Calibration of mechanical anemometer in a wind tunnel using a 3D ultrasonic anemometer.

Fábio Ouverney Costa, Felipe dos Santos Ferreira, Samuel Araújo

National Institute of Metrology, Quality and Technology - Inmetro

E-mail: focosta@inmetro.gov.br, fsferreira@inmetro.gov.br, saraujo@inmetro.gov.br

Abstract: This paper presents the method used by National Institute of Metrology, Quality and Technology (Inmetro) for the calibration of mechanical anemometers, as well as the mathematical modeling and results to one calibration. The calibration is carried out at the exit of the contraction of an open-loop aerodynamic wind tunnel, which was characterized for both turbulence and spatial uniformity, and the correction is achieved by direct comparison with an ultrasonic anemometer, which works as the reference.

Keywords: Mechanical, Calibration, Anemometry, Ultrasonic.

1. INTRODUCTION

Mechanicals anemometers are broadly used in several industries, being the energy industry the most common one. In metrology field, they are used to provide traceability, to do calibration and scientific researches.

The calibration is done to find corrections to the values read by the instrument in calibration, with calculated uncertainty, using a traceable calibrated reference.

The anemometer's calibration is to be conducted in a uniform, horizontal, steady-state flow of low turbulence levels. To follow the standard procedure and to obtain the best results as possible, the requirements for a wind tunnel anemometer calibration facility had to be according to the anemometer test procedures from International Electrotechnical Commission [1].

2. DEVELOPMENT

This work aims to develop a method to calibrate mechanical anemometers using an ultrasonic anemometer as velocity standard and the aerodynamic wind tunnel from the Fluid Dynamics Metrology Division (Dinam) from the National Institute of Metrology, Quality and Technology (Inmetro) as testing bench, which was previously characterized in the exit of its contraction, for turbulence intensity and spatial variation of the velocity profile. It has a square cross section of 500 mm side, and works as a free jet, thus eliminating interferences that the walls could generate. The characterization was made in 15 points, distributed by axis 'x' and 'y', as shown in figure 1. The operation range is from 2.80 $m{\cdot}s^{-1}$ to 23.87 $m{\cdot}s^{-1}$.

The mechanical anemometer that was calibrated was a small vane type [2], with velocity range from 0 $m{\cdot}s^{-1}$ to 60 $m{\cdot}s^{-1}$ and resolution of 0.01 $m{\cdot}s^{-1}$ .The instrument used as standard was a 3 components ultrasonic anemometer, with velocity range from 0 $m{\cdot}s^{-1}$ to 20 $m{\cdot}s^{-1}$ and resolution of 0.005 $m{\cdot}s^{-1}$, calibrated and traceable by National Metrology Institute of Japan (NMIJ).

The ultrasonic anemometer was mounted in a metal structure, fixed by clips at the end of the contraction. The geometric center of the intersection volume of the standard anemometer was positioned in the top center of the tunnel (position (0, +210) mm of the coordinate system using the tunnel as reference, as shown in figure 1). It was aligned so that the axial component of velocity ('z', according to the adopted coordinate system) had the higher value as possible, and 'x' and 'y' components were close to zero. The mechanical anemometer was mounted in an anti-vibration table and installed above a rotational and tilt platform, in which both inclination and rotation could be adjusted. A digital inclinometer was used to verify the inclination of the anemometer. It was positioned in the middle of the aerodynamic wind tunnel (position (0, 0) mm of the coordinate system using the tunnel as reference – figure 1), and both anemometers were positioned 40mm away from the exit of the contraction.

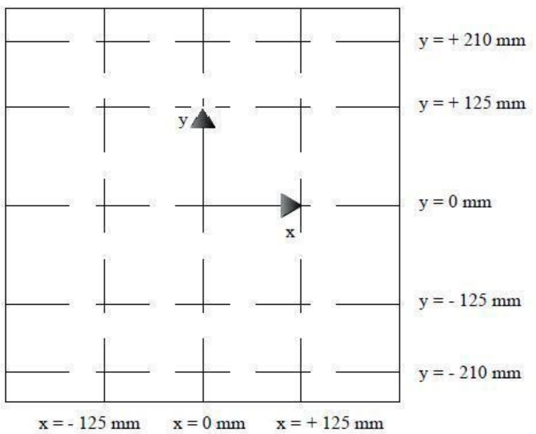

Figure 1 – Coordination system.

The calibration point was chosen based on the previously characterization of the wind tunnel, so that it stands in the position with the less variation of the velocity.

The velocities in this research were made in the following alternating order: 4.0 m·s^{-1}, 8.0 m·s^{-1}, 12.0 m·s^{-1}, 20.0 m·s^{-1}, 16.0 m·s^{-1}, 10.0 m·s^{-1}, 6.0 m·s^{-1}, so that the hysteresis effects were taken into account. Four measures of 60 seconds to each velocity were carried out. After changing the velocity, it was necessary to wait at least 1 minute for the flow to stabilize. The environmental conditions (temperature, pressure and humidity) were observed and registered with a thermo-hygro-barometer.

3. SOURCES OF UNCERTAINTY

The more relevant uncertainty sources are described below:

3.1. Ultrasonic anemometer

The calibration of this standard anemometer was done by the National Metrology Institute of Japan (NMIJ). The uncertainty is provided by calibration certificate.

3.2. Aerodynamic wind tunnel

This tunnel was projected to generate a low turbulence flow. The uncertainties related to the wind tunnel are due to spatial non-uniformity (obtained during the characterization) and the flow turbulence (obtained during the calibration).

3.3. Mechanical anemometer

The uncertainties derived from the mechanical anemometer are due to resolution, random variation and repeatability of the indicated value.

3.4. Misalignment

In order to guarantee in that both anemometers are reading the same measurand they should be correctly aligned. Otherwise, their axial component of velocity would be shifted by cosine of the angle between then. The uncertainty of the alignment angles should then be taken into account.

4. MATHEMATICAL MODELING

4.1. Calibration correction factor

To calculate the correction of the mechanical anemometer the mathematical modeling starts with a simple formula (1):

$$C = V_{zus} - V_{ma} + \delta C \qquad (1)$$

Where,

- *C* – Correction of the indication velocity of the mechanical anemometer;
- *Vzus* – ultrasonic anemometer velocity;
- *Vma* – mechanical anemometer velocity;
- δC – random variation of the correction factor.

4.2. Influence of misalignment

To take into account the misalignment between the reference anemometer and the anemometer under calibration, it was used a rotation matrix in three dimensions. This rotation matrix calculates the velocity of the mechanic anemometer's axial component of velocity, given the velocity components read by the ultrasonic anemometer, by the formula (2):

$$V_z' = v_z \cos(\theta_x) \cos(\theta_x) + v_x[-\cos(\theta_x) \cdot \cos(\theta_z) \sin(\theta_y) + \sin(\theta_x) \sin(\theta_z)] + v_y \cdot [\cos(\theta_z) \sin(\theta_x) + \cos(\theta_x) \sin(\theta_y) \cdot \sin(\theta_z)] \qquad (2)$$

Where,

Vx, Vy, Vz – velocity indicated by the ultrasonic anemometer in axis x, y and z, respectively;

θx, θy, θz – Misalignment of the ultrasonic anemometer in relation to the anemometer to be calibrated in x, y and z axes, respectively.

4.3. Correction of Ultrasonic readings

The readings obtained by ultrasonic anemometer were corrected according to the formula (3) described in the calibration certificate:

$$V_z = V_{zus} \cdot C_{cert}(V_{zus}) \qquad (3)$$

Where $C_{cert}(V_{zus})$ is the polynomial correction obtained with the values available in the calibration certificate of the ultrasonic anemometer.

4.4. Full Mathematical Modelling

Below, it's shown the full modeling – formula (4) – with all velocity components. In some kind of anemometers, this modeling will suffer some alterations. For instance, according to the study, vane anemometers will be affected only by the 'z' component of velocity, whereas cup anemometers will be affected by both 'x' and 'z' components.

$$C = \sqrt{\begin{array}{l}(V_x+\delta R+\delta V_x+\delta V_{POSx}+\delta V_{POLIx})^2 \\ +(V_y+\delta R+\delta V_y+\delta V_{POSy}+\delta V_{POLIy})^2 \\ +(V_z+\delta R+\delta V_z+\delta V_{POSz}+\delta V_{POLIz})^2\end{array}} - (V_{ma}+\delta V_{ma}) + \delta C \qquad (4)$$

Where

δVx, δVy, δVz – random variation of the reference velocity in the axis x, y and z, during the calibration run;

$\delta V_{POS\,x}$, $\delta V_{POS\,y}$, $\delta V_{POS\,z}$ – random variation of the reference velocity in the axis x, y and z, in the mechanical anemometer measurement region;

$\delta V_{POLI\,x}$, $\delta V_{POLI\,y}$, $\delta V_{POLI\,z}$ - random variation of the reference velocity in the axis x, y and z, due to uncertainty of the polynomial adjust;

V_{ma} – velocity indicated by mechanical anemometer;

δV_{ma} – random variation of the velocity indicated by mechanical anemometer;

δR – error due to resolution of the standard anemometer.

4.5. Uncertainty calculation

The uncertainty calculation was done according to the 3rd edition of the Brazilian "Guide to the Expression of Uncertainty in Measurement" (ISO-GUM) [3]. Let Y be the mathematical model of a function of N variables – formula (5):

$$Y = f(x1, x2, \ldots, xN) \quad (5)$$

The combined standard uncertainty, $u_c(y)$, where y is the estimate of the measurand Y, is given by the formula (6):

$$u_c^2(y) = \sum_{i=1}^{N} \left[\frac{\partial f}{\partial x_i}\right] u^2(x_i) \quad (6)$$

Where $u(x_i)$ is the standard uncertainty of the *i-th* variable.

5. RESULTS

For the calibration, four runs to each velocity were made, with an acquisition time of 60 seconds at 20 Hz. Results are shown at table 1.

Table 1. Calibration results of small vane anemometer using an ultrasonic anemometer as a standard.

Mean of Reference Value ($m \cdot s^{-1}$)	Mean of Indicated Value ($m \cdot s^{-1}$)	Expanded Uncertainty (%)	Coverage Factor (*k*)
3.91	4.00	2.66	2.16
5.90	6.00	2.57	2.32
7.92	8.00	1.64	2.21
9.96	10.00	2.09	2.37
12.05	12.00	1.45	2.23
16.15	16.00	1.27	2.21
20.15	20.00	1.17	2.20

The corrected velocity (V_{corr}) is given by the formula (7):

$$V_{corr} = V_{read} + C \quad (7)$$

Table 2 shows the mean influence of each source of uncertainty. As can be seen, the largest contributions are the resolution and random variation of the mechanical anemometer readings and the turbulence of the tunnel.

Table 2. Influence quantities and their means.

Influence Quantity	Mean
$\theta_x, \theta_y, \theta_z$	2.57%
δR	0.91%
δV_z	18.52%
$\delta V_{POS\,z}$	4.70%
V_{ma}	18.18%
δV_{ma}	31.78%
δC	7.18%

As the factors associated to both anemometers (reference and in calibration) can't be changed, only one parameter can be improved, which is turbulence of the wind tunnel (δVz).

By improving internal alignments, balancing the fan and making some modifications in the honeycomb, it is possible to diminish the turbulence and, by consequence, to decrease the type A uncertainty associated to the reference velocity.

6. CONCLUSIONS

This work shows the method used by Inmetro to perform calibrations of vane anemometers in an open wind tunnel, as well as the general mathematical modeling for other types of mechanical anemometers.

7. REFERENCES

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