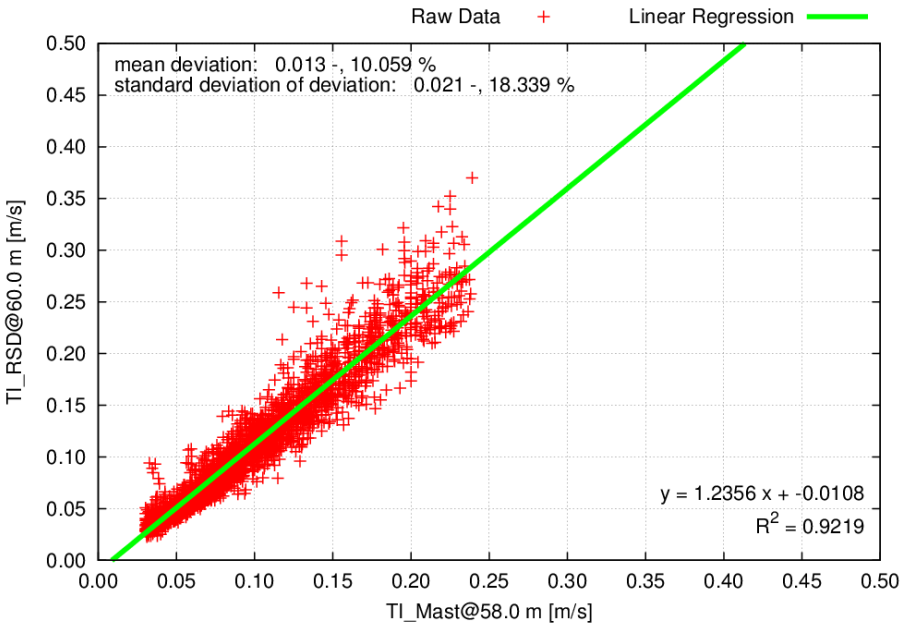

Fig. 6.15 Scatter plot of turbulence intensity and deviation at 58 m.

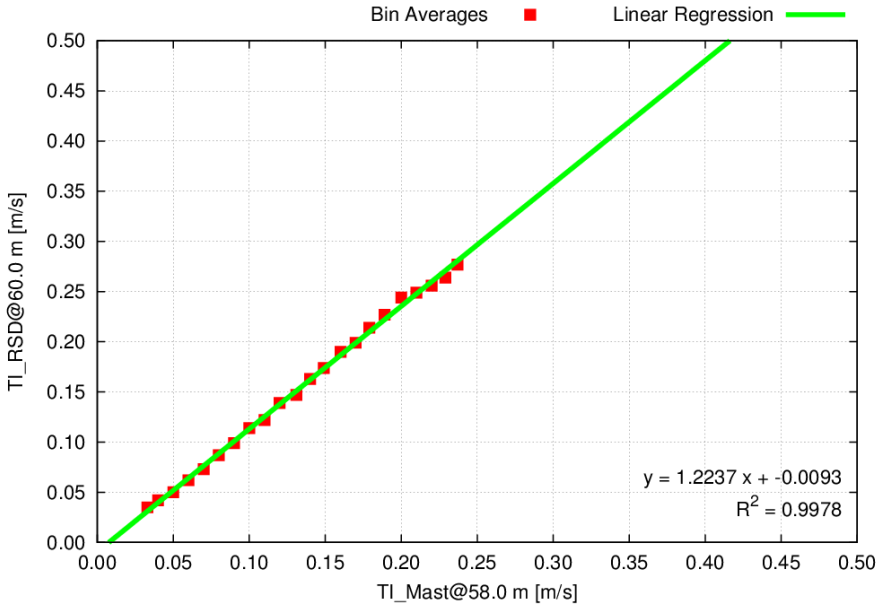

Fig. 6.16 Plot of bin analysis of turbulence intensity and deviation at 58 m.

6.3 Calibration of wind direction measurement

6.3.1 Calibration of wind direction measurement at 125 m

Total number of used data sets: 4535
Average of dir_mast of all used data sets: 180.258 deg
Average of dir_RSD of all used data sets: 177.385 deg

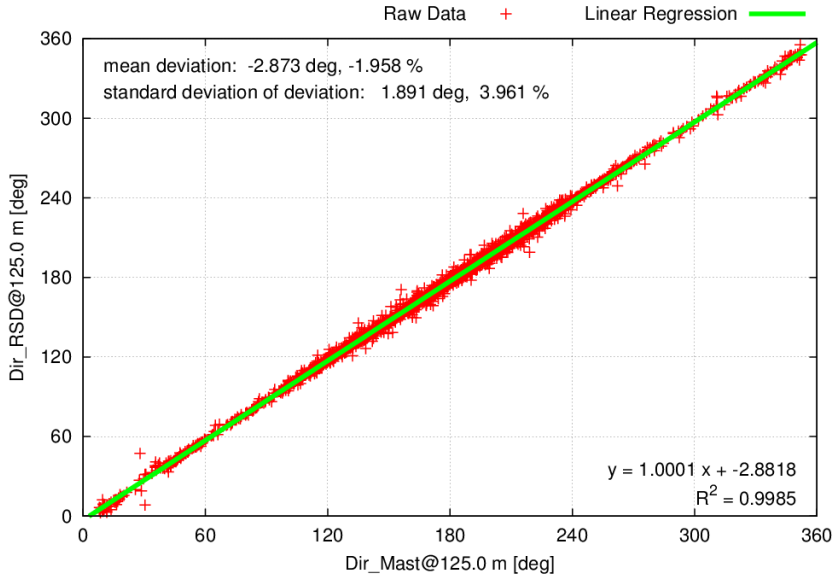

Fig. 6.17 Scatter plot of wind direction and deviation at 125 m.

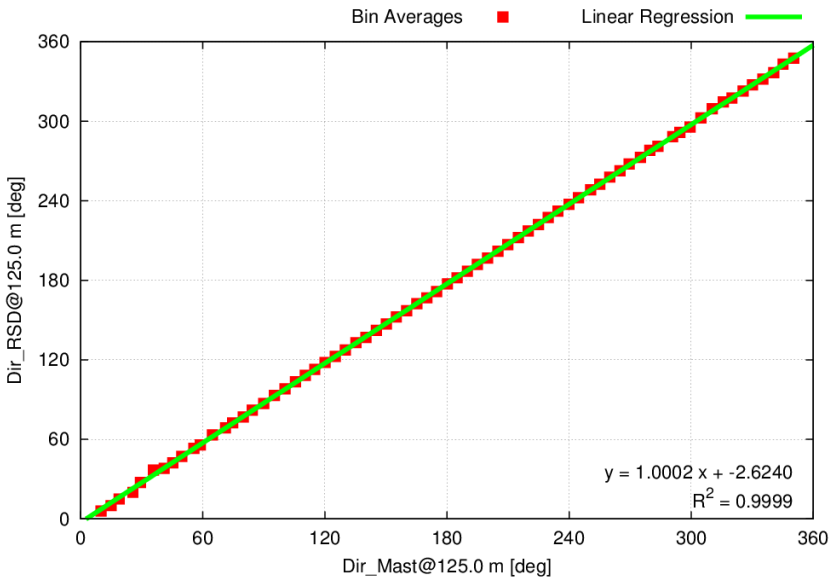

Fig. 6.18 Plot of bin analysis of wind direction and deviation at 125 m.

6.4 Calibration of wind shear

6.4.1 Calibration of wind shear between 125 m and 58 m

Total number of used data sets: 3249
Average shear of v_mast signals of all used data sets: 0.210
Average shear of v_RSD signals of all used data sets: 0.220

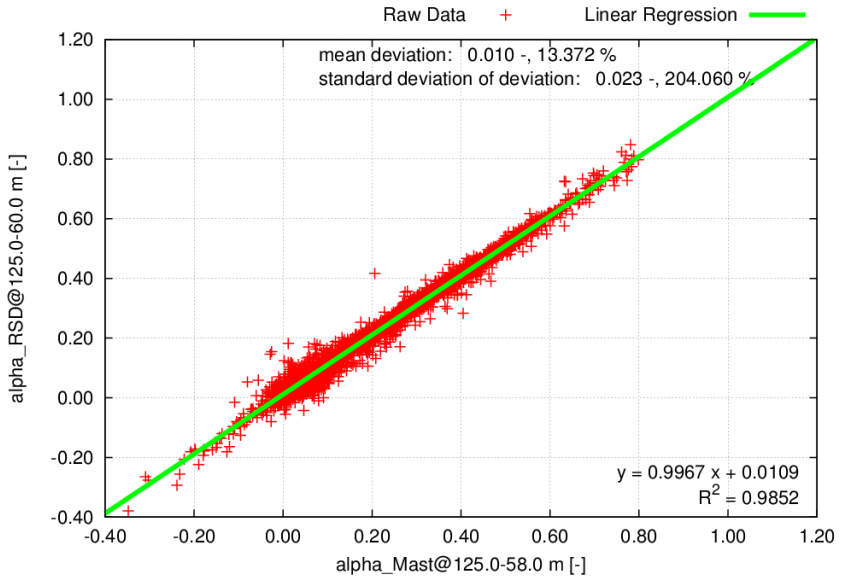

Fig. 6.19 Scatter plot of wind shear and deviation between 125 m and 58 m.

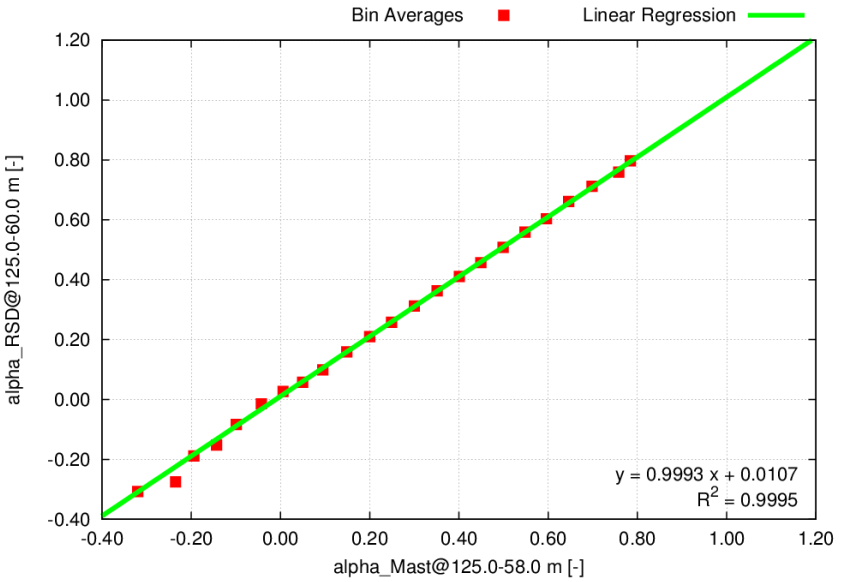

Fig. 6.20 Plot of bin analysis of wind shear and deviation between 125 m and 58 m.

7. COMPLIANCE WITH THE IEC STANDARD REQUIREMENTS

Criterion	Minimum Standard	Reported Value	Criterion fulfilled
Met mast sensors should be compliant with IEC V2		Thies Clima	YES
Data acquisition	Use same averaging intervals for LIDAR and mast measurements	10min	YES
	Record Avg, Std, extreme values, number of samples in 10 min period		YES
	Synchronization of RSD and mast sensors to within 1% of the averaging interval, test for synchronization once a week	No direct synchronization established	NO
	Wind speed measurements binned into 0,5 m/s and wind direction binned into 5° bins		YES
	Each bin centered between 4 m/s and 16 m/s should have at least 3 pairs of measurements	Some bins are empty or incomplete*	NO
	The amount of acquired data shall cover at least 180 hours	3315 data sets for top evaluation => 552 hours	YES
Data preparation	Reference Mast and RSD free from wakes based on annex A	Disturbed sectors excluded	YES
	Reference cup anemometer not influenced by icing	No icing detected	YES
	Filtering for precipitation should only be undertaken if required by manufacturer	Not required	YES
	Correct mast effects on boom mounted anemometers	Disturbed sectors excluded	YES
Use bin averaging to compare the RSD and Mast measurement	Detailed procedure presented in annex L.3 of the standard		YES
Calculate the total uncertainty of the RSD	Follow recommendations of Annex L.4.2 of the standard		YES

** Due to a lack of high wind speeds during the calibration period, some bins are empty or incomplete. The RSD measurement uncertainty could not be evaluated for these bins. The impact of the effect is larger for the levels closer to the ground. UL believes that the most sensitive wind speed range for wind turbine power production is covered. Furthermore, based on the wind speed measurement principle of the RSD as well as the data available in the sparsely populated bins it is reasonable to assume that a correction function can be applied to the wind speed range up to 16 m/s as well.*

8. CONCLUSIONS

UL performed the calibration test of the LiDAR WLS7-436 in flat terrain with an IEC compliant met mast. The evaluation is based on simultaneous measurements ranging from 2019.08.20 to 2019.09.25. The two data bases have been filtered and evaluated following the recommendations in the available version of the IEC 61400-12-1 Ed. 2 Annex L [2].

The correlations of the wind speeds in terms of R^2 are good at all heights ($R^2 > 0.9998$ for the binned results). The RSD measurement uncertainty has been evaluated and is presented in this report bin-wise for each evaluated height. Various correlation functions between the RSD wind speed and the reference sensors wind speed are also presented for each evaluated height.

The correlation of wind direction measurements is very good (slope = 1.0002, $R^2 = 0.9999$). The RSD wind direction is lower than the met mast reported wind direction by a value of 3°. This is probably due to the northing uncertainty for both met mast wind vane and RSD device.

The correlations give good results at all evaluated heights in terms of turbulence intensity. In general, the RSD gives higher binned values (by approximately 0.02) than the reference sensors.

The correlation of calculated wind shear is good (slope = 0.9993, R^2 = 0,9995 for binned averages). The RSD wind shear is higher than the met mast wind shear by approximately 0.01.

The criterion for applying a correction to a RSD measurement is given by the available version of the IEC 61400-12-1 Ed. 2 Annex L [2] explained in section 0.

This version of the IEC 61400-12-1 Ed. 2 Annex L [2] recommends to apply a correction function if the bin-averaged deviations exceeds the reduced uncertainty (as defined in section 5 Uncertainty Calculation).

This criterion is reached for 12 bins for height 130 m. The bins are centered between 4 m/s and 9.5 m/s, and have in total 1556 data couple which represents 47% of the data set.

This criterion is reached for 7 bins for height 125 m. The bins are centered between 4 m/s and 7 m/s, and have in total 719 data couple which represents 21% of the data set.

This criterion is reached for 7 bins for height 94 m. The bins are centered between 4 m/s and 7.5 m/s excluding 7m/s , and have in total 807 data couple which represents 24% of the data set.

This criterion is reached for 4 bins for height 58 m. The bins are centered between 4 m/s and 5 m/s, and 14.5 m/s, they have in total 247 data couple which represents 7.5% of the data set.

As the criterion has been reached for several bins at all heights, a correction function can be applied to the data. One is free to decide on the exact form of correction to apply.

Based on the results of the calibration of this RSD, and following the recommendations of the available version of the IEC 61400-12-1 Ed. 2 Annex L [2], the device WLS7-436 can be used with care in a wind measurement campaign in simple terrain provided the measurement campaign begins within one year of this calibration and the same filter settings are applied.

According to IEC 61400-12-1, a calibration shall be considered as valid if the reference anemometer is mounted with ± 25% of the planned wind turbine hub height. Since the reference anemometer for this calibration is 130 meters, if this test were specifically for a power curve test, this calibration test would be valid for hub heights in the height range 104 m and 173 m.

In case there is major service on the device (software update, speaker/antenna changes, etc.) the test should be repeated before starting a measurement campaign.

9. REFERENCES

[1] IEC 61400-12-1, First edition 2005-12, Wind turbines - part 12-1: Power performance measurements of electricity producing wind turbines. Here focus on the annex F, G and Describing anemometer classification, mounting of sensors.

[2] IEC 61400-12-1, Ed.2, 2017-03, Wind turbines - part 12-1: Power performance measurements of electricity producing wind turbines. Here focus on the annex L.

[3] IEA Wind, First Edition, January 2013, 15. Ground-based vertically-profiling remote sensing for wind resource assessment.

[4] MEASNET, “Evaluation of Site-Specific Wind Conditions”, Version 1, November 2009.

[5] MEASNET, “Cup anemometer calibration procedure”, Version 1, September 1997.

[6] ACCUWIND - Classification of Five Cup Anemometers According to IEC 61400-12-1, T.F. Pedersen, J.-A. Dahlberg, Peter Busche, Risø-R-1556(EN), May 2006/ Thies ClimaAdvanced Anemometer data sheet.

[7] Google Earth.

[8] Shuttle Radar Topography Mission (SRTM) http://srtm.csi.cgiar.org/.

10. APPENDIX

10.1 Description of the test equipment

Tab. 10.1: Table of test equipment.

Sensor	Type	Make	Installation Date	Dismantling Date	Range	Resolution	Accuracy	Measuring Height	Calibration
Wind speed I, v1	Cup anemometer Serial No: 12166019	Thies Clima	2018-05-31	Still mounted	0.3 – 75 m/s	0.05 m/s	1%	130.0m	See Sec 10.2
Wind speed II, v2	Cup anemometer Serial No: 07176835	Thies Clima	2018-05-31	Still mounted	0.3 – 75 m/s	0.05 m/s	1%	125.0m	See Sec 10.2
Wind speed III, v3	Cup anemometer Serial No: 0161808	R.M.Young	2018-05-31	Still mounted	0 – 100 m/s	0.05 m/s	1%	122.0m	-
Wind speed IV, v4	Cup anemometer Serial No: 01180032	Thies Clima	2018-05-31	Still mounted	0.3 – 75 m/s	0.05 m/s	1%	94.0m	See Sec 10.2
Wind speed V, v5	Cup anemometer Serial No: 03176369	Thies Clima	2018-05-31	Still mounted	0.3 – 75 m/s	0.05 m/s	1%	58.0m	See Sec 10.2
Wind direction I, dir1	Wind vane Serial No: 06190414	Thies Clima	2019-08-02	Still mounted	0 – 360°	0.35°	±0.75 %	125.0m	See Sec 10.3
Wind direction II, dir2	Wind vane Serial No: 06190413	Thies Clima	2019-08-02	Still mounted	0 – 360°	0.35°	±0.75 %	122.0m	See Calibration certificate in 10.3
Wind direction III, dir3	Wind vane Serial No: 06190412	Thies Clima	2019-08-02	Still mounted	0 – 360°	0.35°	±0.75 %	94.0m	See Sec 10.3
Wind direction III, dir4	Wind vane Serial No: 06190411	Thies Clima	2019-08-02	Still mounted	0 – 360°	0.35°	±0.75 %	58.0m	See Sec 10.3

Air temperature T1	Serial No: 183591	Galltec/Mela KPC1.S/6-ME	2018-05-31	Still mounted	-35 °C...+70° C	analogue	±0.2°K	121.0 m	See Sec 10.4
Relative Humidity H1	Serial No: 183591	Galltec/Mela KPC1.S/6-ME	2018-05-31	Still mounted	0...100 %	analogue	± % for range 5…95 % at 10…40 °C	121.0 m	See Sec 10.4
Air pressure P1	Serial No: N1720456	Vaisala PTB110	2018-05-31	Still mounted	610 – 1100 mbar	±0.03 hPA	±0.15 hPa	121.0 m	See Sec 10.4
Air temperature T2	Serial No: 176894	Galltec/Mela KPC1.S/6-ME	2018-05-31	Still mounted	-35 °C ...+70°C	analogue	±0.2°K	10.0 m	See Sec 10.4
Relative Humidity H2	Serial No: 176894	Galltec/Mela KPC1.S/6-ME	2018-05-31	Still mounted	0...100%	analogue	± % for range 5…95 % at 10…40 °C	10.0 m	See Sec 10.4
Air pressure P2	Serial No: N1720454	Vaisala PTB110	2018-05-31	Still mounted	610 – 1100 mbar	±0.03 hPA	±0.15 hPa	10.0 m	See Sec 10.4
Data acquisition system	Data logger Serial No.: 2438	CR1000X	2018-06-12	Still mounted	-	-	-	-	See Sec 10.5

10.2 Anemometer calibration protocols

10.2.1 Calibration protocol v_1

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DAkkS Deutsche Akkreditierungsstelle D-K-15140-01-00

1710103
D-K-15140-01-00
01/2017

Calibration certificate
Kalibrierschein

Calibration mark
Kalibrierzeichen

Object *Gegenstand*	Cup Anemometer
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3351.00.000
Serial number *Fabrikat/Serien-Nr.*	12166019
Customer *Auftraggeber*	UL International GmbH - DEWI D-26382 Wilhelmshaven
Order No. *Auftragsnummer*	3710001689
Project No. *Projektnummer*	VT161193
Number of pages *Anzahl der Seiten*	4
Date of Calibration *Datum der Kalibrierung*	02.01.2017

This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DAkkS is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.
The user is obliged to have the object recalibrated at appropriate intervals.
Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
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Date *Datum*	Head of the calibration laboratory *Leiter des Kalibrierlaboratoriums*	Person in charge *Bearbeiter*
02.01.2017	Dipl. Phys. Dieter Westermann	Dipl.-Ing. (FH) Catharina Herold

Calibration object *Kalibriergegenstand*	Cup Anemometer
Calibration procedure *Kalibrierverfahren*	• Deutsche WindGuard Wind Tunnel Services: QM-KL-AK-VA Based on following standards: • MEASNET: Anemometer calibration procedure • IEC 61400-12-1: Power performance measurements of electricity producing wind turbines • IEC 61400-12-2: Power performance of electricity producing wind turbines based on nacelle anemometry • ISO 3966: Measurement of fluid in closed conduits • ISO 16622: Meteorology - Sonic anemometers/thermometers
Place of calibration *Ort der Kalibrierung*	Windtunnel of Deutsche WindGuard WindTunnel Services GmbH, Varel

Test conditions *Messbedingungen*

wind tunnel area	10000 cm²
anemometer frontal area	230 cm²
diameter of mounting pipe	34 mm
blockage ratio [1]	0.023 [-]
software version	7.64

[1] Due to the special construction of the test section no blockage correction is necessary.

Ambient conditions *Umgebungsbedingungen*

air temperature	18.2 °C ± 0.1 °C
air pressure	1018.5 hPa ± 0.3 hPa
relative air humidity	38.4 % ± 2.0 %

Measurement uncertainty *Messunsicherheit*

The expanded uncertainty assigned to the measurement results is obtained by multiplying the standard uncertainty by the coverage factor k = 2. It has been determined in accordance with DAkkS-DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%.
The reference flow speed measurement is traceable to the German NMI (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a PTB owned and calibrated Laser Doppler Anemometer (Standard Uncertainty 0.2 %, k=2)

Additional remarks *Zusätzliche Anmerkungen*

-

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Seite

1710103
D-K-15140-01-00
01/2017

Calibration result
Kalibrierergebnis

Sensor out	Tunnel speed	Uncertainty (k=2)
Hz	m/s	m/s
82.560	4.018	0.050
123.087	5.913	0.051
166.893	7.915	0.051
211.582	9.950	0.051
254.875	11.962	0.052
297.675	13.901	0.052
339.446	15.858	0.052
318.630	14.876	0.053
276.778	12.964	0.052
231.644	10.915	0.051
188.625	8.928	0.051
145.988	6.996	0.050
103.170	5.002	0.050

File: 1710103

Statistical analysis

Slope	0.04591 (m/s)/(Hz) ±0.00007 (m/s)/(Hz)
Offset	0.2591 m/s ±0.015 m/s
Standard error (Y)	0.015 m/s
Correlation coefficient	0.999988

Remarks
The calibrated sensor complies with the demanded linearity of MEASNET

Deutsche WindGuard - Wind Tunnel Services GmbH - measnet

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1710103
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01/2017

Graphical representation of the result
Grafische Darstellung des Ergebnisses

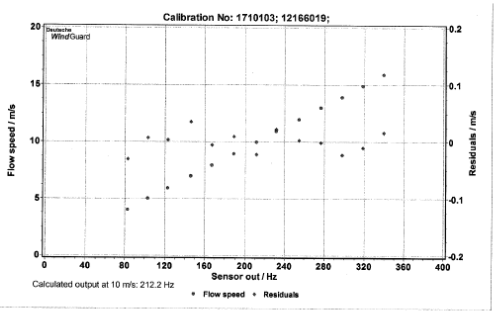
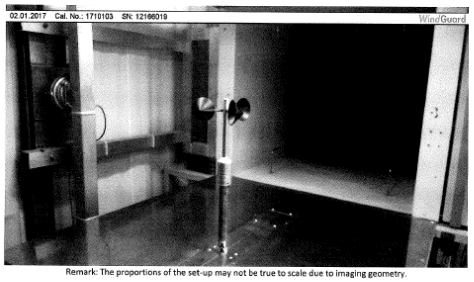


Photo of the measurement setup
Foto des Messaufbaus



Remark: The proportions of the set-up may not be true to scale due to imaging geometry.

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10.2.2 Calibration protocol v_2

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Deutschen Kalibrierdienst

1713081
D-K-15140-01-00
07/2017

Calibration certificate
Kalibrierschein

Calibration mark
Kalibrierzeichen

Object *Gegenstand*	Cup Anemometer
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3351.00.000
Serial number *Fabrikat/Serien-Nr.*	07176835
Customer *Auftraggeber*	UL International GmbH - DEWI D-26382 Wilhelmshaven
Order No. *Auftragsnummer*	3710002609
Project No. *Projektnummer*	VT170756
Number of pages *Anzahl der Seiten*	4
Date of Calibration *Datum der Kalibrierung*	28.07.2017

This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
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Date *Datum*	Head of the calibration laboratory *Leiter des Kalibrierlaboratoriums*	Person in charge *Bearbeiter*
28.07.2017	Dipl. Phys. Dieter Westermann	Alina Roß, B. Eng.

Calibration object *Kalibriergegenstand*	Cup Anemometer
Calibration procedure *Kalibrierverfahren*	• Deutsche WindGuard Wind Tunnel Services: QM-KL-AK-VA Based on following standards: • MEASNET: Anemometer calibration procedure • IEC 61400-12-1: Power performance measurements of electricity producing wind turbines • IEC 61400-12-2: Power performance of electricity producing wind turbines based on nacelle anemometry • ISO 3966: Measurement of fluid in closed conduits • ISO 16622: Meteorology - Sonic anemometers/thermometers
Place of calibration *Ort der Kalibrierung*	Windtunnel of Deutsche WindGuard WindTunnel Services GmbH, Varel
Test conditions *Messbedingungen*	wind tunnel area: 10000 cm² anemometer frontal area: 230 cm² diameter of mounting pipe: 34 mm blockage ratio [1]: 0.023 [-] software version: 7.7 [1] Due to the special construction of the test section no blockage correction is necessary.
Ambient conditions *Umgebungsbedingungen*	air temperature: 25.0 °C ± 0.1 °C air pressure: 1007.3 hPa ± 0.3 hPa relative air humidity: 51.7 % ± 2.0 %
Measurement uncertainty *Messunsicherheit*	The expanded uncertainty assigned to the measurement results is obtained by multiplying the standard uncertainty by the coverage factor k=2. It has been determined in accordance with DAkkS-DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%. The reference flow speed measurement is traceable to the German NMI (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a PTB owned and calibrated Laser Doppler Anemometer (Standard Uncertainty 0.2 %, k=2)
Additional remarks *Zusätzliche Anmerkungen*	-

Calibration result
Kalibrierergebnis

Sensor	Tunnel Speed	Uncertainty
Hz	m/s	m/s
81.874	3.971	0.050
123.184	5.897	0.050
166.589	7.907	0.051
210.873	9.935	0.052
254.221	11.943	0.052
297.036	13.877	0.052
339.494	15.863	0.053
317.145	14.849	0.052
275.321	12.940	0.052
231.793	10.902	0.052
187.688	8.904	0.051
145.484	6.956	0.051
101.578	4.916	0.050

File: 1713081

Statistical analysis

Slope	0.04607 (m/s)/(Hz) ±0.00007 (m/s)/(Hz)
Offset	0.2298 m/s ±0.016 m/s
Standard error (Y)	0.016 m/s
Correlation coefficient	0.999987

Remarks

The calibrated sensor complies with the demanded linearity of MEASNET

Graphical representation of the result
Grafische Darstellung des Ergebnisses

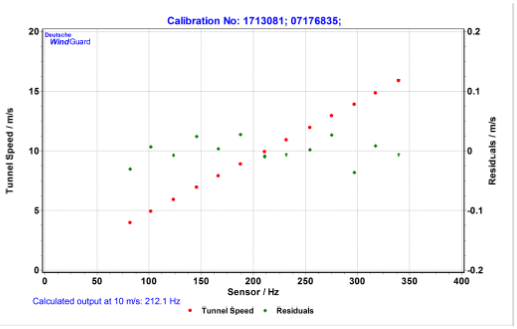
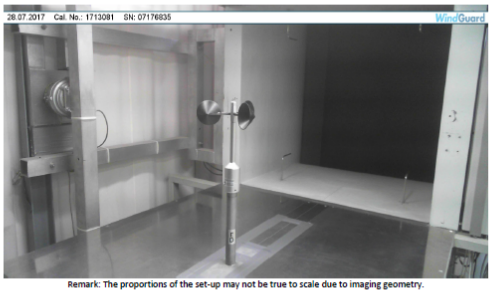


Photo of the measurement setup
Foto des Messaufbaus



Remark: The proportions of the set-up may not be true to scale due to imaging geometry.

10.2.3 Calibration protocol v_4

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Deutschen Kalibrierdienst DKD

1810507
D-K-15140-01-00
02/2018

Calibration certificate
Kalibrierschein

Calibration mark
Kalibrierzeichen

Object *Gegenstand*	Cup Anemometer
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3351.00.000
Serial number *Fabrikat/Serien-Nr.*	01180032
Customer *Auftraggeber*	UL International GmbH - DEWI D-26382 Wilhelmshaven
Order No. *Auftragsnummer*	3710003234
Project No. *Projektnummer*	VT180142
Number of pages *Anzahl der Seiten*	4
Date of Calibration *Datum der Kalibrierung*	01.02.2018

This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DAkkS is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates. The user is obliged to have the object recalibrated at appropriate intervals.
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Date *Datum*	Head of the calibration laboratory *Leiter des Kalibrierlaboratoriums*	Person in charge *Bearbeiter*
01.02.2018	Dipl. Phys. Dieter Westermann	Techniker Bendix Schütz

Calibration object *Kalibriergegenstand*	Cup Anemometer
Calibration procedure *Kalibrierverfahren*	• Deutsche WindGuard Wind Tunnel Services: VA Anemometerkalibrierung Based on following standards: • MEASNET ANEMOMETER CALIBRATION PROCEDURE Version 2 / 2009 • IEC 61400-12-1:2017 Power performance measurements of electricity producing wind turbines • IEC 61400-12-2:2013 Power performance of electricity producing wind turbines based on nacelle anemometry • ISO 3966:2008 Measurement of fluid in closed conduits • ISO 16622:2002 Meteorology - Sonic anemometers/thermometers
Place of calibration *Ort der Kalibrierung*	Wind tunnel of Deutsche WindGuard WindTunnel Services GmbH, Varel
Test conditions *Messbedingungen*	wind tunnel area 10000 cm² anemometer frontal area 230 cm² diameter of mounting pipe 34 mm EN 10217 blockage ratio [1] 0.023 [-] software version 7.7 [1] Due to the special construction of the test section no blockage correction is necessary.
Ambient conditions *Umgebungsbedingungen*	air temperature 21.5 °C ± 0.1 °C air pressure 995.7 hPa ± 0.3 hPa relative air humidity 36.7 % ± 2.0 %
Measurement uncertainty *Messunsicherheit*	The expanded uncertainty assigned to the measurement results is obtained by multiplying the standard uncertainty by the coverage factor k=2. It has been determined in accordance with DAkkS-DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%. The reference flow speed measurement is traceable to the German NMI (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a PTB owned and calibrated Laser Doppler Anemometer (Standard Uncertainty 0.2 %, k=2)
Additional remarks *Zusätzliche Anmerkungen*	-

Calibration result
Kalibrierergebnis

Sensor Hz	Tunnel Speed m/s	Uncertainty m/s
81.129	3.960	0.050
123.572	5.890	0.051
165.682	7.880	0.051
209.967	9.899	0.051
253.347	11.918	0.052
295.364	13.835	0.051
339.072	15.809	0.052
316.483	14.806	0.052
275.448	12.888	0.052
230.849	10.878	0.052
187.361	8.868	0.051
145.668	6.934	0.051
101.652	4.916	0.050

File: 1810507

Statistical analysis	Slope	0.04602 (m/s)/(Hz) ±0.00007 (m/s)/(Hz)
	Offset	0.2344 m/s ±0.015 m/s
	Standard error (Y)	0.015 m/s
	Correlation coefficient	0.99999
Remarks	The calibrated sensor complies with the demanded linearity of MEASNET	

Deutsche WindGuard Wind Tunnel Services GmbH measnet

Graphical representation of the result
Grafische Darstellung des Ergebnisses

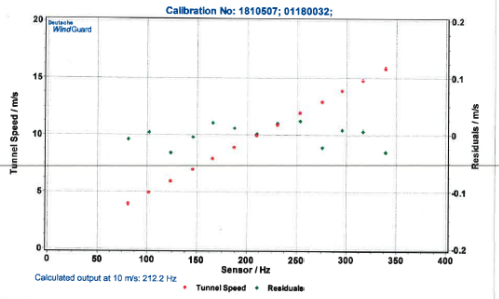
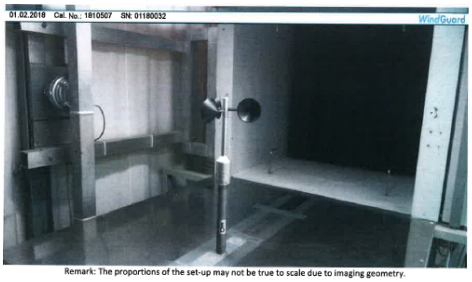


Photo of the measurement setup
Foto des Messaufbaus



Remark: The proportions of the set-up may not be true to scale due to imaging geometry.

10.2.4 Calibration protocol v_5

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DAkkS Deutsche Akkreditierungsstelle D-K-15140-01-00

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Calibration certificate
Kalibrierschein

Calibration mark
Kalibrierzeichen

Object *Gegenstand*	Cup Anemometer
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3351.00.000
Serial number *Fabrikat/Serien-Nr.*	03176369
Customer *Auftraggeber*	UL International GmbH - DEWI D-26382 Wilhelmshaven
Order No. *Auftragsnummer*	88371002454
Project No. *Projektnummer*	VT170352
Number of pages *Anzahl der Seiten*	4
Date of Calibration *Datum der Kalibrierung*	30.03.2017

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Date *Datum*	Head of the calibration laboratory *Leiter des Kalibrierlaboratoriums*	Person in charge *Bearbeiter*
30.03.2017	Dipl. Phys. Dieter Westermann	Alina Roß, B. Eng.

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Calibration object *Kalibriergegenstand*: Cup Anemometer

Calibration procedure *Kalibrierverfahren*:
- Deutsche WindGuard Wind Tunnel Services: QM-KL-AK-VA

Based on following standards:
- MEASNET: Anemometer calibration procedure
- IEC 61400-12-1: Power performance measurements of electricity producing wind turbines
- IEC 61400-12-2: Power performance of electricity producing wind turbines based on nacelle anemometry
- ISO 3966: Measurement of fluid in closed conduits
- ISO 16622: Meteorology - Sonic anemometers/thermometers

Place of calibration *Ort der Kalibrierung*: Windtunnel of Deutsche WindGuard WindTunnel Services GmbH, Varel

Test conditions *Messbedingungen*

wind tunnel area	10000 cm²
anemometer frontal area	230 cm²
diameter of mounting pipe	34 mm
blockage ratio [1]	0.023 [-]
software version	7.64

[1] Due to the special construction of the test section no blockage correction is necessary.

Ambient conditions *Umgebungsbedingungen*

air temperature	23.5 °C ± 0.1 °C
air pressure	1021.3 hPa ± 0.3 hPa
relative air humidity	37.9 % ± 2.0 %

Measurement uncertainty *Messunsicherheit*: The expanded uncertainty assigned to the measurement results is obtained by multiplying the standard uncertainty by the coverage factor k = 2. It has been determined in accordance with DAkkS-DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%.
The reference flow speed measurement is traceable to the German NMI (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a PTB owned and calibrated Laser Doppler Anemometer (Standard Uncertainty 0.2 %, k=2)

Additional remarks *Zusätzliche Anmerkungen*: -

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Calibration result
Kalibrierergebnis

Sensor output Hz	Tunnel speed m/s	Uncertainty (k=2) m/s
82.207	3.996	0.050
123.522	5.911	0.050
166.688	7.909	0.051
210.496	9.921	0.051
254.161	11.955	0.052
296.054	13.877	0.052
339.766	15.882	0.053
318.287	14.860	0.053
275.810	12.953	0.051
231.348	10.921	0.052
187.419	8.888	0.051
145.107	6.947	0.051
102.450	4.951	0.050

File: 1711469

Statistical analysis

Slope	0.04607 (m/s)/(Hz) ±0.00007 (m/s)/(Hz)
Offset	0.2339 m/s ±0.016 m/s
Standard error (Y)	0.016 m/s
Correlation coefficient	0.999987

Remarks The calibrated sensor complies with the demanded linearity of MEASNET

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Graphical representation of the result
Grafische Darstellung des Ergebnisses

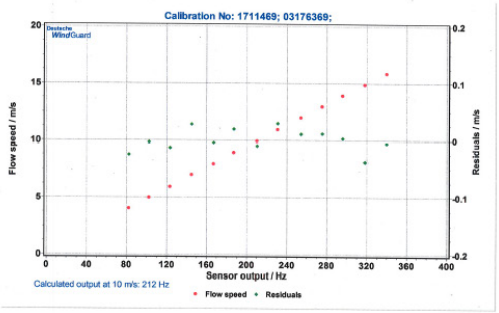

Photo of the measurement setup
Foto des Messaufbaus

Remark: The proportions of the set-up may not be true to scale due to imaging geometry.

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10.3 Wind vane calibration protocol

10.3.1 Calibration protocol dir_1

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DAkkS Deutsche Akkreditierungsstelle D-K-15140-01-00

Calibration certificate *Kalibrierschein*	Calibration mark *Kalibrierzeichen*
	1922036
	D-K-15140-01-00
	06/2019

Object *Gegenstand*	Wind Vane
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3151.00.212
Serial number *Fabrikat/Serien-Nr.*	06190414
Customer *Auftraggeber*	UL International GmbH - DEWI D-26382 Wilhelmshaven
Order No. *Auftragsnummer*	3710004959
Project No. *Projektnummer*	VT190539
Number of pages *Anzahl der Seiten*	6
Date of Calibration *Datum der Kalibrierung*	20.06.2019

This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
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The user is obliged to have the object recalibrated at appropriate intervals.
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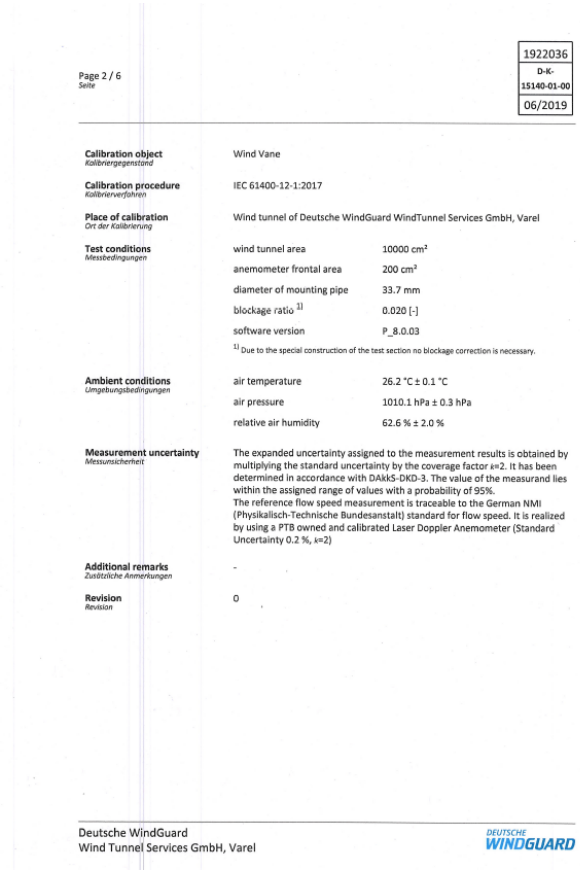
Date *Datum*	Head of the calibration laboratory *Leiter des Kalibrierlaboratoriums*	Person in charge *Bearbeiter*
20.06.2019	Dipl. Phys. Dieter Westermann	Kai Schuster, B. Eng.



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Calibration object *Kalibriergegenstand*	Wind Vane
Calibration procedure *Kalibrierverfahren*	IEC 61400-12-1:2017
Place of calibration *Ort der Kalibrierung*	Wind tunnel of Deutsche WindGuard WindTunnel Services GmbH, Varel
Test conditions *Messbedingungen*	wind tunnel area 10000 cm² anemometer frontal area 200 cm² diameter of mounting pipe 33.7 mm blockage ratio [1] 0.020 [-] software version P_8.0.03
Ambient conditions *Umgebungsbedingungen*	air temperature 26.2 °C ± 0.1 °C air pressure 1010.1 hPa ± 0.3 hPa relative air humidity 62.6 % ± 2.0 %
Measurement uncertainty *Messunsicherheit*	The expanded uncertainty assigned to the measurement results is obtained by multiplying the standard uncertainty by the coverage factor k=2. It has been determined in accordance with DAkkS-DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%. The reference flow speed measurement is traceable to the German NMI (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a PTB owned and calibrated Laser Doppler Anemometer (Standard Uncertainty 0.2 %, k=2)
Additional remarks *Zusätzliche Anmerkungen*	-
Revision *Revision*	0

[1] Due to the special construction of the test section no blockage correction is necessary.

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Calibration result (1/3)
Kalibrierergebnis (1/3)

Reference Air velocity	Reference Unc	Reference Yaw angle	Reference Unc	Test item Source	Test item Wiper	Test item Ratio
m/s	m/s	deg	deg	V	V	-
8.00	0.05	5.01	0.80	8.000	0.129	0.0162
7.99	0.05	10.02	0.80	8.000	0.242	0.0302
8.00	0.05	15.00	0.80	8.000	0.353	0.0441
8.00	0.05	19.95	0.80	8.000	0.464	0.0580
7.99	0.05	24.61	0.80	8.000	0.567	0.0709
8.00	0.05	30.04	0.80	8.000	0.689	0.0861
7.99	0.05	35.00	0.80	8.000	0.798	0.0998
8.00	0.05	39.98	0.80	8.000	0.910	0.1137
8.00	0.05	45.06	0.80	8.000	1.025	0.1282
8.00	0.05	50.06	0.80	8.000	1.138	0.1423
7.99	0.05	55.01	0.80	8.000	1.249	0.1561
7.99	0.05	60.10	0.80	8.000	1.364	0.1704
8.00	0.05	65.17	0.80	8.000	1.476	0.1845
7.99	0.05	70.09	0.80	8.000	1.585	0.1981
7.99	0.05	75.03	0.80	8.000	1.696	0.2120
7.99	0.05	79.99	0.80	8.000	1.807	0.2258
7.99	0.05	84.98	0.80	8.000	1.917	0.2397
7.99	0.05	90.02	0.80	8.000	2.029	0.2537
7.99	0.05	95.01	0.80	8.000	2.141	0.2676
8.00	0.05	100.02	0.80	8.000	2.253	0.2816
8.00	0.05	105.00	0.80	8.000	2.363	0.2953
7.99	0.05	109.93	0.80	8.000	2.472	0.3090
7.99	0.05	114.95	0.80	8.000	2.584	0.3230
7.99	0.05	119.96	0.80	8.000	2.695	0.3369
7.99	0.05	124.96	0.80	8.001	2.806	0.3508
7.99	0.05	129.96	0.80	8.000	2.918	0.3647
7.99	0.05	134.98	0.80	8.000	3.029	0.3787
8.00	0.05	140.00	0.80	8.000	3.140	0.3925
8.00	0.05	145.01	0.80	8.000	3.253	0.4066
7.99	0.05	149.91	0.80	8.000	3.361	0.4201
7.99	0.05	154.97	0.80	8.000	3.472	0.4340

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Calibration result (2/3)
Kalibrierergebnis (2/3)

Reference Air velocity	Reference Unc	Reference Yaw angle	Reference Unc	Test item Source	Test item Wiper	Test item Ratio
m/s	m/s	deg	deg	V	V	-
8.00	0.05	160.02	0.80	8.000	3.583	0.4479
8.00	0.05	164.97	0.80	8.000	3.693	0.4617
7.99	0.05	170.00	0.80	8.000	3.805	0.4755
7.99	0.05	174.96	0.80	8.000	3.915	0.4894
8.00	0.05	179.96	0.80	8.000	4.028	0.5035
7.99	0.05	185.01	0.80	8.000	4.140	0.5174
7.99	0.05	190.00	0.80	8.000	4.252	0.5315
8.00	0.05	195.04	0.80	8.000	4.365	0.5456
7.99	0.05	200.04	0.80	8.000	4.475	0.5594
7.99	0.05	204.94	0.80	8.000	4.587	0.5734
7.99	0.05	210.00	0.80	8.000	4.700	0.5874
7.99	0.05	215.06	0.80	8.000	4.813	0.6016
8.00	0.05	220.03	0.80	8.000	4.923	0.6153
7.99	0.05	225.04	0.80	8.000	5.035	0.6293
7.99	0.05	230.05	0.80	8.000	5.146	0.6432
7.99	0.05	235.03	0.80	8.000	5.258	0.6573
7.99	0.05	239.96	0.80	8.000	5.369	0.6711
8.00	0.05	245.00	0.80	8.000	5.480	0.6850
7.99	0.05	250.04	0.80	8.000	5.590	0.6987
7.99	0.05	255.01	0.80	8.000	5.702	0.7127
8.00	0.05	260.03	0.80	8.000	5.813	0.7266
7.99	0.05	265.02	0.80	8.000	5.924	0.7405
8.00	0.05	270.07	0.80	8.000	6.037	0.7546
7.99	0.05	275.05	0.80	8.000	6.146	0.7682
7.99	0.05	279.99	0.80	8.000	6.255	0.7818
7.99	0.05	285.05	0.80	8.000	6.368	0.7959
8.00	0.05	290.01	0.80	8.000	6.474	0.8092
8.00	0.05	295.02	0.80	8.000	6.577	0.8221
8.00	0.05	300.04	0.80	8.000	6.690	0.8362
8.00	0.05	304.95	0.80	8.000	6.800	0.8499
8.00	0.05	309.98	0.80	8.000	6.912	0.8640

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Calibration result (3/3)
Kalibrierergebnis (3/3)

Reference Air velocity	Reference Unc	Reference Yaw angle	Reference Unc	Test item Source	Test item Wiper	Test item Ratio
m/s	m/s	deg	deg	V	V	-
8.00	0.05	315.02	0.80	8.000	7.025	0.8780
8.00	0.05	319.98	0.80	8.000	7.136	0.8920
7.99	0.05	324.94	0.80	8.000	7.246	0.9057
8.00	0.05	329.95	0.80	8.000	7.358	0.9198
8.00	0.05	335.01	0.80	8.000	7.471	0.9339
8.00	0.05	339.91	0.80	8.000	7.580	0.9475
8.00	0.05	344.99	0.80	8.000	7.694	0.9617
7.99	0.05	350.03	0.80	8.000	7.808	0.9759
8.00	0.05	355.00	0.80	8.000	7.917	0.9895

Statistical analysis

Slope	359.758076 deg/-
Offset	-1.1566 deg

Graphical representation of the result
Grafische Darstellung des Ergebnisses

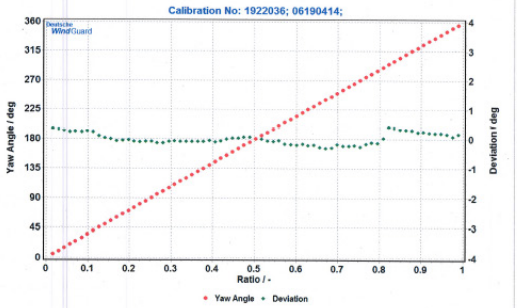
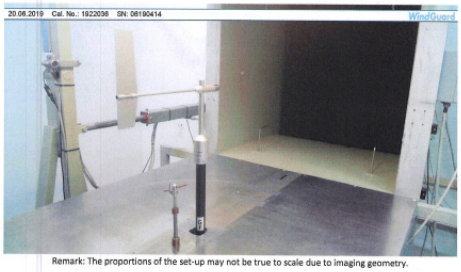


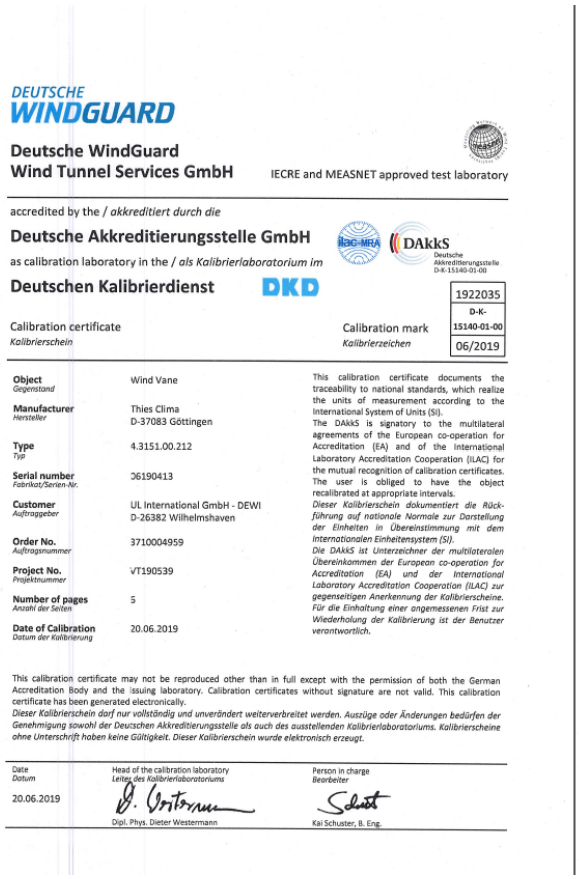
Photo of the measurement setup
Foto des Messaufbaus



Remark: The proportions of the set-up may not be true to scale due to imaging geometry.

- End of document / Ende des Dokuments -

10.3.2 Calibration protocol dir_2



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Deutschen Kalibrierdienst DKD

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15140-01-00
06/2019

Calibration certificate
Kalibrierschein

Calibration mark
Kalibrierzeichen

Object *Gegenstand*	Wind Vane
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3151.00.212
Serial number *Fabrikat/Serien-Nr.*	06190413
Customer *Auftraggeber*	UL International GmbH - DEWI D-26382 Wilhelmshaven
Order No. *Auftragsnummer*	3710004959
Project No. *Projektnummer*	VT190539
Number of pages *Anzahl der Seiten*	5
Date of Calibration *Datum der Kalibrierung*	20.06.2019

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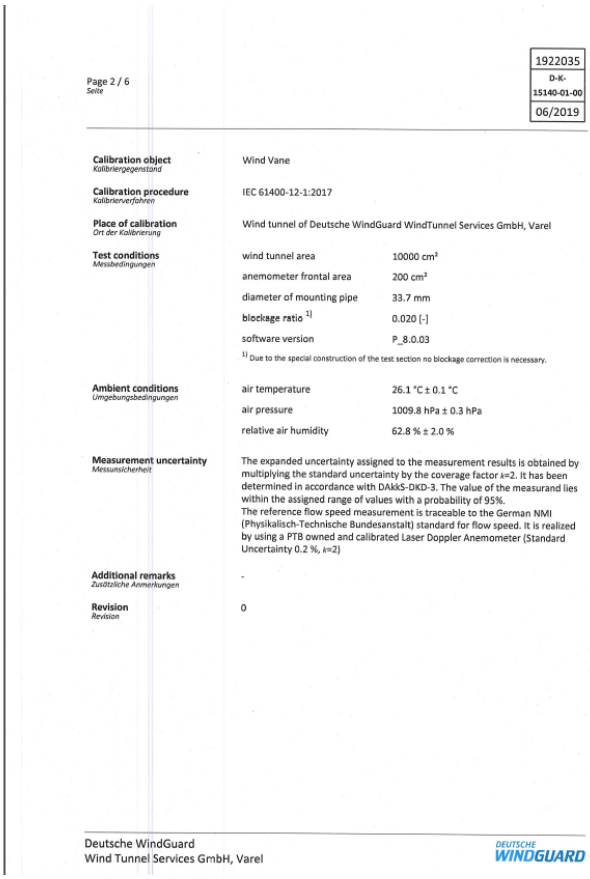
Date *Datum*	Head of the calibration laboratory *Leiter des Kalibrierlaboratoriums*	Person in charge *Bearbeiter*
20.06.2019	Dipl. Phys. Dieter Westermann	Kai Schuster, B. Eng.



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Calibration object *Kalibriergegenstand*	Wind Vane
Calibration procedure *Kalibrierverfahren*	IEC 61400-12-1:2017
Place of calibration *Ort der Kalibrierung*	Wind tunnel of Deutsche WindGuard WindTunnel Services GmbH, Varel
Test conditions *Messbedingungen*	wind tunnel area 10000 cm²
	anemometer frontal area 200 cm²
	diameter of mounting pipe 33.7 mm
	blockage ratio [1] 0.020 [-]
	software version P_8.0.03
	[1] Due to the special construction of the test section no blockage correction is necessary.
Ambient conditions *Umgebungsbedingungen*	air temperature 26.1 °C ± 0.1 °C
	air pressure 1009.8 hPa ± 0.3 hPa
	relative air humidity 62.8 % ± 2.0 %
Measurement uncertainty *Messunsicherheit*	The expanded uncertainty assigned to the measurement results is obtained by multiplying the standard uncertainty by the coverage factor k=2. It has been determined in accordance with DAkkS-DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%. The reference flow speed measurement is traceable to the German NMI (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a PTB owned and calibrated Laser Doppler Anemometer (Standard Uncertainty 0.2 %, k=2)
Additional remarks *Zusätzliche Anmerkungen*	-
Revision *Revision*	0

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Calibration result (1/3)
Kalibrierergebnis (1/3)

Reference Air velocity	Reference Unc	Reference Yaw angle	Reference Unc	Test item Source	Test item Wiper	Test item Ratio
m/s	m/s	deg	deg	V	V	-
7.90	0.05	5.02	0.80	7.999	0.104	0.0130
7.90	0.05	10.03	0.80	7.999	0.215	0.0268
7.90	0.05	15.03	0.80	7.999	0.327	0.0408
7.90	0.05	19.98	0.80	7.999	0.436	0.0545
7.90	0.05	24.65	0.80	7.999	0.538	0.0672
7.90	0.05	30.02	0.80	7.999	0.657	0.0821
7.90	0.05	34.97	0.80	7.999	0.765	0.0956
7.90	0.05	39.96	0.80	7.999	0.877	0.1096
7.90	0.05	45.08	0.80	8.000	0.993	0.1241
7.91	0.05	50.09	0.80	7.999	1.105	0.1381
7.90	0.05	55.01	0.80	7.999	1.215	0.1519
7.90	0.05	60.03	0.80	7.999	1.326	0.1658
7.90	0.05	65.06	0.80	7.999	1.438	0.1798
7.90	0.05	70.03	0.80	7.999	1.549	0.1936
7.90	0.05	75.02	0.80	7.999	1.659	0.2074
7.90	0.05	80.07	0.80	7.999	1.772	0.2215
7.90	0.05	85.05	0.80	7.999	1.881	0.2352
7.90	0.05	89.96	0.80	7.999	1.991	0.2488
7.90	0.05	94.97	0.80	7.999	2.104	0.2630
7.90	0.05	100.00	0.80	7.999	2.215	0.2769
7.90	0.05	104.98	0.80	8.000	2.325	0.2906
7.90	0.05	109.95	0.80	7.999	2.435	0.3044
7.90	0.05	114.97	0.80	7.999	2.547	0.3184
7.90	0.05	120.00	0.80	7.999	2.658	0.3323
7.90	0.05	125.03	0.80	7.999	2.770	0.3463
7.91	0.05	129.97	0.80	7.999	2.879	0.3599
7.90	0.05	134.98	0.80	8.000	2.990	0.3738
7.90	0.05	139.95	0.80	7.999	3.102	0.3878
7.90	0.05	145.00	0.80	8.000	3.213	0.4017
7.90	0.05	149.97	0.80	7.999	3.323	0.4154
7.90	0.05	154.92	0.80	8.000	3.434	0.4292

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Wind Tunnel Services GmbH, Varel

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Calibration result (2/3)
Kalibrierergebnis (2/3)

Reference Air velocity	Referer ce Unc	Reference Yaw angle	Reference Unc	Test item Source	Test item Wiper	Test item Ratio
m/s	m/s	deg	deg	V	V	-
7.90	0.05	159.96	0.80	7.999	3.545	0.4431
7.90	0.05	164.99	0.80	7.999	3.656	0.4570
7.90	0.05	169.95	0.80	7.999	3.767	0.4710
7.90	0.05	174.98	0.80	7.999	3.880	0.4850
7.90	0.05	180.00	0.80	7.999	3.991	0.4989
7.90	0.05	184.99	0.80	8.000	4.103	0.5129
7.90	0.05	189.97	0.80	7.999	4.213	0.5266
7.90	0.05	195.00	0.80	7.999	4.323	0.5404
7.90	0.05	200.03	0.80	8.000	4.436	0.5545
7.91	0.05	204.96	0.80	7.999	4.545	0.5682
7.90	0.05	209.98	0.80	7.999	4.657	0.5822
7.90	0.05	215.04	0.80	7.999	4.771	0.5964
7.90	0.05	220.04	0.80	8.000	4.882	0.6103
7.90	0.05	224.99	0.80	8.000	4.991	0.6240
7.90	0.05	230.03	0.80	8.000	5.104	0.6380
7.91	0.05	235.02	0.80	7.999	5.216	0.6520
7.90	0.05	239.95	0.80	8.000	5.326	0.6658
7.90	0.05	244.98	0.80	7.999	5.438	0.6799
7.90	0.05	249.97	0.80	8.000	5.548	0.6936
7.91	0.05	255.00	0.80	7.999	5.659	0.7075
7.91	0.05	260.05	0.80	8.000	5.772	0.7216
7.90	0.05	265.01	0.80	8.000	5.884	0.7355
7.90	0.05	270.04	0.80	8.000	5.996	0.7495
7.90	0.05	275.04	0.80	8.000	6.107	0.7634
7.91	0.05	280.04	0.80	8.000	6.218	0.7773
7.90	0.05	285.03	0.80	8.000	6.328	0.7910
7.90	0.05	289.96	0.80	8.000	6.434	0.8043
7.90	0.05	295.02	0.80	8.000	6.541	0.8177
7.90	0.05	300.02	0.80	8.000	6.652	0.8316
7.91	0.05	304.93	0.80	7.999	6.762	0.8454
7.90	0.05	309.93	0.80	8.000	6.875	0.8594

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Calibration result (3/3)
Kalibrierergebnis (3/3)

Reference Air velocity	Reference Unc	Reference Yaw angle	Reference Unc	Test item Source	Test item Wiper	Test item Ratio
m/s	m/s	deg	deg	V	V	-
7.90	0.05	314.97	0.80	7.999	6.987	0.8735
7.90	0.05	319.94	0.80	8.000	7.099	0.8875
7.90	0.05	324.93	0.80	8.000	7.212	0.9016
7.90	0.05	330.01	0.80	8.000	7.325	0.9157
7.91	0.05	335.09	0.80	8.000	7.437	0.9296
7.91	0.05	340.03	0.80	7.999	7.550	0.9438
7.90	0.05	345.03	0.80	7.999	7.662	0.9579
7.90	0.05	350.01	0.80	7.999	7.772	0.9717
7.90	0.05	355.02	0.80	7.999	7.889	0.9862

Statistical analysis

Slope	359.970027 deg/-
Offset	0.3876 deg

Graphical representation of the result
Grafische Darstellung des Ergebnisses

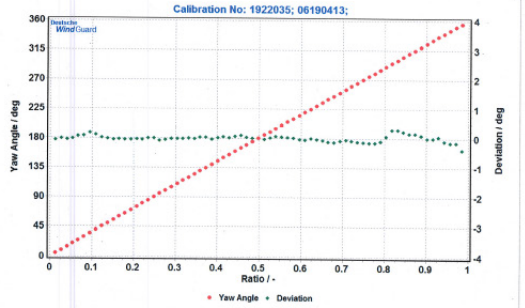
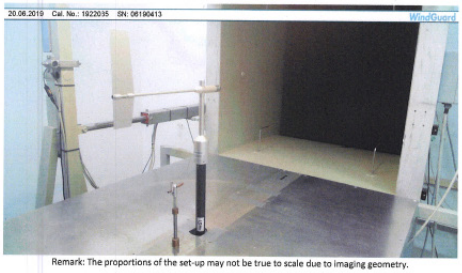


Photo of the measurement setup
Foto des Messaufbaus



Remark: The proportions of the set-up may not be true to scale due to imaging geometry.

- End of document / Ende des Dokuments -

10.3.3 Calibration protocol dir$_3$

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Deutsche Akkreditierungsstelle GmbH

as calibration laboratory in the / *als Kalibrierlaboratorium im*

Deutschen Kalibrierdienst DKD

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Calibration certificate
Kalibrierschein

Calibration mark
Kalibrierzeichen

Object *Gegenstand*	Wind Vane
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3151.00.212
Serial number *Fabrikat/Serien-Nr.*	06190412
Customer *Auftraggeber*	UL International GmbH - DEWI D-26382 Wilhelmshaven
Order No. *Auftragsnummer*	3710004959
Project No. *Projektnummer*	VT190539
Number of pages *Anzahl der Seiten*	6
Date of Calibration *Datum der Kalibrierung*	20.06.2019

This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DAkkS is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.
The user is obliged to have the object recalibrated at appropriate intervals.
Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Die DAkkS ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.

Date *Datum*	Head of the calibration laboratory *Leiter des Kalibrierlaboratoriums*	Person in charge *Bearbeiter*
20.06.2019	Dipl. Phys. Dieter Westermann	Kai Schuster, B. Eng.

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Calibration object *Kalibriergegenstand*	Wind Vane	
Calibration procedure *Kalibrierverfahren*	IEC 61400-12-1:2017	
Place of calibration *Ort der Kalibrierung*	Wind tunnel of Deutsche WindGuard WindTunnel Services GmbH, Varel	
Test conditions *Messbedingungen*	wind tunnel area	10000 cm²
	anemometer frontal area	200 cm²
	diameter of mounting pipe	33.7 mm
	blockage ratio [1]	0.020 [-]
	software version	P_8.0.03
	[1] Due to the special construction of the test section no blockage correction is necessary.	
Ambient conditions *Umgebungsbedingungen*	air temperature	26.0 °C ± 0.1 °C
	air pressure	1009.7 hPa ± 0.3 hPa
	relative air humidity	62.9 % ± 2.0 %
Measurement uncertainty *Messunsicherheit*	The expanded uncertainty assigned to the measurement results is obtained by multiplying the standard uncertainty by the coverage factor k=2. It has been determined in accordance with DAkkS-DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%. The reference flow speed measurement is traceable to the German NMI (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a PTB owned and calibrated Laser Doppler Anemometer (Standard Uncertainty 0.2 %, k=2)	
Additional remarks *Zusätzliche Anmerkungen*	-	
Revision *Revision*	0	

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Calibration result (1/3)
Kalibrierergebnis (1/3)

Reference Air velocity	Reference Unc	Reference Yaw angle	Reference Unc	Test item Source	Test item Wiper	Test item Ratio
m/s	m/s	deg	deg	V	V	-
7.91	0.05	5.02	0.80	8.000	0.097	0.0121
7.90	0.05	10.01	0.80	8.000	0.208	0.0260
7.90	0.05	14.98	0.80	8.000	0.320	0.0400
7.90	0.05	19.96	0.80	8.000	0.431	0.0539
7.90	0.05	24.64	0.80	8.000	0.535	0.0669
7.90	0.05	30.00	0.80	8.000	0.654	0.0817
7.90	0.05	34.97	0.80	8.000	0.763	0.0954
7.91	0.05	39.99	0.80	8.000	0.874	0.1093
7.90	0.05	45.00	0.80	8.000	0.988	0.1235
7.90	0.05	49.98	0.80	8.000	1.101	0.1376
7.90	0.05	55.00	0.80	8.000	1.212	0.1515
7.91	0.05	60.04	0.80	8.000	1.325	0.1657
7.90	0.05	65.02	0.80	8.000	1.436	0.1795
7.90	0.05	70.00	0.80	8.001	1.547	0.1934
7.90	0.05	75.04	0.80	8.001	1.658	0.2072
7.90	0.05	80.00	0.80	8.001	1.769	0.2211
7.90	0.05	84.98	0.80	8.001	1.880	0.2350
7.90	0.05	90.00	0.80	8.001	1.990	0.2487
7.90	0.05	95.00	0.80	8.000	2.103	0.2628
7.90	0.05	100.00	0.80	8.001	2.215	0.2768
7.90	0.05	105.04	0.80	8.001	2.326	0.2908
7.90	0.05	110.08	0.80	8.001	2.437	0.3046
7.90	0.05	115.06	0.80	8.001	2.549	0.3186
7.90	0.05	120.04	0.80	8.000	2.660	0.3324
7.90	0.05	125.00	0.80	8.001	2.770	0.3463
7.90	0.05	130.02	0.80	8.001	2.882	0.3602
7.90	0.05	134.99	0.80	8.001	2.992	0.3739
7.90	0.05	139.98	0.80	8.001	3.103	0.3878
7.90	0.05	144.96	0.80	8.001	3.214	0.4017
7.90	0.05	150.00	0.80	8.000	3.325	0.4156
7.90	0.05	155.02	0.80	8.001	3.438	0.4297

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Calibration result (2/3)
Kalibrierergebnis (2/3)

Reference Air velocity	Reference Unc	Reference Yaw angle	Reference Unc	Test item Source	Test item Wiper	Test item Ratio
m/s	m/s	deg	deg	V	V	-
7.90	0.05	160.00	0.80	8.001	3.549	0.4436
7.90	0.05	164.97	0.80	8.001	3.659	0.4574
7.90	0.05	170.00	0.80	8.001	3.770	0.4712
7.90	0.05	175.02	0.80	8.001	3.883	0.4853
7.90	0.05	179.95	0.80	8.001	3.992	0.4990
7.91	0.05	185.00	0.80	8.001	4.105	0.5130
7.90	0.05	190.01	0.80	8.001	4.216	0.5269
7.90	0.05	195.01	0.80	8.001	4.327	0.5409
7.90	0.05	200.01	0.80	8.001	4.439	0.5549
7.90	0.05	204.98	0.80	8.001	4.551	0.5688
7.90	0.05	210.02	0.80	8.001	4.664	0.5829
7.90	0.05	214.99	0.80	8.001	4.775	0.5968
7.90	0.05	219.99	0.80	8.001	4.887	0.6108
7.90	0.05	225.03	0.80	8.001	5.000	0.6249
7.90	0.05	230.03	0.80	8.001	5.112	0.6390
7.90	0.05	234.97	0.80	8.001	5.223	0.6529
7.90	0.05	239.98	0.80	8.001	5.336	0.6670
7.91	0.05	245.05	0.80	8.001	5.449	0.6811
7.90	0.05	250.05	0.80	8.001	5.559	0.6948
7.90	0.05	254.97	0.80	8.001	5.668	0.7085
7.90	0.05	259.99	0.80	8.001	5.782	0.7227
7.90	0.05	265.04	0.80	8.001	5.895	0.7369
7.90	0.05	269.99	0.80	8.001	6.005	0.7506
7.90	0.05	274.99	0.80	8.001	6.116	0.7644
7.90	0.05	280.03	0.80	8.001	6.229	0.7786
7.90	0.05	285.05	0.80	8.001	6.341	0.7926
7.91	0.05	289.75	0.80	8.001	6.445	0.8056
7.90	0.05	295.01	0.80	8.000	6.553	0.8191
7.90	0.05	299.94	0.80	8.001	6.665	0.8330
7.90	0.05	304.99	0.80	8.001	6.777	0.8471
7.90	0.05	310.05	0.80	8.001	6.890	0.8611

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Calibration result (3/3)
Kalibrierergebnis (3/3)

Reference Air velocity	Reference Unc	Reference Yaw angle	Reference Unc	Test item Source	Test item Wiper	Test item Ratio
m/s	m/s	deg	deg	V	V	-
7.90	0.05	315.03	0.80	8.001	7.002	0.8751
7.90	0.05	319.96	0.80	8.001	7.113	0.8890
7.91	0.05	325.01	0.80	8.001	7.224	0.9030
7.90	0.05	330.02	0.80	8.001	7.335	0.9168
7.90	0.05	334.95	0.80	8.001	7.444	0.9304
7.90	0.05	339.89	0.80	8.001	7.554	0.9442
7.90	0.05	344.96	0.80	8.001	7.667	0.9583
7.90	0.05	350.01	0.80	8.001	7.780	0.9724
7.90	0.05	354.95	0.80	8.001	7.891	0.9862

Statistical analysis

Slope	359.161355 deg/-
Offset	0.6295 deg

Graphical representation of the result
Grafische Darstellung des Ergebnisses

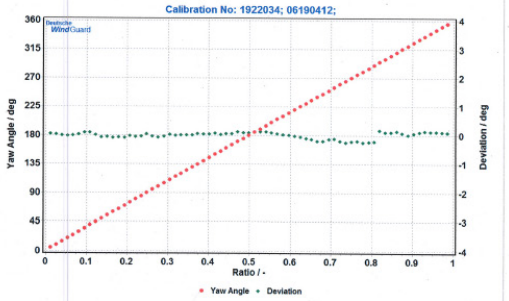

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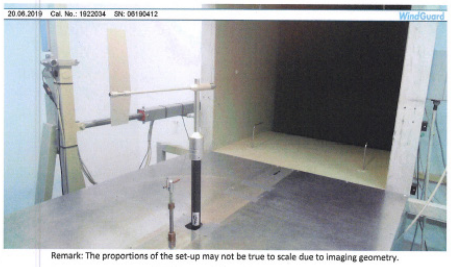
Photo of the measurement setup
Foto des Messaufbaus



Remark: The proportions of the set-up may not be true to scale due to imaging geometry.

- End of document / Ende des Dokuments -

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

10.3.4 Calibration protocol dir$_4$

DEUTSCHE WINDGUARD

Deutsche WindGuard
Wind Tunnel Services GmbH

IECRE and MEASNET approved test laboratory

accredited by the / *akkreditiert durch die*

Deutsche Akkreditierungsstelle GmbH

as calibration laboratory in the / *als Kalibrierlaboratorium im*

Deutschen Kalibrierdienst

DKD

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Calibration certificate
Kalibrierschein

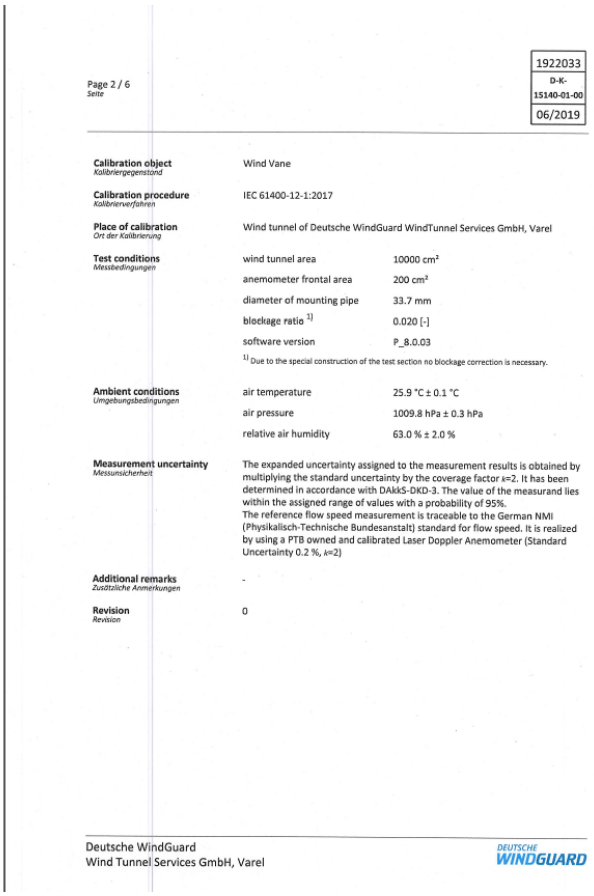
Calibration mark
Kalibrierzeichen

Object *Gegenstand*	Wind Vane
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3151.00.212
Serial number *Fabrikat/Serien-Nr.*	06190411
Customer *Auftraggeber*	UL International GmbH - DEWI D-26382 Wilhelmshaven
Order No. *Auftragsnummer*	3710004959
Project No. *Projektnummer*	VT190539
Number of pages *Anzahl der Seiten*	6
Date of Calibration *Datum der Kalibrierung*	20.06.2019

This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DAkkS is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates. The user is obliged to have the object recalibrated at appropriate intervals.
Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Die DAkkS ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine. Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.

This calibration certificate may not be reproduced other than in full except with the permission of both the German Accreditation Body and the issuing laboratory. Calibration certificates without signature are not valid. This calibration certificate has been generated electronically.
Dieser Kalibrierschein darf nur vollständig und unverändert weiterverbreitet werden. Auszüge oder Änderungen bedürfen der Genehmigung sowohl der Deutschen Akkreditierungsstelle als auch des ausstellenden Kalibrierlaboratoriums. Kalibrierscheine ohne Unterschrift haben keine Gültigkeit. Dieser Kalibrierschein wurde elektronisch erzeugt.

Date *Datum*	Head of the calibration laboratory *Leiter des Kalibrierlaboratoriums*	Person in charge *Bearbeiter*
20.06.2019	Dipl. Phys. Dieter Westermann	Kai Schuster, B. Eng.



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Calibration object *Kalibriergegenstand*	Wind Vane	
Calibration procedure *Kalibrierverfahren*	IEC 61400-12-1:2017	
Place of calibration *Ort der Kalibrierung*	Wind tunnel of Deutsche WindGuard WindTunnel Services GmbH, Varel	
Test conditions *Messbedingungen*	wind tunnel area	10000 cm²
	anemometer frontal area	200 cm²
	diameter of mounting pipe	33.7 mm
	blockage ratio [1]	0.020 [-]
	software version	P_8.0.03
	[1] Due to the special construction of the test section no blockage correction is necessary.	
Ambient conditions *Umgebungsbedingungen*	air temperature	25.9 °C ± 0.1 °C
	air pressure	1009.8 hPa ± 0.3 hPa
	relative air humidity	63.0 % ± 2.0 %
Measurement uncertainty *Messunsicherheit*	The expanded uncertainty assigned to the measurement results is obtained by multiplying the standard uncertainty by the coverage factor k=2. It has been determined in accordance with DAkkS-DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%. The reference flow speed measurement is traceable to the German NMI (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a PTB owned and calibrated Laser Doppler Anemometer (Standard Uncertainty 0.2 %, k=2)	
Additional remarks *Zusätzliche Anmerkungen*	-	
Revision *Revision*	0	

Calibration result (1/3)
Kalibrierergebnis (1/3)

Reference Air velocity	Reference Unc	Reference Yaw angle	Reference Unc	Test item Source	Test item Wiper	Test item Ratio
m/s	m/s	deg	deg	V	V	-
7.90	0.05	5.01	0.80	8.000	0.116	0.0145
7.90	0.05	10.00	0.80	8.000	0.226	0.0283
7.90	0.05	14.99	0.80	8.000	0.338	0.0422
7.90	0.05	19.97	0.80	8.000	0.450	0.0562
7.90	0.05	24.61	0.80	8.000	0.551	0.0689
7.90	0.05	30.03	0.80	8.001	0.672	0.0840
7.90	0.05	35.08	0.80	8.001	0.783	0.0979
7.90	0.05	40.06	0.80	8.001	0.894	0.1118
7.90	0.05	45.12	0.80	8.001	1.008	0.1260
7.90	0.05	50.12	0.80	8.001	1.121	0.1401
7.90	0.05	55.14	0.80	8.001	1.233	0.1541
7.90	0.05	60.13	0.80	8.001	1.344	0.1679
7.90	0.05	65.03	0.80	8.001	1.453	0.1816
7.90	0.05	69.98	0.80	8.001	1.562	0.1952
7.90	0.05	75.02	0.80	8.001	1.674	0.2093
7.90	0.05	80.03	0.80	8.001	1.786	0.2233
7.91	0.05	85.00	0.80	8.001	1.896	0.2370
7.90	0.05	89.94	0.80	8.001	2.007	0.2508
7.90	0.05	94.94	0.80	8.001	2.119	0.2648
7.90	0.05	99.92	0.80	8.001	2.230	0.2787
7.91	0.05	104.94	0.80	8.001	2.339	0.2924
7.90	0.05	109.96	0.80	8.001	2.451	0.3064
7.90	0.05	114.98	0.80	8.001	2.564	0.3205
7.90	0.05	120.02	0.80	8.001	2.675	0.3343
7.90	0.05	124.99	0.80	8.001	2.785	0.3481
7.90	0.05	129.90	0.80	8.001	2.895	0.3618
7.90	0.05	134.95	0.80	8.001	3.006	0.3757
7.90	0.05	139.97	0.80	8.001	3.119	0.3898
7.90	0.05	144.91	0.80	8.001	3.228	0.4035
7.90	0.05	149.91	0.80	8.001	3.340	0.4174
7.90	0.05	154.96	0.80	8.001	3.452	0.4314

Calibration result (2/3)
Kalibrierergebnis (2/3)

Reference Air velocity	Reference Unc	Reference Yaw angle	Reference Unc	Test item Source	Test item Wiper	Test item Ratio
m/s	m/s	deg	deg	V	V	-
7.89	0.05	160.01	0.80	8.001	3.563	0.4454
7.90	0.05	165.00	0.80	8.001	3.675	0.4593
7.90	0.05	170.01	0.80	8.001	3.786	0.4732
7.90	0.05	175.02	0.80	8.001	3.898	0.4872
7.90	0.05	179.99	0.80	8.001	4.010	0.5012
7.90	0.05	185.01	0.80	8.001	4.122	0.5152
7.90	0.05	189.98	0.80	8.001	4.232	0.5290
7.90	0.05	194.95	0.80	8.001	4.343	0.5428
7.90	0.05	199.98	0.80	8.001	4.455	0.5568
7.91	0.05	205.01	0.80	8.001	4.569	0.5710
7.90	0.05	210.05	0.80	8.001	4.682	0.5851
7.90	0.05	215.02	0.80	8.001	4.793	0.5990
7.90	0.05	219.96	0.80	8.001	4.903	0.6128
7.90	0.05	224.98	0.80	8.001	5.015	0.6268
7.91	0.05	230.02	0.80	8.001	5.128	0.6409
7.91	0.05	234.96	0.80	8.001	5.239	0.6548
7.90	0.05	239.94	0.80	8.001	5.350	0.6687
7.90	0.05	245.03	0.80	8.001	5.463	0.6828
7.90	0.05	250.05	0.80	8.001	5.572	0.6964
7.90	0.05	255.00	0.80	8.001	5.682	0.7102
7.90	0.05	259.99	0.80	8.000	5.795	0.7243
7.90	0.05	265.03	0.80	8.000	5.907	0.7384
7.90	0.05	270.01	0.80	8.000	6.019	0.7524
7.90	0.05	274.99	0.80	8.000	6.129	0.7662
7.90	0.05	280.08	0.80	8.000	6.242	0.7803
7.90	0.05	285.13	0.80	8.000	6.356	0.7945
7.90	0.05	290.05	0.80	8.000	6.458	0.8073
7.90	0.05	295.01	0.80	8.000	6.564	0.8206
7.90	0.05	299.96	0.80	8.000	6.676	0.8345
7.90	0.05	304.91	0.80	8.000	6.786	0.8483
7.90	0.05	309.89	0.80	8.000	6.898	0.8623

Calibration result (3/3)
Kalibrierergebnis (3/3)

Reference Air velocity	Reference Unc	Reference Yaw angle	Reference Unc	Test item Source	Test item Wiper	Test item Ratio
m/s	m/s	deg	deg	V	V	-
7.90	0.05	314.95	0.80	8.000	7.012	0.8765
7.90	0.05	319.96	0.80	8.000	7.125	0.8906
7.90	0.05	325.03	0.80	8.000	7.237	0.9046
7.91	0.05	330.08	0.80	8.000	7.349	0.9186
7.90	0.05	335.06	0.80	8.000	7.461	0.9326
7.90	0.05	340.02	0.80	8.000	7.572	0.9465
7.90	0.05	345.00	0.80	8.000	7.684	0.9605
7.90	0.05	350.05	0.80	8.000	7.797	0.9747
7.91	0.05	355.00	0.80	8.000	7.907	0.9884

Statistical analysis

Slope	359.390170 deg/-
Offset	-0.1740 deg

Graphical representation of the result
Grafische Darstellung des Ergebnisses

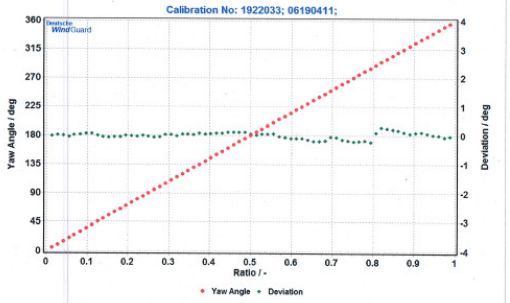
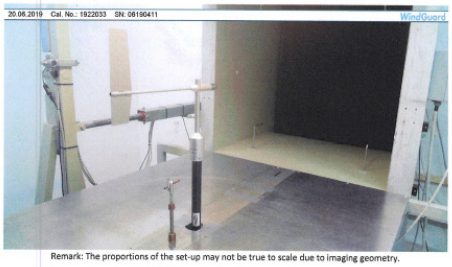


Photo of the measurement setup
Foto des Messaufbaus



Remark: The proportions of the set-up may not be true to scale due to imaging geometry.

- End of document / Ende des Dokuments -

10.4 Air temperature and humidity sensor

10.4.1 Air temperature and humidity sensor 1

Zentrum für Messen und Kalibrieren & ANALYTIK GmbH

akkreditiert durch die / *accredited by the*

Deutsche Akkreditierungsstelle GmbH

als Kalibrierlaboratorium im / *as calibration laboratory in the*

Deutschen Kalibrierdienst DKD

14-0177
D-K-15186-01-00
2017-03

Kalibrierschein / *Calibration certificate* — Zweitschrift — Kalibrierzeichen / *Calibration mark*

Gegenstand / *Object*	**Temperatur-/Feuchtefühler**
Hersteller / *Manufacturer*	**Galltec + mela**
Typ / *Type*	**KPC1.S/6-ME**
Fabrikat/Serien-Nr. / *Serial number*	**176894**
Auftraggeber / *Customer*	**UL International GmbH Ebertstraße 96 26382 Wilhelshaven**
Auftragsnummer / *Order No.*	**37100001895**
Anzahl der Seiten des Kalibrierscheines / *Number of pages of the certificate*	**3**
Datum der Kalibrierung / *Date of calibration*	**03.03.2017**

Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem internationalen Einheitensystem (SI).
Die DAkkS ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.
This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the international System of Units (SI).
The DAkkS is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.
The user is obliged to have the object recalibrated at appropriate intervals.

Dieser Kalibrierschein darf nur vollständig und unverändert weiterverbreitet werden. Auszüge oder Änderungen bedürfen der Genehmigung sowohl der Deutschen Akkreditierungsstelle GmbH als auch des ausstellenden Kalibrierlaboratoriums. Kalibrierscheine ohne Unterschrift haben keine Gültigkeit.
This calibration certificate may not be reproduced other than in full except with the permission of both the Deutsche Akkreditierungsstelle GmbH and the issuing laboratory. Calibration certificates without signature are not valid.

Datum / *Date*	Stellv. Leiter des Kalibrierlaboratoriums / *Deputy Head of the calibration laboratory*	Bearbeiter / *Person in charge*
06.03.2017	Frau Dr. Jehnert	Frau Lange

Kalibrierlaboratorium für Länge, elektrische, mechanische, thermodynamische und analytische Messgrößen
Calibration laboratory for length, electrical, mechanical, thermodynamical and analytical measuring quantities
Ortsteil Wolfen, P-D ChemiePark Bitterfeld-Wolfen, Areal A, Filmstraße Nr.7, 06766 Bitterfeld-Wolfen
Telefon (03494) 69730 • FAX (03494) 697334 • email info@zmk-wolfen.de

DQS-zertifiziert nach DIN EN ISO 9001
Reg.-Nr.: 084774 QM

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Kalibriergegenstand

Temperatur-/Feuchtefühler

Typ:	KPC1.S/6-ME
Hersteller:	Galltec + mela
Serien-Nr.:	176894
Messbereich:	rel. Feuchte: (0...100) % // Temp.: (-30 ... 70) °C
Ausgangsspannung:	(0...1) V
Kalibrierpunkte:	(30/50/70) % bei 20 °C (-10/10/40) °C

Normale

Taupunktspiegel mit Anzeigegerät	Typ:	D-2-XR // HYGRO-M3
	Hersteller:	General Eastern
	Nr.:	GD14/G004
	Kalibrierung:	D-K-15186-01
Platin-Widerstandsthermometer	Typ:	Pt 100
	Ident.-Nr.:	GD14/G045
	Kalibrierung:	D-K-15186-01
DC-Temperaturmessbrücke	Typ:	MKT 50
	Ident.-Nr.:	GD14/G038
	Kalibrierung:	D-K-15186-01
Multifunktionskalibrator:	Typ:	MC 5
	Nr.:	GD14/G034
	Hersteller:	Beamex
	Kalibrierung:	D-K-15186-01

Kalibrierverfahren

Die Kalibrierung erfolgt im direkten Vergleich der Anzeige des Prüflings mit der Temperatur und der relativen Feuchte (Bezugswert), welche aus der Taupunkttemperatur, der Gastemperatur und dem Luftdruck berechnet wurde.

Messbedingungen

Der Prüfling befand sich während der Kalibrierung innerhalb eines thermostatisierten Volumens in der Klimakammer im direkten Feuchtluftstrom. Die Messung wurde erst nach Einstellung stabiler Temperaturen und Feuchtewerte vorgenommen, d.h. wenn die Anzeige des Prüflings und die zur Berechnung der relativen Feuchte (Bezugswert) notwendigen Parameter keine systematischen Änderungen mehr erkennen ließen.
Die in der Tabelle angegebenen Werte sind Mittelwerte aus Mehrfachmessungen
Der Messumformer wurde mit einer Betriebsspannung von 24 V versorgt. Die der relativen Feuchte bzw. Lufttemperatur proportionale Ausgangsspannung (0 V bis 1 V entsprechend 0 % bis 100 % bzw. -30 °C bis 70 °C) wurde mit dem Multifunktionskalibrator gemessen.

Umgebungsbedingungen

Temperatur : (23,0 ± 5,0) °C
rel. Feuchte : (50 ± 20) %

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Messergebnisse

Feuchtemessung

Temperatur des Feucht-luftstromes	relative Feuchte Bezugswert	Ausgangsspannung Messumformer	relative Feuchte Prüfling *	Anzeigekorrektion	Messunsicherheit
in °C	in %	in V	in %	in %	in %
20	27,5	0,27694	27,7	-0,2	0,42
20	49,1	0,48429	48,4	0,7	0,62
20	69,6	0,68988	69,0	0,6	0,92

* die relative Feuchte wurde aus der Ausgangsspannung berechnet

Die relative Feuchte ergibt sich aus der Beziehung:

rel. Feuchte = rel. Feuchte Prüfling + Anzeigekorrektion

Temperaturmessung

Temperatur Normal	Ausgangsspannung Messumformer	Temperatur Prüfling *	Anzeigekorrektion	Messunsicherheit
in °C	in V	in °C	in K	in K
-10,424	0,19474	-10,53	0,11	0,15
9,978	0,39904	9,90	0,08	0,15
20,065	0,50219	20,22	-0,15	0,15
39,935	0,69950	39,95	-0,01	0,15

* die Temperatur wurde aus der Ausgangsspannung berechnet

Die Temperatur ergibt sich aus der Beziehung:

Temperatur = Temperatur Prüfling + Anzeigekorrektion

Messunsicherheit

Angegeben ist die erweiterte Messunsicherheit, die sich aus der Standardmessunsicherheit durch Multiplikation mit dem Erweiterungsfaktor $k = 2$ ergibt. Sie wurde gemäß DAkkS-DKD-3 ermittelt. Der Wert der Messgröße liegt mit einer Wahrscheinlichkeit von annähernd 95% im zugeordneten Werteintervall.

Hinweis

Die Deutsche Akkreditierungsstelle GmbH ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine. Die weiteren Unterzeichner innerhalb und außerhalb Europas sind den Internetseiten von EA (www.european-accreditation.org) und ILAC (www.ilac.org) zu entnehmen.

Die Werte gelten für den Zustand des Kalibriergegenstandes zum Zeitpunkt der Kalibrierung.

10.4.2 Air temperature and humidity sensor 2

Zentrum für Messen und Kalibrieren & ANALYTIK GmbH

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Deutsche Akkreditierungsstelle GmbH

als Kalibrierlaboratorium im / *as calibration laboratory in the*

Deutschen Kalibrierdienst DKD

Kalibrierschein
Calibration certificate

Kalibrierzeichen
Calibration mark

14-1215
D-K-15186-01-00
2017-11

Gegenstand *Object*	**Temperatur-/Feuchtefühler**
Hersteller *Manufacturer*	**Galltec + mela**
Typ *Type*	**KPC1.S/6-ME**
Fabrikat/Serien-Nr. *Serial number*	**183591**
Auftraggeber *Customer*	**UL International GmbH Ebertstraße 96 26382 Wilhelmshaven**
Auftragsnummer *Order No.*	**3710002980**
Anzahl der Seiten des Kalibrierscheines *Number of pages of the certificate*	**3**
Datum der Kalibrierung *Date of calibration*	**24.11.2017**

Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Die DAkkS ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.
This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DAkkS is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.
The user is obliged to have the object recalibrated at appropriate intervals.

Dieser Kalibrierschein darf nur vollständig und unverändert weiterverbreitet werden. Auszüge oder Änderungen bedürfen der Genehmigung sowohl der Deutschen Akkreditierungsstelle GmbH als auch des ausstellenden Kalibrierlaboratoriums. Kalibrierscheine ohne Unterschrift haben keine Gültigkeit.
This calibration certificate may not be reproduced other than in full except with the permission of both the Deutsche Akkreditierungsstelle GmbH and the issuing laboratory. Calibration certificates without signature are not valid.

Datum *Date*	Stellv. Leiter des Kalibrierlaboratoriums *Deputy Head of the calibration laboratory*	Bearbeiter *Person in charge*
27.11.2017	Frau Dr. Jelpert	Frau Lange

Kalibrierlaboratorium für Länge, elektrische, mechanische, thermodynamische und analytische Messgrößen
Calibration laboratory for length, electrical, mechanical, thermodynamical and analytical measuring quantities
Ortsteil Wolfen, P-D ChemiePark Bitterfeld-Wolfen, Areal A, Filmstraße Nr.7, 06766 Bitterfeld-Wolfen
Telefon (03494) 69730 • FAX (03494) 697334 • email info@zmk-wolfen.de

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Reg.-Nr.: 054774 QM

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Kalibriergegenstand

Temperatur-/Feuchtefühler

Typ:	KPC1.S/6-ME
Hersteller:	Galltec + mela
Serien-Nr.:	183591
Messbereich:	rel. Feuchte: (0...100) % // Temp.: (-30 ... 70) °C
Ausgangsspannung:	(0...1) V
Kalibrierpunkte:	(30/50/70) % bei 20 °C (-10/10/40) °C

Normale

Taupunktspiegel mit Anzeigegerät	Typ:	473-SHX
	Hersteller:	MBW Calibration AG
	Nr.:	GD14/G057
	Kalibrierung:	SCS0125
Platin-Widerstandsthermometer	Typ:	Pt 100
	Ident.-Nr.:	GD14/G007
	Kalibrierung:	D-K-15186-01
DC-Temperaturmessbrücke	Typ:	MKT 50
	Ident.-Nr.:	GD14/G035
	Kalibrierung:	D-K-15186-01
Multifunktionskalibrator:		
	Typ:	MC 5
	Nr.:	GD14/G034
	Hersteller:	Beamex
	Kalibrierung:	D-K-15186-01

Kalibrierverfahren

Die Kalibrierung erfolgt im direkten Vergleich der Anzeige des Prüflings mit der Temperatur und der relativen Feuchte (Bezugswert), welche aus der Taupunkttemperatur, der Gastemperatur und dem Luftdruck berechnet wurde.

Messbedingungen

Der Prüfling befand sich während der Kalibrierung innerhalb eines thermostatisierten Volumens in der Klimakammer im direkten Feuchtluftstrom. Die Messung wurde erst nach Einstellung stabiler Temperaturen und Feuchtewerte vorgenommen, d.h. wenn die Anzeige des Prüflings und die zur Berechnung der relativen Feuchte (Bezugswert) notwendigen Parameter keine systematischen Änderungen mehr erkennen ließen.
Die in der Tabelle angegebenen Werte sind Mittelwerte aus Mehrfachmessungen
Der Messumformer wurde mit einer Betriebsspannung von 24 V versorgt. Die der relativen Feuchte bzw. Lufttemperatur proportionale Ausgangsspannung (0 V bis 1 V entsprechend 0 % bis 100 % bzw. -30 °C bis 70 °C) wurde mit dem Multifunktionskalibrator gemessen.

Umgebungsbedingungen

Temperatur : (23,0 ± 5,0) °C
rel. Feuchte : (50 ± 20) %

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Messergebnisse

Feuchtemessung

Temperatur des Feucht-luftstromes	relative Feuchte Bezugswert	Ausgangsspannung Messumformer	relative Feuchte Prüfling *	Anzeigekorrektion	Messursicherheit
in °C	in %	in V	in %	in %	in %
20	28,4	0,30129	30,1	-1,7	0,42
20	49,3	0,50262	50,3	-1,0	0,62
20	69,8	0,69169	69,2	0,6	0,92

* die relative Feuchte wurde aus der Ausgangsspannung berechnet

Die relative Feuchte ergibt sich aus der Beziehung:

rel. Feuchte = rel. Feuchte Prüfling + Anzeigekorrektion

Temperaturmessung

Temperatur Normal	Ausgangsspannung Messumformer	Temperatur Prüfling *	Anzeigekorrektion	Messunsicherheit
in °C	in V	in °C	in K	in K
-9,861	0,19998	-10,00	0,14	0,15
9,851	0,39813	9,81	0,04	0,15
19,962	0,49898	19,90	0,06	0,15
40,063	0,70075	40,07	-0,01	0,15

* die Temperatur wurde aus der Ausgangsspannung berechnet

Die Temperatur ergibt sich aus der Beziehung:

Temperatur = Temperatur Prüfling + Anzeigekorrektion

Messunsicherheit

Angegeben ist die erweiterte Messunsicherheit, die sich aus der Standardmessunsicherheit durch Multiplikation mit dem Erweiterungsfaktor $k = 2$ ergibt. Sie wurde gemäß DAkkS-DKD-3 ermittelt. Der Wert der Messgröße liegt mit einer Wahrscheinlichkeit von annähernd 95% im zugeordneten Werteintervall.

Hinweis

Die Deutsche Akkreditierungsstelle GmbH ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC; zur gegenseitigen Anerkennung der Kalibrierscheine. Die weiteren Unterzeichner innerhalb und außerhalb Europas sind den Internetseiten von EA (www.european-accreditation.org) und ILAC (www.ilac.org) zu entnehmen.

Die Werte gelten für den Zustand des Kalibriergegenstandes zum Zeitpunkt der Kalibrierung.

10.5 Air pressure sensor

10.5.1 Air pressure sensor 1

VAISALA

1 (1)
Certificate report no. H47-17170021

CALIBRATION CERTIFICATE

Instrument PTB110 Barometer
Serial number N1720456
Manufacturer Vaisala Oyj, Finland
Calibration date 26th April 2017

This instrument has been calibrated against a Vaisala PTB220 factory working standard. The Vaisala PTB220 is traceable to the National Institute of Standards and Technology (NIST, USA) via Vaisala Measurement Standards Laboratory (MSL). Vaisala MSL has been accredited by FINAS according to ISO/IEC 17025 standard.

At the time of shipment, the instrument described above was within its operating specifications.

Calibration results

Reference pressure hPa	Calculated pressure hPa	Observed voltage Vdc	Correction* hPa	Uncertainty** hPa
809.9	809.9	0.191	0.0	± 0.15
900.2	900.2	1.927	0.0	± 0.15
1000.3	1000.3	3.852	0.0	± 0.15
1060.0	1060.0	5.000	0.0	± 0.15

*To obtain the true pressure, add the correction to the barometer reading. Interpolated corrections may be used at intermediate readings of the scale of the barometer.
**The calibration uncertainty given at 95 % confidence level, k = 2

Equipment used in calibration

Type	Serial number	Calibration date	Certificate number
HP34970A	EM 14611	2016-10-24	1250-307079098
PTB220	PA 14019	2016-08-02	K008-Z02342

Ambient conditions
Humidity: 31 ± 5 %RH
Temperature: 22 ± 2 °C
Pressure: 994 ± 20 hPa

Technician

Doc214685-B

Vaisala Oyj | PO Box 26, FI-00421 Helsinki, Finland
Phone +358 9 894 91 | Fax +358 9 8949 2227
Email firstname.lastname@vaisala.com | www.vaisala.com
Domicile Vantaa, Finland | VAT FI01244162 | Business ID 0124416-2

10.5.2 Air pressure sensor 2

VAISALA

1 (1)
Certificate report no. H47-17170019

CALIBRATION CERTIFICATE

Instrument	PTB110 Barometer
Serial number	N1720454
Manufacturer	Vaisala Oyj, Finland
Calibration date	26th April 2017

This instrument has been calibrated against a Vaisala PTB220 factory working standard. The Vaisala PTB220 is traceable to the National Institute of Standards and Technology (NIST, USA) via Vaisala Measurement Standards Laboratory (MSL). Vaisala MSL has been accredited by FINAS according to ISO/IEC 17025 standard.

At the time of shipment, the instrument described above was within its operating specifications.

Calibration results

Reference pressure hPa	Calculated pressure hPa	Observed voltage Vdc	Correction* hPa	Uncertainty** hPa
809.9	809.9	0.191	0.0	± 0.15
900.2	900.2	1.927	0.0	± 0.15
1000.3	1000.3	3.852	0.0	± 0.15
1060.0	1060.0	5.000	0.0	± 0.15

*To obtain the true pressure, add the correction to the barometer reading. Interpolated corrections may be used at intermediate readings of the scale of the barometer.
**The calibration uncertainty given at 95 % confidence level, k = 2

Equipment used in calibration

Type	Serial number	Calibration date	Certificate number
HP34970A	EM 14611	2016-10-24	1250-307079098
PTB220	PA 14019	2016-08-02	K008-Z02342

Ambient conditions
Humidity: 31 ± 5 %RH Temperature: 22 ± 2 °C Pressure: 994 ± 20 hPa

Technician

Doc214685-B

Vaisala Oyj | PO Box 26, FI-00421 Helsinki, Finland
Phone +358 9 894 91 | Fax +358 9 8949 2227
Email firstname.lastname@vaisala.com | www.vaisala.com
Domicile Vantaa, Finland | VAT FI01244162 | Business ID 0124416-2