Measuring-Network of Wind Energy Institutes

Procedure for wind direction sensor calibration

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1. Introduction

The MEASNET Wind Direction Sensor Calibration Procedure is the measurement procedure agreed upon by the MEASNET members to be mutually used and accepted. The procedure provides the basis for a common interpretation and understanding in accordance with the MEASNET Quality Evaluation Program whose main objective is the continuous improvement of the measurement quality.

The MEASNET Wind Direction Sensor Calibration Procedure applies Annex A of IEC 61400-50-1 (Edition 1, 2022)[1].

The MEASNET Expert Group – Wind Sensor Calibration has agreed to compile the present document which provides the common understanding and implementation of the Reference Standard among the MEASNET organization. The procedure includes -where required- interpretations of specific technical issues, guidance for implementation of flow quality tests and specific additional requirements such as a methodology for quantifying the Proficiency Test results.

The document will also be utilized in the assessment of MEASNET applicants.

2. Reference Measurement Procedure

The Reference Measurement Procedure on which the present MEASNET Wind Direction Calibration Procedure is based on:

IEC 61400-50-1, Edition 1, 2022(Annex A- Wind tunnel calibration procedure for wind direction sensors).

3. MEASNET implementation of the Reference Measurement Procedure

In the IEC 61400-50-1, Ed.1 – Annex A several terms are used with ambiguous definitions. The following usage is suggested for MEASNET members:

Term used in the IEC standard	MEASNET recommendation
Reference wind direction sensor Quality control wind direction sensor	Reference wind direction sensor and quality control wind direction sensor: It is understood that both terms refer to a sensor which has been designated by the calibration laboratory to check the integrity of the wind tunnel. Thus, it is hereby recommended to use the term “quality control sensor”.
Calibration certificate Calibration report	Although ISO 17025 states that the terms calibration certificate and calibration report are equivalent for the ease of reading it is understood that calibration certificate shall be used.
Wind tunnel centreline	MEASNET underlines that the wind tunnel centreline is not necessarily aligned with the flow direction. Thus, the reference for the sensor to be calibrated shall be done with reference to the flow direction.

The following sections are numbered according to the relevant clauses of IEC 61400-50-1, Ed.1 – Annex A. The IEC standard sets a list of requirements which are interpreted below when required.

A.1. General requirements

Point b of the list in the standard states that *“(...) All reference standards used during the calibration of the wind direction sensor shall be stated within the test report of the calibration campaign.”*

As the term “Test report of the measurement campaign” is not clearly defined, MEASNET recommends documenting the used reference standards in the Quality Management System of the Calibration Laboratory.

Point c of the list in the standard states that *"Prior to every calibration campaign (when a batch of wind direction sensors is being calibrated) the integrity of the experimental setup shall be verified by means of a comparative calibration of the calibration facility's "quality control wind direction sensor".*

MEASNET recommends doing the corresponding quality control measurement regularly, preferably daily.

A.2. Requirements of the wind tunnel

The standard states that *"The wind tunnel shall meet the requirements of Clause 8."*

MEASNET states that more specifically the requirements of clause 8.2 must be met. Especially for the assessment of flow uniformity the requirements of chapter 8.2 shall be followed.

The standard states that *"(…) the blockage ratio – defined as the ratio of the wind direction sensor frontal area with the fin oriented in line with the flow plus its mounting system to the total test section area – shall not exceed 0 for an open test section and 0,05 for a closed test section."*

MEASNET understands that blockage ratio of 0 is a typo in the standard. It is understood that the same logic as in chapter 8.2 applies, which demands that the ratio for open and closed test sections shall not exceed 0.05 in both cases.

The wind tunnel facility shall undertake repeatability and reproducibility tests as per VIM 2.25 definition. The laboratory shall assign one quality control sensor for that purpose.

It is understood that the quality control sensor (reference wind direction sensor) shall only be used internally by the calibration laboratory to check the performance of wind tunnels. The sensor can be used for different wind tunnels **within** the same laboratory but must not be used outside the laboratory for that purpose.

The standard defines that the maximum difference between calibrations of the same reference sensor (compared to average) should be less than 0.5° at 8 m/s. MEASNET recommends setting a limit of 0.5° for the repeatability tests (10 consecutive measurements) and 1° for the reproducibility tests. The reproducibility test shall be based on a statistically significant number (at least 50) of calibrations gathered during a period of at least 3 months that form the reference average values.

The repeatability and reproducibility shall be examined at the establishment of the wind tunnel facility and again after any modification of it.

A.3. Instrumentation and calibration setup requirements

The standard states that *"The reference angle measurement sensor shall be positioned in the tunnel as accurately as possible, and it may not disturb the wind direction sensor under test. The maximum deviation allowed is 0,1°."*

MEASNET clarifies that **any** equipment in the measurement chain and within the wind tunnel shall not influence the wind direction calibration.

In line with the requirements of the anemometer calibration the tolerance of mounting tube diameter should be +/- 1.5 mm, following the correction done in Section 10.2.

For sensors that route the cables outside the mounting boom the cable mounting should be as close as possible to the field/customer mounting as possible.

Mounting arrangement alternative to tubes may be used in the calibration set-up if instructed by the client and must be reported within the calibration certificate.

The standard requires that the wind direction sensor shall be aligned relative to the datum line (centreline) of the wind tunnel and that the mechanical reference indicator (usually the north mark) of the wind direction sensor shall be properly aligned in relation to the datum line of the wind tunnel.

Most importantly the wind direction sensor must be aligned with the flow of the wind tunnel, which might or might not be parallel to the datum line of the same.

A.4. Calibration procedure

For stepwise calibration procedure the duration of measurement at each step shall be selected according to the sampling frequency of the measurement system as well as the characteristics of the device under test.

The sampling frequency shall be high enough (usually 1 Hz or faster) to have a sampling bias within acceptable limits. Furthermore, the averaging time of the wind direction sensor has to be considered, especially for a continuous calibration with a constant rate of rotation.

The wind speed must be kept within the limits of 8 m/s ± 0.8 m/s during the whole calibration procedure.

A.6. Uncertainty analysis

Point c of the list in the standard states an uncertainty contribution related to the *"mounting uncertainty of the wind direction sensor (alignment of north mark and fin relative to the wind tunnel centreline)"*.

As stated in "Annex A – General" the wind tunnel centreline is not necessarily aligned with the flow direction. Therefore, the mounting uncertainty of the wind direction sensor (alignment of north mark and fin relative to the **horizontal flow direction**) and additionally an uncertainty component for the determination of the horizontal flow direction shall be considered in the uncertainty analysis.

The uncertainty when measuring the electrical or non-electrical signal of the wind direction sensor (electrical transducer, digital conversion, etc.) must be taken into account for the uncertainty analysis.

A.7. Reporting format

Beside the required information in the standard the test report on the calibration facility setup shall contain repeatability documentation of wind direction sensor calibration as well as documentation of the reproducibility.

According to point h) the calibration certificate shall state the regression parameters (offset and slope), in tabular and graphical presentation of all calibration points. MEASNET agrees that additional evaluation methods for transfer function could be used such as the mean deviation between reference sensor and wind direction sensor under test.

The information of measured north dead-band width can be omitted as the standard provides no procedure how to measure the north dead-band.

The graphical representation of the measurement results shall contain “uncertainty associated with each measuring point”. It is understood that here bins are meant rather than individual measuring points.

Annex A. MEASNET wind direction sensor Proficiency Test (PT) rules

The MEASNET proficiency test (PT) on wind direction calibration is organized under the responsibility of the MEASNET Expert Group Wind Sensor Calibration. The MEASNET Expert Group Wind Sensor Calibration nominates the coordinator for each PT.

A.1. PT plan

A PT plan should be agreed upon and shall be documented before commencement of the scheme, and should include the following information:

a) the name and address of the PT provider,
b) the name and address of the coordinator and other personnel involved in the design and operation of the scheme,
c) the nature and purpose of the scheme,
d) the reference procedures (the MEASNET ExG must decide whether to use a continuous or a step wise measurement procedure for the proficiency test. This procedure must be used by all participating laboratories),
e) the expected participants (Names and addresses)

Additionally, to the above the PT plan should include information on the following:

- Identification of wind direction sensors to be calibrated. This should include at least the following:
  - Wind direction sensor type and manufacturer
  - Wind direction sensor individual identification (serial number, equipment code etc.)
  - Mounting method and main dimensions. It is recommended that a common mounting boom is supplied for each wind direction sensor and where possible is used by all institutions. Where the wind tunnel layout of an individual institution does not allow for the use of the provided common mounting boom, a different boom may be used, provided that at least the part of the boom immersed in the wind tunnel flow is identical to the “common mounting boom” provided for the PT.
  - Information about electrical connections and operating principles for each wind direction sensor (preferably copies of the respective manufacturers manuals)
- A time schedule including the expected initial and target dates or deadlines of the scheme, and, where appropriate, the dates on which testing is to be carried out by participants
- Outline of the statistical analysis to be used, including the determination of assigned values and any outlier detection techniques
- A description of the data or information to be returned to participants
- A description of the extent to which the PT results and conclusions are to be made public

Special issues:

- Two or more institutions using the same wind tunnel but with different instrumentation are counted as different participants.
- One institution with two or more wind tunnels will decide which wind tunnel will be used for defining the "MEASNET reference value". The other wind tunnel(s) of the same institution will be assessed for compliance if requested but will not be included in the estimation of the reference MEASNET value. It is not mandatory to have all wind tunnels assessed, but **if only one wind tunnel is assessed** and it fails, it will then be handled as if all wind tunnels of this institution have failed.

A.2. Statistical analysis of PT results

The following steps are followed:

Step 1: Assessment of wind direction sensors integrity.

When receiving the wind direction sensor(s), the participant must assess the physical condition of the sensor. In case of signs of damage or irregular operation the coordinator must be informed immediately.

After the end of the measurement campaign by all participants, the physical condition of the wind direction sensors used will be assessed by the laboratory providing the initial and final calibration. In case any sign of damage, degradation, or irregular operation that could possibly have effect on the PT results is identified on any of the wind direction sensors used in the PT, then this wind direction sensor must be discarded from the PT and the result obtained must not be used in the compilation of the PT results.

Step 2: For each wind direction sensor three output values are determined, corresponding to wind directions of about 0, 180, 360 degrees.

Step 3: For each wind direction sensor and for each of the three values the wind direction according to the calibration results (slope and offset) of the PT participants are calculated.

Step 4: As a first estimate of the MEASNET-reference wind direction deviation the results per wind direction sensor and per wind direction of all institutes recognized by MEASNET for wind direction sensor calibration are averaged. The standard uncertainty of this reference wind direction deviation is $\frac{\sigma}{\sqrt{N}}$ in which N is the number of MEASNET institutes that calibrated the regarded wind direction sensor and σ is the standard deviation of the values reported by the laboratories.

Step 5: Per wind direction sensor the results of the calibration of a MEASNET recognized institute are discarded when the average deviation with respect to the estimated average reference wind direction deviation is deviating more than $1 + \frac{\sigma}{\sqrt{N}}$ degree from the reference. This step is carried out several times until no more data is discarded. The measurements are discarded in the order of their deviation, the biggest deviation first.

Step 6: For each wind direction sensor and for each output value the MEASNET-reference wind direction deviation is defined as the average value of the non-discarded values.

Step 7: For each wind direction sensor and for each output values the difference between the wind direction obtained with the various calibration results of the participating institutes and the MEASNET-reference wind direction is determined.

Step 8: At each wind direction the differences obtained from each institute for all wind direction sensors result in a series of values with an averaged value and a standard deviation. 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 a quantity that characterizes the compliance of the calibration institute with the MEASNET-reference wind direction deviation. (stdevp = standard deviation of the population).

Step 9: The values (|AV|+stdevp) are averaged for the wind direction bins/steps.

PASS / FAIL Criterion: The institutes with an average value of the Compliance Factor ≤ 1.5 degrees comply with the MEASNET requirement for wind direction sensor calibration uncertainty.

It is recommended to perform an in-depth comparison of interlaboratory calibrations taking into account air temperature, pressure and indirect air density or other relevant parameters (e.g. turbulence) for explaining/investigating deviations. The motivation should be to reduce the differences of calibration results between different calibration facilities for the benefit of the industry.

Annex B. Compatibility Index En

Compatibility index En measures the ratio between the deviation of the measurements of the laboratory and the declared uncertainty. It is defined as:

$$En = \frac{|x_L - x_{PT}|}{\sqrt{U^2(x_L) + U^2(x_{PT})}}$$

where x_L is the direction deviation value according to the laboratory calibration, x_{PT} is the proficiency test reference wind direction deviation value and $U(x_L)$ and $U(x_{pt})$ are the expanded uncertainties (k=2) of the laboratory's measurement and of the proficiency test reference wind direction deviation, respectively (see equation B.6 of ISO/IEC 17043:2023). The test reference wind speed uncertainty is estimated as:

$$U(x_{pt}) = 2 * \frac{\sigma}{\sqrt{N}}$$

where σ is the standard deviation of the direction deviations declared by the laboratories and N is the number of laboratories that have been used to calculate the proficiency test reference wind direction deviation.

The compatibility index En, which is based on the participants' reported estimates of measurement uncertainty, are only meaningful if the uncertainty estimates are determined in a consistent manner by all participants; this requirement is fulfilled in the present application.

A compatibility index bigger than 1 indicates that the deviation of the laboratory from the PT reference value is not compliant with the laboratory's declared uncertainty.

References

[1] IEC 61400-50-1, Ed.1 – Annex A, November 2022.