ON THE CUP ANEMOMETER WORKING CONDITION MONITORING

Santiago Pindado, Alejandro Martínez, Enrique Vega, Encarnación Meseguer, Luis García, Ángel Sanz-Andrés
Instituto Universitario de Microgravedad "Ignacio Da Riva" (IDR/UPM)
Universidad Politécnica de Madrid.
ETS de Ing. Aeronáutica y del Espacio, Pza. Del Cardenal Cisneros 3, Madrid 28040, Spain
+34 91 336 63 53 / +34 91 336 63 63; santiago.pindado@upm.es

Summary

The analysis of the harmonic terms related to the rotational speed of a cup anemometer is a way to detect anomalies such as wear and tear, rotor non-symmetries (rotor damage) or problems at the output signal system. The research already done in this matter at the IDR/UPM Institute is now taken to cup anemometers working on the field. A 1-2 year testing campaign is being carried out in collaboration with Kintech Engineering. 2 Thies First Class Advanced installed at 58 m and 73 m height in a meteorology tower are constantly monitored. The results will be correlated to the anemometer performance evolution studied through several calibrations planned to be performed along the testing campaign.

1. Introduction

As a cup anemometer loses performance, due to the normal wear and tear process or to sudden incidents such as lightning, the wind speed measurement given by the instrument diverges from the real wind speed. This error can be translated into a wrong wind turbine operation or inaccurate data when studying the energy production of a specific geographic location, causing a negative impact on the revenue. Around 30% of mast-mounted anemometers return for recalibration far from normal operational conditions [1]. See Fig. 1.

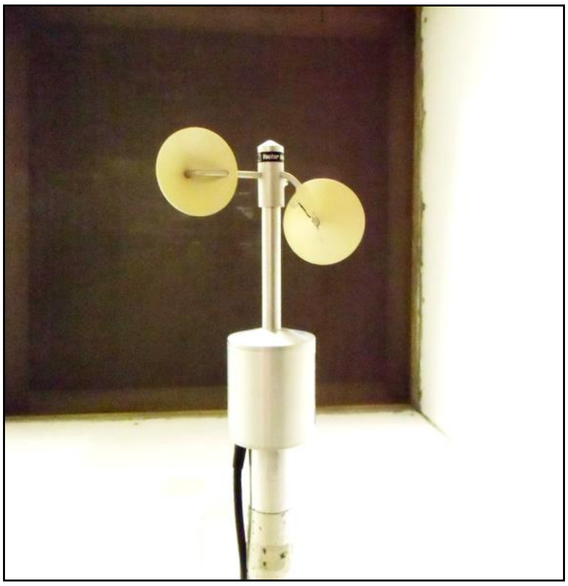

Fig. 1 Vector Instruments A100 LK cup anemometer calibrated at the IDR/UPM Institute after a service period on the field.

Today, the only solution for keeping anemometers in a proper working condition is to check them through frequent calibrations [2]. Calibration-on-the-field procedures are also a cost-effective solution for reducing anemometer maintenance and the number of recalibrations [3,4].

As said, different situations can affect the cup anemometer performance:

- Rotor damage due to severe storms, hail or lightning.
- Wear and tear (that affects mainly the anemometer bearings).
- Failure at the opto-electronic output signal system.

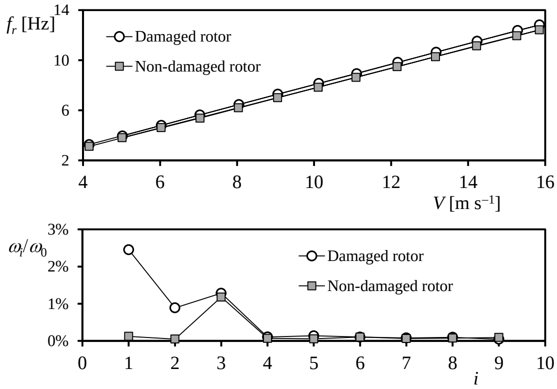

Fig. 2 (Top) Calibration curves of a Vector Instruments A100 LK cup anemometer with damaged (Fig. 1) and non-damaged rotors. (Bottom) Rotational speed Fourier decomposition terms of the anemometer with both damaged and non-damaged rotors.

Estimating a cup anemometer working condition is not an easy task, even when results from several consecutive calibrations are available [5]. One of the biggest troubles that people responsible for wind speed sensors condition face is that even in a damaged condition, the cup anemometer can produce a quite regular output signal. As an example, see in Fig. 2 the calibration curve of the cup anemometer from Fig. 1, equipped with the damaged rotor of the figure and with an undamaged rotor. It can be appreciated that the calibration curve of the anemometer with the damaged rotor is as linear as the one related to the anemometer equipped with the undamaged rotor. And even more, the damaged case seems to be better in terms of aerodynamic efficiency, as the rotation rate is higher. Of course, this not entirely right as the damaged rotor has a lower moment of inertia when compared to the undamaged one (the damaged cup is closer to the rotation axis), consequently increasing the rotation rate.

Another example that can illustrate the consequences of a damaged rotor is the case of a rotor with one cup missing. This rotor is able to rotate quite regularly, as the broken one from Figs. 1 and 2, with a linear relationship between the rotation rate and the wind speed. However, due to the unsymmetrical configuration of the cups this rotor has two equilibrium or “flag” positions, one of them being stable [6,7]. See in Fig. 3 a one-missing cup anemometer at “flag” position.

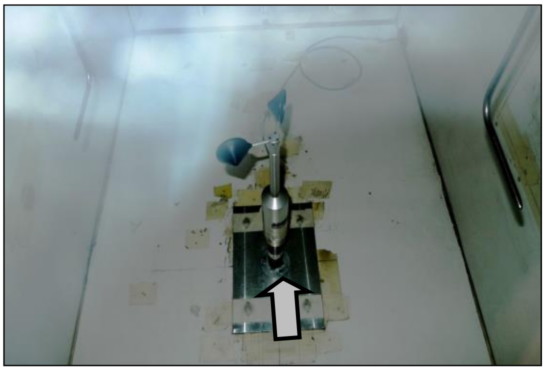

Fig. 3. Damaged cup anemometer with one cup missing at “flag” position during the testing campaign (wind tunnel wind speed is around V = 6 m/s; wind-flow direction is indicated with an arrow in the picture). View from the top-window of the calibration tunnel at the IDR/UPM Institute.

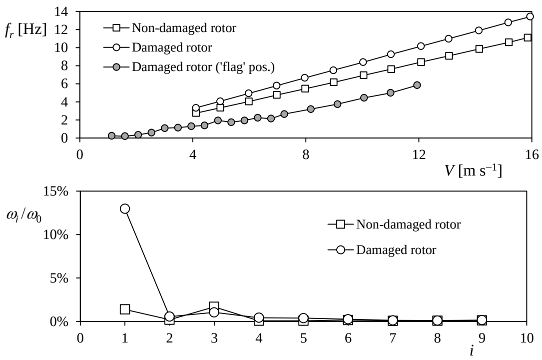

Fig. 4. (Top) Calibration curves of a Climatronics 100075 cup anemometer with non-damaged and damaged (one cup missing, see Fig. 3) rotors. The rotational frequency regarding the damaged rotor has been included, as a function of the wind speed, in both the normal rotating situation, and the “flag” position situation. (Bottom) Rotational speed Fourier decomposition terms of the anemometer in the described cases.

As said before and stated in Fig. 4, this one-cup-missing rotor can rotate quite linearly. Besides, in case of being in “flag” position, a signal output can be produced due to the rotor oscillations, that is, a pulse train that can be misinterpreted as a correct wind speed by the sensor data logger (see in Fig. 4 the false rotation frequency given by a one-cup-missing rotor at “flag” position as a function of the wind speed). This false pulse train can be produced in most of Class-1 cup anemometers, as they are equipped with opto-electronic systems that give a quite number of square pulses per turn [8].
In the present work, a new methodology to monitor cup anemometer status when working on the field is described. This methodology is under development by the IDR/UPM Institute in collaboration with Kintech Engineering. This method could help to optimize the maintenance of these sensors, if it is implemented on the corresponding data loggers.

2. The harmonic series decomposition

Under a perfectly constant, horizontal and uniform wind speed, it is reasonable to suppose that the rotational speed corresponding to a 3-cup rotor can be decomposed along one turn into a constant term, ω_0, plus one harmonic term that corresponds to a frequency three times bigger than the one related to the mentioned constant term, $3\omega_0$, and its multiples, $6\omega_0$, $9\omega_0$, $12\omega_0$...:

$$\omega(t) = \omega_0 + \sum_{n=1}^{\infty} \omega_{3n} \sin\left(3n\omega_0 t + \varphi_{3n}\right). \qquad (1)$$

However, due to turbulence, wakes in the flow pattern, and mechanical non-uniformities such as bearings degradation, other harmonic terns different from the multiples of $3\omega_0$ are present in the rotational speed [9,10].

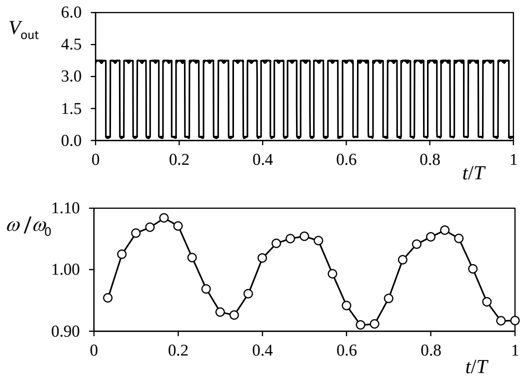

Fig. 5. (Top) Pulse train (voltage output, V_{out}) of a Climatronics 100075 cup anemometer at a constant wind speed. (Bottom) Non-dimensional rotational speed, ω/ω_0, extracted from the pulse train [9].

In Fig. 5 the pulse train (output signal voltage) generated on one turn (i.e., one rotational period) by a Climatronics 100075 cup anemometer (30 pulses per turn), is shown, together with the non-dimensional velocity extracted from that pulse train. It can be observed in the figure that leaving aside the average rotational speed, ω_0, there is a harmonic term with a frequency three times larger than the rotation speed. The rotational speed also presents some irregularities that are taken into account by other harmonic terms.

The described Fourier decomposition of the rotational speed allows anomaly detection on the sensor, as any asymmetric effect on the rotor-shaft system (dirt, damage, wear and tear…) is reflected mainly on the first term of the rotational speed Fourier series decomposition, see Figs. 2 and 4.

3. Present research: cup anemometer status based on harmonic terms analysis. Field measurements

Based on the good results already obtained with damaged anemometers [6,7,11], or equipped with non-symmetrical rotors [10], the IDR/UPM Institute is now carrying out a testing campaign in collaboration with Kintech Engineering, a Spanish enterprise leader in wind speed measurement systems and wind turbines power performance measurements.

Fig. 6. Kintech Engineering meteorological tower located at Zaragoza (Spain).

Two Thies First Class Advanced cup anemometers are installed in the meteorological tower of Kintech Engineering in Zaragoza (Spain), see Fig. 6. The first one was installed in December 2014 at 58 m height, and the second one was installed in April 2015 at 73 m height.
The anemometers are constantly monitored. The Kintech data logger provides measurements of the mean, maximum and minimum wind speed, together with the wind turbulence level. Also, the Kintech measurement system provides information of the temperature.
A second measurement system (Compact RIO by National Instruments) provided by the IDR/UPM Institute takes measurements of the anemometers output signals (20 seconds at 5 kHz each 5 min.). This system was programmed in LabView.
In Fig. 7 a comparison between the wind speed measurements taken by the Kintech data logger and the Compact Rio system in relation to the 58 m height anemometer, is shown. The data obtained by the Compact Rio system is post-processed in order to obtain the first and the third harmonic terms related to the average wind speed, that is, ω_1/ω_0 and ω_3/ω_0.

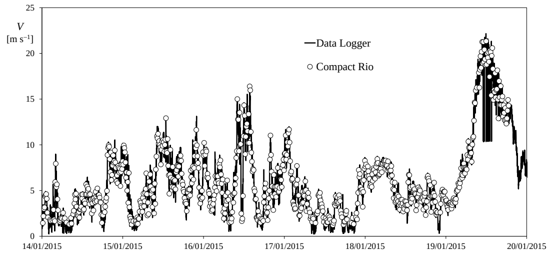

Fig. 7. Wind speed measurements taken with the Kintech Engineering data logger and the Compatct Rio systems, from the 58 height anemometer installed at the meteorological tower (see Fig. 6).

In Fig. 8 the first and the third harmonic terms corresponding to measurements of the 58 m height anemometer taken at several periods are plotted as a function of the wind speed, together with the values from the initial calibration.

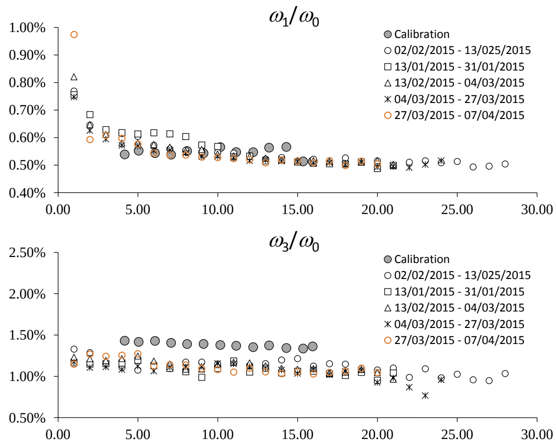

Fig. 8. First and third harmonic terms corresponding to the 58 m height anemometer installed at the Kintech Engineering meteorological tower. In the graphs the values corresponding to 5 different periods are included.

At present, data from the two anemometers corresponding to 10-15 consecutive days are continuously post-processed. The aim of the planned research is to identify the evolution of the first and third harmonic terms with changes on the anemometers' performance. For this reason several recalibrations at the IDR/UPM Institute are foreseen in the next year. Besides, the effect of the atmospheric turbulence and the temperature on the harmonic terms will be taken into account. Initial results indicate a reduced effect of the temperature but quite great effect of the turbulence, especially on the third harmonic term.

4. Conclusions

The analysis of the harmonic terms related to the rotational speed of a cup anemometer is a way to identify anomalies on its performance such as:

- Non-symmetries at the rotor (dirt, rotor damage).
- Wear and tear.
- Partial failure of the opto-electronic output signal system.

At present, this analysis is performed on cup anemometers working on the field. The testing campaign is being carried out thanks to the research agreement between IDR/UPM Institute and Kintech Engineering. It is expected to have results in 12-18 months from now.

5. References

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On the cup anemometer working condition monitoring

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IDR/UPM, E.T.S.I. Aeronáutica y del Espacio, U.P.M., Madrid, Spain

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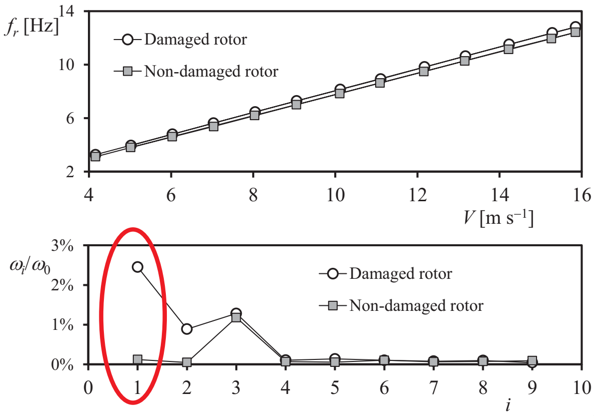
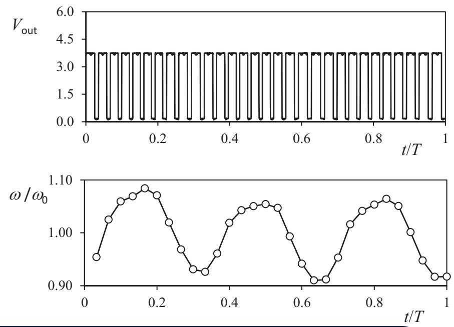
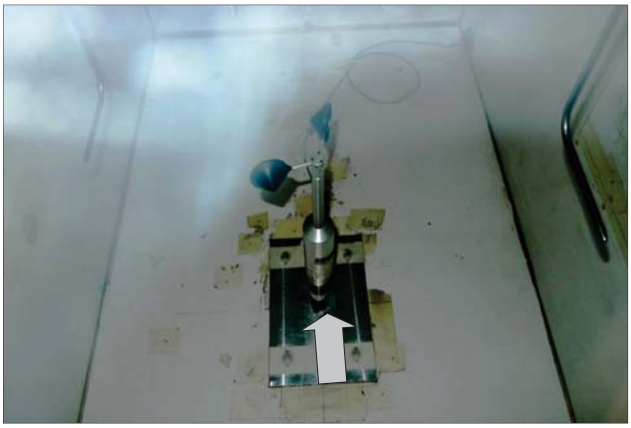
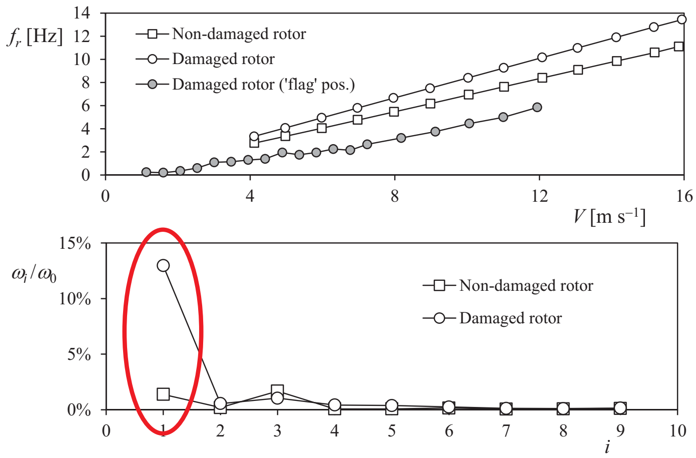
DAMAGED CUP ANEMOMETERS



HARMONIC ANALYSIS

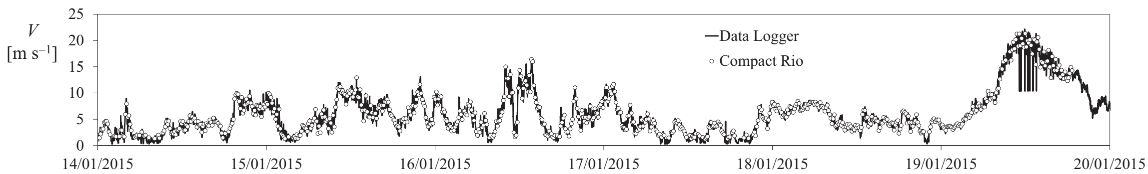


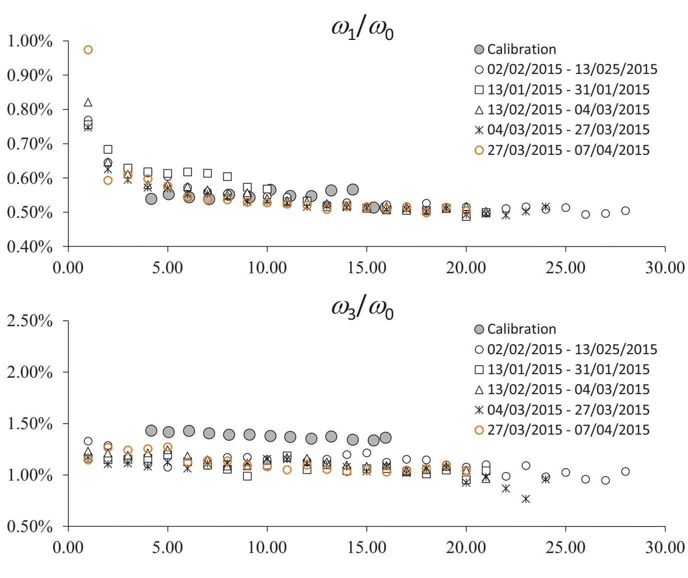




$$\omega(t)=\omega_0+\omega_1\sin(\omega_0 t+\varphi_1)+\omega_2\sin(2\omega_0 t+\varphi_2)+\omega_3\sin(3\omega_0 t+\varphi_3)\ldots=\omega_0+\sum_{n=1}^{\infty}\omega_n\sin(n\omega_0 t+\varphi_n)$$

TESTING CAMPAIGN ON THE FIELD (in collaboration with Kintech Engineering)





Testing campaign:

- 2 cup anemometers
- Meteorological tower (Kintech Engineering)
- 12-18 months
- Turbulence and temperature correlation
- Periodical calibrations
- Correlation harmonic terms vs performance