Effects of long term operation on the performance characteristics of cup anemometers

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Summary

This work investigates the effect of operation duration on the response characteristics of cup anemometers. These effects are studied through the statistical analysis of consecutive calibrations of cup anemometers before and after usage. The results of the analysis suggest that the recalibration interval of VECTOR A100K anemometers could be increased to 18 months of operation on site, without affecting the reliability or the uncertainty of measurements.

1. Introduction

The importance of the accuracy of anemometer calibrations in wind energy applications is well established within the wind energy community. International Energy Agency (IEA) issued a first set of recommendations for use of anemometers [1]. MEASNET Network, has issued since 1997 a detailed recommended procedure [1] for to cup anemometer calibrations focusing on wind energy applications. Recently, MEASNET procedure was incorporated in IEC 61400-12-1:2005 as Annex F [2].

Anemometers used in wind energy applications usually operate under harsh conditions. The Laboratory for Wind Turbine Testing of CRES applies as a standard procedure the recalibration of cup anemometers after 12 months of operation in the field, a common practice among Testing Laboratories. A large data base of recalibrations of cup anemometers has evolved through the Laboratory's operation in the last years. In the present work, statistical analysis of the differences seen in the response characteristics of cup anemometers before and after their use is made. A total of 137 recalibrations are examined. The differences are compared to the overall uncertainty of the calibration procedure, and the effect of operation duration is examined. The statistical analysis aims at providing a sound base for the decisions related to the determination of the recalibration interval of cup anemometers.

2. Method

2.1 Use of cup anemometers at LWTT

Cup anemometers are the main instruments used by LWTT for wind speed measurement in all wind energy related projects. Although more sophisticated instruments (like sonic anemometers) are commercially available and technically capable for use in remote applications today, cup anemometers remain the instrument recommended by standardization institutions for wind energy related measurements [1], [3].

The cup anemometers used by LWTT are installed usually in complex terrain sites in the Mediterranean basin, both coastal and inland. For coastal applications the typical operating conditions would include a temperature range from 5^{o}C to 40^{o}C, abrasive atmosphere due to air salinity and dust accretion. For inland applications (usually in mountainous areas) a typical temperature range would be from -10 ^{o}C to 30^{o}C, with snow and frost occurrence quite often in winter months.

Figure 1. Anemometer damaged from lightning strike

As expected, open air measurement campaigns in exposed sites (as the overwhelming majority of wind energy measurement campaigns is) have a relatively large instrument failure rate. Of all mast mounted instruments leaving the storage area of the Laboratory for installation on site, about 30% do not return in operational status. The most frequent cause of damage of anemometers on-site as observed by the Laboratory is lightning strikes. In most cases, electronic parts of the instruments are damaged by induction currents. In some cases, secondary lightning attachments cause surge currents that produce small but decisive damage on the instrument

body (spot welding, bearing damage, rotor damage see Fig. 1).
Direct lightning hits which result in complete destruction of the units are less frequent. Snow accumulation or frost may also damage anemometers directly (rotor deformation, cups destruction) or indirectly (bearing damage). Mast mounted instruments are also damaged in cases of meteorological mast destruction as a result of extreme conditions (frost accumulation, storms).

From the experience of the Laboratory, at least for the type of anemometers mainly used (VECTOR A100K) it is observed that the damages to the anemometers are due mainly to specific "extreme situations'' namely lightning strikes, snow/ frost etc. Under "normal operating conditions" limited wear is observed for continuous operating periods more than two years.

2.2 Calibration procedure

As recommended by the standardization bodies [1], [3], the Laboratory for Wind Turbine Testing of CRES calibrates all anemometers before use. Anemometers used in long duration campaigns are recalibrated after 12 months of operation in the field. Being a member of MEASNET, LWTT applies MEASNET procedure for anemometer calibration [2] since 1997. The reference wind speed is measured using a pitot tube, velocity values are corrected for air density actual values calculated from atmospheric pressure, temperature and humidity. Detailed description of the procedure can be found in [2] and [3].
The LWTT is accredited by DAP (Deutsches Accreditierungsystem Prufwessen) a Testing laboratory according to ISO 17025 standard. Anemometer calibrations are included in the accreditation scope. All anemometers used by the Laboratory for wind energy applications as well as a large number of anemometers for third parties are calibrated in house by LWTT. More than 2000 anemometers have been calibrated by LWTT until today.
Until April 2002, calibrations were made at the Wind tunnel of the Aerodynamics Laboratory of National Technical University of Athens (NTUA). After April 2002 all anemometer calibrations by the LWTT are made at CRES wind tunnel. The test set up and instrumentation used in both wind tunnels is identical. The major difference between the two calibration facilities is the size of the test section used. NTUA wind tunnel has a considerably larger area (2.15 m^2) compared to the CRES wind tunnel ($0.64 m^2$). For calibration of anemometers used by the Laboratory (like VECTOR A100K and NRG Max#40) the test section difference is not affecting the reliability of the measurements because even at CRES wind tunnel the blockage factor including mounting is smaller than 4%).

2.3 Traceability and repeatability of calibrations

Traceability of the calibration procedure is established through the calibration of all reference instruments (differential pressure sensors, temperature, humidity, atmospheric pressure and anemometer output recorders) traceable to National or International Standards. Further support in obtaining universally accepted values for calibration coefficients is given by the participation of LWTT to MEASNET network anemometer calibration Round Robins. MEASNET network regularly runs Interlaboratory Comparisons (Round Robins) for anemometer calibrations. In these exercises anemometers are calibrated by all participants in a blind test arrangement and the results are compared. Acceptability criteria apply in order to characterize the successful participation. CRES LWTT has successfully participated in all MEASNET Round Robins since 1997.

Figure 2. CRES wind tunnel.

The integrity and the repeatability of the anemometer calibration set-up is checked regularly by calibrating the reference anemometer at the wind tunnel. The reference anemometer is not used in the filed and is used only for checking the calibration set-up. As required by [2] & [3], the maximum allowed deviation from the long term average should be less than 0.5% at 10m/sec. Any deviation greater than this indicates a possible error in the procedure or malfunction of some of the instruments and triggers corrective actions (change of reference instruments, recalibrations etc).
Results from reference anemometer calibrations for the last 5 years are given in Figure 3. Deviation is lower than the estimated typical error of calibration and within the limits set by [2], [3].

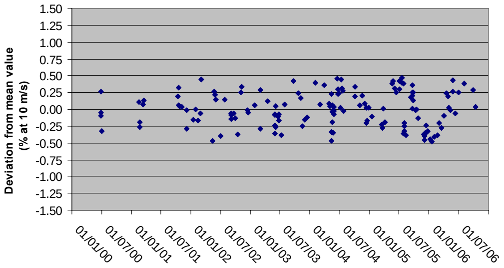


Figure 3. Results from Reference anemometer calibrations.

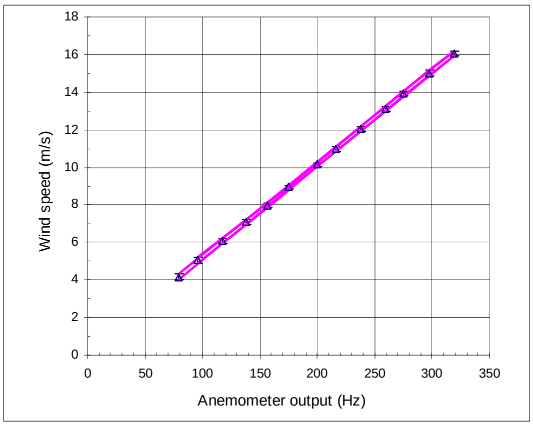


Figure 4 Response characteristics of a VECTOR A100K cup anemometer with calibration error limits (typical error 95%)

2.4 Uncertainty estimation

Uncertainty estimations for the anemometer calibration are made according to the requirements of [2] and [3]. The main uncertainty contributions come from differential pressure sensor sensitivity, and blockage correction. All other uncertainty factors recommended by [2], [3] are also included in the calculations. Table 1 presents average Total uncertainty per wind speed calibration point blockage correction. The associated typical error is also given. Calibration results with error margins for a typical anemometer calibration are presented in Figure 4.

Table 1. Calibration Total Uncertainty and typical error

Reference wind speed V (m/s)	Calibration Total Uncertainty s (m/s)	Calibration typical error ε= 2*s	
		(m/sec)	(%)
4.0	0.085	0.17	4.25
5.0	0.07	0.14	2.80
6.0	0.065	0.13	2.17
7.0	0.06	0.12	1.71
8.0	0.055	0.11	1.38
9.0	0.055	0.11	1.22
10.0	0.055	0.11	1.10
11.0	0.055	0.11	1.00
12.0	0.06	0.12	1.00
13.0	0.065	0.13	1.00
14.0	0.065	0.13	0.93
15.0	0.07	0.14	0.93
16.0	0.07	0.14	0.88

2.5 The Management System

The Management System of the Laboratory is the connecting tissue for all testing activity in the laboratory, anemometer calibrations included. The key-elements of the Management System are:

- Written procedures that are always kept up to the valid standards and recommendations
- Use of competent personnel
- Use of instruments traceably calibrated
- Internal Auditing scheme in combination with continuous efforts for improvements

Through the application of the Management System the Quality and Reliability of all testing activities is assured.

2.6 Method of work for the present article

To get a measurable value for the effect of usage on the operational characteristics, the difference in wind velocity (DV) corresponding to the same frequency output as estimated from the calibration characteristics before (a_1, b_1) and after the use (a_2, b_2) is calculated, as in the following equations

$$DV = V_1 - V_2$$

where

$$V_1 = a_1 * f + b_1$$

$$V_2 = a_2 * f + b_2$$

f selected frequency

a_1, b_1, response characteristics as defined by the calibration <u>before</u> use

a_2, b_2, response characteristics as defined by the calibration <u>after</u> use

Wind Velocity difference is calculated for three characteristic velocity values (6 m/s, 10m/s, 14sm/s) which cover the most important part of the operational range of a wind turbine.

In the present work, no distinction is made between coastal or inland use or any other operating condition. As **usage time** is considered the time the instrument remained outside the storage area of the Laboratory. “Real operating time” on site should be considered to be 10 to 30 days less than usage time (typical travel time range from the storage area to the measurement mast). In all cases within this article, the total usage time is considered (including travel time).

Five Usage Classes are considered:

Class 1: 60 to 180 days. This class covers a limited number of anemometers used as replacements in already running campaigns

Class 2: 180 to 360 days. Anemometers used for medium duration campaigns (site calibration, power curve, loads) or replacement of damaged sensors in larger campaigns

Class 3: 360 to 540 days. Anemometers used in large duration campaigns (wind potential measurements)

Class 4 : More than 540 days. This class includes mainly anemometers that remained in operational condition on site after the end of the measurement campaigns.

Anemometers with usage time less than 60 days are not studied, since in most cases they represent instruments sent on site as spare units (during system installation) and returned back with out being used.

Some of the results presented include instruments where minor electronic repair was made after their return from site. Recalibrations of anemometers where major service work (bearing replacement/removal, rotor change) was made after return from site are not included in the present work.

3. *Results*

Results from the recalibration of 137 anemometers are presented. These calibrations were made in the period 1998 until today. In 1998 the Quality Assurance System of the Laboratory was in full operation. Accreditation was given in 1999. All anemometers presented are VECTOR A100K anemometers. Limited numbers of recalibrations of NRG Max#40, and Climatronics F460 were also available, but are not included in this work. The number of units of anemometers other than VECTOR A100K is not statistically significant to be presented as a separate data base, while their inclusion in the results from VECTR A100K units could introduce distortions to the results.

Two sample recalibration cases are presented in Figures 5 & 6.

In Figure 5 recalibration results of a VECTOR A100K anemometer recalibrated after 15 months of field use are presented. The graph includes the typical error limits (95%) of the initial calibration and the response characteristics as calculated by the recalibration. No damage was observed on the anemometer after use on the field. The anemometer response characteristics as calculated from the recalibration are well within the uncertainty limits of the initial calibration throughout the operational range. A different case is presented in Figure 6. Again a VECTOR A100K anemometer returned after 15 months of operation on site. Bearing damage was detected, and the unit was withdrawn from service, for the bearings to be changed. A recalibration was made before the change of the bearings. As observed in Figure 6, deviations between the initial calibration and the calibration after bearing damage was detected are significant (2 to 3%) in all operating range.

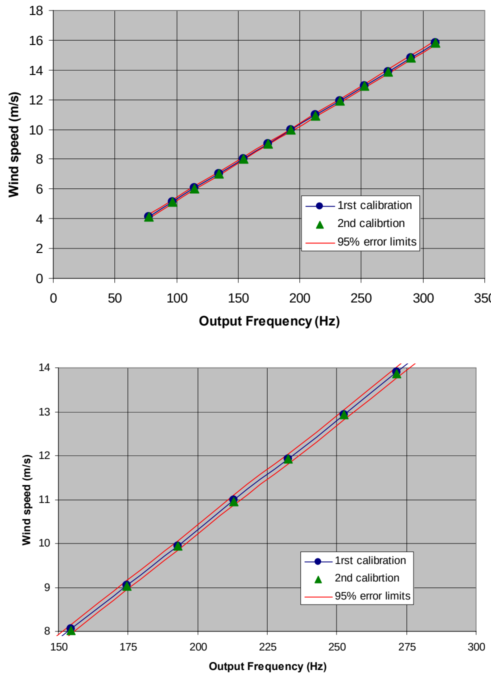


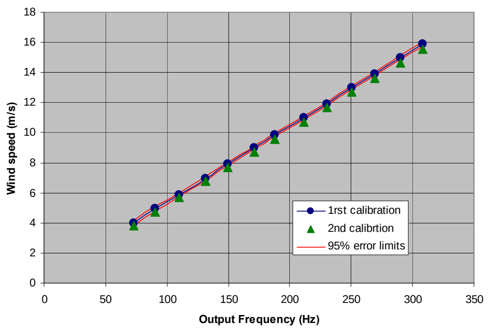
Figure 5. Recalibration results – undamaged unit, 15 months of operation on site
a: full calibration scale b: detail
95% error limits correspond to the 1rst calibration

Statistics per usage class for the anemometers examined are given in Table 2.

Table 2. Statistics per usage class

Usage Class	Number of cases	Average usage days
60d-180d	23	110.9
181d-360d	32	252.6
361d-540d	44	452.5
>540d	35	732.9

A scatter plot of the wind velocity deviation (DV) between the operational characteristics of the anemometer as estimated by calibration before and after use versus the days of use is given in Figure 7. As seen, for up to ~700 days of use, no trend of increasing deviation with increasing time is seen. After 700 days, a trend showing increased deviation can be observed.



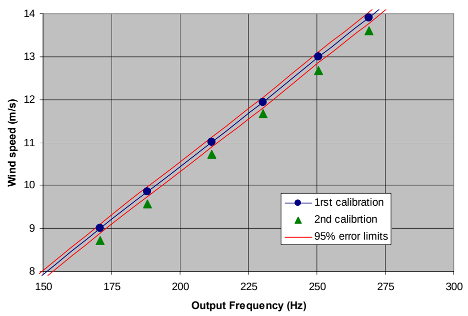


Figure 6. Recalibration results – unit with bearing damage, 15 months of operation on site
a: full calibration scale b: detail
95% error limits correspond to the 1rst calibration

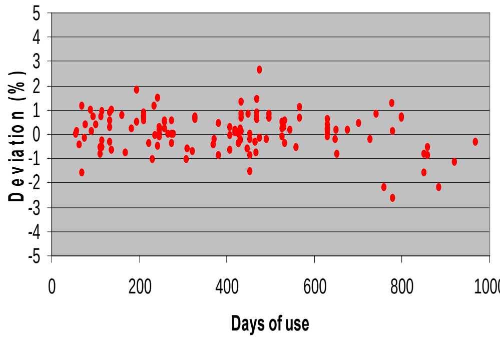


Figure 7. Deviation at 10m/sec for recalibrated units, as a function of usage time (Vector A100K , 137 cases)

The mean absolute deviation per usage class (Figure 8) remains below the calibration uncertainty limits for all usage classes. A trend for increasing deviation for usage above 540 days can be observed.

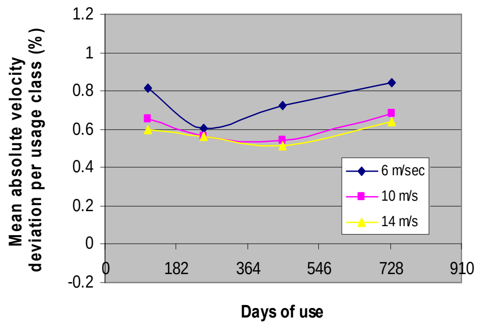
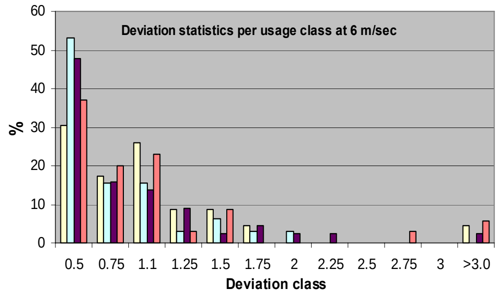
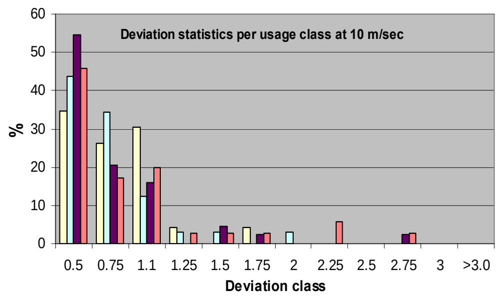


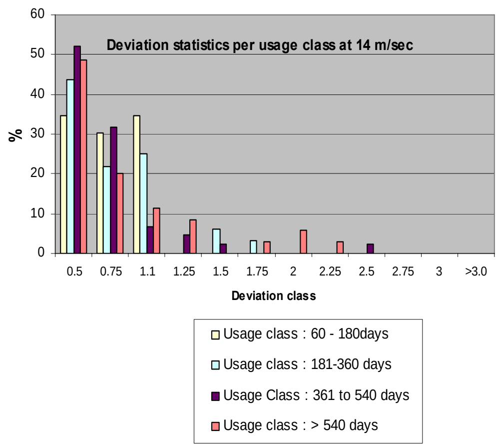
Figure 8 Mean absolute deviation per usage class



a: Reference wind speed 6 m/s

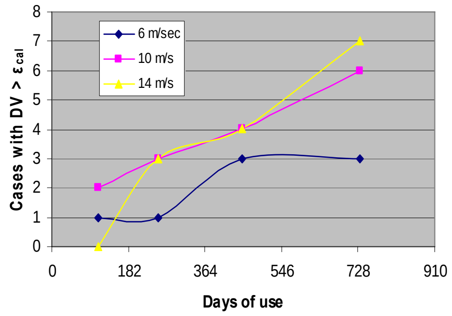


b: Reference wind speed 10 m/s

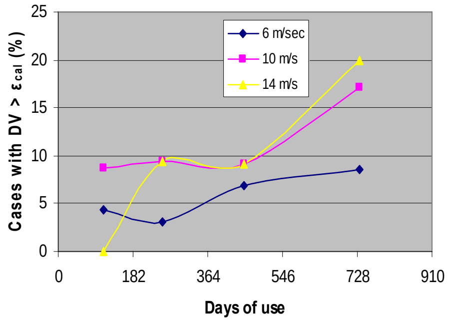


c: Reference wind speed 14 m/s
Figure 9. Distribution of recalibrations per deviation class

In the majority of cases studied for the usage classes up to 540 days, deviation in wind velocity is within the calibration error limits.
The same trend is demonstrated more clear in Figure 10 where the recalibration cases per usage class that exceed the error margins of calibration uncertainty are presented. The calibration error limit is taken from Table 1, for the respective reference wind speeds (6m/s, 10 m/s, 14 m/s). A low drop out rate (below 10%) is seen for classes up to 540 days of use. For the usage class greater than 540 days a trend to increase the rate of recalibrations with deviations exceeding the calibration uncertainty is clearly seen.



a: absolute number



bb

: relative (%)

Figure 10. Recalibration cases per usage class where the velocity deviation exceeds calibration uncertainty error margins.

4. Conclusions

A representative number of recalibrations of VECTOR A100K cup anemometers after various duration of operation were examined. The traceability and repeatability of the calibration procedure is assured by the strict implementation of the requirements IEC61400-12-1:2005/Annex F [3] and MEASNET Cup Anemometer Measurement Procedure [2].
The differences in the response characteristics of the anemometers are kept within the calibration typical error interval for the majority (>90%) of cases studied for all usage class up to 540 days (18 months). The deviation indexes examined show a week trend for increasing deviation for usage more than 18 months (540 days).
The above results suggest that the calibration interval for VECTOR A100K anemometers could be increased up to 18 months with out affecting the reliability or the uncertainty of the measurements.
Although for the majority of the recalibration cases examined, the deviations in operational characteristics before and after use were within the calibration uncertainty limits, a limited number of outliers with differences up to 3% was also seen. Therefore the response characteristics of anemometers after extended periods of operation should be verified by means of recalibration or in-situ calibration through a back-up anemometer.
Additional work on the effect of anemometer type, and operating conditions – temperature range, air salinity, and dust etc- could provide important information to the manufacturers and users of cup anemometers that could help in improve the reliability of wind speed measurements.

References

[1] International Energy Agency (IEA) Recommended Practices: Wind speed measurement and cup anemometry 1991
[2] MEASNET – Cup Anemometer Calibration Procedure.
[3] IEC61400-12-1:2005 Wind Turbines-Part 12-1: Power performance measurements of electricity producing wind turbines