Summary report AK151023-1.3

Cup Anemometer Classification

According to IEC 61400-12-1 Edition 2.0 (2017- 03) Classification Scheme

Description of Anemometer

Manufacturer: Adolf Thies GmbH&Co.KG
Hauptstrasse 76
37083 Göttingen

Identification: First Class Advanced II

4.3352.00.000; 4.3352.10.000

SN: 0113001; 0113002;0113003;0113004;0113005

Dimension:

Body diameter:	50 mm	Body length:	95 mm
Total length:	290 mm	Shaft diameter:	18 mm
Top:	38 mm		
Rotor diameter:	240 mm	Cup diameter:	80 mm
Cup tilt angle:	2.5 deg	Flaps (approx):	28 x 31 mm

Reference:

Deutsche WindGuard Wind Tunnel Services GmbH
Measuring period: 04.2014 – 05.2017
Test site: Varel, Germany
Wind Tunnel: Deutsche WindGuard Wind Tunnel Services GmbH, Varel

Procedure:

The classification is based on numerical integration of the differential equation which describes the response of a cup anemometer to fluctuating wind speeds. The chosen spectrum of the wind speed time series was a *Kaimal* spectrum for non-isotropic condition (turbulence length scale 350 m. The time series have been generated with a software tool provided by Risø - National Laboratory, Denmark. Other parameters which influence the response of an anemometer in fluctuating wind conditions are:

- Off axis response for different tilt angles
- Friction changes in bearings due different ambient temperatures and air pressure
- Driving and braking torque of the cups during rotation
- Inertia of the rotor
- Air density

All relevant parameters have been measured in various wind tunnels of Deutsche WindGuard Wind Tunnels Services GmbH. The driving and braking forces used in the numerical model have been derived from the measured step response (step up and step down test) of the tested anemometer according to IEC 61400-12-1 Edition 2.0. The direct influence of air density was measured using a specially designed variable air density wind tunnel, instead of calculating the influence of the air density by using torque measurements.
In addition, results of the field comparison are presented in this summary.

Tilt angular responce

Reference:

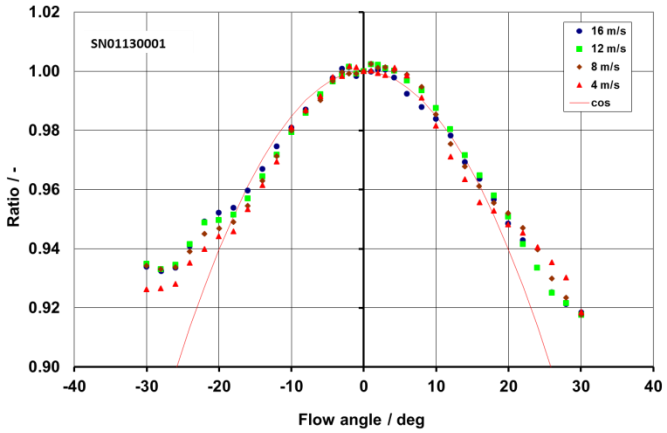
IEC 61400-12-1 Edition 2.0
Wind Turbine Power Performance Testing
2017-03

WindGuard *quality system procedure for calibration of wind speed sensors at non-horizontal inflow conditions:*
D 5832

Accredited according to IEC 17025

Result:

Figure showing the of axis response of Thies First Class advanced anemometer type 4.3352.00.000 for tunnel speeds of 4 m/s, 8 m/s, 12 m/s and 16 m/s.



Five anemometers have been tested. Each individual tilt data have been used for classification

Tested anemometer:

SN 01130001
SN 01130002
SN 01130003
SN 01130004
SN 01130005

Step responce

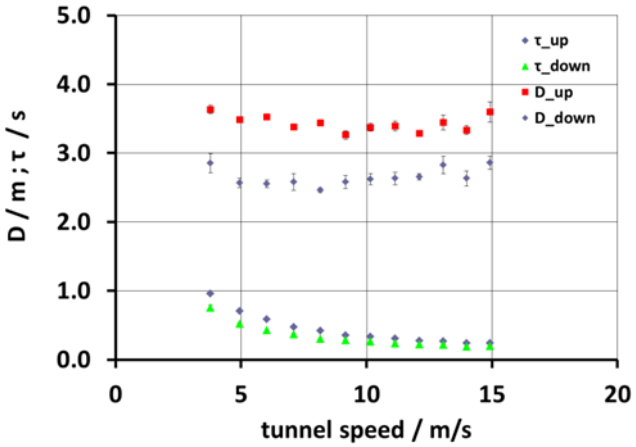
Reference:

IEC 61400-12-1 Edition 2.0
Wind Turbine Power Performance Testing
2017-03

Result:

Figure showing the step up und step down time constants ”**τ**” of Thies First Class Advanced anemometer type 4.3352.00.000 for different wind tunnel speeds. The calculated distance constant ”D” for step up is 2.6 m and 3.5 m for step down.

Uncertainty: 0.1 m



Tested anemometer:

SN 01130001
SN 01130002
SN 01130003
SN 01130004
SN 01130005

Directional characteristic

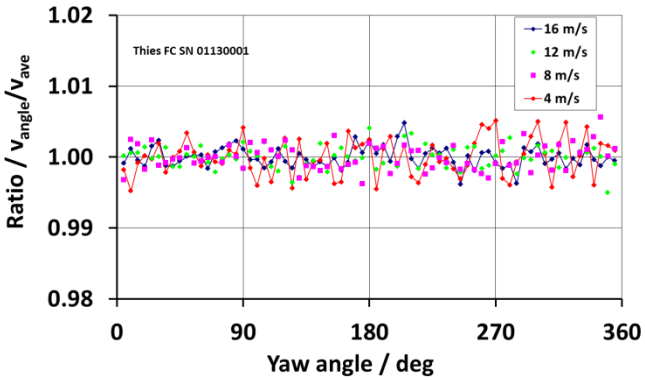
Reference:

WindGuard *quality system procedure for calibration of wind direction sensors: D 5836*

Accredited according to IEC 17025

Result:

Figure showing the yaw sensitivity of the Thies First Class Advanced anemometer type 4.3352.00.000. The sensor was yawed for 0-400 deg and back to 0 deg. The information presented show the bin averaged data for 5 deg bin's. The variation is due to statistical scatter.



Tested anemometer:
SN 01130001

Air temperature induced effects

Reference:

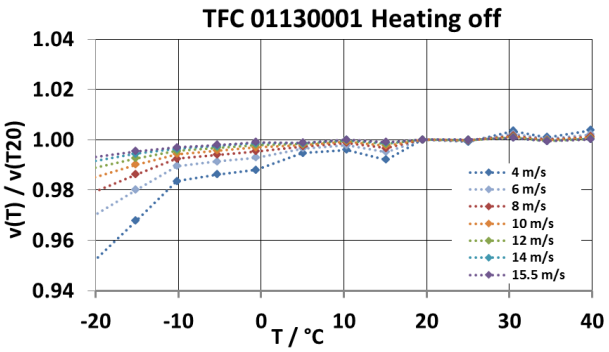
WindGuard quality system procedure for calibration of wind speed sensors at variable air temperature (in preparation).

Result:

Figure showing the influence of air density on the anemometer behaviour at tunnel speeds of 4, 6, 8, 10, 12, 14 and 15.5 m/s.
Thies First Class Advanced anemometer type 4.3352.00.000.

Uncertainty in temperature : <1 K
Uncertainty in flow speed: < 0.1 m/s

Internal shaft heating OFF



Five anemometers have been tested. Each individual temperature-ratio data have been used for classification

Tested anemometer:

SN 01130001
SN 01130002
SN 01130003
SN 01130004
SN 01130005

Air temperature induced effects

Reference:

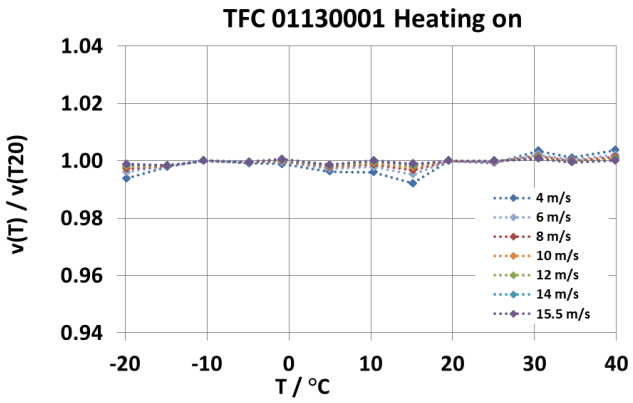
WindGuard quality system procedure for calibration of wind speed sensors at variable air temperature (in preparation).

Result:

Figure showing the influence of air density on the anemometer behaviour at tunnel speeds of 4, 6, 8, 10, 12, 14 and 15.5 m/s.
Thies First Class Advanced anemometer type 4.3352.00.000.

Uncertainty in temperature : <1 K
Uncertainty in flow speed: < 0.1 m/s

Internal shaft heating ON



Five anemometers have been tested. Each individual temperature-ratio data have been used for classification

Tested anemometer:

SN 01130001
SN 01130002
SN 01130003
SN 01130004
SN 01130005

Air density induced effects

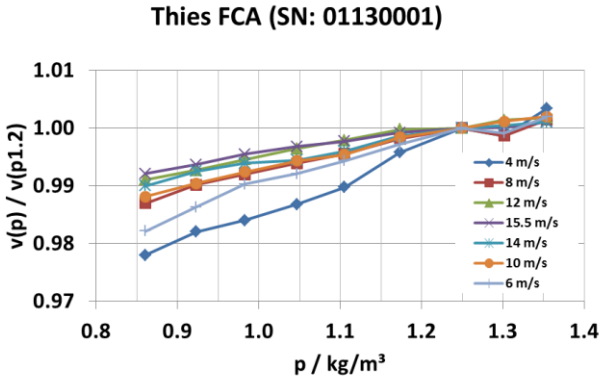
Reference:

WindGuard quality system procedure for calibration of wind speed sensors at variable air density (in preparation).

Result:

Figure showing the influence of air density on the anemometer behaviour at tunnel speed of 4, 6, 8, 10,12, 14 and 15.5 m/s.
Thies First Class Advanced anemometer type 4.3352.00.000.

Uncertainty in temperature: <1 K
Uncertainty in air pressure : < 2 hPa
Uncertainty in flow speed: < 0.1 m/s



Five anemometers have been tested. Each individual air density-ratio data have been used for classification

Tested anemometer:

SN 01130001
SN 01130002
SN 01130003
SN 01130004
SN 01130005

Classification parameters

	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	Class S[34] Special class with user defined ranges
	Range	Range	Range	Range	Range
Wind speed V (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	**0,03 to 0,12 + 0.96/V**
Turbulence structure $\sigma_u/\sigma_v/\sigma_w$ [35]	1/0,8/0,5*	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	**-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	**1.05 to 1.35**
Average upflow angle (°)	−3 to 3	−15 to 15	−3 to 3	−15 to 15	**-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°	Cups: 0° to 360° Sonics: user defined
* A non-isotropic Kaimal turbulence spectrum with turbulence length scale 350 m.					

Table 1 Classification parameters according to IEC 61400-12-1 Edition 2.0 2017-03 used for classification

Class A Classification

Reference:

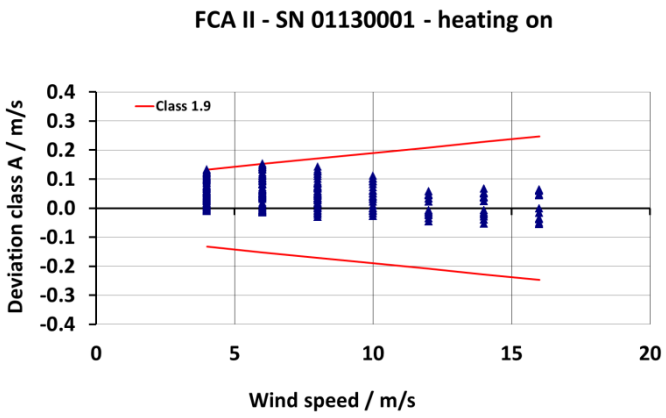
IEC 61400-12-1 Edition 2.0
Wind Turbine Power Performance Testing 2017-03

Result:

Figure showing the calculated total deviation of the Thies First Class Advanced anemometer type 4.3352.00.000 taking into account all influencing parameters according to Class A definition.

Internal shaft heating: ON

Classification index: A 1.8
(average of five sensors)



Class A Classification

Reference:

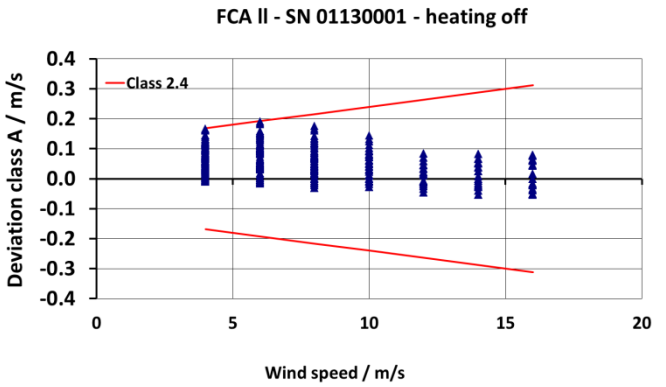
IEC 61400-12-1 Edition 2.0
Wind Turbine Power Performance Testing 2017-03

Result:

Figure showing the calculated total deviation of the Thies First Class Advanced anemometer type 4.3352.00.000 taking into account all influencing parameters according to Class A definition.

Internal shaft heating: OFF

Classification index: A 2.3
(average of five sensors)



Class B Classification

Reference:

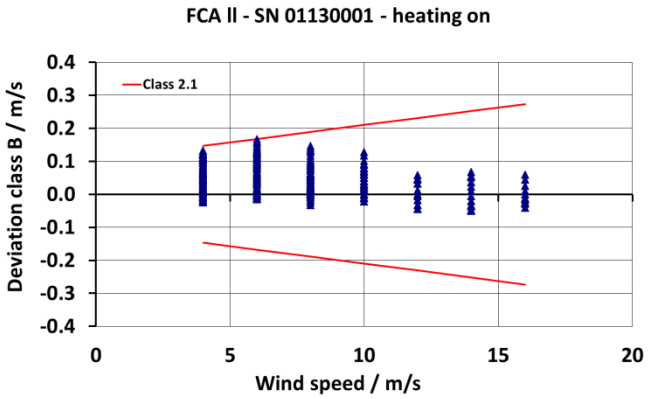
IEC 61400-12-1 Edition 2.0
Wind Turbine Power Performance Testing 2017-03

Result:

Figure showing the calculated total deviation of the Thies First Class Advanced anemometer type 4.3352.00.000 taking into account all influencing parameters according to Class B definition.

Internal shaft heating ON

Classification index: B 2.0
(average of five sensors)



Class B Classification

Reference:

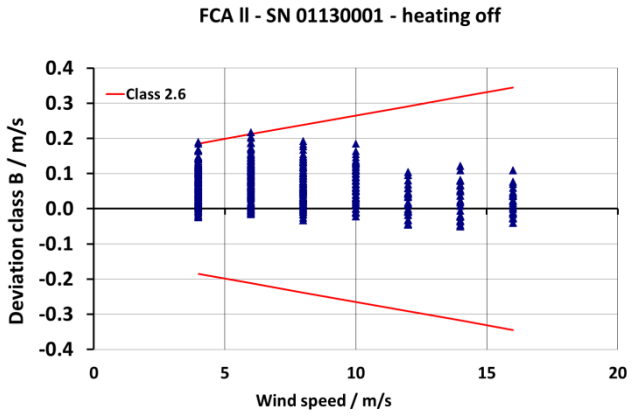
IEC 61400-12-1 Edition 2.0
Wind Turbine Power Performance Testing 2017-03

Result:

Figure showing the calculated total deviation of the Thies First Class Advanced anemometer type 4.3352.00.000 taking into account all influencing parameters according to Class B definition.

Internal shaft heating OFF

Classification index: B 2.7
(average of five sensors) :



Class C Classification

Reference:

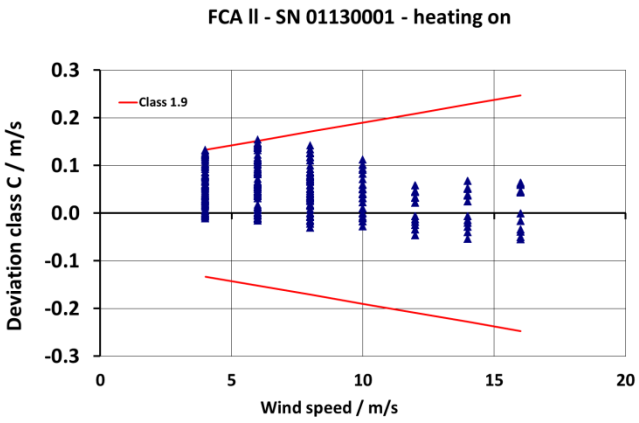
IEC 61400-12-1 Edition 2.0
Wind Turbine Power Performance Testing 2017-03

Result:

Figure showing the calculated total deviation of the Thies First Class Advanced anemometer type 4.3352.00.000 taking into account all influencing parameters according to Class C definition.

Internal shaft heating ON

Classification index: C 1.8
(average of five sensors)



Class C Classification

Reference:

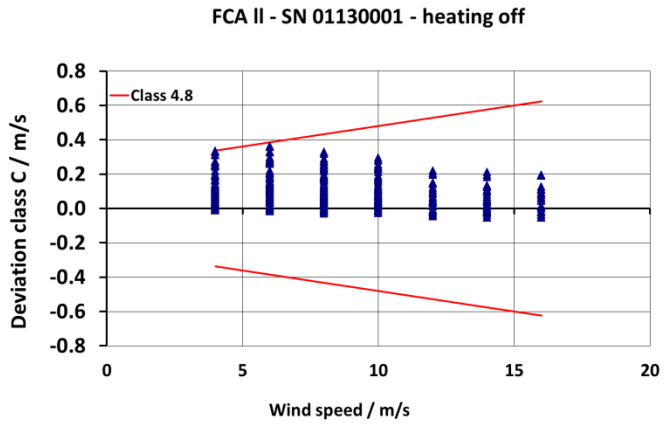
IEC 61400-12-1 Edition 2.0
Wind Turbine Power Performance Testing 2017-03

Result:

Figure showing the calculated total deviation of the Thies First Class Advanced anemometer type 4.3352.00.000 taking into account all influencing parameters according to Class C definition.

Internal shaft heating OFF

Classification index C 4.4
(average of five sensors) :



Class D Classification

Reference:

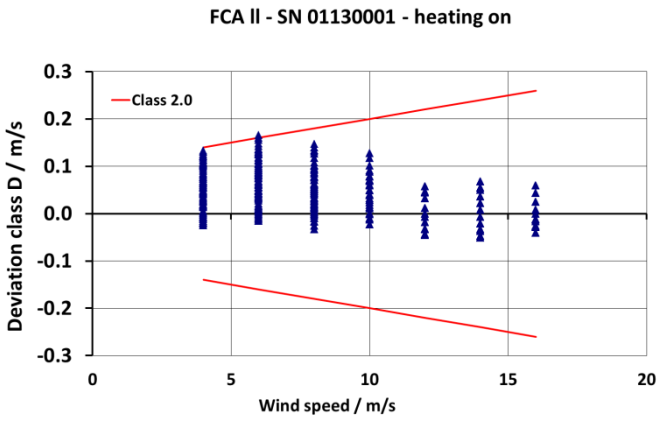
IEC 61400-12-1 Edition 2.0
Wind Turbine Power Performance Testing 2017-03

Result:

Figure showing the calculated total deviation of the Thies First Class Advanced anemometer type 4.3352.00.000 taking into account all influencing parameters according to Class D definition.

Internal shaft heating ON

Classification index: D 2.0
(average of five sensors)



Class D Classification

Reference:

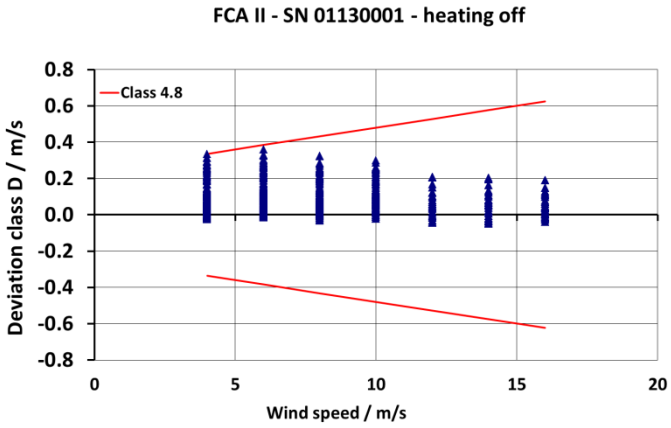
IEC 61400-12-1 Edition 2.0
Wind Turbine Power Performance Testing 2017-03

Result:

Figure showing the calculated total deviation of the Thies First Class Advanced anemometer type 4.3352.00.000 taking into account all influencing parameters according to Class D definition.

Internal shaft heating OFF

Classification index: D 4.6
(average of five sensors)



Class S Classification

Reference:

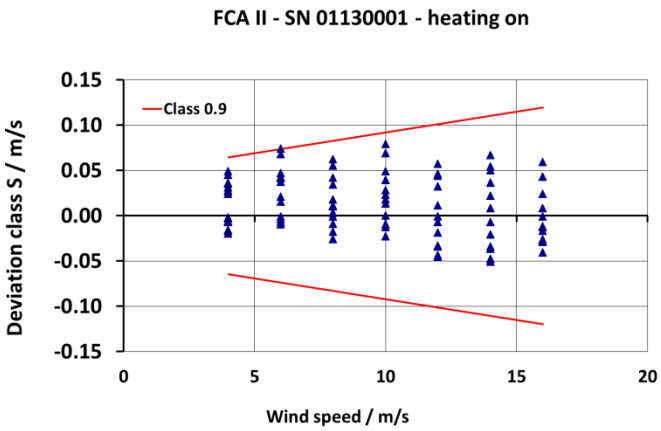
IEC 61400-12-1 Edition 2.0
Wind Turbine Power Performance Testing 2017-03

Result:

Figure showing the calculated total deviation of the Thies First Class Advanced anemometer type 4.3352.00.000 taking into account all influencing parameters according to Class S definition.

Internal shaft heating ON

Classification index: S 0.9
(average of five sensors)



Class S Classification

Reference:

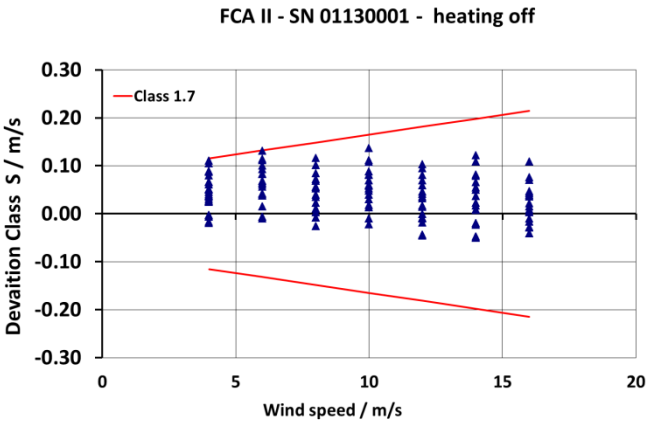
IEC 61400-12-1 Edition 2.0
Wind Turbine Power Performance Testing 2017-03

Result:

Figure showing the calculated total deviation of the Thies First Class Advanced anemometer type 4.3352.00.000 taking into account all influencing parameters according to Class S definition.

Internal shaft heating OFF

Classification index: S 1.7
(average of five sensors)



Field comparison

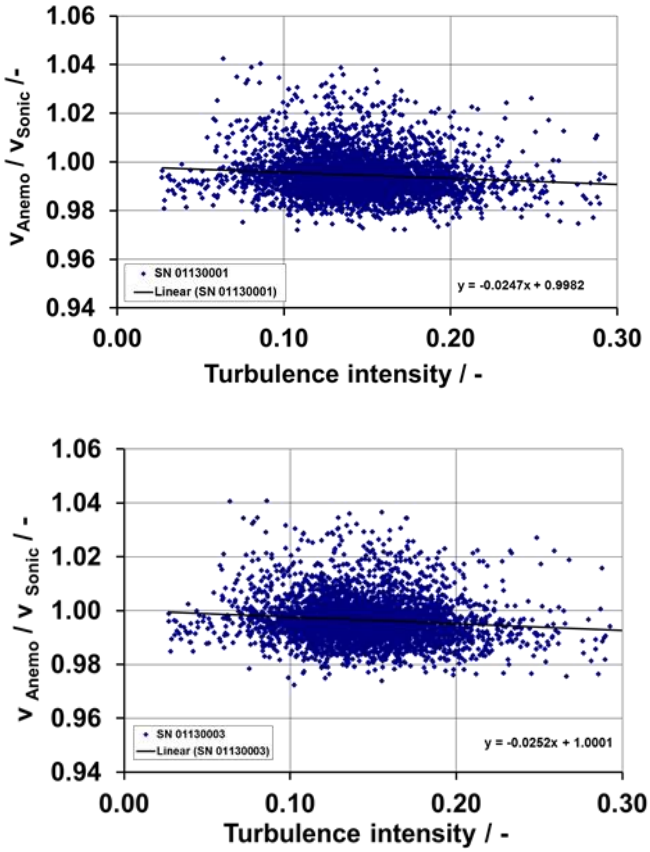
Reference:

IEC 61400-12-1 Edition 2.0
Wind Turbine Power Performance Testing
2017-03

Result:

Figure showing the field comparison measurements at 30 m height of Thies First Class Advanced anemometer type 4.3352.00.000 compared to a calibrated 3D ultrasonic anemometer.

Uncertainty: 0.5 %



Results presented in this report are valid for the item tested only.

Deutsche WindGuard *Wind Tunnel Services GmbH*
Oldenburger Str. 65, 26316 Varel
Tel. #49 (0)4451 9515 0; Fax: #49 (0) 4451 9515 29
e-mail d.westermann@windguard.de, www.windguard.de

Varel, 2017 - 09 - 18

Deutsche WindGuard
Wind Tunnel Services GmbH
Oldenburger Straße 65
D-26316 Varel
Tel.: 04451 / 95 15 - 0 · Fax: 95 15 - 29

Dipl. Phys. D. Westermann