Calibration of wind direction sensors at Deutsche WindGuard Wind Tunnel Services GmbH

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

Deutsche WindGuard Wind Tunnel Services GmbH is accredited by Deutsche Akkreditierungsstelle GmbH(DAkkS) as a calibration laboratory according to DIN EN ISO/IEC 17025:2005 (DAkkS registry-no: D-K-15140) for the calibration in the field of fluid quantities of velocity of gases (anemometers) and direction of flow (wind vanes).

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	23.07.2018	1st issue	

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

Contents

This report covers 17 pages.

1 Introduction

The calibration of wind direction sensors is very important to ensure the correct evaluation of gathered measurement data. In the new edition of the IEC 61400-12-01 international standard, Wind energy generation systems – Power performance measurements of electricity producing wind turbines [1], Annex N, the recommended wind tunnel calibration procedure for wind direction sensors is described.

There are other standards which cover the calibration or testing of wind direction sensors for example the ISO 16622:2002 Meteorology – Sonic anemometers/thermometers – Acceptance test methods for mean wind measurements [2] or the ASTM D 5366 – 96 Standard Test Method for Determining the Dynamic Performance of a Wind Vane [3].

This document describes the standard calibration procedure of wind direction sensors in a wind tunnel of Deutsche WindGuard Wind Tunnel Services GmbH, where it is possible to calibrate different kinds of wind direction sensors, wind vanes as well as ultrasonic anemometers with different wind direction output signals (analog and digital outputs).

First the wind tunnel and the instrumentation are specified. Further, the setup of the wind direction sensor in the wind tunnel and the measurement procedure are explained. Afterwards, the evaluation of the different sensor outputs is described and at the end, the associated uncertainties are listed, followed by a conclusion.

2 Wind tunnel

Deutsche WindGuard Wind Tunnel Services GmbH is currently 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 1.

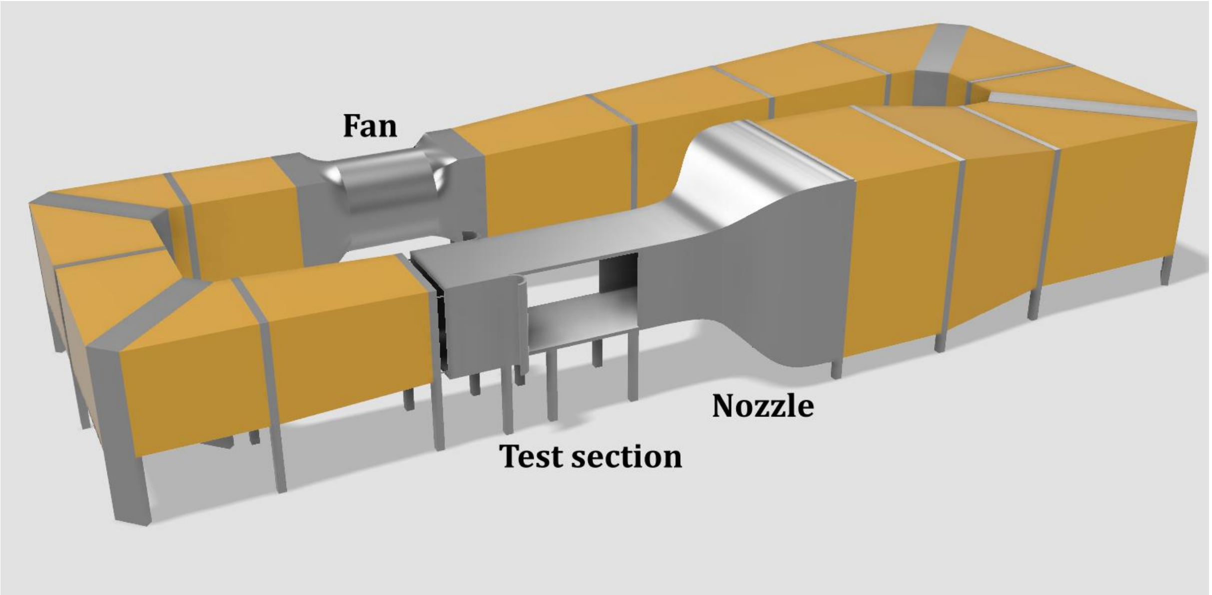

Figure 1: Basic layout of WindGuard calibration tunnels at the Varel facility.

The calibration of wind direction sensors is performed in wind tunnel WK2, which has the following specifications:

Test section size:	1000 x 1000 mm
Test section length:	1800 mm
Contraction ratio:	5.6 : 1
Accredited air velocity range:	ca. 0.5 – 38.0 m/s
Turbulence intensity:	< 0.2 %
Wind tunnel length:	38 m
Wind tunnel height:	2.5 m

Some tests were performed to evaluate the suitability of the wind tunnel as a calibration wind tunnel for wind direction sensors. First the test section centerline was determined with an uncertainty of 0.1 degree. To verify that the horizontal air flow is aligned parallel in relation to the test section centerline, measurements with a wedge type probe were done also with an accuracy of 0.1 degree. The flow quality was examined with an 2D ultrasonic anemometer, resulting in a statistical uncertainty in flow direction of 0.1 degree. In addition, a permanently installed 2D ultrasonic anemometer is used as a secondary instrument to further monitor the actual flow quality with respect to wind direction and flow speed. [4]

The yaw angle of the test item is measured by a rotary encoder with a traceable angular calibration. Further, an encoder calibration check is performed in place at least once every year by means of comparing geometric proportions which are transferred via centerline punch marks to the wind tunnel test section floor plate. The latest measurements resulted in a deviation of about 0.2 degree, while the calibration uncertainty of the rotary encoder according to the calibration certificate is 0.3 degree. [4]

2.1 Instrumentation for wind direction sensor calibration

To calibrate a wind direction sensor the flow speed (usually 8 m/s) is kept constant while the sensor is rotated around its vertical axis. The rotation is induced by a drive unit and the reference angle is measured with a rotary encoder, which is connected via a bellows coupling with the drive unit. The axis of the rotary encoder is concentric and coaxial in respect to the sensor and drive unit rotation axis. The setup of the instrumentation is therefore identical with the example given in the IEC standard (see Figure 2).

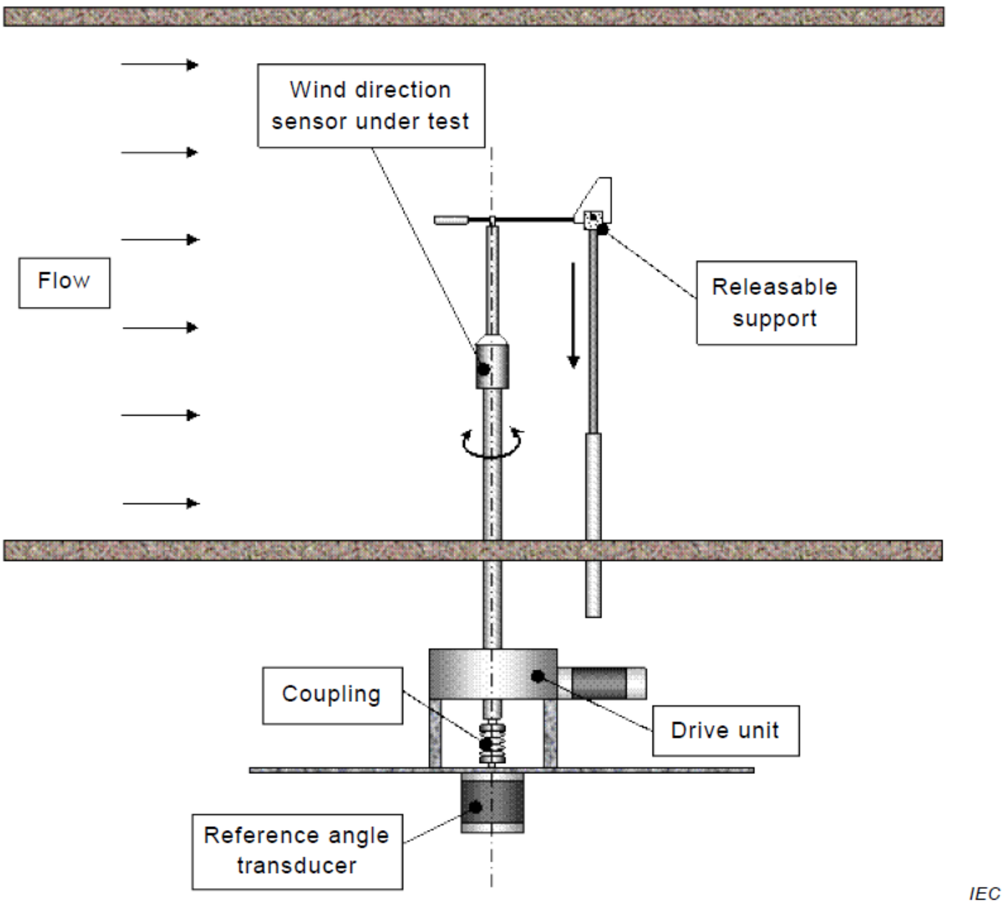

Figure 2: Calibration setup of wind direction sensor and measurement instrumentation. [1]

3 Calibration procedure

The calibration procedure starts with the installation of the sensor in the wind tunnel, followed by the measurement of the yaw response. Finally, the measurement data is evaluated and provided in a calibration report.

3.1 Setup of the wind direction sensor

The wind direction sensor with its yaw reference mark has to be aligned relative to the centerline of the wind tunnel. Two line lasers are permanently installed in the wind tunnel to generate laser beams which intersect the centerline of the wind tunnel and are vertically orientated. The mechanical reference indicator (typically the north mark) of the sensor and the laser beams are used to properly align the sensor with the centerline of the wind tunnel. For common types of wind direction sensors, a custom made precision alignment device by WindGuard is used to further increase the accuracy of the initial alignment.

In case of a wind vane type wind direction sensor, the fin is likewise aligned with the laser beam and therefore the centerline of the wind tunnel (see Figure 3). The position of the fin is fixed with a releasable support.

Customers will usually align the sensor according to the north mark. As there can be a deviation between north mark and electrically indicated northern direction, it is not adequate to align the wind direction sensor with help of the electrical output signal. Therefore, the north mark has to be used during the setup in the wind tunnel to align the sensor.

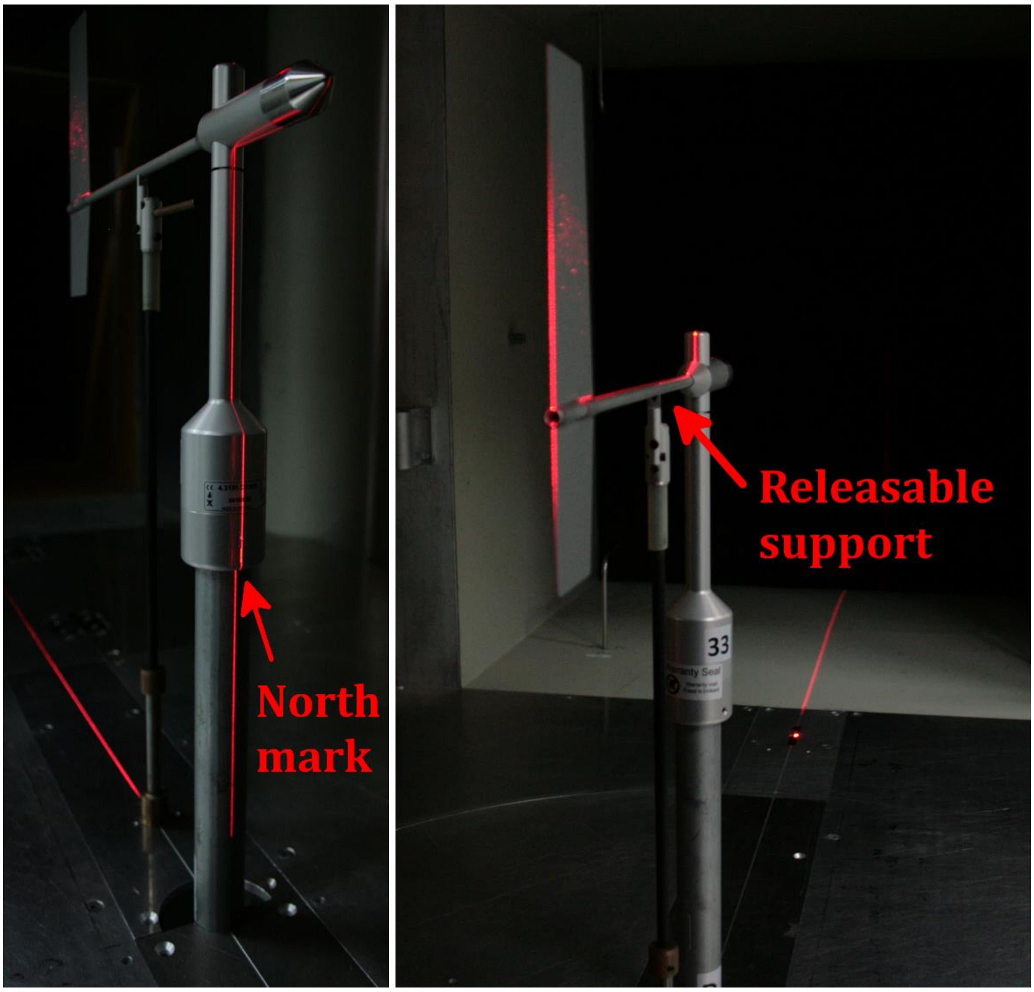

Figure 3: Setup of a wind direction sensor by means of a line laser beam in wind tunnel WT2 of Wind-Guard (left: view out of the nozzle, right: view into the nozzle).

3.2 Measurement procedure

Prior to the measurement campaign a measurement with a statistical quality control wind direction sensor is done. The purpose of this measurement is to verify the integrity of the whole measurement setup, the data handling, the air flow quality and the adjustment of the rotary encoder.

After the installation of the sensor the measurement procedure starts with a measurement at 0 m/s (static offset: Deviation between test item output signal and mechanical yaw alignment). The air velocity is then increased (normally to 8 m/s) and in the case of a wind vane the support of the fin is released. If the wind vane has an optimal aerodynamic behavior, the position of the vane will not change after releasing the support. If the vane is asymmetrical (e.g. bent fin) a new stable position will be taken and the dynamic offset will be measured.

As already explained, the air velocity and flow direction remain constant during the calibration of the wind direction sensor, while the sensor itself is rotated around its vertical axis. This rotation can be done at a constant yaw rate or stepwise. If done stepwise, it is possible to miss erroneous direction data from the sensor. Therefore, the measurement is done with a constant yaw rate of approximately 0.5 °/s and a sampling frequency of 4 Hz.

Two complete yaw sweeps are performed. To cover possible hysteresis effects, the sweeps are of opposite direction and an overlap of at least 20° ensures that the sweep covers the measuring range of the test item entirely. The sequence covers a counter clock-wise rotation of the drive unit from 0° to at least 380° and a clockwise rotation from at least 380° to 0°.

3.3 Evaluation

During the evaluation, the output signal of the wind direction sensor is assessed in relation to the reference angle measurement system (rotary encoder). The measurement data is evaluated as bin-averages, where the bin-width is usually 5° ranging from 2.5° up to 357.5°. The evaluated angle range may be modified due to the width of the deadband, which is excluded from the evaluation data. The analysis is done by vector averaging as described in ISO 16622:2002 [2] and VDI 3786 [6].

For each different kind of wind direction sensor output signal a different evaluation method is required. The possible wind direction sensor and output signal combinations are listed in Table 1.

Table 1: Possible combinations of wind direction sensor type and output signal.

Sensor Type	Output Signal	No.
Wind vane	Digital	1
	Analog	2
	Ratiometric	3
2D Ultrasonic Anemometer	Digital [magnitude v horizontal, direction]	4
	Analog [magnitude v horizontal, direction]	5
	Digital [u,v]	6
	Analog [u,v]	7
3D Ultrasonic Anemometer	Digital [magnitude v horizontal, w, direction]	8
	Analog [magnitude v horizontal, w, direction]	9
	Digital [u,v,w]	10
	Analog [u,v,w]	11

3.3.1 Digital output signal of the wind direction

In the case of a digital output signal, giving the wind direction already in degree (Table 1, No. 1, 4 and 8), it is not applicable to calculate a slope and offset of the measurement data. As the output signal reaches from 0° to 360° as well as the reference yaw angle, in theory the offset should be 0 and the slope has to be 1. It is possible that there is an offset due to a wrong position of the north mark (static offset) or a fin misalignment (dynamic offset). Nevertheless, the ideal slope should remain 1.

Therefore, in the calibration certificate the air velocity and the reference yaw angle are listed with their uncertainty values together with the output of the wind direction sensor and the calculated deviation between sensor wind direction output and the reference yaw angle (see Figure 4). The deviation values are used to calculate an average offset. This offset value comprises the dynamic and static offset.

Reference Air velocity m/s	Reference Unc m/s	Reference Yaw angle deg	Reference Unc deg	Test item Direction deg	Test item Deviation deg
8.11	0.05	150.00	0.80	149.85	0.15
8.11	0.05	154.99	0.80	154.85	0.14
8.11	0.05	159.94	0.80	159.88	0.06

Figure 4: Example of the listed measurement results of a wind wind vane with digital output signal.

Furthermore, the reference yaw angle and the deviation are plotted against the output of the wind direction sensor (see Figure 5).

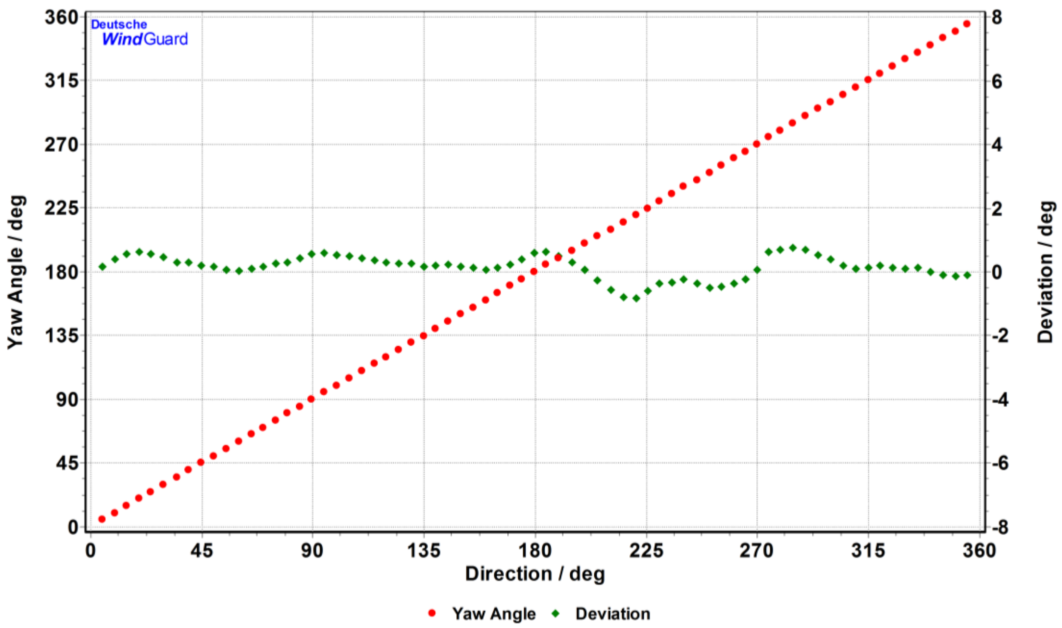

Figure 5: Example of the graphical representation of the results of a wind direction sensor with a digital output signal.

3.3.2 Analog output signal of the wind direction

If the wind direction sensor indicates the wind direction with an analog output signal (voltage or current) (Table 1, No. 2, 5 and 9), a linear regression is necessary to convert the output signal to a wind direction in degree. It is important to point out that the calibration function in this case contains the information of the conversion from the analog signal to the physical value 'degree' and also considers the linear correction of the 'non-ideal' behavior of the wind direction itself.

In the calibration certificate, the air velocity and reference yaw angle with the corresponding uncertainty values are given as well as the sensor output (see Figure 6). The slope and the offset are calculated for the bin average data, where the offset again comprises the dynamic and static offset.

Reference Air velocity m/s	Reference Unc m/s	Reference Yaw angle deg	Reference Unc deg	Test item Sensor out V
8.091	0.05	149.939	0.800	1.025
8.089	0.05	155.034	0.800	1.059
8.092	0.05	160.024	0.800	1.093

Figure 6: Example of the listed measurement results of a wind direction sensor with an analog output signal.

Furthermore, the reference yaw angle and residuals are plotted against the sensor output (see Figure 7).

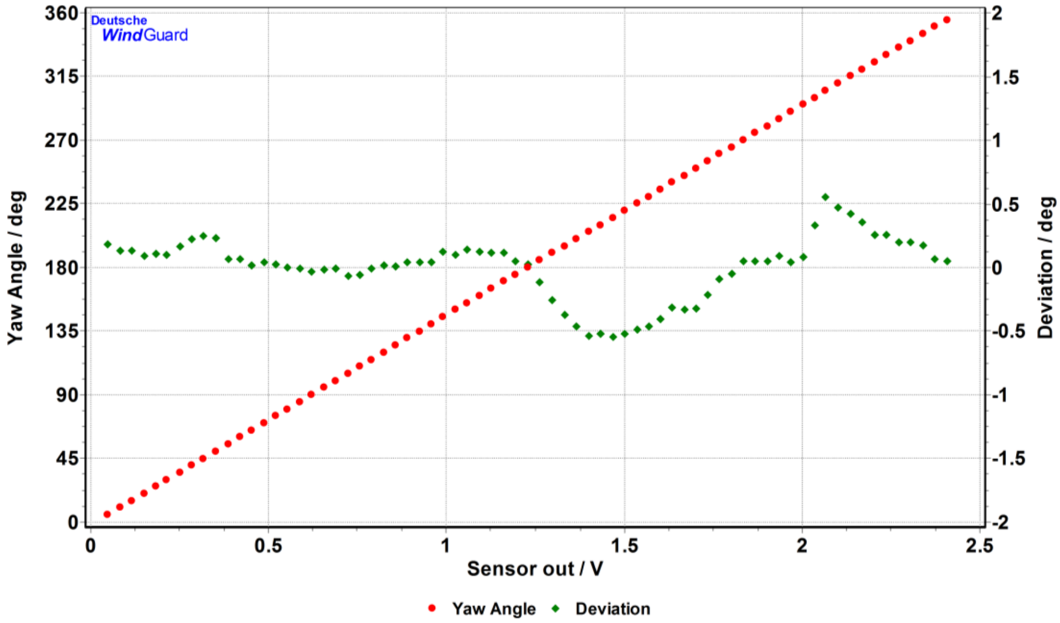

Figure 7: Example of the graphical representation of the results of a wind direction sensor with an analog output signal.

3.3.3 Potentiometer wind vane

A potentiometer wind vane (Table 1, No. 3) produces a ratiometric output signal.

The potentiometer acts as a variable resistor depending on the wiper position, which moves in accordance with the yaw rotation of the fin (see Figure 8). The output signal voltage is produced by the voltage drop across the potentiometer. Thus, the signal output voltage depends on the supply voltage given, but the ratio of signal output voltage divided by supply voltage is independent.

The signal output voltage can reach from 0 V up to a maximum which is equal to the supply voltage. There can be a decreased voltage range due to protective circuits (e.g. resistors). Furthermore, a potentiometer wind vane usually has a deadband. When the wiper is within this deadband zone it will either behave as a short circuit or will have high impedance.

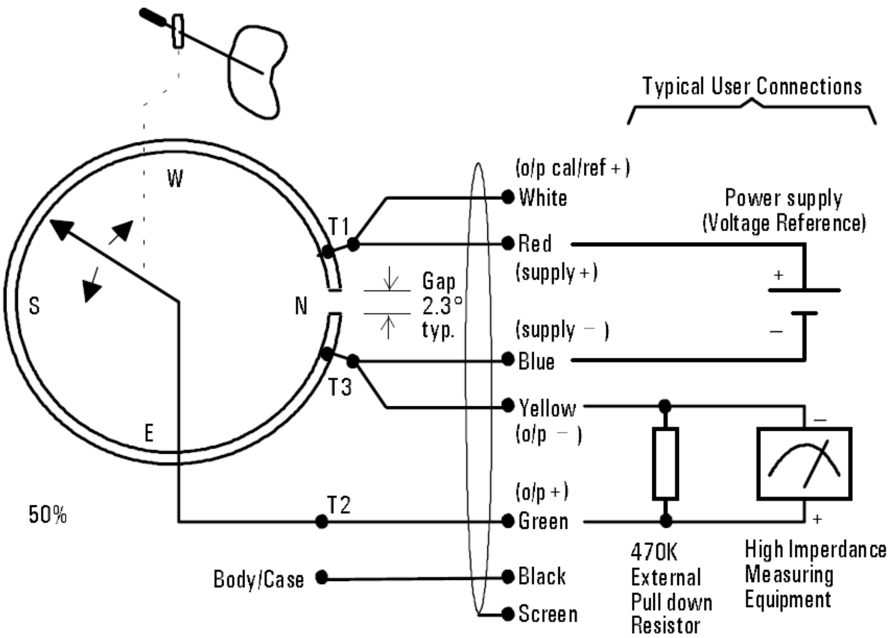

Figure 8: Graphical representation of a typical application circuit of a potentiometer wind vane given in the specification sheet of the Windspeed Ltd. (Vector Instruments), W200P. [7]

The supply voltage in the field can differ from the voltage supplied during the calibration. As the output signal depends on the input signal, a linear regression analysis of the measured sensor output signal is not applicable. Instead, the ratio of supply voltage and output signal voltage is used for a linear regression analysis. The slope and offset values can be used by the costumer to calculate the correct wind direction from the ratio measured in the field.

If the output would only be influenced by the deadband of the potentiometer and the deadband would perfectly be located around the north mark, the wind direction could be calculated with the following equation [8]:

$$\alpha = (360 - D)x + \frac{D}{2} \quad (1)$$

where:

D is the deadband in degrees,

x is the ratio between output signal voltage and input/supply voltage.

Hence, the slope and offset values given in the calibration certificate provide an indication of the deadband width and also comprise the static and dynamic offset of the wind vane. Furthermore, in the calibration certificate the flow speed, the reference yaw angle as well as their uncertainty values are given (see Figure 9). Additionally, the input/supply voltage and the output signal voltage are listed, together with a ratio of output signal voltage divided by input voltage.

Reference Air velocity m/s	Reference Unc m/s	Reference Yaw angle deg	Reference Unc deg	Test item Source V	Test item Wiper V	Test item Ratio -
7.92	0.05	150.01	0.80	7.999	3.314	0.4143
7.92	0.05	155.04	0.80	7.999	3.426	0.4284
7.92	0.05	160.00	0.80	7.999	3.538	0.4424

Figure 9: Example of the listed measurement results of a potentiometer wind vane.

Furthermore, a scatter plot shows the reference yaw angle and residuals against the ratio (see Figure 10).

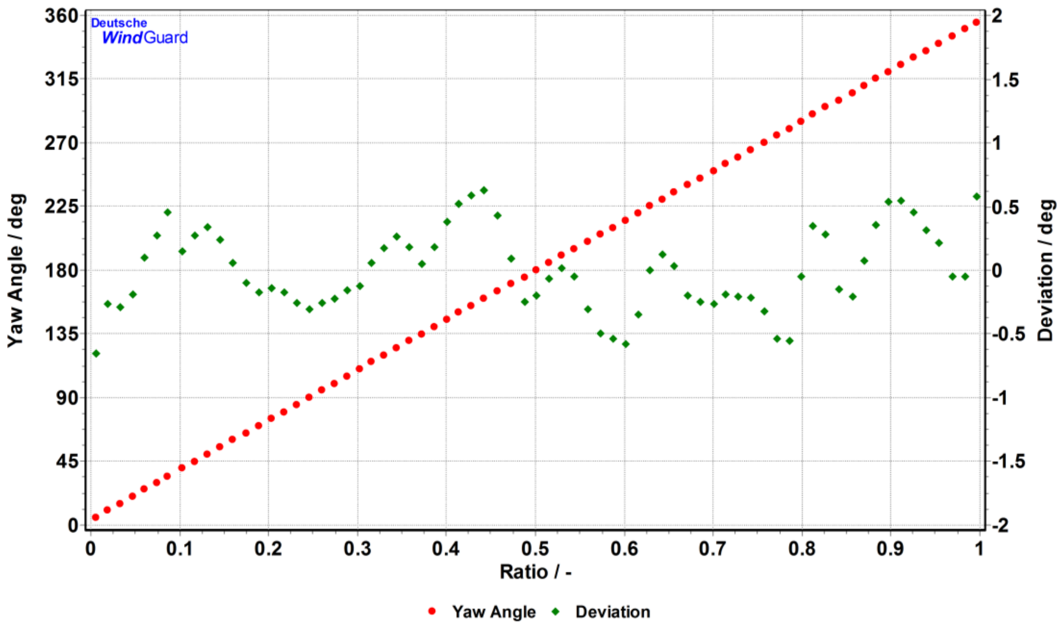

Figure 10: Example of the graphical representation of the results of a potentiometer wind vane.

3.3.4 Output signal of wind direction vector [u,v(,w)]

Some ultrasonic anemometers are adjusted to indicate the single wind direction vector components as output signal (Table 1, No. 6, 7, 10 and 11). With the two horizontal components [u,v] the wind direction can be calculated with the same equation as used for the vector averaging, mentioned in section 3.3.

The calibration certificate lists the air velocity and the reference yaw angle together with their uncertainty values, as well as the single wind direction vector components measured with the tested ultrasonic anemometer.

The output signal can be digital or analog. But, as we are measuring single wind speed components, a linear regression for each component and the reference yaw angle is not appropriate. The customer can use the measurement data to calculate the wind direction from the measured sensor output or can calculate the wind speed components from the reference wind speed and yaw angle.

As the single horizontal wind direction vector components have a sin- and cosinusoidal relation to the reference yaw angle, there will be no graphical representation of the measurement data in the calibration certificate.

4 Measurement uncertainty

The measurement uncertainty is composed of an uncertainty in the determination of the flow direction and uncertainties attributed to the tested sensor.

The uncertainty in the determination of the flow direction covers repeatability, determination of geometrical centerline, determination of the flow direction, the rotary encoder and its inclination angle as well as eccentricity. The uncertainty attributed to the tested sensor covers the output signal, the mounting of the wind direction sensor, as well as the inclination angle and eccentricity.

The total uncertainty is calculated to be 0.4 degree. In the calibration certificate the uncertainty values are specified as an expanded uncertainty with a coverage probability of 95% (coverage factor k=2). It has been determined in accordance with DAkkS-DKD-3, the given uncertainty has to be equal or greater than the minimum uncertainty arranged with the DAkkS (min. 0.8 degree, k=2).

5 Conclusion

First, the wind tunnel successfully proved to be suitable for the calibration of wind direction sensors. Furthermore, the standard calibration of a wind direction sensor at Deutsche WindGuard is performed on the basis of the IEC 61400-12-1 Annex N [1] and can be done for the different kinds of output signals possible.

The different evaluation methods depending on the output signal are described in section 3.3, where it is pointed out that a linear regression analysis isn't always applicable. Therefore, the content of the calibration certificate regarding the evaluation of the measurement data deviates slightly from the suggested content in the IEC Annex N.

Anyhow, it is also possible to perform customized measurements, for example at different air velocities or for a specific reference yaw angle range. Furthermore, starting threshold and overshoot measurements can be performed according to the ASTM D 5366 – 96 [3], as well as ultrasonic wind tunnel tests according to ISO 16622:2002 [2].

6 References

[1] IEC 61400-12-1, Edition 2.0, Wind energy generation systems – Power performance measurements of electricity producing wind turbines, March 2017

[2] ISO 16622:2002, Meteorology – Sonic anemometers/thermometers – Acceptance test methods for mean wind measurements, September 2002

[3] ASTM D 5366 – 96, Standard Test Method for Determining the Dynamic Performance of a Wind Vane, 2017

[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 Kalibrieren von Windrichtungssensoren, ID: D5836, Revision: 4, July 2017
- AA Arbeitsanweisung Windrichtungskalibrierung, ID: D5835, Revision: 1, November 2012

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

[6] VDI 3786, Part 2, Meteorological measurements concerning questions of air pollution – Wind, Dezember 2000

[7] Windspeed Ltd (Vector Instruments), 050-202-07 (S-W200P-7), W200P Potentiometer Windvane Specification Sheet, June 2003

[8] Windspeed Ltd (Vector Instruments), 010-211-02 (OI-W200P-7), W200P Potentiometer Windvane Operating Instructions