Calibration Uncertainty Comparisons Between Various Anemometers

Rachael V. Coquilla and John Obermeier
Otech Engineering, Inc., Davis ,CA

INTRODUCTION

This poster presents a comparison of calibration uncertainties from various types of anemometers commonly used in the wind energy industry. The anemometers were calibrated in the wind tunnel laboratory at Otech Engineering, Inc located in Davis, California. Calibration test protocols were based on procedures defined in IEC 61400-12-1, ASTM D 5096, and ISO 17713-1. Anemometer calibration uncertainty values presented here were calculated based on the guidelines provided in the Windpower 2007 podium presentation, "Anemometer Calibration Uncertainty". According to the IEC standard, the uncertainty to be reported in anemometer calibration reports is the uncertainty in the wind tunnel reference speed. The presentation given in Windpower 2007 expands the anemometer calibration uncertainty methodology by including the uncertainty in the anemometer output and in the linear regression analysis. This expanded uncertainty analysis provides a more complete representation of the linear performance of an anemometer under controlled test conditions and gives a method of understanding the differences between various anemometer types.

OTECH WIND TUNNEL FACILITY

Suction-Type

Closed Test Section

LabVIEW Data Acquisition

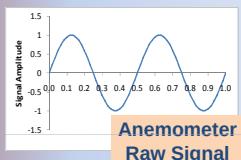
REFERENCE WIND SPEED MEASUREMENT

Pitot-static Tube System

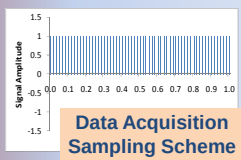
Temp/RH Probe

Barometer

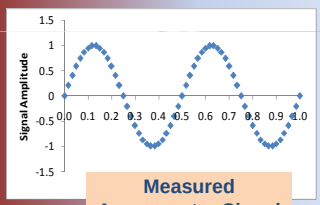
ANEMOMETER SIGNAL ACQUISITION



Anemometer Raw Signal



Data Acquisition Sampling Scheme



Measured Anemometer Signal

Perform FFT analysis using LabVIEW to obtain anemometer signal frequency

CALIBRATION EXPANDED UNCERTAINTY ANALYSIS

$$U_{cal} = \sqrt{(U_V)^2 + (U_{IUT})^2 + (U_{LR})^2}$$

REFERENCE WIND SPEED UNCERTAINTY

$$U_V = \sqrt{B_V^2 + (tS_V)^2}$$

Bias Errors

- Manufacturer's spec
- Calibration errors
- Data acquisition

Random Errors

Standard deviations in instrument readings

Δp, P, T_K, ϕ

ANEMOMETER SIGNAL UNCERTAINTY

$$U_{IUT} = \sqrt{B_{IUT}^2 + (tS_{IUT})^2}$$

Bias Errors

Data acquisition

Random Errors

Standard deviations in anemometer frequency

LINEAR REGRESSION UNCERTAINTY

$$U_{LR} = \sqrt{\left(t\frac{STE_V}{V_i}\right)^2}$$

Uncertainty in the curve fit based on the standard error of the linear regression

Expanded Uncertainty Analysis For Vestas Cup

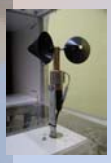
Slope (m/s per Hz) = 0.267
Offset (m/s) = 0.14
Standard Error (m/s) = 0.037

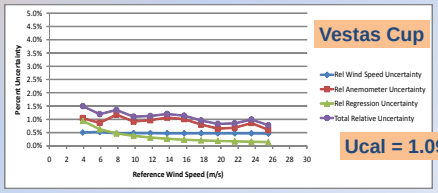
DAQ Sampling Rate (Hz) = 10000
DAQ Number of Samples = 10000
Frequency Resolution (Hz) = 1.00

Frequency Range
Min Freq 2
Max Freq 4998

Mean Relative Uncertainty = 1.09%
Mean Total Uncertainty (m/s) = 0.15

Wind Speed (m/s)	Wind Speed STD (m/s)	Wind Speed Bias Error (m/s)	Wind Speed Random Error (m/s)	Wind Speed Uncertainty	Relative Wind Speed Uncertainty	Anemometer Output (Hz)	Anemometer STD (Hz)	Anemometer DAQ Bias Error (Hz)	Anemometer Random Error (Hz)	Anemometer Uncertainty (Hz)	Relative Anemometer Uncertainty	Relative Regression Uncertainty	Total Relative Uncertainty	Total Uncertainty (m/s)
3.91	0.004	0.018	0.004	0.020	0.51%	14.34	0.075	0.00143	0.075	0.150	1.05%	0.94%	1.50%	0.06
5.87	0.007	0.027	0.007	0.031	0.53%	21.53	0.093	0.00215	0.093	0.187	0.87%	0.63%	1.19%	0.07
7.83	0.004	0.036	0.004	0.037	0.47%	28.86	0.170	0.00289	0.170	0.340	1.18%	0.47%	1.35%	0.11
9.81	0.006	0.045	0.006	0.047	0.48%	36.16	0.166	0.00362	0.166	0.333	0.92%	0.38%	1.10%	0.11
11.78	0.009	0.054	0.009	0.057	0.48%	43.45	0.210	0.00434	0.210	0.420	0.97%	0.31%	1.12%	0.13
13.73	0.008	0.063	0.008	0.065	0.47%	50.86	0.272	0.00509	0.272	0.545	1.07%	0.27%	1.20%	0.16
15.71	0.009	0.072	0.009	0.074	0.47%	58.28	0.294	0.00583	0.294	0.588	1.01%	0.23%	1.14%	0.18
17.69	0.010	0.081	0.011	0.084	0.47%	65.70	0.264	0.00657	0.264	0.529	0.80%	0.21%	0.96%	0.17
19.62	0.013	0.090	0.013	0.094	0.48%	73.11	0.238	0.00731	0.238	0.477	0.65%	0.19%	0.83%	0.16
21.58	0.014	0.099	0.014	0.103	0.48%	80.41	0.275	0.00804	0.275	0.550	0.68%	0.17%	0.85%	0.18
23.55	0.015	0.108	0.015	0.112	0.48%	88.03	0.379	0.00880	0.379	0.758	0.86%	0.16%	1.00%	0.23
25.51	0.013	0.117	0.013	0.120	0.47%	95.11	0.288	0.00951	0.288	0.575	0.61%	0.14%	0.78%	0.20
AVE	0.009	0.068	0.009	0.070	0.48%	AVE	0.227	0.0055	0.227	0.454	0.89%	0.34%		





Vestas Cup

Ucal = 1.09%

NRG #40

Ucal = 1.48%

Risoe Cup

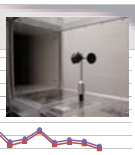
Ucal = 1.43%

RM Young Wind Sentry

Ucal = 1.02%

NRG IceFree

Ucal = 1.66%



Thies 1st Class

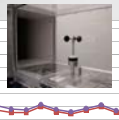
Ucal = 2.04%

RM Young Wind Monitor

Ucal = 0.75%

SecondWind C3

Ucal = 1.64%



Vaisala WAA252

Ucal = 1.98%

RM Young Propeller

Ucal = 0.50%