

Abstract

Atmospheric wind measurements are critical in the wind energy industry. Thus, it is essential that calibrated anemometers be deployed in field installations. An anemometer calibration produces a transfer function that relates an anemometer raw signal to a corresponding controlled reference wind speed. In order to account for the errors associated in a field wind measurement, it is also important that the uncertainty in the calibration test be estimated. The most widely referred published standard in the wind energy industry that defines the requirements, procedures, and uncertainty method for cup anemometer calibration is IEC 61400-12-1. According to this standard, anemometer calibration uncertainty is reported based on the uncertainty analysis of the controlled reference wind speed. However, the resulting calibration transfer function, which includes errors from the test anemometer output reading, is what is typically programmed in field data loggers. Thus, the uncertainty in the controlled reference wind speed is just a portion of the total uncertainty in the calibration.

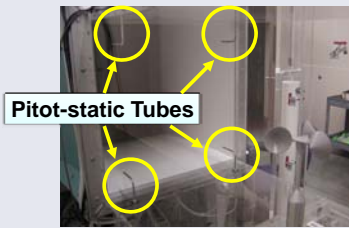
Objective

The objective of this poster is to propose a method of extending the anemometer calibration uncertainty to also include the error contributions from the anemometer output signal and the degree of linearity defined from the calibration transfer function. For sample applications, extended uncertainty analysis was performed on calibrations from commonly deployed anemometers in the wind energy industry.

Wind Tunnel Calibration Test Facility

Otech Wind Tunnel Facility, WT3A

Otech Engineering, Inc. is an ISO/IEC 17025:2005 accredited laboratory. WT3A is a suction-type (Eiffel-type) wind tunnel of test section size 61.0 cm crosswind width x 61.0 cm height x 121.9 cm downwind length and is driven by a 30 hp (22 kW) fan motor, which can generate winds up to 45 m/s. Controls and data acquisition are performed using National Instruments hardware and LabVIEW software.



Pitot-static Tubes



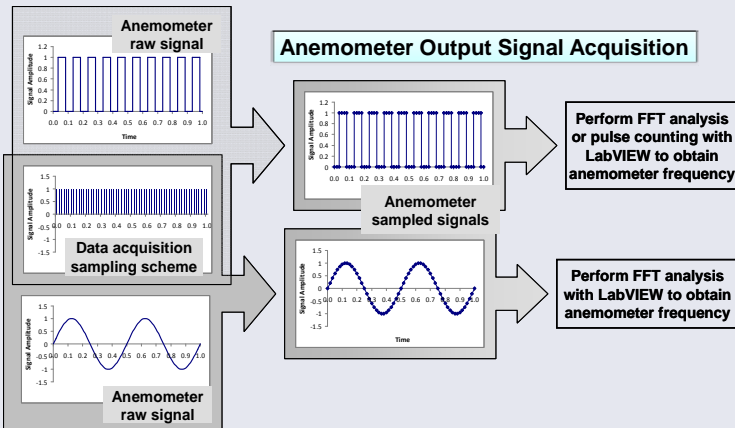
MKS Transducer



Setra Barometer



Omega Temp/RH Probe



Uncertainty Analysis Methods

Anemometer Uncertainty Analysis According to IEC 61400-12-1

Reference Wind Speed
Uncertainty Only

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

$$V = k_b \sqrt{\frac{2k_c}{C_h} \frac{\Delta p}{\rho}}$$

$$\rho = \frac{1}{T} \left[\frac{P}{R_{air}} - 0.01 \rho P_w \left(\frac{1}{R_{air}} - \frac{1}{R_w} \right) \right]$$

$$P_w = 0.0000205 \exp(0.0631846T)$$

$$R_{air} = \frac{R}{M_{air}} \quad R_w = \frac{R}{M_w}$$

Proposed Expanded Anemometer Uncertainty Analysis

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

Reference Wind Speed Uncertainty

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

Linear Regression Uncertainty

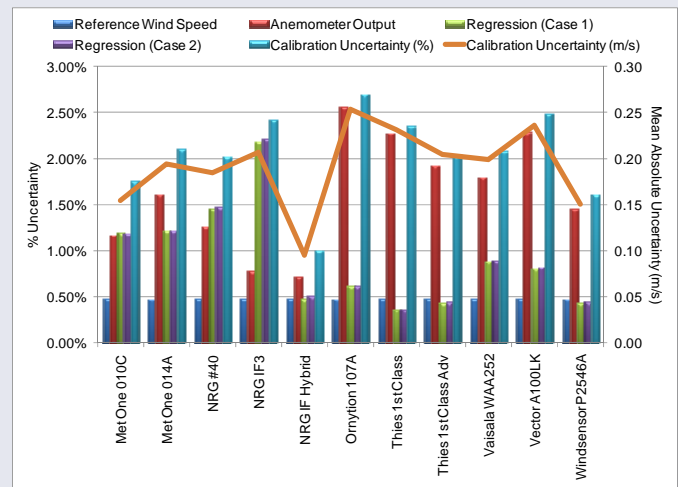
$$U_{LR_{Case1}} = \sqrt{\left(t \frac{STE_V}{V_i} \right)^2}$$

Anemometer Output Uncertainty

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

$$U_{LR_{Case2}} = \sqrt{\left(t \frac{STE_{m-f_i}}{V_i} \right)^2 + \left(t \frac{STE_b}{V_i} \right)^2}$$

Uncertainty Results



Conclusions

- According to IEC 61400-12-1, a calibration uncertainty analysis based on the reference wind speed is typically similar for all calibration tests, ~ 0.47%.
- Differences in the calibrations from each sensor type are mainly evident in the uncertainty analysis of the anemometer output and the linear regression.
 - Anemometer output uncertainty ~ 0.72% to 2.56%
 - Linear Regression Uncertainty (Case 1) ~ 0.36% to 2.18%
 - Linear Regression Uncertainty (Case 2) ~ 0.37% to 2.21%
- Expanded anemometer calibration uncertainty values range from approximately 1.00% to 2.56% (0.10 to 0.25 m/s) for cup anemometers calibrated according to the IEC 61400-12-1 test speeds of 4 to 16 m/s.

References

- IEC 61400-12-1 1st ed 2005-12 (2005). Wind turbines – Part 12-1: Power performance measurements of electricity producing wind turbines.
- Coleman, H.W. and W.G. Steele, Jr. (1999). *Experimentation and Uncertainty Analysis for Engineers*, 2nd ed. John Wiley & Sons, Inc, New York, NY.
- Eecen, P.J. and M. de Noord (2005). ECN-C-05-66, Uncertainties in cup anemometer calibrations: Type A and Type B uncertainties. Energy Research Center of the Netherlands.