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NRG S1 CLASSIFICATION

IEC 61400-12-1 Edition 2.0 Report Summary

Prepared for: NRG Systems

Revision 03, September 16, 2019

Report Summary:

This report characterizes the NRG S1 sensor following the IEC 61400-12-1 Edition 2.0, Annex I and Annex J methods. The anemometer classification process is done to characterize an anemometer's change in performance due to various influences. Known influences on cup anemometer measurements include turbulence, air temperature, air density, and average up flow angle. Tests were performed at SOH Wind Engineering to determine the impact of the following characteristics.

- Tilt angular response characteristics
- Yaw angular response characteristics
- Temperature induced effects
- Dynamic effects due to rotor torque characteristics

Test results were analyzed using software *AnemCq8.exe.
The following NRG S1 sensors were tested at each characteristic test during classification.

- 94050000054
- 94050000055
- 94050000056
- 94050000057
- 94050000063

Wind tunnels used for classification at SOH Wind Engineering meet or exceed the requirements described in
IEC 61400-12-1 Edition 2.0, Annex F.

*AnemCq8.exe released 14 February 2019 by Steven Clark of NRG Systems is a modified version of AnemCq7.exe, originally released 25 September 2012 by Troels Pedersen of DTU. Modifications include:

- The parameter Ncorrect is set to 1, enabling the code to correct the u, v, and w turbulent wind flow data so the average and standard deviations are accurate and consistent with the Mann model
- In addition to this change to the classification code, the following inputs have been modified to comply with the requirements set forth in the Table I.1 of IEC 61400-12-1 Edition 2.0:
    - The longitudinal turbulent length scale is set to 350m consistent with the IEC 61400-12-1 standard (both editions).
    - Class B non-isotropic turbulence is specified as 1.0, 0.8, and 0.5 for the component wind speed standard deviation ratios (u/u, v/u, and w/u). Note, Class A already specifies non-isotropic turbulence.

Parameters obtained from Calibration Certificates:

Sensor	Slope (m/s/Hz)	Offset (m/s)
94050000054	0.09376	0.1307
94050000055	0.09353	0.1307
94050000056	0.09366	0.1432
94050000057	0.09371	0.1313
94050000063	0.09359	0.1380

Table 1, Sensor calibration equations

Miscellaneous parameters related to classification:

Cup diameter	0.061 m
Cup area, *A*	0.002922 m^2
Radius to cup center, *R*	0.0507 m
Rotor Inertia, *I*	0.00007594 kgm^2
Rotor mass, *m*	33.8 grams
Pulses per Revolution	14
Equilibrium speed ratio, λ_o	0.2423
Calibration temperature	23.4°C
Calibration barometric pressure	995.5 hPa
Calibration air density, ρ	1.16795 kg/m^3
Calibration turbulence intensity	0.003
Calibration coefficients *A* and *B*	0.09353 m/s/Hz and 0.13073m/s
Calibration friction coefficients F_0, F_1, F_2 at 20°C	Refer to NRG S1_Bearing Friction
Torque coefficient slopes K_{low} and K_{high}	-6.0294 and -5.0274

Table 2, Misc. parameter data is based on serial number 94050000055

Influence parameter ranges of Class A, B, C, & D (IEC 61400-12-1 Edition 2.0 Table I.1)

	Class A Terrain meets requirements in Annex B	Class B Terrain does not meet requirements in Annex B	Class C Terrain meets requirements in Annex B	Class D Terrain does not meet requirements in Annex B
	Range	Range	Range	Range
Wind speed V (m/s)	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
Turbulence [35] 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*
Air temperature (°C)	0 to 40	−10 to 40	−20 to 40	−20 to 40
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
Average upflow angle (°)	−3 to 3	−15 to 15	−3 to 3	−15 to 15
Wind direction (°) [36]	Cups and sonics: 0° to 360°	Cups and sonics: 0° to 360°	Cups and sonics: 0° to 360°	Cups and sonics: 0° to 360°

* A non-isotropic Kaimal turbulence spectrum with turbulence length scale 350 m.

Table 3, Influence parameter ranges of Classes A, B, C, & D (IEC 61400-12-1 Edition 2.0)

Classification Index Results

NRG S1 combined Class Index based on IEC 61400-12-1 Edition 2.0, Section I.3 equation

NRG S1			
Class A	Class B	Class C	Class D
1.274	4.186	4.153	6.134

Class Indexes for five NRG S1 anemometers based on IEC 61400-12-1 Edition 2.0

Sensor	Class A	Class B	Class C	Class D
94050000054	1.112	3.588	2.956	4.770
94050000055	1.151	3.914	3.620	5.583
94050000056	1.255	3.730	3.725	5.595
94050000057	1.337	4.363	4.547	6.488
94050000063	1.188	4.215	3.619	5.754

Class A Classification

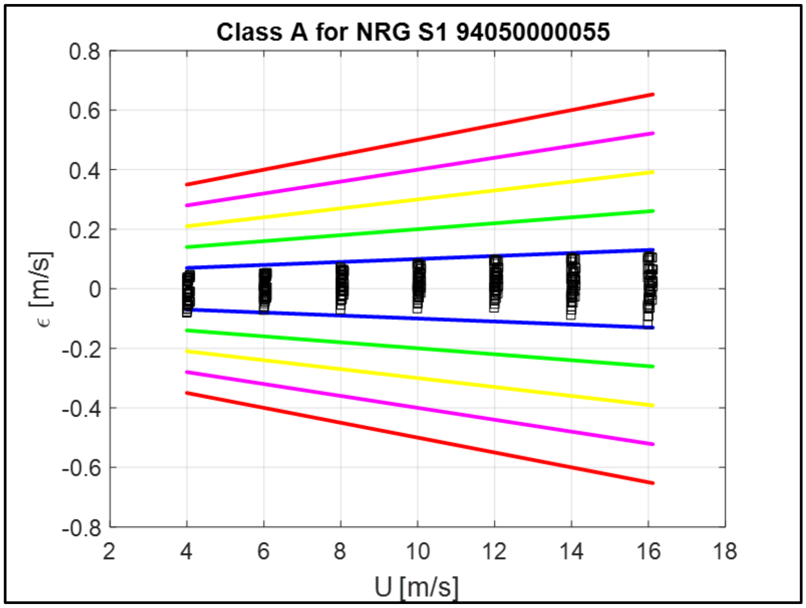

Figure 6, Calculated deviations based on the combination of all Class A Index parameters.

Class B Classification

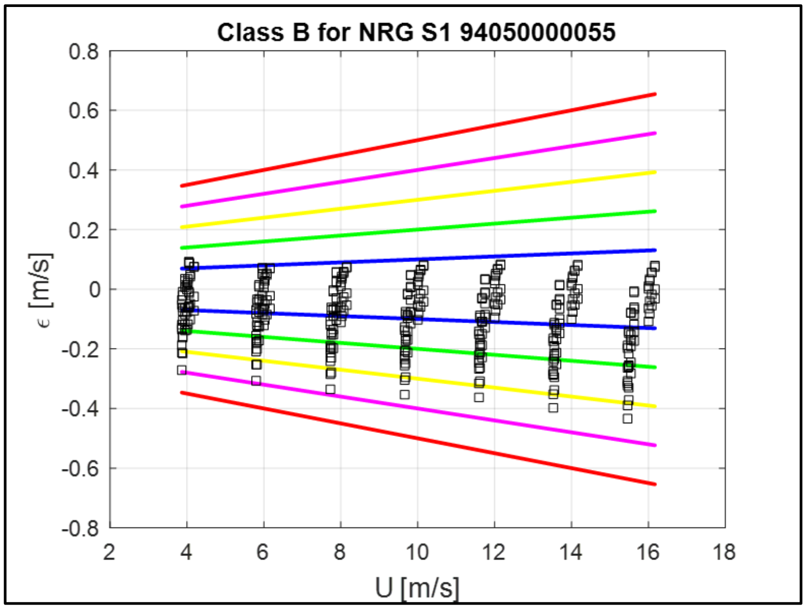

Figure 7, Calculated deviations based on the combination of all Class B Index parameters.

Class C Classification

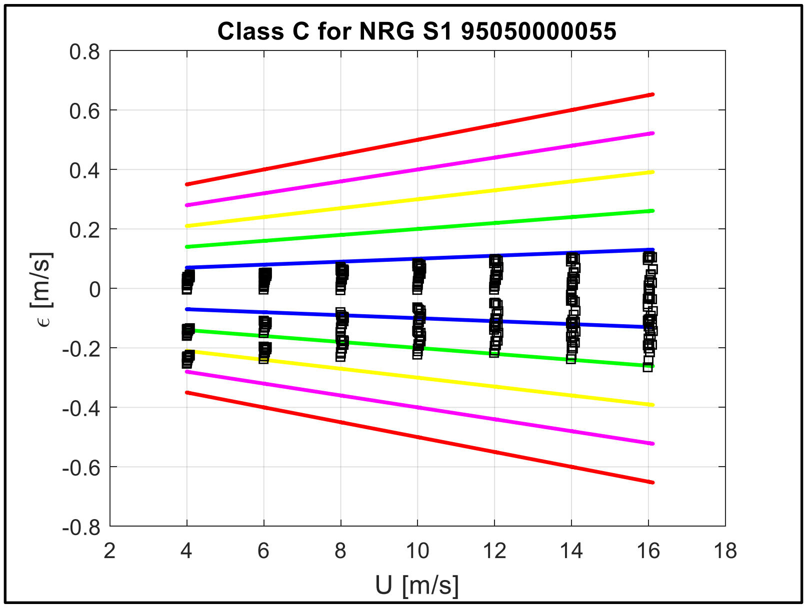

Figure 8, Calculated deviations based on the combination of all Class C Index parameters.

Class D Classification

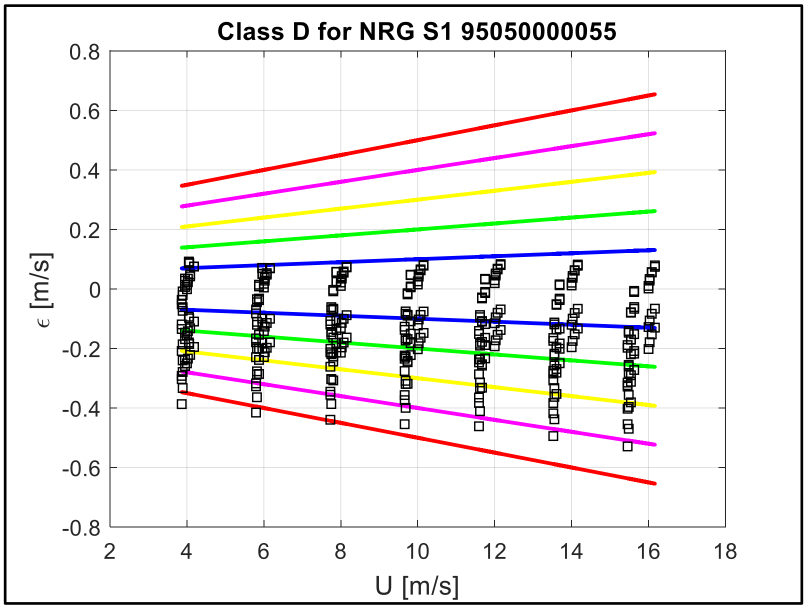

Figure 9, Calculated deviations based on the combination of all Class D Index parameters.

Tilt Angular Response Characteristics (IEC 61400-12-1 Edition 2.0 Section J.2.1)

Figure 1 shows the typical tilt response of an NRG S1 sensor. SOH Wind tests the tilt response from -35° to 35° at 4 m/s, 8 m/s, 12 m/s, and 16 m/s. Additional data points were taken around zero degrees for finer resolution.

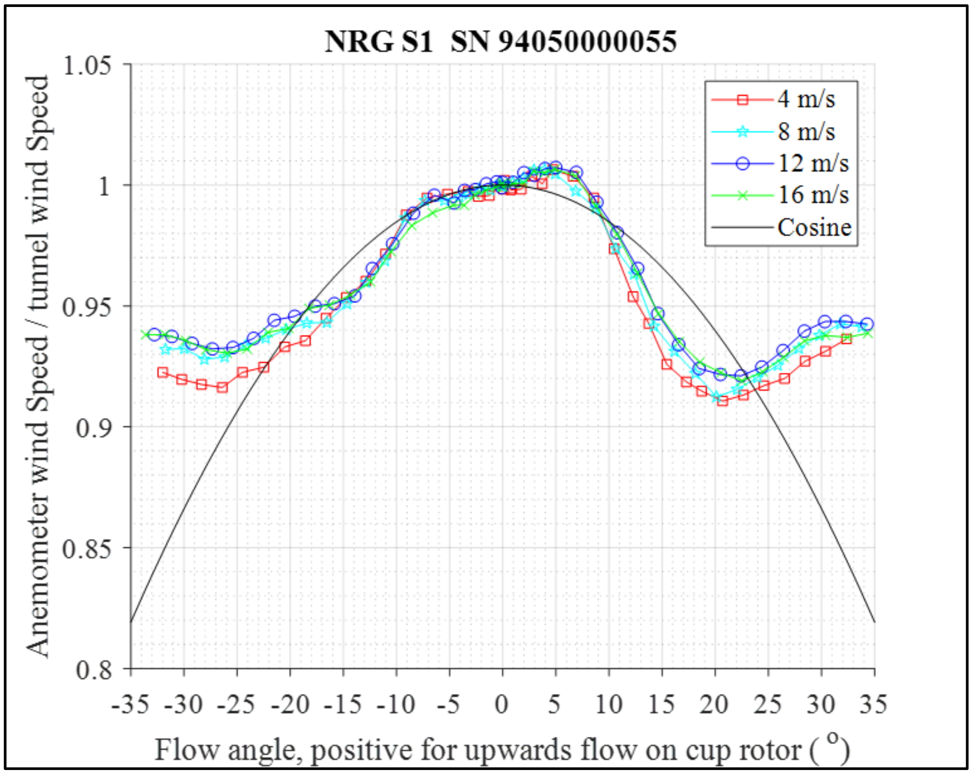

Figure 1, NRG S1 tilt response curve compared to the "ideal" cosine curve

Yaw angular response characteristics (IEC 61400-12-1 Edition 2.0 Section J.2.2)

The directional characteristics of the five anemometers were analyzed using a three-step procedure, in which the anemometer frequency data from yaw tests were analyzed under wind speeds of 4 m/s, 8 m/s, 12 m/s and 16 m/s. The mean value, standard deviation and coefficient of variation of the anemometer indicated velocities hardly changed in different angle ranges. In addition, anemometer indicated velocities don't exhibit strong similarity across different wind speed scenarios. These indicate that NRG S1 anemometers have consistent wind speed readings when exposed by wind flow from different directions. The performance of anemometer at different orientations are considered to be stable, and the differences of the anemometer wind speed indications at different orientations can be ignored.

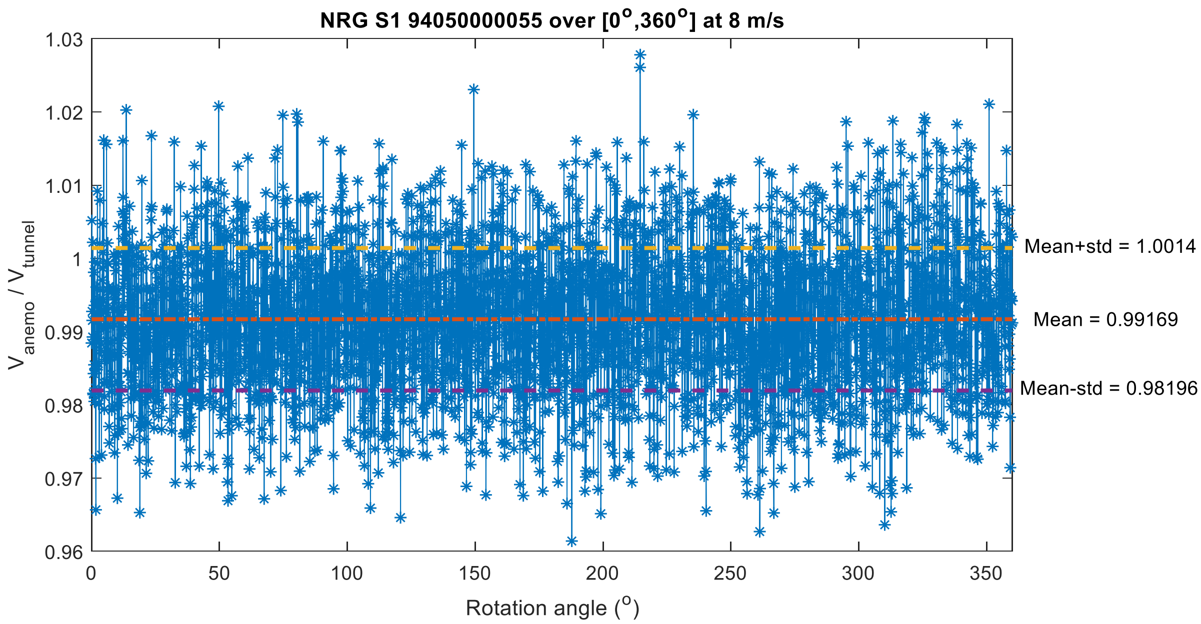

Figure 2, NRG S1 typical Yaw angular response

Temperature induced effects on performance (IEC 61400-12-1 Edition 2.0 Section J.2.5)

Bearing friction measurements were made by replacing the sensors rotor with an aluminum flywheel of equivalent mass. A climate-controlled chamber was used to test the sensor from - 20°C to +40°C in 5°C increments.

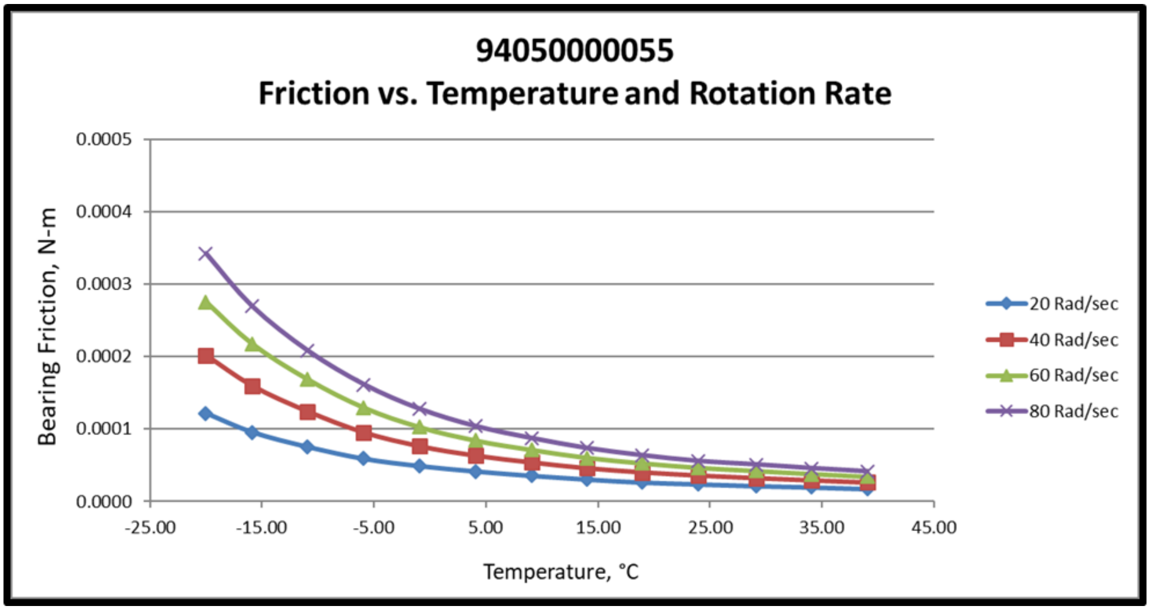

Figure 3, Typical NRG S1 bearing friction torque as a function of temperature

Dynamic effects due to rotor torque characteristics (IEC 61400-12-1 Edition 2.0 Section J.2.3)

Rotor torque measurements were taken to calculate the acceleration and deceleration during a "speed up" or "slow down" phase during wind tunnel testing.

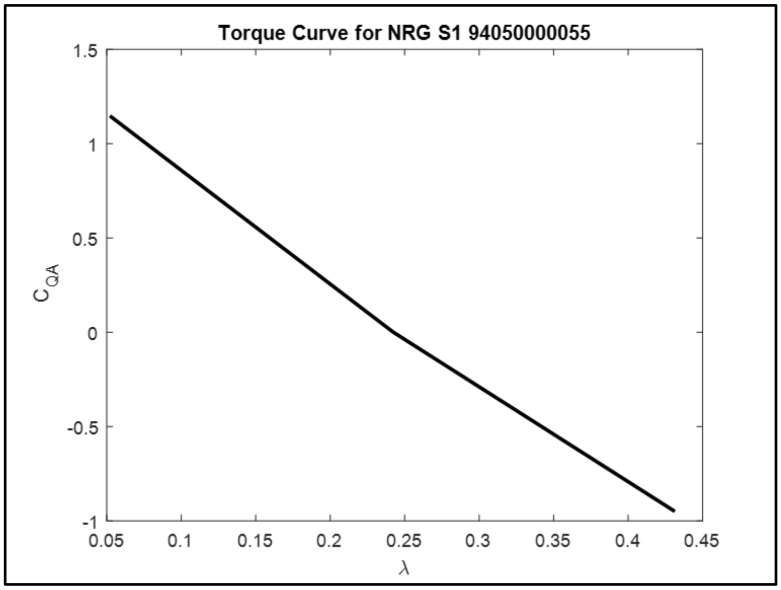

Figure 4, Typical NRG S1 torque curve