CUP ANEMOMETER CLASSIFICATION
WindSensor P2546-OPR

Reference procedure: IEC 61400-12-1:2017
Power performance measurements of electricity producing wind turbines

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Summary

This summary reports the classification of the WindSensor P2546-OPR Cup Anemometer compiled by the Department of Wind Energy, Technical University of Denmark, in compliance with the procedures outlined in the IEC 61400-12-1:2017 standard Annex F, I and J. The tests were carried out in the ISO 17025 accredited SOH wind tunnel and the resulting class numbers for the four predefined terrain and climate ranges are shown in table 1.

Five anemometer samples of the P2546A-OPR Cup Anemometer model were tested and a resulting class number, k, determined as a weighted average of the five individual class numbers. However, 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.

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 1. Individual and combined class number for Class A, B, C and D

The standard defines an additional Class S with user-defined ranges of the influence parameters as indicated in table 2. 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.

Classification – an overview

To estimate the uncertainty of a wind turbine power curve measurement, various uncertainty components are combined. A main uncertainty component is the wind speed uncertainty consisting of a number of uncertainty components and subcomponents, one being the uncertainty associated with the operational characteristics, $u_{VS,class,i}$, of the wind speed sensor. This uncertainty component is determined by the class number weighted by a wind speed function and reduced by a rectangular probability function.

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.

The standard defines five different terrain and environment classes with individual combinations of the range of a number of known influence parameters as shown in table 2. 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.

Class numbers has been calculated from the classification deviations according to IEC 61400-12-1:2017 Annex I.4 using Equation I.3 as shown below. Results are presented in the document summary.

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

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 2. Input parameter ranges of Class A, B, C, D and S

Measurements

All wind tunnel and laboratory measurements comply with the requirements set forth in IEC 61400-12-1:2017 annex J. Table 3 lists the classification procedures used for characterizing the cup anemometers.

Classification procedure	Reference	Figure
Wind tunnel calibration	IEC 61400-12-1:2017 Annex F	
Directional characteristics	IEC 61400-12-1:2017 Annex J.2.2	1
Tilt angular response characteristics	IEC 61400-12-1:2017 Annex J.2.1	2
Rotor torque characteristics	IEC 61400-12-1:2017 Annex J.2.3	3
Bearing friction characteristics	IEC 61400-12-1:2017 Annex J.2.5.1	4
Classification	IEC 61400-12-1:2017 Annex I.4 IEC 61400-12-1:2017 Annex J.3	5
Validation of classification method	IEC 61400-12-1:2017 Annex J.3.2	

Table 3. List of classification procedures

Basic cup anemometer parameters

Make	WindSensor
Types	P2546A-OPR, P2546C-OPR and P2546D-OPR
Rotor diameter	188 mm
Cup diameter	70 mm (conical)
Cup area	0.00385 m^2
Pulses per revolution	2
Rotor mass (SN 16264)	0.064 kg
Rotor inertia (SN 16264)	0.000111 kg m^2

Table 4. Basic cup anemometer data

Wind tunnel calibration

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

WindSensor P2546A-OPR Serial Number	Slope [m]	Offset [m/s]	Correlation
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 factors

Validation of classification method

The method used for classifying the WindSensor P2546-OPR cup anemometers has been verified according to the example specified in IEC 61400-12-1:2017 Annex J.3.2. This example contain a physical model that simulates a cup anemometer response in the time domain. From the simulated cup anemometer the expected class numbers has been specified when using influence parameters for Class A, B, C and D.

Applying the method used for classifying the WindSensor P2546-OPR on the simulated cup anemometer provide a standard of comparison with the method described in IEC 61400-12-1:2017. Table 6 shows the class numbers specified in IEC 61400-12-1:2017 and the class numbers calculated when applying the method used for classifying the WindSensor P2546-OPR cup anemometers.

	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
Class numbers using P2546-OPR method	1,693	6,558	8,013	9,941

Table 6. Class numbers from IEC example validated using P2546A-OPR method

As seen from the table the method used for classifying the WindSensor P2546-OPR cup anemometers give the same results as required by IEC 61400-12-1:2017.

Date: 27 Februrary, 2020

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Directional characteristics

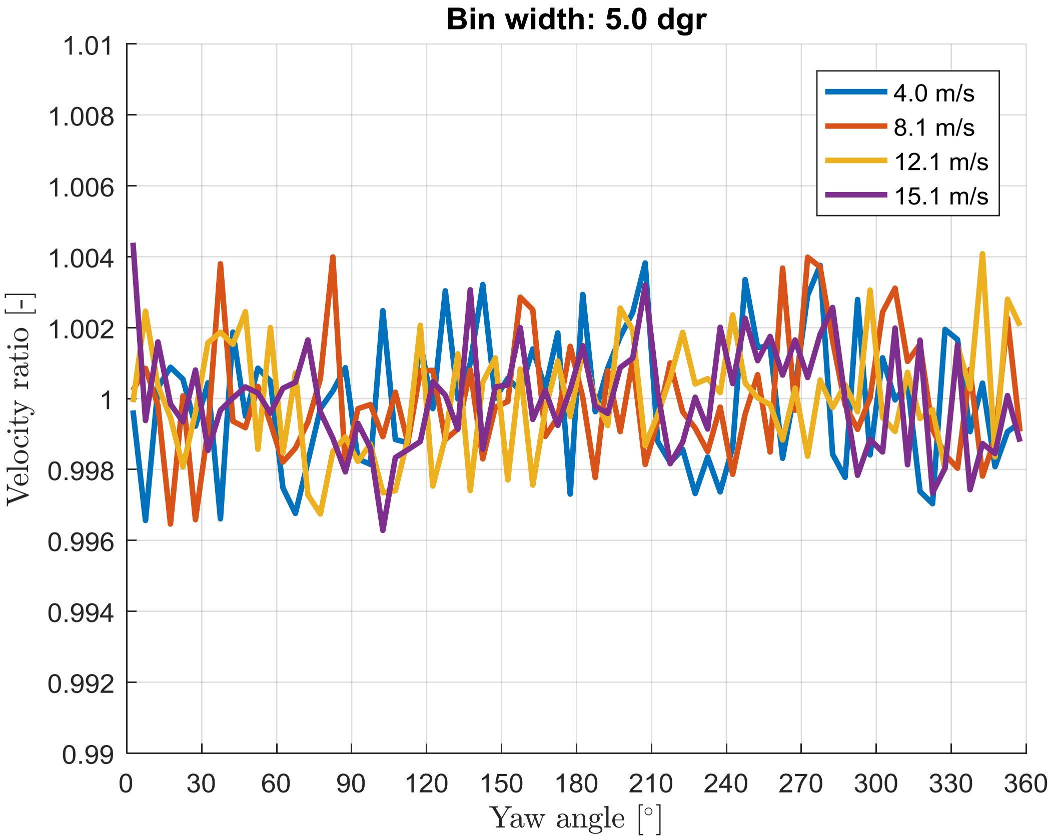

Figure 1. Ratio between the wind speed displayed by the anemometer and the reference wind speed as a function of the yaw angle for different target wind speeds on selected P2546A-OPR.

Tilt angular response characteristics

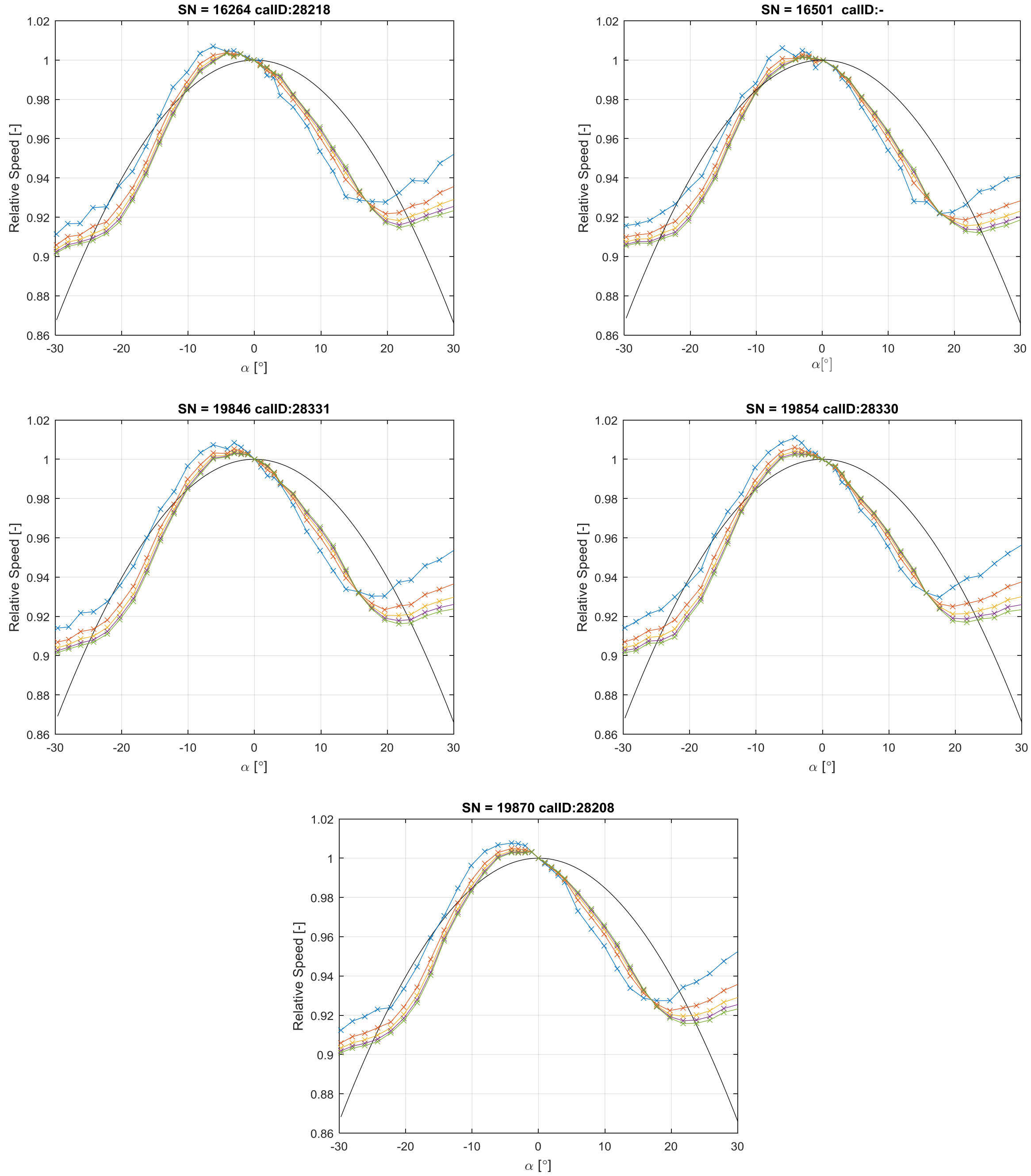

Figure 2. Relative wind speed as function of tilt angle, α, at 4, 7, 10, 13 and 16 m/s (blue, red, yellow, purple and green). A perfect cosine fit is shown with a black line.

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Rotor torque characteristics

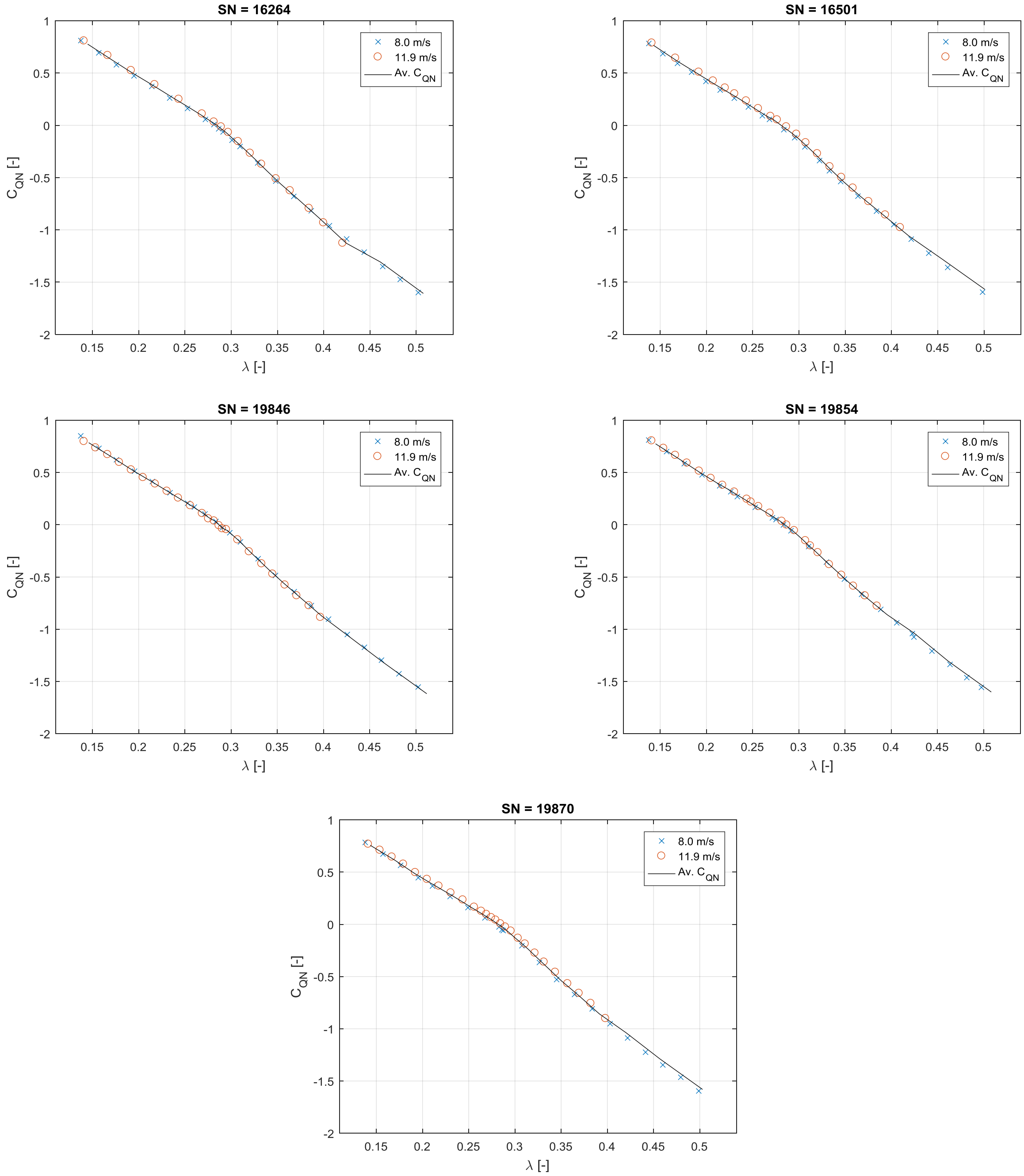

Figure 3. Generalised measured net torque coefficients for 8 and 12 m/s (blue and, red markers). Averaged torque curves Av, C_{Qn} as function of speed ratio, λ shown as a black line.

Bearing friction characteristics

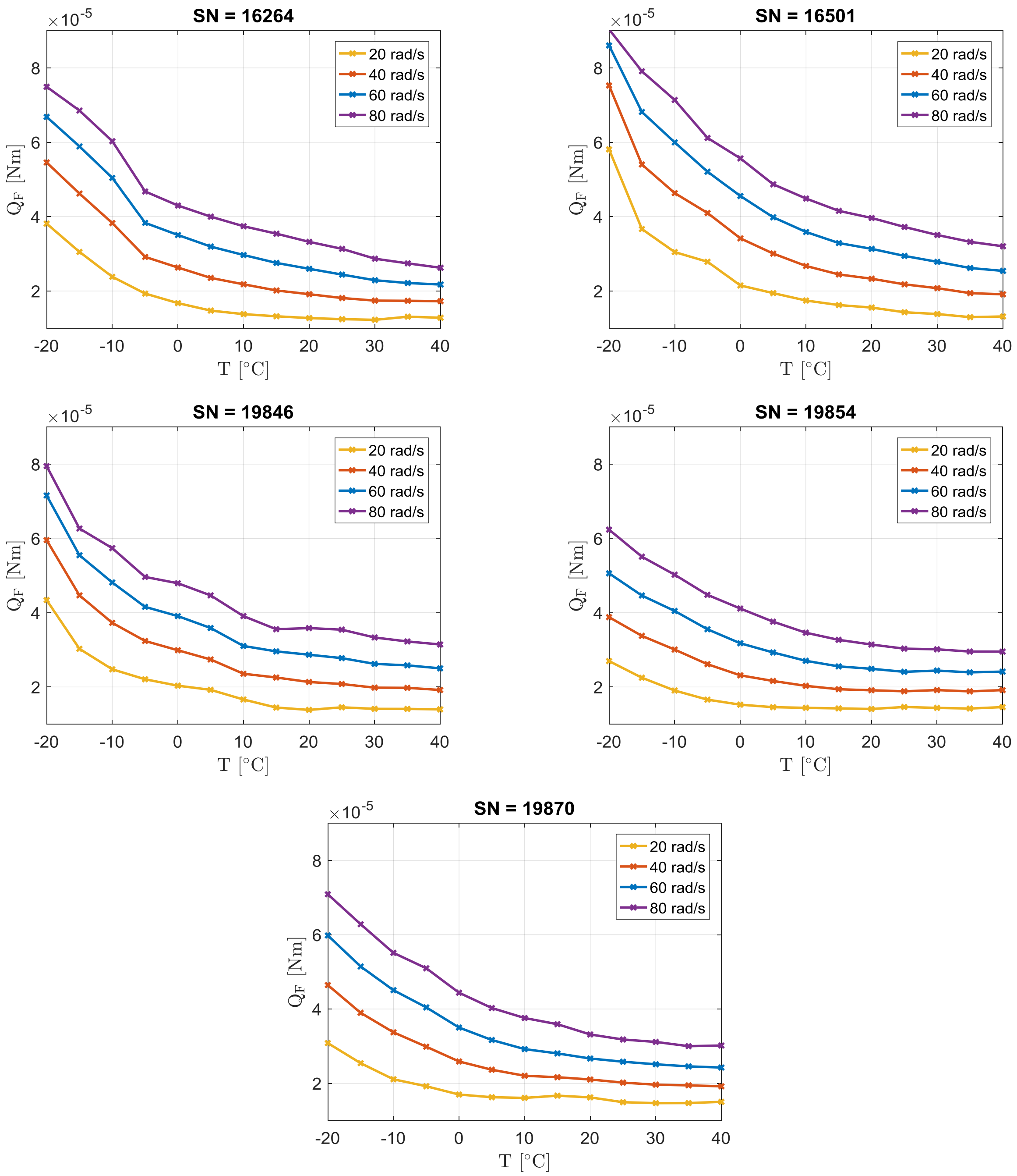

Figure 4. Friction torque as a function of temperature at angular speeds of 20, 40, 60 and 80 rad/s (yellow, red, blue and purple)

Classification

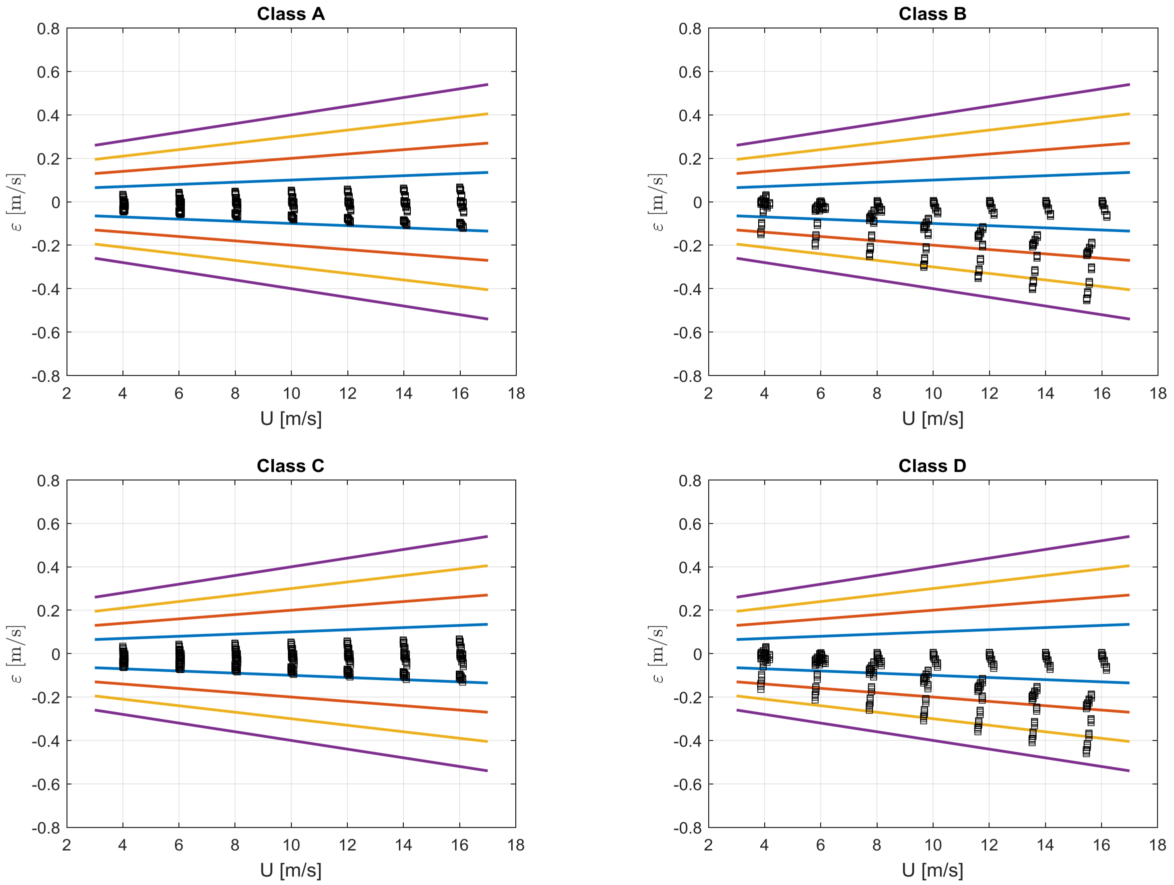

Figure 5. Classification deviations for SN 19870 using Class A, B, C and D influence parameters with boundaries for class numbers of 1, 2, 3, and 4 (blue, red, yellow and purple)