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WIND
ENGINEERING
FLUID
DYNAMICS

CLASSIFICATION REPORT

WindSensor P2546-OPR Cup Anemometer

Classification performed in accordance with
IEC 61400-12-1:2017
Power performance measurements of electricity producing wind turbines

Conducted by Svend Ole Hansen ApS,
accredited to ISO/IEC 17025:2017
for cup anemometer classification

CLASSIFICATION REPORT

Classified items

Type	WindSensor Cup Anemometer P2546A-OPR, P2546C-OPR, P2546D-OPR
Serial numbers	16264, 16501, 19846, 19854, 19870
Manufacturer	WindSensor, Frederiksborgvej 399, 4000 Roskilde, Denmark
Items received	2019-05-21, 2019-05-27

Classification

Laboratory	Svend Ole Hansen ApS, Sct. Jørgens Allé 5C, DK-1615 København V
Procedure	IEC 61400-12-1:2017, Annex F, I and J
Wind tunnel	Calibration wind tunnel, octagonal cross section, height 1.2 m
Client	The work was performed as part of the EUDP TrueWind project, journal number 64015-0635.
Test period	2019 - 2020
Approved by	SOH

Test report

Test report number	CL.20.01
Date of issue	2021-02-21
Issued by	SOH

Classification results

The resulting class numbers for the four predefined terrain and climate ranges are shown below. Five anemometer samples of the cup anemometer model were tested and a resulting class number**,** *k*, was determined as a weighted average of the five individual class numbers.

Terrain and climate ranges	**Class A**	**Class B**	**Class C**	**Class D**
Resulting class number, *k*	**1.04**	**3.76**	**1.32**	**3.80**

Accreditation

The laboratory is accredited to ISO/IEC 17025:2017 for cup anemometer classification by DANAK.
The laboratory is accredited to ISO/IEC 17025:2017 for anemometer calibration by DANAK.
The laboratory is approved by MEASNET and IECRE for calibration of anemometers.
DANAK is signatory to the European co-operation for Accreditation (EA) Multilateral Agreement and to the International Laboratory Accreditation Cooperation (ILAC) Mutual Recognition Arrangement.

Svend Ole Hansen

Authorized Signatory, Svend Ole Hansen

DANAK

TEST Reg.nr. 452

1. Accredited classification of the WindSensor P2546-OPR Cup Anemometer

The basic cup anemometer parameters of P2546-OPR are given in Table 1. A photo of a cup anemometer of the same type as the classified one is shown in Figure 1.

Make	WindSensor
Types	P2546A-OPR, P2546C-OPR and P2546D-OPR
Body diameter	46 mm
Overall height	282 mm
Swept diameter of rotor	188 mm
Cup diameter	70 mm (conical)
Cup area	0.00385 m^2
Pulses per revolution	2
Rotor mass (individually determined)	0.064 kg
Rotor inertia (individually determined)	0.000111 kg m^2

Table 1. Basic cup anemometer data (consult the datasheet for further details)

Figure 1. The shown anemometer is of the same type as the classified one.

The resulting class numbers for the four predefined terrain and climate ranges are shown in table 2. Five anemometer samples of the P2546A-OPR Cup Anemometer model were tested and a resulting class number, determined as a weighted average of the five individual class numbers.

WindSensor P2546A-OPR Serial Number	**Class A**	**Class B**	**Class C**	**Class D**
16264	1.06	3.59	1.21	3.63
16501	0.98	3.75	1.46	3.81
19846	0.84	3.78	1.11	3.83
19854	1.07	3.78	1.13	3.81
19870	0.94	3.57	1.01	3.62
Resulting class number, k	**1.04**	**3.76**	**1.32**	**3.80**

Table 2. Individual and combined class number for Classes A, B, C and D

By identical aerodynamic response due to identical geometry, parts and materials and by similarity in calibration this classification is also valid for the P2546C-OPR and P2546D-OPR Cup Anemometers.

IEC 61400-12-1:2017 defines an additional Class S with user-defined ranges of the influence parameters as indicated in table 3. An online Class Calculator on WindSensor's web site allows for determining the S class number for any measured and filtered combination of the influence parameters.

2. IEC 61400-12-1:2017 classification influence parameter ranges

Classification is the process of determining the weighted systematic deviation from the wind tunnel calibration as expressed by a class number when the sensor is subject to a number of known influence parameters when operating in the field.

IEC 61400-12-1:2017 defines five different classes with individual combinations of terrain and climate influence parameter ranges as shown in table 3. For each class, a class number can be determined as the maximum weighted systematic deviation from the wind tunnel calibration of a cup anemometer sample. A class number of 1 corresponds to 1% deviation from the wind tunnel calibration at 10 m/s, but more than 1% below 10 m/s and less than 1% above 10 m/s.

Classification category	**Class A**	**Class B**	**Class C**	**Class D**	**Class S**
	Terrain meets requirements in Annex B	Terrain does not meet requirements in Annex B	Terrain meets requirements in Annex B	Terrain does not meet requirements in Annex B	Special class with user defined ranges
	Range	Range	Range	Range	Range
Wind speed [m/s]	4 to 16	4 to 16	4 to 16	4 to 16	4 to 16
Turbulence intensity	0,03 to 0,12 + 0,48/V	0,03 to 0,12 + 0,96/V	0,03 to 0,12 + 0,48/V	0,03 to 0,12 + 0,96/V	User defined
Turbulence structure $\sigma_u/\sigma_v/\sigma_w$	1/0,8/0,5*	1/0,8/0,5*	1/0,8/0,5*	1/0,8/0,5*	User defined or 1/0,8/0,5*
Air temperature [°C]	0 to 40	−10 to 40	–20 to 40	−20 to 40	User defined
Air density [kg/m^3]	0,9 to 1,35	0,9 to 1,35	0,9 to 1,35	0,9 to 1,35	User defined
Average upflow angle [°]	−3 to 3	−15 to 15	−3 to 3	−15 to 15	User defined
Wind direction [°]	Cups and sonics: 0° to 360°	Cups and sonics: 0° to 360°	Cups and sonics: 0° to 360°	Cups and sonics: 0° to 360°	Cups: 0° to 360° Sonics: User defined
* A non-isotropic Kaimal turbulence spectrum with turbulence length scale 350 m.					

Table 3. Influence parameter ranges of Classes A, B, C, D and S (from IEC 61400-12-1:2017 Annex I)

3. Measurements and classification method

All wind tunnel and laboratory measurements comply with the requirements set forth in IEC 61400-12-1:2017. Table 4 lists the classification method used for characterizing the cup anemometers.

Classification procedure	Reference
A. Wind tunnel calibration	IEC 61400-12-1:2017 Annex F
B. Tilt angular response characteristics – wind tunnel tests	IEC 61400-12-1:2017 Annex J.2.1
C. Directional characteristics – wind tunnel tests	IEC 61400-12-1:2017 Annex J.2.2
D. Rotor torque characteristics – wind tunnel tests	IEC 61400-12-1:2017 Annex J.2.3
E. Bearing friction torque characteristics – laboratory tests	IEC 61400-12-1:2017 Annex J.2.5.1
F. Classification based on wind tunnel and laboratory tests, and cup anemometer modelling	IEC 61400-12-1:2017 Annex I IEC 61400-12-1:2017 Annex J.3
G. Verification of cup anemometer model	IEC 61400-12-1:2017 Annex J.3.2

Table 4. List of classification procedures

The classification deviations in Section 3.F were calculated using the cup anemometer model verified in Section 3.G. The verification was based on the results for the example cup anemometer specified in IEC 61400-12-1:2007 Annex J.3.2.2.

A. Wind tunnel calibration

All five anemometers were calibrated according to IEC 61400-12-1:2017 Annex F. Table 5 shows the resulting calibration constants and correlation coefficients.

WindSensor P2546A-OPR Serial Number	Slope [m]	Offset [m/s]	Correlation coefficients
16264	0.62046	0.18584	0.999991
16501	0.62041	0.19507	0.999992
19846	0.61956	0.20731	0.999988
19854	0.61965	0.20549	0.999990
19870	0.61886	0.21590	0.999995

Table 5. Calibration constants and correlation coefficients

B. Tilt angular response characteristics – wind tunnel tests

Tilt angular response was measured by stepwise fixed angular position measurements, where the response at each tilt angle is determined by IEC 61400-12-1:2017 Annex F wind tunnel calibrations. The tilt response is subsequently calculated for the wind speeds of 4, 7, 10, 13 and 16 m/s. Figure 2 shows the tilt angular response curves and the fixed angular positions are indicated in the figure.

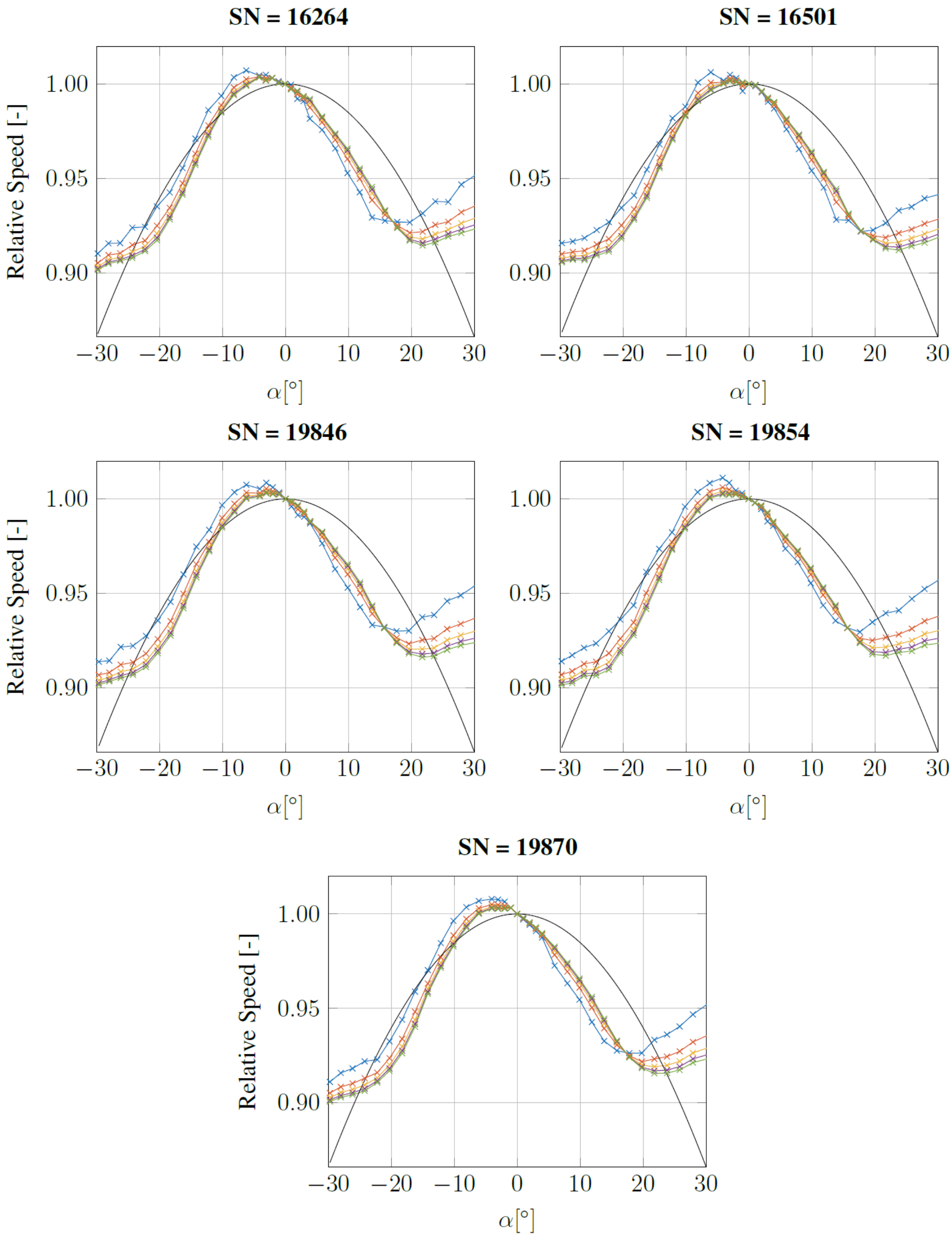

Figure 2. Relative wind speed as function of tilt angle, α, at 4, 7, 10, 13 and 16 m/s (blue, red, yellow, purple and green). A perfect cosine fit is shown with a black line.

C. Directional characteristics – wind tunnel tests

For a selected P2546A-OPR anemometer, Figure 3 shows the yaw sensitivity curves at 4 wind speeds as specified in IEC 61400-12-1:2017 Annex J.2.2. No clear pattern is observed and the cup anemometer is found not to be yaw sensitive.

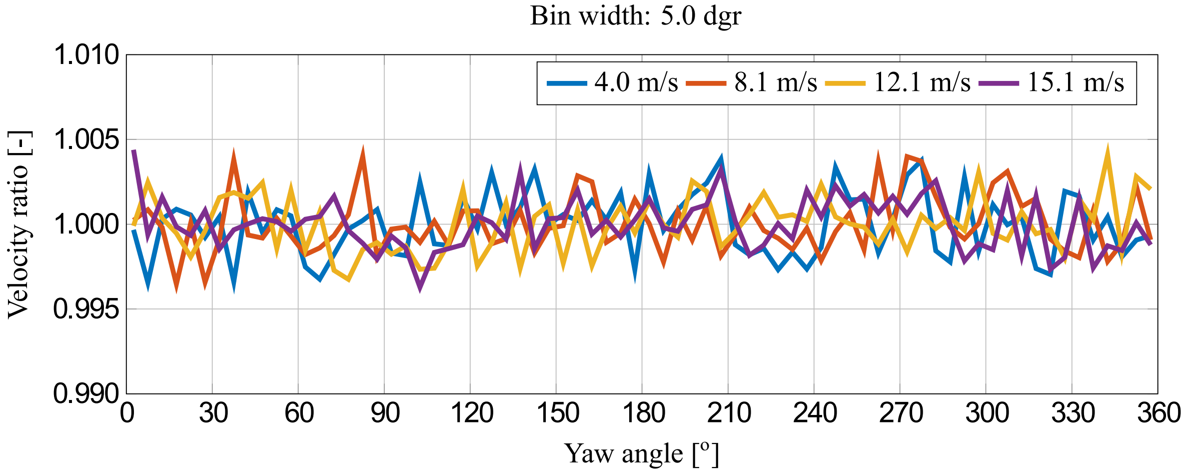

Figure 3. Ratio between the wind speed displayed by the anemometer and the reference wind speed as a function of the yaw angle for different target wind speeds for the P2546A-OPR.

D. Rotor torque characteristics – wind tunnel tests

The aerodynamic torques were measured by forcing the rotors to turn at off-equilibrium specific angular speeds while measuring the torque with a torque sensor, see IEC 61400-12-1:2017 Annex J.2.3. Figure 4 shows the rotor torque curves determined.

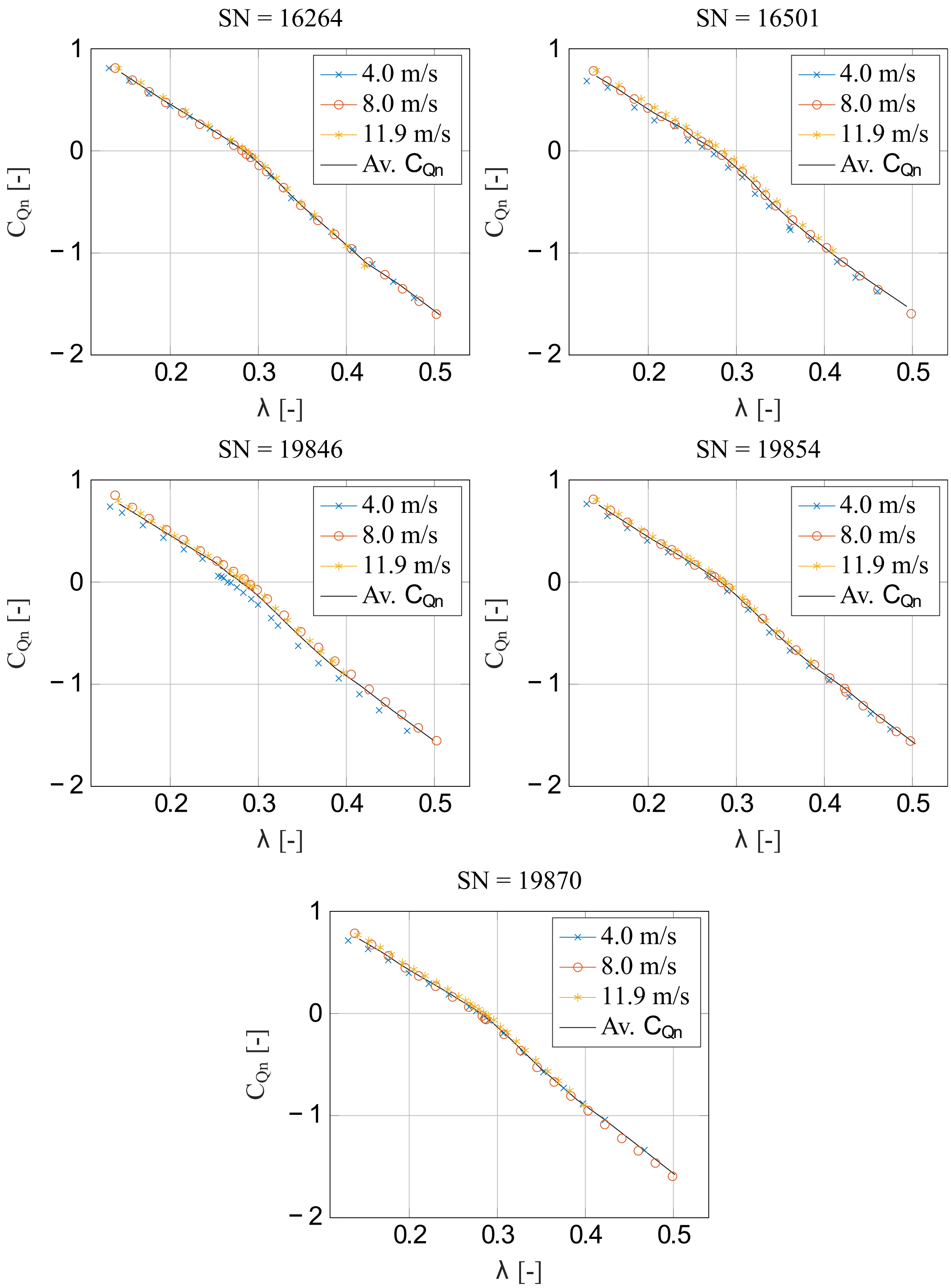

Figure 4. Generalised measured net torque coefficients for 4, 8 and 12 m/s (blue, red and yellow markers). Averaged torque curves Av, C_{Qn} as function of speed ratio, λ shown as a black line.

E. Bearing friction torque characteristics – laboratory tests

The temperature-dependant effects due to bearing friction were assessed by a flywheel test in a temperature-controlled chamber. The cup anemometer rotor was replaced by a flywheel, and the deceleration from a rotational speed corresponding to 20 m/s was measured. Figure 5 shows the bearing friction torque curves.

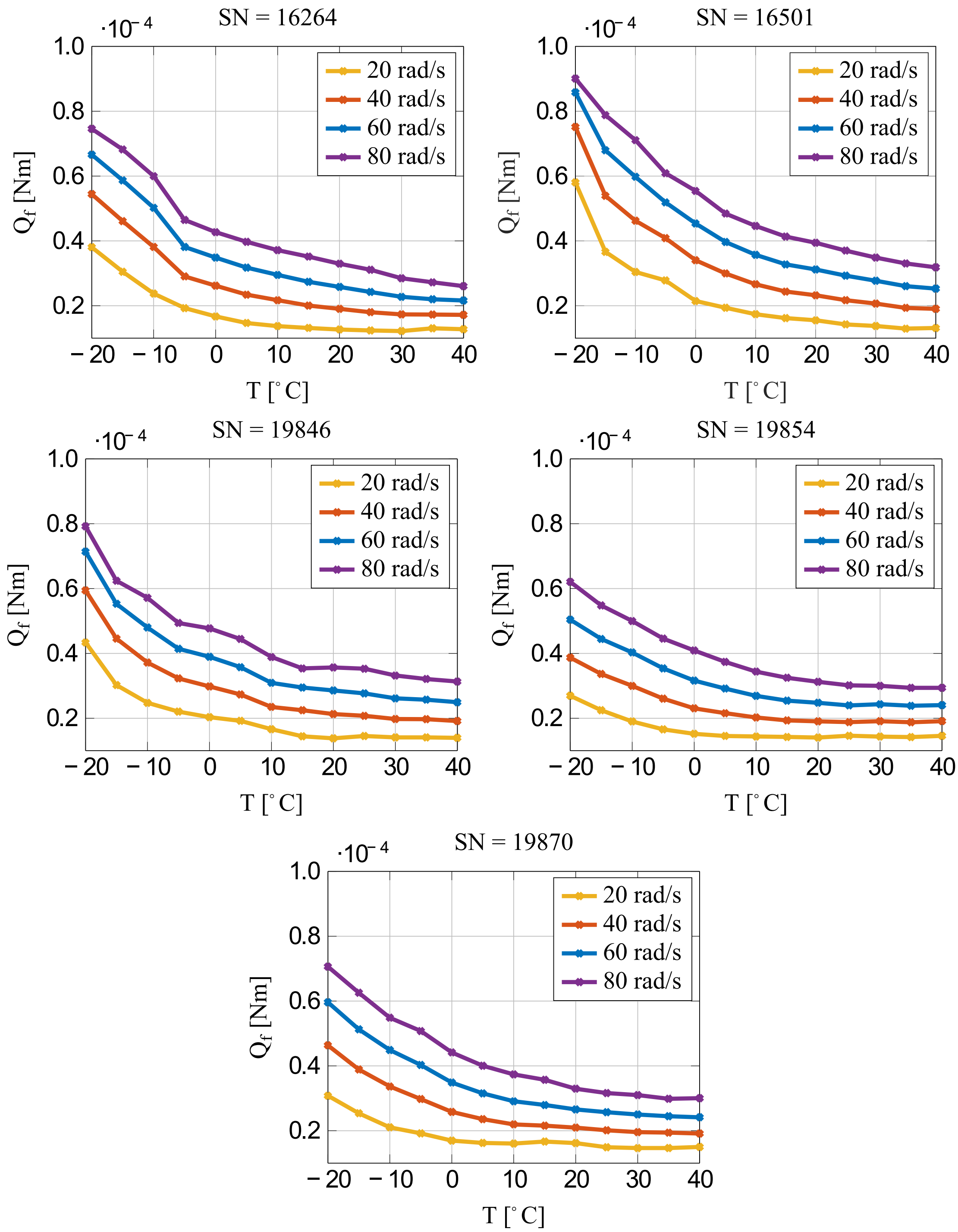

Figure 5. Bearing friction torque as a function of temperature at angular speeds of 20, 40, 60 and 80 rad/s (yellow, red, blue and purple)

F. Classification based on wind tunnel and laboratory tests, and cup anemometer modelling

For all five anemometers, classification deviations were calculated. The simulations carried out by the cup anemometer model calculate the deviations as function of class and wind velocity U as shown in Figure 6. Figure 6 shows the calculated classification deviations for one selected anemometer SN 19870.

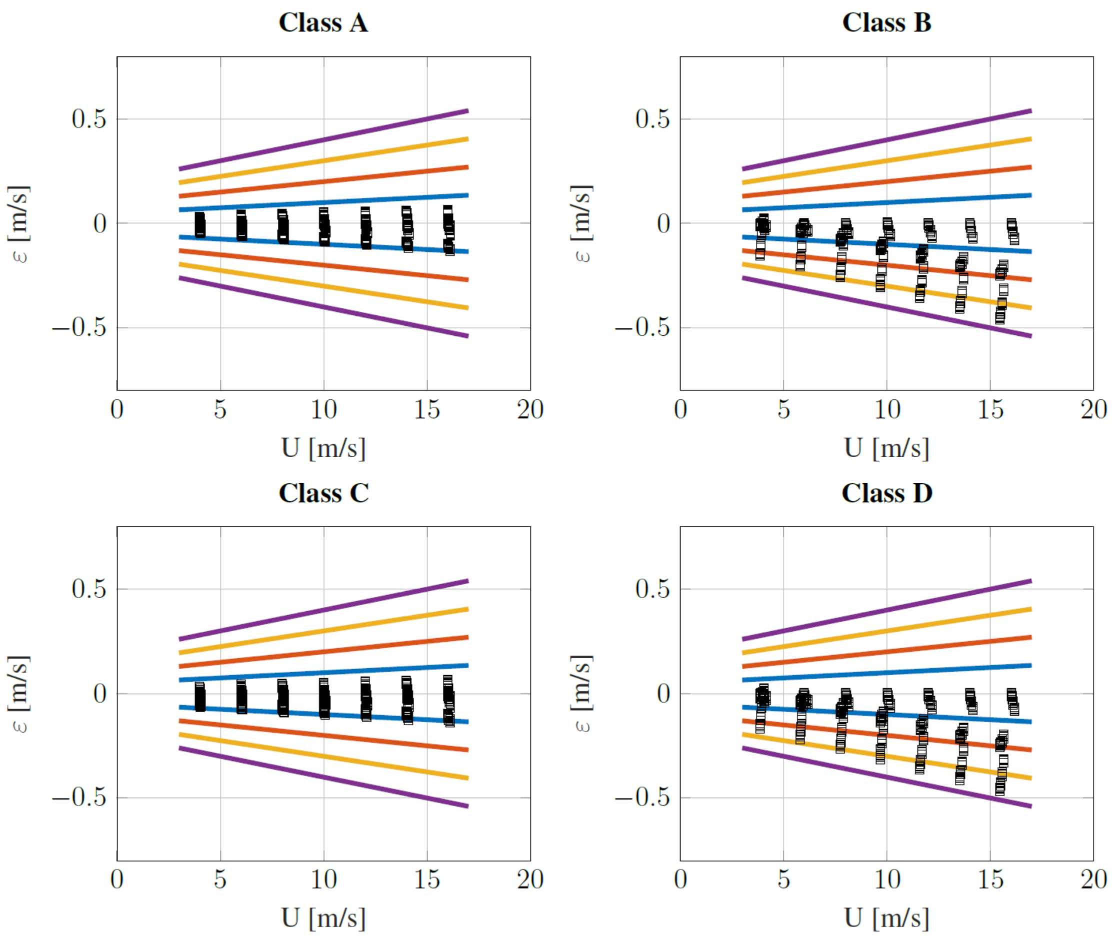

Figure 6. Classification deviations for SN 19870 using Class A, B, C and D influence parameters with boundaries for classification indices of 1, 2, 3, and 4 (blue, red, yellow and purple)

Classification indices were calculated from the classification deviations according to IEC 61400-12-1:2017 Annex I.4 using the equation shown below. The results are presented in table 2.

$$k = \frac{1}{5}\sum_{n=1}^{5} k_n + \frac{k_{max} - k_{min}}{2} \cdot \frac{1}{\sqrt{3}} \qquad \text{(I.3)}$$

G. Verification of cup anemometer model

According to IEC 61400-12-1:2007 Annex J.3, the cup anemometer model applied in Section 3.F above shall be verified. The verification was based on the results for the example cup anemometer given in IEC 61400-12-1:2007 Annex J.3.2.2.

The cup anemometer model of Section 3.F above gives the class numbers listed in Table 6 for Class A, B, C and D. The class numbers calculated are identical to the class numbers specified in IEC 61400-12-1:2017 Annex J.3.2.2 for the same example data. This verifies the cup anemometer model used in the classification.

IEC example cup anemometer	**Class A**	**Class B**	**Class C**	**Class D**
Class numbers required by IEC 61400-12-1:2017	1,69	6,56	8,01	9,94

Table 6. Class indices from IEC example verified using P2546A-OPR method