Measuring-Network of Wind Energy Institutes

Anemometer Calibration Proficiency Test

Results of 16ac01 for MEASNET wind tunnels

Document: ACEXG.MST.DOC05/19

Acknowledgement

This project has been carried out in the framework of MEASNET, in close collaboration with the SG551 group of IECRE. The collaboration of the MEASNET secretariat and the SG551 convener in the development of the Proficiency Test is highly appreciated.

Abstract

This document presents the results of the 16ac01 Proficiency Test organized by MEASNET in collaboration with IECRE. This proficiency test is organized according to the MEASNET Anemometer Calibration Procedure, version 2, which in its annex A establishes the methodology for the Anemometer Calibration Proficiency Tests.

In general, according to ISO/IEC 17043 standard (Conformity Assessment – General requirements for proficiency testing), Proficiency Testing involves the use of inter-laboratory comparison for the determination of laboratory performance with typical purposes:

a) evaluation of the performance of laboratories for specific tests or measurements and monitoring laboratories' continuing performance;

b) identification of problems in laboratories and initiation of actions for improvement which, for example, may be related to inadequate test or measurement procedures, effectiveness of staff training and supervision, or calibration of equipment;

c) establishment of the effectiveness and comparability of test or measurement methods;

d) provision of additional confidence to laboratory customers;

e) identification of inter-laboratory differences;

Since there is not a standard for wind speed, the comparison is performed by sending the same cup anemometers to the participating wind tunnels and comparing the calibration results. The participants of the Proficiency test involved both MEASNET (10) and non-MEASNET members (1).

The present document presents the results obtained for the MEASNET participants of the PT as of the date of publication. The current MEASNET laboratories which participated in this Proficiency test were:

- Deutsche WindGuard Wind Tunnel Services GmbH
- ProfEC Ventus GmbH
- International Wind Engineering IWE
- Center for Renewable Energy Sources CRES
- WIND-consult GmbH
- Ammonit Wind Tunnel GmbH
- SOH Wind Engineering LLC
- Svend Ole Hansen ApS
- Instituto Universitario “Ignacio Da Riva” IDR/UPM

The results have been analyzed by IDR/UPM acting as the conductor of the proficiency test. Measures have been taken in order to prevent the conductor from accessing the results of the other institutions before having presented to the MEASNET secretariat its own results.

The Proficiency Test *reference wind speed* is determined by the calibration results of the participant institutes. The reference wind speed is used to determine whether the institutes comply with the Proficiency Test requirement.

The compliance factor, as defined in the MEASNET Anemometer calibration procedure, is the performance indicator selected for this proficiency test. A factor equal to 1% or below is considered as a pass value, while a factor above 1% is considered a fail value.

The compliance factors for the MEASNET wind tunnels ranged from 0.08% to 0.52% (average value 0.29%). Therefore all the MEASNET participant laboratories have passed the proficiency test.

1. Introduction

Within the framework of the MEASNET network internal quality evaluation program, the collaboration with the IECRE organization and the consideration of proficiency testing as a service offered to its customers, an anemometer calibration Proficiency Testing was organized and performed formulated as an Inter-laboratory Comparison.

The present document presents the results obtained for the MEASNET participants of the PT as of the date of publication. The current MEASNET laboratories which participated in this Proficiency test were (number of tunnels in parenthesis):

- Deutsche WindGuard Wind Tunnel Services GmbH (4)
- ProfEC Ventus GmbH
- International Wind Engineering IWE
- Center for Renewable Energy Sources CRES
- WIND-consult GmbH
- Ammonit Wind Tunnel GmbH
- SOH Wind Engineering LLC (2)
- Svend Ole Hansen ApS (2)
- Instituto Universitario "Ignacio Da Riva" IDR/UPM

The calibration results have been analyzed by IDR/UPM according to the MEASNET Anemometer Calibration Round robin rules described in Annex A of its procedure. Measures have been taken in order to prevent the conductor from accessing the results of the other institutions before having presented to the Measnet secretariat its own results.

Some institutes participated with more than one set of calibration results corresponding to different wind tunnels. In order to avoid bias of the results due to the expected correlation of results from different wind tunnels of the same laboratory, each participating institute defined its primary wind tunnel. The "reference" wind speed was determined from the results of the primary wind tunnels only (one set for each participant). The "reference" wind speed is the reference value (in the absence of a "true" value) against which the performance of each participant is evaluated.

In this context the following apply:

- The primary wind tunnel for *Deutsche WindGuard Wind Tunnel Services GmbH* is the one designated as #2.
- *SOH Wind Engineering LLC (USA)* and *Svend Ole Hansen ApS (DK)* which are inter-related companies have selected SOH-USA Njord-1 as their primary wind tunnel for the PT.
- *WIND-consult GmbH* and *Ammonit Wind Tunnel GmbH* which are inter-related companies have selected *Ammonit* as their primary wind tunnel for the PT.

Therefore, the primary wind tunnels are 7, while results are available for additional 7 "secondary" wind tunnels.

2. Test anemometers

Two cup anemometers have been used in the MEASNET Round Robin exercise on cup anemometer calibration:

- Thies First class advanced, serial number CA-2016-001
- Windsensor P2546A-OPR, serial number CA-2016-002

Original serial numbers for the anemometers have been covered in order to allow the same anemometers to be used in further exercises while keeping the participants unaware of the actual anemometer used and therefore unaware of previous results.

These anemometers have been calibrated by each participant according to its own (MEASNET-compliant) procedure. As first and last calibration the anemometers where calibrated in the wind tunnel of IDR/UPM in Madrid.

The recalibration results by IDR-UPM suggested that there are differences for the case of the Thies anemometer (0.9% at 7 m/s and about 0.7% for 10 and 13 m/s). The difference for the Windsensor was below 0.1%. The detailed analysis has indicated that the anemometers essentially maintained their characteristics during the PT procedure.

3 Results provided by the institutes

The results submitted by the various institutes that form the Proficiency Test Reference Wind Speed are presented in the table 1 below.

Results are presented anonymized and the date of calibration is also omitted in order to assure the confidentiality of each laboratory's results.

The results correspond to calibrations performed from August 2nd, 2016 to May 27th, 2017. Results were sent to the Measnet secretariat from May 22nd, 2017 to may 27th, 2017, along with the corresponding calibration certificates in PDF format.

Table 1 Results provided by the participants to form the Reference Wind Speed.

	Institute	A	B	C	E	F	G	H
Risø CA-2016-002	slope [(m/s)/Hz]	0.61471	0.61594	0.61573	0.61770	0.61759	0.61785	0.61499
	offset [m/s]	0.27300	0.21470	0.28300	0.24000	0.23866	0.23808	0.24981
Thies Clima CA-2016-001	slope [(m/s)/Hz]	0.04620	0.04611	0.04587	0.04600	0.04616	0.04608	0.04599
	offset [m/s]	0.21500	0.23010	0.23100	0.24000	0.25325	0.26715	0.26069

4 Evaluation of the Results

4.1. Cup Anemometers integrity check

Both anemometers were checked before and after the Proficiency test by the IDR/UPM. The results are shown in Table 2.

Some deviations have been found in the Thies Clima anemometer. These differences could be attributed to the running-in of the bearings.

Therefore those laboratories that show very different performances between both anemometers might have to take caution in the analysis of these proficiency test results.

Table 1 Results of the integrity check calibrations

7 m/s	s.n.	output freq [Hz]	Post [m/s]	Pre [m/s]	Difference [m/s]	Difference [%]
WindSensor	CA-2016-002	10.92	6.98473	6.98980	0.00507	0.073
Thies Clima	CA-2016-001	145.99	6.99431	7.02938	0.03507	0.501

10m/s	s.n.	output freq [Hz]	Pre [m/s]	Post [m/s]	Difference [m/s]	Difference [%]
WindSensor	CA-2016-002	15.78	9.99030	9.98429	-0.00602	-0.060
Thies Clima	CA-2016-001	211.07	9.99307	10.03725	0.04418	0.442

13m/s	s.n.	output freq [Hz]	Pre [m/s]	Post [m/s]	Difference [m/s]	Difference [%]
WindSensor	CA-2016-002	20.65	12.99588	12.97877	-0.01711	-0.132
Thies Clima	CA-2016-001	276.14	12.99183	13.04512	0.05329	0.410

4.2. Anemometer output frequencies

For each anemometer and each participant three output frequencies have been determined corresponding to nominal wind speeds of 7, 10 and 13 m/s. The frequencies were derived from the provided slope/offset values provided by the participants. From these frequencies an average frequency at each wind speed and for each anemometer is calculated. These frequencies are used in the next steps to calculate the wind speeds for each laboratory and compare the results in terms of wind speed. Only the values declared as "primary" are taken into account in this phase.

Table 3 Output frequencies (Hz) corresponding to 7, 10 and 13 m/s

7 m/s	Institute	A	B	C	E	F	G	H	Average
WindSensor CA-2016-002		10.943	11.016	10.909	10.944	10.948	10.944	10.976	10.954
Thies Clima CA-2016-001		146.849	146.821	147.569	146.957	146.160	146.112	146.532	146.714

10 m/s	Institute	A	B	C	E	F	G	H	Average
WindSensor CA-2016-002		15.824	15.887	15.781	15.801	15.806	15.800	15.854	15.822
Thies Clima CA-2016-001		211.778	211.882	212.971	212.174	211.151	211.216	211.761	211.848

13 m/s	Institute	A	B	C	E	F	G	H	Average
WindSensor CA-2016-002		20.704	20.757	20.654	20.657	20.663	20.655	20.733	20.689
Thies Clima CA-2016-001		276.708	276.944	278.374	277.391	276.143	276.321	276.990	276.981

4.3. Calculation of wind speeds

For each anemometer and for each of the three frequencies the wind speeds according to the calibration results of the institutes have been calculated.

Table 4 Wind speeds for each laboratory for averaged speeds of 7, 10 and 13 m/s

Calculated Wind speeds (Average 7 m/s)								
	output freq	A	B	C	E	F	G	H
WindSensor	10.954 Hz	7.007	6.962	7.028	7.007	7.004	7.006	6.987
Thies Clima	146.714 Hz	6.994	6.995	6.961	6.989	7.026	7.028	7.008

Calculated Wind speeds (Average 10 m/s)								
	output freq	A	B	C	E	F	G	H
WindSensor	15.822 Hz	9.999	9.960	10.025	10.013	10.010	10.014	9.980
Thies Clima	211.848 Hz	10.003	9.998	9.948	9.985	10.032	10.029	10.004

Calculated Wind speeds (Average 13 m/s)								
	output freq	A	B	C	E	F	G	H
WindSensor	20.689 Hz	12.991	12.958	13.022	13.020	13.016	13.021	12.973
Thies Clima	276.981 Hz	13.013	13.002	12.936	12.981	13.039	13.030	13.000

According to Annex A of the MEASNET Anemometer Calibration Procedure, each wind speed is assumed to have a standard uncertainty of 1%.

The first estimate of the Proficiency test reference wind speed is derived for each wind speed (i.e. 7, 10 and 13 m/s) and anemometer (Wind Sensor, Thies Clima) as the average value from all the participants (population N=7).

The standard uncertainty of this reference wind speed is (1/√N) %.

4.4. Calculation of deviation in percentage and outliers discard

The deviation of each laboratory from the averaged wind speed is expressed as a percentage of the wind speed.

Table 5 Wind speeds deviation for each laboratory

Differences in % (Velocity average = 7m/s)							
	A	B	C	E	F	G	H
WindSensor CA-2016-002	0.10%	-0.54%	0.40%	0.09%	0.06%	0.09%	-0.19%
Thies Clima CA-2016-001	-0.09%	-0.07%	-0.56%	-0.16%	0.36%	0.40%	0.12%

Differences in % (Velocity average = 10m/s)							
	A	B	C	E	F	G	H
WindSensor CA-2016-002	-0.01%	-0.40%	0.25%	0.13%	0.10%	0.14%	-0.20%
Thies Clima CA-2016-001	0.03%	-0.02%	-0.52%	-0.15%	0.32%	0.29%	0.04%

Differences in % (Velocity average = 13m/s)							
	A	B	C	E	F	G	H
WindSensor CA-2016-002	-0.07%	-0.40%	0.17%	0.15%	0.12%	0.16%	-0.21%
Thies Clima CA-2016-001	0.10%	-0.02%	-0.49%	-0.15%	0.30%	0.23%	0.00%

Per anemometer and per output frequency, the results of the calibration of an institute are discarded when the deviation with respect to the estimated reference wind speed was one standard uncertainty of the difference or more. The standard uncertainty of the difference is equal to:

$$\sqrt{1+\left(\frac{1}{\sqrt{N}}\right)^2}\ \% = 1.069\ \%\ \text{for N=7}$$

where N is the number of non-discarded results per anemometer and output frequency. This step is carried out several times until no more data are discarded. The measurements are discarded in the order of their deviation, the biggest deviation first.

According to Table 5, all entries are less than the limit of 1.069%, therefore no result is discarded and the final number of non-discarded results is N=7.

4.5. Definition of Proficiency Test's Reference Wind Speed

For each anemometer and for each output frequency the reference wind speed is defined as the average value of the non-discarded values. The result of this process is shown in the Table 6.

The deviation of each laboratory from the averaged wind speed is expressed as a percentage of the wind speed.

Table 6 Wind speeds for each laboratory and proficiency test reference wind speed

Calculated Wind speeds at nominal 7 m/s									16ac01 reference speed
		A	B	C	E	F	G	H	
WindSensor	CA-2016-002	7.007	6.962	7.028	7.007	7.004	7.006	6.987	7.000
Thies Clima	CA-2016-001	6.994	6.995	6.961	6.989	7.026	7.028	7.008	7.000

Calculated Wind speeds at nominal 10 m/s									16ac01 reference speed
		A	B	C	E	F	G	H	
WindSensor	CA-2016-002	9.999	9.960	10.025	10.013	10.010	10.014	9.980	10.000
Thies Clima	CA-2016-001	10.003	9.998	9.948	9.985	10.032	10.029	10.004	10.000

Calculated Wind speeds at nominal 13 m/s									16ac01 reference speed
		A	B	C	E	F	G	H	
WindSensor	CA-2016-002	12.991	12.958	13.022	13.020	13.016	13.021	12.973	13.000
Thies Clima	CA-2016-001	13.013	13.002	12.936	12.981	13.039	13.030	13.000	13.000

The wind speed deviations are now recalculated using the 16ac01 reference wind speeds.

Table 7 Wind speed deviation to reference wind speed expressed as a percentage

Differences in % (Velocity average = 7m/s)								#of non-discarded results	Uncertainty of difference from reference
	A	B	C	E	F	G	H		
WindSensor CA-2016-002	0.10%	-0.54%	0.40%	0.09%	0.06%	0.09%	-0.19%	7	1.069%
Thies Clima CA-2016-001	-0.09%	-0.07%	-0.56%	-0.16%	0.36%	0.40%	0.12%	7	1.069%

Differences in % (Velocity average = 10m/s)								#of non-discarded results	Uncertainty of difference from refer-
	A	B	C	E	F	G	H		
WindSensor CA-2016-002	-0.01%	-0.40%	0.25%	0.13%	0.10%	0.14%	-0.20%	7	1.069%
Thies Clima CA-2016-001	0.03%	-0.02%	-0.52%	-0.15%	0.32%	0.29%	0.04%	7	1.069%

Differences in % (Velocity average = 13m/s)								#of non-discarded results	Uncertainty of difference from refer-
	A	B	C	E	F	G	H		
WindSensor CA-2016-002	-0.07%	-0.40%	0.17%	0.15%	0.12%	0.16%	-0.21%	7	1.069%
Thies Clima CA-2016-001	0.10%	-0.02%	-0.49%	-0.15%	0.30%	0.23%	0.00%	7	1.069%

4.6. Calculation of the Compliance Factor for each laboratory

For each participant and reference wind speed (nominal values of 7, 10 and 13 m/s), there are two values (from Table 7) which characterize the differences of its results from the PT reference values (one for each anemometer tested). The average value (AV) and the standard deviation (stdevp[1]) value are calculated for each participant and reference wind speed. Ideally, both values should be close to zero.

The sum of the absolute value of the average and the standard deviation (|AV| + stdevp) is used as the quantity that characterizes the compliance of the participant with each MEASNET-reference-wind speed (3 values).

For each participant, the values (|AV|+stdevp) at 7, 10 and 13 m/s are averaged to calculate the final compliance factor.

Success Criterion: The participants with a final compliance factor ≤ 1% comply with the 16ac01 proficiency test requirement for anemometer calibration.

Table 8 Compliance factors for the 'primary' results provided by all the laboratories

Compliance factors per wind speed and averaged								
	Reference speed	A	B	C	E	F	G	H
|avg| + stdev	7 m/s	0.10%	0.54%	0.56%	0.16%	0.36%	0.40%	0.19%
|avg| + stdev	10 m/s	0.03%	0.40%	0.52%	0.15%	0.32%	0.29%	0.20%
|avg| + stdev	13 m/s	0.10%	0.32%	0.49%	0.15%	0.30%	0.23%	0.21%
|avg| + stdev	averaged	0.08%	0.42%	0.52%	0.15%	0.33%	0.31%	0.20%

4.7. Assessment of PT results

The compliance factor, as defined in the MEASNET Anemometer calibration procedure is the performance indicator selected for this proficiency test. A factor equal to 1% or below is considered as a pass value, while a factor above 1% is considered a fail value.

The compliance factors for the MEASNET wind tunnels ranged from 0.08% to 0.52% (average value 0.29%). **Therefore all the MEASNET participant laboratories have passed the proficiency test.**

The previous inter-laboratory test conducted in 2014 (6 participants) resulted to a range of compliance factors 0.17% to 0.33% with an average of 0.24%.

[1] Stdevp denotes the corresponding Excel function – standard deviation of population

5 Performance of the MEASNET Laboratories including the secondary wind tunnels

In total 14 wind tunnels have been used from all the participants belonging to MEASNET at the time of issuance of the present report. The reference wind speed has been calculated from the 7 primary wind tunnels of Section 4. The results for the additional 7 (secondary) wind tunnels have been assessed against the reference wind speed.

Table 9 provides the compliance factors for all 14 wind tunnels. The compliance factors for the MEASNET wind tunnels ranged from 0.08% to 0.59% (average value 0.33%). **Therefore all the MEASNET participant laboratories (primary and secondary) have passed the proficiency test**.

Table 9 Compliance factor for the wind tunnels in the MEASNET network

Compliance factors per wind speed and averaged														
approx wind speed	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**
7 m/s	0.54%	0.56%	0.10%	0.16%	0.19%	0.36%	0.40%	0.52%	0.36%	0.19%	0.32%	0.44%	0.53%	0.37%
10 m/s	0.40%	0.52%	0.03%	0.15%	0.20%	0.32%	0.29%	0.40%	0.21%	0.15%	0.19%	0.62%	0.55%	0.47%
13 m/s	0.32%	0.49%	0.10%	0.15%	0.21%	0.30%	0.23%	0.34%	0.18%	0.12%	0.12%	0.71%	0.56%	0.52%
Avg.	0.42%	0.52%	0.08%	0.15%	0.20%	0.33%	0.31%	0.42%	0.25%	0.15%	0.21%	0.59%	0.55%	0.45%

Note: The letters corresponding to each wind tunnel DO NOT correspond to the letter assignation applied in the chapter 4 of this report.

5.1. Deviations between anemometers

The recalibration results by IDR-UPM suggested that there are differences for the case of the Thies anemometer (0.9% at 7 m/s and about 0.7% for 10 and 13 m/s). The difference for the Windsensor was below 0.1%. For this reason, it is useful to address if the actual scatter of the results among the participants is significantly affected by the anemometer tested. This has been checked through the results of Table 10.

For each reference wind speed and anemometer, the |AV| values have been averaged over all 14 wind tunnels. Indeed, Table 10 indicates that the scatter of results is somewhat larger for Thies than for Wind Sensor. Yet, the difference is not so significant to support the argument that the Thies “change” in behavior in the recalibration affected significantly the results of the PT test.

Table 10 Average deviation % of participants from the reference speed separately evaluated for each tested anemometer

Reference wind speed	WindSensor CA-2016-002	Thies Clima CA-2016-001
7 m/s	0.21%	0.28%
10 m/s	0.19%	0.26%
13 m/s	0.20%	0.25%

6 References

[1] IEC 61400-12-1, Edition 1.0, WIND TURBINES, Power performance measurements of electricity producing wind turbines, December 2005

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