Influence of mounting tube diameter on anemometer output

- WindSensor P2546A-OPR -
- Windspeed A100L2 -
- Thies First Class Advanced -

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Deutsche WindGuard Wind Tunnel Services GmbH is an associated Member of MEASNET and is accepted by MEASNET for the Calibration of Anemometers.

Deutsche WindGuard Wind Tunnel Services GmbH is an approved testing laboratory for the anemometer calibration competence area within the IECRE scheme.

Revision History

Revision No.	Date	Status	Amendment
Rev0	06.04.2018	1st issue	

Note: The last revision replaces all previous versions of the report.

Contents

1 Introduction

In March 2017 a new edition of the IEC 61400-12-01 [1] international standard for wind energy generation systems was released. Part 12-1 deals with the power performance measurement of electricity producing turbines. In Annex G.2 Single top-mounted anemometer and G.4 Site mounted instruments, the standard instructs:

'The anemometer shall be mounted on a round vertical tube of the same (± 0,1 mm) outer diameter as used during calibration (and classification), but of no larger diameter than the body of the anemometer.'

A first study regarding the influence of the variation in mounting tube diameter onto the measurement result of an anemometer is given in VT170985_01_Rev0 [2]. The results indicate that a change of 1 mm in mounting tube diameter doesn't influence the measurement result. Therefore, the restriction of the mounting tube diameter given in the IEC 61400-12-1 should be reviewed. Furthermore investigations for different anemometers should be done.

As an expansion to VT170985_01_Rev0, in this study different anemometers are tested. An investigation of the influence of a change in mounting tube diameter is done for a WindSensor, a Windspeed and a Thies anemometer. Different mounting tubes were specifically manufactured for this study. A part of these mounting tubes was supplied by Thies and one customized mounting tube was given by the Technical University of Denmark (DTU). The tube diameters are between 24 mm and 50 mm and were tested with our statistical quality control (SQC) cup anemometers:

- 'REF16', a WindSensor P2546A-OPR
- 'REF05', a Windspeed A100L2
- 'REF10', a Thies First Class Advanced 4.3351.00.000.

The bases for this study are the results in the calibration certificates which are listed in Appendix 7.2.

2 Test procedure

First the diameters of all mounting tubes were checked with a digital caliper. Afterwards calibration measurements with different mounting tubes and SQC anemometer were done. The different tubes corresponding to one anemometer were tested in alternating diameter size (e.g. 24.0, 26.9, 25.0 …). After setting up the mounting tube with one anemometer five successive measurements, using the same tube diameter, were carried out without changing the setup. The measurement procedure followed the MEASNET / IEC 61400-12-1 standard and covered a wind speed range of 4 m/s – 16 m/s.

General information:

- All tests in a speed range of 4 - 16 m/s were performed in wind tunnel 'Varel 1'. A detailed description of this wind tunnel is given in Appendix 7.1
- The ambient conditions during the calibrations are documented in the calibration certificates listed in Appendix 7.2
- The inclination angle in x- and y-direction for all setups was 90° ±0.1°

2.1 Setup

The setup of the SQC anemometer 'REF16' (type P2546A-OPR) with the smallest mounting tube in wind tunnel 'Varel 1' is shown in Figure 1. The setup of the 'REF05' anemometer (type A100L2) with a middle sized mounting tube in wind tunnel 'Varel 1' is illustrated in Figure 2 and the 'REF10' (type 4.3351.00.000) with a mounting tube corresponding to the outer diameter of the anemometers body is shown in Figure 3. The views are into the nozzle of the wind tunnel. The setup of the other mounting tubes was done in a similar manner.

Figure 1: Setup of the SQC anemometer 'REF16', type P2546A-OPR in wind tunnel 'Varel 1'.

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

Figure 2: Setup of the SQC anemometer ‘REF05’, type A100L2 in wind tunnel ‘Varel 1’.
Remark: The proportions of the set-up may not be true to scale due to imaging geometry.

Figure 3: Setup of the SQC anemometer ‘REF10’, type 4.3351.00.000 in wind tunnel ‘Varel 1’.
Remark: The proportions of the set-up may not be true to scale due to imaging geometry.

The SQC anemometers were tested with different mounting tubes, as they have different dimensions.

For the WindSensor 'REF16' and the Windspeed 'REF05' the same mounting tubes could be used, only the height had to be adjusted to make sure the cup position is on the centerline of the wind tunnel. Both anemometers were tested with five mounting tubes with diameters between 24.0 mm and 26.5 mm. Additionally, a mounting tube matching the outer diameter of the anemometers body was used for each type. As the two anemometers have different outer dimensions, the largest diameter used for the WindSensor anemometer was 46.0 mm and for the Windspeed anemometer 37.6 mm.

The seven different tubes are shown in Figure 4. They are labeled with the nominal-value of the diameter and a letter code. Note the decreasing/increasing shaft diameter at the anemometer position to allow proper anemometer seating.

The Thies First Class Advanced 'REF10' was tested with six different mounting tubes with diameters between 33.0 mm and 50.0 mm, where 50.0 mm matches the outer diameter of the anemometer. The six different tubes are shown in Figure 5. They are likewise labeled with the nominal-value of the diameter and a letter code. Again, note the decreasing/increasing shaft diameter at the anemometer position to allow proper anemometer seating.

Figure 4: Seven mounting pipes with different diameters manufactured for the tests with the WindSensor and Windspeed anemometer.
Remark: The proportions of the tubes may not be true to scale due to imaging geometry.

Figure 5: Seven mounting pipes with different tiameters partially supplied by Thies. FU is a customized mounting tube supplied by DTU.
Remark: The proportions of the tubes may not be true to scale due to imaging geometry.

For the WindSensor anemometer a mounting tube with a diameter of 25.0 mm (here: FP) is recommended by the manufacturer. Windspeed recommends a mounting tube with a diameter of 25.4 mm (here: FN) and Thies 33.7 mm (here: FY).

3 Results

In this Chapter the results of the measurements done for the different anemometers and mounting tube diameters will be presented. The detailed calibration data is documented in the calibration certificates listed in Appendix 7.2.

3.1 WindSensor P2546A-OPR

The calibration results covering the slope, offset and calculated frequency at 10 m/s for the WindSensor SQC 'REF16' anemometer and the six different mounting tubes are listed in Table 1.

Table 1: Calibration results for 'REF16' and six different mounting tube diameters.

Nominal-value / mm	Calibration Number	Slope / (m/s)/Hz		Offset / m/s		Calculated Frequency at 10 m/s / Hz	Frequency at 10 m/s divided by mean value of recommended diameter size
24.0	1810332	0.61557	±0.00084	0.2219	±0.014	15.88463	0.99979
	1810333	0.61539	±0.00080	0.2235	±0.013	15.88667	0.99992
	1810334	0.61571	±0.00087	0.2190	±0.015	15.88573	0.99986
	1810335	0.61557	±0.00083	0.2199	±0.014	15.88788	1.00000
	1810336	0.61523	±0.00079	0.2239	±0.013	15.89015	1.00014
25.0 (recom-mended)	1810347	0.61451	±0.00084	0.2377	±0.014	15.88632	0.99990
	1810348	0.61605	±0.00067	0.2125	±0.011	15.88751	0.99997
	1810349	0.61608	±0.00095	0.2115	±0.016	15.88836	1.00003
	1810350	0.61608	±0.00074	0.2108	±0.012	15.88949	1.00010
	1810351	0.61510	±0.00086	0.2273	±0.014	15.88799	1.00000
25.4	1810362	0.61668	±0.00114	0.2076	±0.019	15.87922	0.99945
	1810363	0.61604	±0.00104	0.2175	±0.017	15.87965	0.99948
	1810364	0.61566	±0.00104	0.2200	±0.018	15.88539	0.99984
	1810365	0.61607	±0.00094	0.2114	±0.016	15.88878	1.00005
	1810366	0.61702	±0.00081	0.2071	±0.014	15.87128	0.99895
26.0	1810352	0.61526	±0.00087	0.2170	±0.015	15.90059	1.00080
	1810353	0.61505	±0.00109	0.2252	±0.018	15.89269	1.00030
	1810354	0.61641	±0.00075	0.2054	±0.013	15.88975	1.00011

Nominal-value / mm	Calibration Number	Slope / (m/s)/Hz		Offset / m/s		Calculated Frequency at 10 m/s / Hz	Frequency at 10 m/s divided by mean value of recommended diameter size
	1810355	0.61616	±0.00094	0.2084	±0.016	15.89133	1.00021
	1810356	0.61584	±0.00095	0.2164	±0.016	15.88659	0.99992
26.9	1810342	0.61689	±0.00094	0.1944	±0.016	15.89522	1.00046
	1810343	0.61598	±0.00069	0.2111	±0.012	15.89159	1.00023
	1810344	0.61618	±0.00088	0.2084	±0.015	15.89081	1.00018
	1810345	0.61599	±0.00086	0.2097	±0.015	15.89360	1.00036
	1810346	0.61605	±0.00075	0.2115	±0.013	15.88913	1.00008
46.0	1810357	0.61001	±0.00076	0.2029	±0.013	16.06056	1.01087
	1810358	0.60993	±0.00065	0.1996	±0.011	16.06807	1.01134
	1810359	0.61010	±0.00046	0.1981	±0.008	16.06605	1.01121
	1810360	0.61096	±0.00053	0.1857	±0.009	16.06374	1.01107
	1810361	0.60978	±0.00057	0.2104	±0.010	16.05431	1.01047

The percent deviation of the mean calculated frequency at 10 m/s compared to the mean value of the recommended diameter size (here: 25.0 mm) for each mounting tube diameter is illustrated in Figure 6. The error bars indicate the standard deviation of the 5 measurements per diameter.

The results for diameters between 24.0 mm and 26.9 mm lie between -0.04 % and +0.03 %. They seem to have an arbitrary distribution, which is not related to the tube diameter. Only the results for a diameter of 46.0 mm show an influence of the increased tube diameter. The deviation compared to the mean value of the recommended diameter size is about 1.10 %.

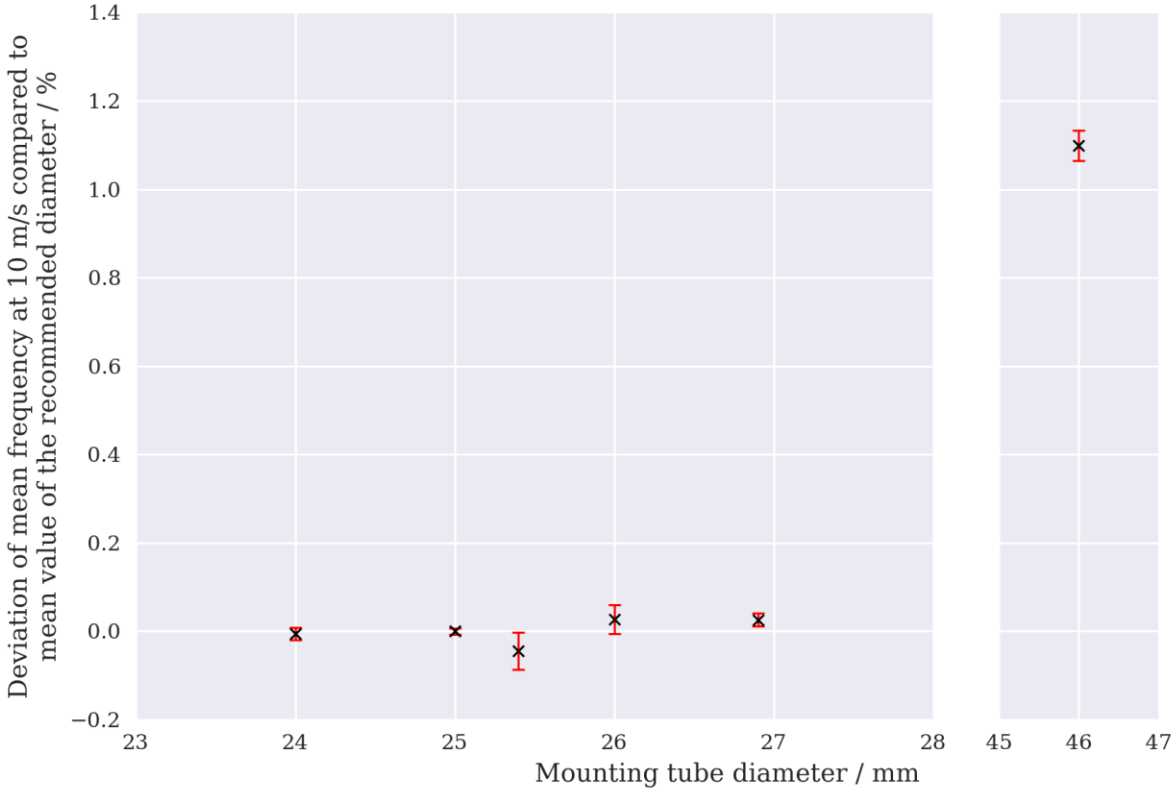

Figure 6: Deviation of the mean frequency at 10 m/s compared to the mean value of the recommended diameter size for the WindSensor anemometer 'REF16'. The error bars indicate the standard deviation of the 5 measurements.

3.1 Windspeed A100L2

The calibration results covering the slope, offset and calculated frequency at 10 m/s for the Windspeed SQC 'REF05' anemometer and the six different mounting tubes are listed in Table 2.

Table 2: Calibration results for 'REF05' and six different mounting tube diameters.

Nominal-value / mm	Calibration Number	Slope / (m/s)/Hz		Offset / m/s		Calculated Frequency at 10 m/s / Hz	Frequency at 10 m/s divided by mean value of recommended diameter size
24.0	1810337	0.04971	±0.00008	0.1967	±0.016	197.20982	1.00164
	1810338	0.04969	±0.00009	0.2111	±0.019	196.99940	1.00057
	1810339	0.04975	±0.00007	0.1941	±0.014	197.10352	1.00110
	1810340	0.04969	±0.00008	0.2056	±0.017	197.11008	1.00113

Nominal-value / mm	Calibration Number	Slope / (m/s)/Hz		Offset / m/s		Calculated Frequency at 10 m/s / Hz	Frequency at 10 m/s divided by mean value of recommended diameter size
	1810341	0.04968	±0.00008	0.2000	±0.017	197.26248	1.00190
25.0	1810760	0.04963	±0.00008	0.2005	±0.017	197.45114	1.00286
	1810761	0.04958	±0.00009	0.2216	±0.019	197.22469	1.00171
	1810762	0.04965	±0.00012	0.2027	±0.025	197.32729	1.00223
	1810763	0.04966	±0.00006	0.2041	±0.012	197.25936	1.00189
	1810764	0.04954	±0.00008	0.2224	±0.018	197.36778	1.00244
25.4 (recom-mended)	1810747	0.04966	±0.00009	0.2201	±0.019	196.93717	1.00025
	1810748	0.04976	±0.00012	0.2029	±0.026	196.88706	1.00000
	1810749	0.04966	±0.00008	0.2205	±0.016	196.92912	1.00021
	1810750	0.04965	±0.00005	0.2276	±0.009	196.82578	0.99969
	1810751	0.04962	±0.00007	0.2319	±0.015	196.85812	0.99985
26.0	1810752	0.04959	±0.00009	0.2293	±0.020	197.02964	1.00072
	1810753	0.04954	±0.00005	0.2260	±0.010	197.29512	1.00207
	1810754	0.04961	±0.00007	0.2201	±0.016	197.13566	1.00126
	1810755	0.04956	±0.00004	0.2342	±0.009	197.05004	1.00083
	1810756	0.04957	±0.00009	0.2302	±0.019	197.09098	1.00103
26.9	1810742	0.04960	±0.00006	0.2269	±0.013	197.03831	1.00077
	1810743	0.04952	±0.00009	0.2389	±0.018	197.11430	1.00115
	1810744	0.04954	±0.00009	0.2419	±0.020	196.97416	1.00044
	1810745	0.04958	±0.00008	0.2301	±0.017	197.05325	1.00084
	1810746	0.04965	±0.00007	0.2135	±0.015	197.10977	1.00113
37.6	1810765	0.04914	±0.00007	0.2088	±0.015	199.25112	1.01201
	1810766	0.04916	±0.00006	0.2034	±0.013	199.27990	1.01215
	1810767	0.04908	±0.00010	0.2096	±0.020	199.47840	1.01316
	1810768	0.04913	±0.00006	0.2026	±0.013	199.41787	1.01285
	1810769	0.04907	±0.00007	0.2267	±0.014	199.17057	1.01160

The percent deviation of the mean calculated frequency at 10 m/s compared to the mean value of the recommended diameter size (here: 25.4 mm) for each mounting tube diameter is illustrated in Figure 7. The error bars likewise indicate the standard deviation of the 5 measurements per diameter.

The results for diameters between 24.0 mm and 26.9 mm lie between 0.00 % and 0.22 %. Compared to the Windspeed anemometer, the standard deviation for the different mounting tube diameters is slightly increased. Again the results seem to have an arbitrary distribution, which is not related to the tube diameter. Only the results for a diameter of 37.6 mm, which corresponds to the outer diameter of the anemometer, show an influence of the increased tube diameter. The deviation compared to the mean value of the recommended diameter size is about 1.24 %.

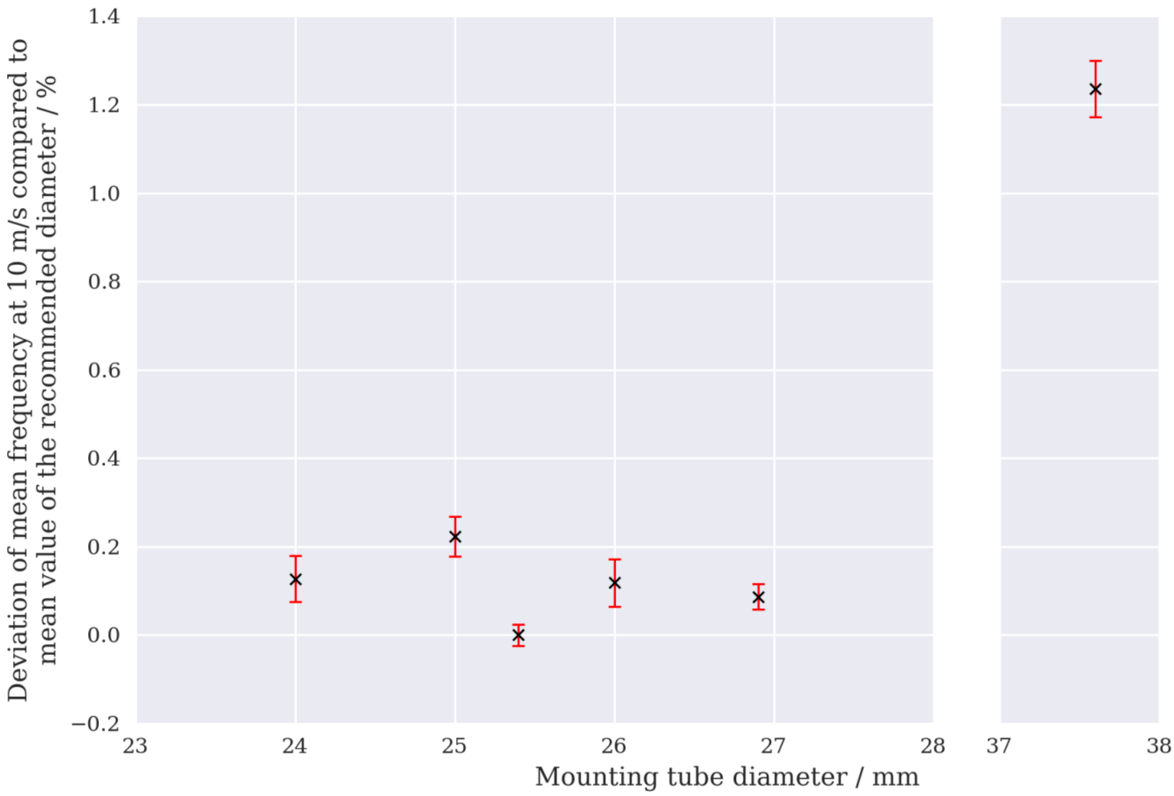

Figure 7: Deviation of the mean frequency at 10 m/s compared to the mean value of the recommended diameter size for the Windspeed anemometer ‘REF05’. The error bars indicate the standard deviation of the 5 measurements.

3.2 Thies First Class Advanced

The calibration results covering the slope, offset and calculated frequency at 10 m/s for the Thies SQC ‘REF10’ anemometer and the six different mounting tubes are listed in Table 3.

Table 3: Calibration results for 'REF10' and six different mounting tube diameters.

Nominal-value / mm	Calibration Number	Slope / (m/s)/Hz		Offset / m/s		Calculated Frequency at 10 m/s / Hz	Frequency at 10 m/s divided by mean value of recommended diameter size
33.0	1811546	0.04590	±0.00005	0.2136	±0.012	213.21133	0.99985
	1811547	0.04600	±0.00005	0.1877	±0.012	213.31087	1.00032
	1811548	0.04596	±0.00006	0.1989	±0.015	213.25283	1.00005
	1811549	0.04592	±0.00007	0.2064	±0.016	213.27526	1.00015
	1811550	0.04584	±0.00007	0.2239	±0.015	213.26571	1.00011
33.5	1811531	0.04588	±0.00007	0.2104	±0.015	213.37402	1.00062
	1811532	0.04600	±0.00005	0.1895	±0.011	213.27174	1.00014
	1811533	0.04590	±0.00007	0.2084	±0.015	213.32462	1.00038
	1811534	0.04602	±0.00005	0.1930	±0.011	213.10300	0.99934
	1811535	0.04594	±0.00005	0.2028	±0.010	213.26077	1.00008
33.7 (recom-mended)	1811541	0.04600	±0.00006	0.1999	±0.013	213.04565	0.99908
	1811542	0.04600	±0.00007	0.1989	±0.016	213.06739	0.99918
	1811543	0.04602	±0.00005	0.1791	±0.010	213.40504	1.00076
	1811544	0.04599	±0.00007	0.1829	±0.015	213.46162	1.00103
	1811545	0.04591	±0.00005	0.2104	±0.011	213.23459	0.99996
34.0	1811551	0.04600	±0.00006	0.1839	±0.013	213.39348	1.00071
	1811552	0.04594	±0.00005	0.2031	±0.012	213.25424	1.00005
	1811553	0.04595	±0.00006	0.1958	±0.014	213.36670	1.00058
	1811554	0.04606	±0.00006	0.1718	±0.013	213.37820	1.00063
	1811555	0.04599	±0.00008	0.1908	±0.018	213.28985	1.00022
35.0 (DTU)	1811526	0.04597	±0.00005	0.1968	±0.011	213.25212	1.00004
	1811527	0.04590	±0.00006	0.2086	±0.013	213.32026	1.00036
	1811528	0.04592	±0.00005	0.2061	±0.012	213.28179	1.00018
	1811529	0.04607	±0.00005	0.1778	±0.012	213.20165	0.99981
	1811530	0.04584	±0.00005	0.2186	±0.011	213.38133	1.00065

Nominal-value / mm	Calibration Number	Slope / (m/s)/Hz		Offset / m/s		Calculated Frequency at 10 m/s / Hz	Frequency at 10 m/s divided by mean value of recommended diameter size
50.0	1811536	0.04589	±0.00006	0.1962	±0.013	213.63696	1.00185
	1811537	0.04581	±0.00006	0.2144	±0.013	213.61275	1.00173
	1811538	0.04594	±0.00004	0.1960	±0.009	213.40879	1.00078
	1811539	0.04590	±0.00005	0.1973	±0.012	213.56645	1.00152
	1811540	0.04594	±0.00005	0.1896	±0.011	213.54811	1.00143

The percent deviation of the mean calculated frequency at 10 m/s compared to the mean value of the recommended diameter size (here: 33.7 mm) for each mounting tube diameter is illustrated in Figure 8. The error bars again indicate the standard deviation of the 5 measurements per diameter.

The results for diameters between 33.0 mm and 35.0 mm lie between 0.00 % and +0.04 %. As for the other two tested anemometers, they seem to have an arbitrary distribution, which is not related to the tube diameter. Only the results for the mounting tube with a diameter corresponding to the outer diameter of the anemometers body show an influence of the increased tube diameter, which is quite small. The deviation compared to the mean value of the recommended diameter size is about 0.15 %.

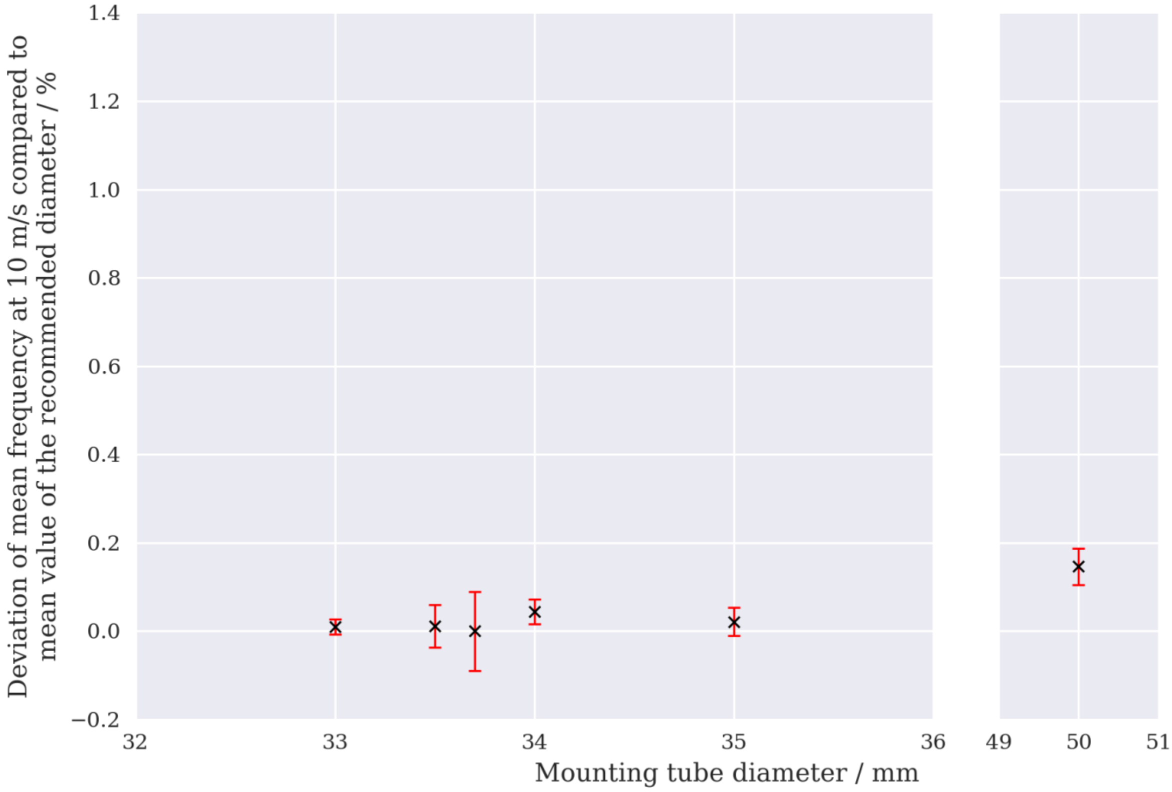

Figure 8: Deviation of the mean frequency at 10 m/s compared to the mean value of the recommended diameter size for the Thies anemometer 'REF10'. The error bars indicate the standard deviation of the 5 measurements.

4 Measurement uncertainty

Tests were carried out in wind tunnel 'Varel 1'. The attributed uncertainties in flow speed are specified below:

- Flow speed wind tunnel 'Varel 1': The accredited uncertainty in flow speed is specified as 0.05 m/s in a speed range from 4 m/s to 16 m/s.

Uncertainty values are specified as an expanded uncertainty with a coverage probability of 95 % (coverage factor of k=2). It has been determined in accordance with DAkkS-DKD-3.

The long-term scatter between the mean value of all measurements at 10 m/s and each measurement of the 'REF16' anemometer fluctuate between ±0.1 %. The results for the 'REF05' anemometer fluctuate between ±0.2 % and for the 'REF10' anemometer fluctuate between ±0.1 %.

5 Conclusion

The calculated frequencies at 10 m/s don't show a diameter related change for deviations in mounting tube diameter of about 2.0 mm or rather ±1 mm. The variation of the results for small diameter changes presented in Figure 6, Figure 7 and Figure 8 is apparently due to statistical scatter. For these mounting tube diameters, the maximum deviation for each anemometer lies within the statistical scatter of the long-term SQC measurements.

The results for the largest diameter sizes, which are equal to the outer diameters of each tested anemometer, show significant changes in the frequency output at 10 m/s for the WindSensor and Windspeed anemometer. The increase in diameter size for these anemometers is about 10 mm to 20 mm. The percent deviation of the mean frequency at 10 m/s compared to the recommended diameter size of the corresponding anemometer lies between 1.10 % and 1.24 %, which is no longer within the statistical scatter of the long-term SQC measurements.

For the Thies anemometer the increase in diameter size is about 15 mm for the largest mounting tube. The deviation of the mean frequency at 10 m/s compared to the recommended diameter size is about 0.15 %, which is only a small deviation compared to the results for the other two anemometers. It could still indicate a diameter related increase, as the long-term SQC measurements lie between ±0.1 %.

Nevertheless, the measurements indicate that a change in mounting tube diameter of ±1 mm doesn't have an influence on the calibration result of the WindSensor P2546A-OPR, the Windspeed A100L2 and the Thies First Class Advanced 4.3351.00.000 anemometers.

As already stated in the previous study [2], the restriction in the IEC 61400-12-01 international standard for wind energy generation systems of 0.1 mm should be reviewed. But still a further investigation is necessary to set a feasible maximum value for the tolerated difference between outer mounting tube diameter during calibration and on site measurement. This value should be at least ±1.0 mm instead of ±0.1 mm.

6 References

[1] IEC 61400-12-1, Edition 2.0, WIND TURBINE GENERATOR SYSTEMS, Power performance measurements of electricity producing wind turbines, March 2017

[2] A. Roß, VT17985_01_Rev0, Influence of mounting tube diameter on anemometer output, November 2017

[3] MEASNET, ANEMOMETER CALIBRATION PROCEDURE Version 2, October 2009

[4] Quality management documentation of WindGuard Wind Tunnel Services GmbH is part of the accreditation according to DAkkS [5] and DIN ISO EN 17025:2005
below an excerpt of the quality management documentation most relevant for the tests conducted
- H Handbuch Kalibrierlabor, ID: D5927, Revision: 30, August 2017
- VA Verfahrensanweisung Anemometerkalibrierung, ID: D5831, Revision: 13, July 2017
- AA Arbeitsanweisung Kalibrierung von Standard Cup-Anemometern, ID: D5829, Revision: 0, March 2013

[5] DAkkS Accreditation certificate D-K-15140-01-00, July 2017

7 Appendix

7.1 Description of wind tunnel 'Varel 1' of Deutsche WindGuard Wind Tunnel Services GmbH

As of 2016 Deutsche WindGuard Wind Tunnel Services GmbH is operating four calibration wind tunnels and two research wind tunnels at the Varel facility. All four calibration tunnels are of the 'Göttinger" wind tunnel layout with a closed return design. The basic layout of the calibration wind tunnels can be seen in Figure 9.

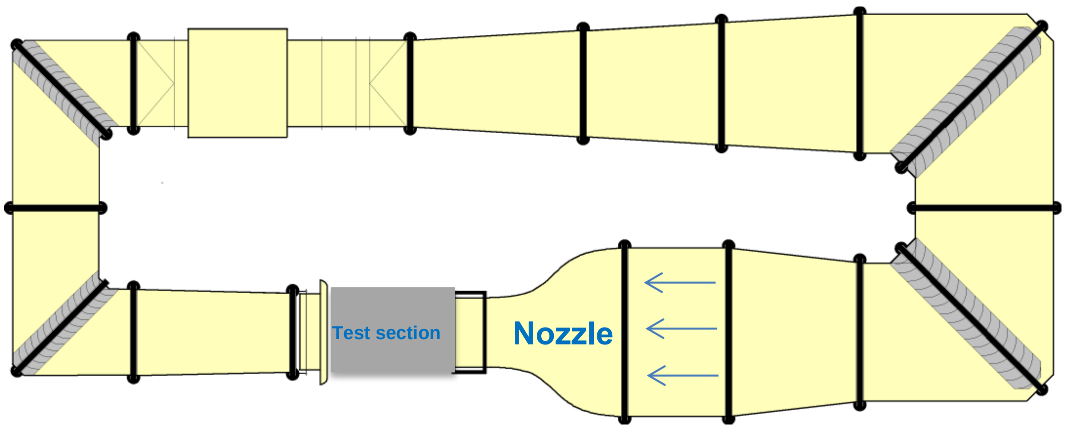

Figure 9: Basic layout of WindGuard calibration tunnels at the Varel facility.

All measurement surveys conducted for this report were performed in wind tunnel 'Varel 1'.

Features of wind tunnel 'Varel 1':

- Test section size of 1 m x 1 m
- Length of test section 1.75 m
- Turbulence intensity < 0.2%
- Excellent flow quality in space and time
- Test section layout of semi open design, thus reducing blockage effects substantially
- Accredited speed range: 4 – 16 m/s
- Recognized by MEASNET following / IEC 61400-12-1 Annex F [1] anemometer calibration procedure

7.2 Calibration certificates of project VT180177

The calibration certificates belonging to the project VT180177 will be listed according to the SCQ anemometer.

Certificate numbers for the Wind Sensor 'REF16':

- 1810332
- 1810333
- 1810334
- 1810335
- 1810336
- 1810342
- 1810343
- 1810344
- 1810345
- 1810346
- 1810347
- 1810348
- 1810349
- 1810350
- 1810351
- 1810352
- 1810353
- 1810354
- 1810355
- 1810356
- 1810357
- 1810358
- 1810359
- 1810360
- 1810361
- 1810362
- 1810363
- 1810364
- 1810365
- 1810366

Certificate numbers for the Windspeed 'REF05':

- 1810337
- 1810338
- 1810339
- 1810340
- 1810341
- 1810742
- 1810743
- 1810744
- 1810745
- 1810746
- 1810747
- 1810748
- 1810749
- 1810750
- 1810751
- 1810752
- 1810753
- 1810754
- 1810755
- 1810756
- 1810760
- 1810761
- 1810762
- 1810763
- 1810764
- 1810765
- 1810766
- 1810767
- 1810768
- 1810769

The certificate numbers for the Thies 'REF10':

- 1811526
- 1811527
- 1811528
- 1811529
- 1811530
- 1811531
- 1811532
- 1811533
- 1811534
- 1811535
- 1811536
- 1811537
- 1811538
- 1811539
- 1811540
- 1811541
- 1811542
- 1811543
- 1811544
- 1811545
- 1811546
- 1811547
- 1811548
- 1811549
- 1811550
- 1811551
- 1811552
- 1811553
- 1811554
- 1811555

On request access can be given.