On the signature of cup anemometers' opto-electronic output signal: extraction based on Fourier analysis

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Abstract:

The output signal of cup anemometers equipped with opto-electronic output signal generators (such as Vector Instruments A100 LK or Thies First Class Advanced) is analyzed to extract the signature of the anemometer. This signature is a unique information for each single anemometer whose output signal is a train of square-pulses. This signature reflects errors introduced within the fabrication process of the slotted wheels from the opto-electronic output signal generator. The signature of a cup anemometer can be used to filter the output signal, increasing the accuracy of the wind sensor.

1 Introduction

The output signal of a cup anemometer is generated usually either by magnets (sinusoidal wave) or by an opto-electronic system (square wave) [1]. The opto-electronic system consists of a slotted wheel fixed to the anemometer shaft and an electronic device that registers led-generated light through the aforementioned wheel, generating two different voltage levels (the higher one if the light sensor receives light through the wheel slots, and the other lower one if that sensor is not illuminated), see Figure 1. It should be also mentioned that this is a quite classic output generator design. More modern technologies allow a much higher resolution. The

use of these technologies has been recently suggested in relation to wind sensors [2]. However, to the authors' knowledge they haven't been integrated in commercial cup anemometers yet.

Figure 1. Opto-electronic output signal generator system of the Climatronics 100075 cup anemometer.

As the top-accuracy cup anemometers have from 25 (Vector Instruments A100 LK) to 37 (Thies First Class Advanced) pulses per turn of the rotor, it can be said that the three accelerations of the rotor (and corresponding decelerations) caused by the aerodynamic forces on each one of the three cups can be reasonably measured by the system. Therefore, it is possible to analyze the cup performance using Fourier analysis [3–5]. However, the accuracy of this technique can be compromised due to fabrication errors and misalignment of the slotted wheel in relation to the electronic light sensor, in the opto-electronic output system.

In a previous work, the output signal harmonic terms from large series of two different and well-known first-class cup anemometers were analyzed [5]. Significant differences related to the first and third harmonic terms were observed among the results from this research, one of these anemometers showing a greater statistical dispersion than the other one.

The train of pulses during one turn is called the signature of the cup anemometer, these pulses being characteristic in each individual anemometer as some differences among pulses

might exist due to the fabrication process. In a work by Dalberg et al. the signature of a 44-output pulse cup anemometer was measured (see Section 2), revealing differences up to 10% between pulses [6]. This signature was directly measured at high frequency (100 kHz) in still air.

In the present technical note a procedure to measure cup anemometers' signature from a calibration is described. This methodology can help to study the cup anemometer's performance by analyzing the changes in the signature along the life of the instrument. Finally, this work is part of a project devoted to analyzing the cup anemometer's output signal [7], in order to develop new methodologies to improve the accuracy of this wind sensor. Until now, the efforts have been focused on the rotor aerodynamics, in order to better understand the rotor performance. Future research is planned to be related to the signal post-processing to reduce the overspeeding effect.

2 Analysis of the cup anemometer output signal and experimental set-up

The signature of the 44-output pulse cup anemometer measured by Dalberg et al. [6] is plotted in Figure 2. In the graph from this figure, the length of a pulse in relation to the average one (that is, the average length) is plotted. The aforementioned authors used that information to correct the pulses measured in one turn of the rotor rotating in $8 \text{ m}\cdot\text{s}^{-1}$ air flow. See in Figure 3 both the uncorrected and corrected train of pulses. It can be clearly observed the three accelerations of the rotor in the corrected signal, as noted by Dalberg et al.

The first twelve Fourier harmonic terms of both the uncorrected and corrected signals are plotted in Figure 4. The third harmonic is the most relevant term extracted from the uncorrected signal, as it reflects the aerodynamic forces that accelerate the rotor three times per turn. Besides, it can be observed in Figure 3 that this third harmonic term from the uncorrected signal is very similar to the corresponding one from the corrected signal.

Figure 2. Relative-to-the-average length of the pulses from a Thies 4.3520 cup anemometer, measured in still air [6]. The results from the indirect approach described in the present work have been also included in the graph.

Therefore, it is reasonable to assume that the effect of the aforementioned three accelerations of the rotor during one turn can be properly reflected on the third harmonic term extracted even from an uncorrected signal. In the graph from Figure 3, the third harmonic from the uncorrected signal has been also plotted. It can be clearly noted the similarities between this harmonic and the corrected signal.

If the influence of the most important aerodynamic effect (that is, the third harmonic term) is subtracted from the uncorrected signal, only other minor effects such as turbulence and measurement errors will remain together with the signature as the main contributions to detach the length of the pulses from the average value. In Figure 2, the signature calculated in the present work subtracting the third harmonic term from the uncorrected signal obtained from Dahlberg et al. data is also included in the graph. As it can be observed, the calculated signature (with an error within $\pm 0.75\%$ bracket) is very similar to the one measured by Dahlberg et al. Consequently, it can be assumed that the signature from an individual cup anemometer can be extracted by this indirect process.

Figure 3. Relative-to-the-average length of the pulses from a Thies 4.3520 cup anemometer, measured at $8 \text{ m}\cdot\text{s}^{-1}$ wind speed [6]. The uncorrected signal as well as the corrected one (with de signature, see Figure 2) are shown. The 3rd harmonic term of the uncorrected signature has been also included in the graph.

Figure 4. First twelve harmonic terms, A_i , from the uncorrected and corrected signals from a Thies 4.3520 cup anemometer measured at $8 \text{ m}\cdot\text{s}^{-1}$ wind speed [6].

2.1 Experimental setup

In the present work, the signature of a Climatronics 100075 cup anemometer (Figure 1) is studied by being measured both in still air and in wind tunnel. The measurements in still air were carried out at constant velocity, by using a DC-motor geared to the anemometer (see Figure 5). The facility used for the measurements carried out in wind tunnel is the calibration wind tunnel at IDR/UPM. This is an open-circuit wind tunnel described in previous works [1,8–10]. The cup anemometer's output signal was sampled at 20 kHz for the measurements in still air, initially. Additionally, other set of measurements were carried out at larger frequency (25 kHz), to check the possible effect of the sampling rate. In contrast, the cup anemometer's output signal was sampled at 125 kHz in the testing carried out in the wind tunnel. This larger frequency was selected to obtain new insights into the effect of the turbulence (in this case, very low turbulence level) on the anemometer's performance for a parallel research. Besides, the higher sampling rate helped to better reproduce the third harmonic term of the signal and its first multiples.

Figure 5. Testing set-up for measuring the Climatronics 100075 cup anemometer signature in still air.

3 Results

In Figure 6, the signature directly measured (see Figure 5) at 20 and 25 kHz is shown. This signature is presented as the percentage length of each one of the 30 pulses per turn of the wheel (see Figure 1), in relation to the average length of the pulses (that is, $1/30$ of the total turn), d_p . The results indicate a sinusoidal pattern, indicating a displacement of the pulse wheel center from the rotation axis of the anemometer shaft. In Figure 7 the harmonic terms, A_i , of these two signatures are shown. As expected and in accordance with the results from Figure 6, the first harmonic term is the most relevant one.

Figure 6. Signature of the Climatronics 100075 cup anemometer directly measured (see Figure 5) at 20 and 25 kHz. The indirect signature extracted with the data recorded in wind tunnel at $2 \text{ m}\cdot\text{s}^{-1}$ is also included in the graph.

The pulse lengths of the anemometer measured in wind tunnel at $2, 4, 6$ and $8 \text{ m}\cdot\text{s}^{-1}$ are shown in Figure 8. In this figure, the 9-term Fourier approximation to the pulse length measured at $2 \text{ m}\cdot\text{s}^{-1}$ has been also included to show the high accuracy of this mathematical tool. See also in Figure 7 the values of the 9 harmonic terms of this approximation. It can be observed that the harmonic terms of the signature measured in wind tunnel are similar to the ones from the signature directly measured (at constant rotation rate in still air), with the exception of the third harmonic term which represents the 3 accelerations of the rotor in one turn due to the anemometer cups.

Finally, the signature obtained from the one measured at $2 \text{ m}\cdot\text{s}^{-1}$ once the third harmonic term has been extracted is included in Figure 6, to be compared to the signatures directly measured. The results are in accordance with the ones based on the work by Dalberg et al. (included in section 2), indicating the possibility of extracting a cup anemometer signature from a calibration process and not using an specific procedure in still air.

Figure 7. First nine harmonic terms, A_i , from signature of the Climatronics 100075 cup anemometer directly measured. The harmonic terms from the pulse length data recorded at $2 \text{ m}\cdot\text{s}^{-1}$ is also included in the graph.

Figure 8. Pulse length data of the Climatronics 100075 cup anemometer recorded at 2, 4, 6 and $8 \text{ m}\cdot\text{s}^{-1}$. A 9-term Fourier approximation to the $2 \text{ m}\cdot\text{s}^{-1}$ data is also included in the graph.

4 Conclusions

A procedure to extract the signature of a cup anemometer indirectly is described in this short note. This not-direct procedure is based on data recorded in wind tunnel. This promising result indicates the possibility of extracting this information (which is unique for each single anemometer equipped with an opto-electronic output signal generator), during the calibration of the wind speed sensor. Therefore, it facilitates the use of the signature to filter the cup anemometer's output signal in order to increase the accuracy of this wind speed sensor.

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Cup anemometer's rotation rate comprises a constant term plus harmonic terms

Anemometer's output signal system integrates a slotted wheel to generate pulses
Differences between slots is a unique information called the anemometer's signature
This signature can be extracted from anemometer's output signal measurements
This extraction uses the Fourier decomposition of the rotation rate in one turn

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