Guidelines on the Calibration of Solid Anemometers Part 2: Thermal Anemometers

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Guidelines on the Calibration of Solid Anemometers
Part 2: Thermal Anemometers

Purpose

This document has been produced to ensure traceability in air speed calibration by using solid anemometers. The purpose of this second part is to outline the basic technical requirements for the calibration of Thermal Anemometers (TAs). It provides the users with the fundamental information necessary for establishing and applying calibration procedures.

Content

1 INTRODUCTION

The purpose of this EURAMET Calibration Guide is to outline the basic technical requirements for the calibration of Thermal Anemometers (TAs) for calibration laboratories and for accreditation bodies. It is the second part of the series of guidelines concerning the calibration of solid anemometers. (see also reference [4]).

This Guideline provides the users of TA with the fundamental information necessary for establishing and applying calibration procedures.

This Guideline applies to all types of TA and is limited to the calibration in air.

2 SYMBOLS

Symbol	Quantity	Dimensions	SI unit
K	coefficient of calibration	-	-
$v_{display}$	displayed velocity of the Thermal Anemometer	LT^{-1}	$m\ s^{-1}$
v_{TA}	measured velocity of the Thermal Anemometer	LT^{-1}	$m\ s^{-1}$
$v_{reference}$	reference velocity	LT^{-1}	$m\ s^{-1}$
Δv	velocity difference of reference and device under test	LT^{-1}	$m\ s^{-1}$
ρ	density of the fluid	ML^{-3}	kg/m^3

3 GENERAL COMMENTS

The calibration is performed in a suitable test equipment, e.g. wind tunnel, towing tank or rotating arm, where the velocity is measured with a reference instrument or a reference method. The purpose of the calibration is then to determine either the velocity deviation (Δv) between the reference and the TA or the calibration coefficient (K_{TA}) of the TA according to the Equation (1) or (2), respectively. The velocity deviation (Δv) or calibration coefficient (K_{TA}) must be determined over the whole calibration range.

$$\Delta v = v_{TA} - v_{reference} \quad (1) \qquad K_{TA} = \frac{v_{reference}}{v_{TA}} \quad (2)$$

where

v_{TA} is the measured velocity by the TA (m/s),

$v_{reference}$ is the reference velocity measured by the reference device or method (m/s).

This Guideline is applicable for different types of TA as outlined in Section 3.1.

In Section 3.2 and Section 3.3 the determination of required fluid density and the necessary corrections are described, respectively.

3.1 Thermal Anemometer

3.1.1 Types of Thermal Anemometer

Most common types of TA are the hot-ball, hot-wire and hot-film anemometers (see Figure 1). Their main working principle is the cooling of an electrically heated resistance by the air flow. This gives a relationship between the deposited power and the flow speed. With hot-ball anemometers it is possible to record the velocity magnitude regardless of the flow direction, while single hot-wire and single hot-film anemometers record only one component. Therefore, hot-wire and hot-film anemometers show an orientation dependence.

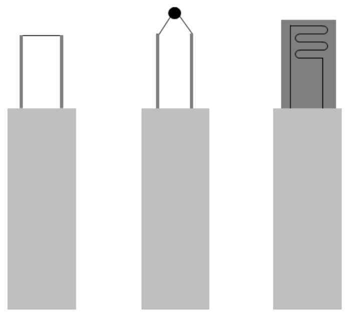

Figure 1. Schematic view of hot-wire (left), hot-ball (center) and hot-film (right) anemometer type.

3.1.2 Thermal Anemometers with digital output in units of velocity

The TA is considered as a complete measuring instrument whose measurement is directly converted and displayed in units of velocity. If corrections for actual pressure, temperature and humidity of air are incorporated in the meter reading, then, v_{TA} is replaced by $v_{display}$ in the calibration result according to Equation (1) or (2).

$$v_{TA} = v_{display} \quad (3)$$

where

v_{TA} is the velocity indicated by the device corrected for actual conditions of temperature, pressure and humidity,

$v_{display}$ is the velocity output of the device display.

If the corrections for the calibration conditions are not incorporated in the meter reading, then corrections according to manufacturer's recommendations or according to the Section 4.3 should be applied.

3.1.3 Thermal Anemometer with an analog output in units of voltage, current or frequency

For a TA, the analog output is usually specified in units of voltage, current or frequency. If an analog output is used, then the additional uncertainty contribution from the analog to digital conversion or read out method to the uncertainty budget has to be considered.

3.2 Determination of the Air Density

The relation between air velocity and TA output depends, apart from instrumental constants, on air viscosity and air thermal conductivity: air thermal conductivity depends on air density. Therefore, the air density in which the calibration is performed must be recorded. This implies that pressure, temperature and humidity must be determined. For each calibration point a mean air density value during the measurement time has to be determined and the corresponding uncertainty has to be specified. In the case of air, the formula presented in reference [1] can be used. Additionally, it may be necessary to apply correction related to air density to the output of the TA according to the manufacturer's recommendations.

3.3 Corrections for Operating Conditions

Since TAs are instruments based on heat exchange, all parameters influencing the heat exchange will influence their response. Of course, the main influence will come from the heat exchange coefficient, which is essentially the parameter which is calibrated, but secondary influences derive from the heat capacity of the impacting fluid, i.e. from its nature and density. In the following it will be assumed that TAs are calibrated in air, and the influence of humidity on the specific heat capacity will be assumed negligible, therefore only the density effect will be considered.

The mentioned corrections are appropriate for changes in pressure, temperature and humidity conditions, but not for gases different from the one for which the device has been designed. Further some TA can be set to predefined conditions. This means that these conditions are set as a default in the meter and the meter calculates the velocity output from that if actual conditions are not supplied to the meter. Actual conditions can be measured either by the TA itself or by an external instrument and set in the TA.

Users shall contact the manufacturer to have information on the type of correction to apply.

3.3.1 TA density correction

If there is no option for changing the predefined temperature, pressure and humidity values, then it should be noted that the displayed velocity is not referred to actual conditions, but to predefined reference conditions. The reference conditions are predefined by the manufacturer. The following correction must then be applied to convert the display value to the actual reference value:

$$v_{TA} = v_{display} \cdot \frac{\rho_{display}}{\rho_{actual}} \quad (4)$$

where

v_{TA} is the velocity indicated by the device corrected for actual conditions of temperature, pressure and humidity.

$v_{display}$ is the velocity output of the device display,

ρ_{actual} is the fluid density in actual conditions,

$\rho_{display}$ is the fluid density in predefined conditions.

3.3.2 TA with implemented pressure, temperature and humidity measurement

If the temperature, pressure and humidity values are measured by the evaluated unit, then usually the velocity value can be displayed in actual conditions. Thus, if the appropriate mode is chosen no further corrections have to be applied.

3.3.3 TA pressure correction

Due to their operation principle the majority of thermal anemometers has a temperature measurement implemented and the temperature is corrected internally. If additionally, the influence of humidity is assumed negligible, only a pressure correction can be applied. For example, the influence of humidity can be neglected if uncertainties greater than 1% are sufficient.

$$v_{TA} = v_{display} \cdot \frac{p_{display}}{p_{actual}} \qquad (5)$$

where

v_{TA} is the velocity indicated by the device corrected for actual conditions of temperature, pressure,

$v_{display}$ is the velocity output of the device display,

p_{actual} is the actual air pressure in the calibration device,

p_{display} is the pressure in predefined conditions.

4 CALIBRATION PROCEDURE FOR THERMAL ANEMOMETERS

4.1 Preliminary Operations

The following instructions should be considered when installing the instrument:

- Place the TA at an appropriate location in the test rig according to the characterisation done where a stable and homogeneous flow profile is achieved, e.g. a location with a low turbulence degree and a velocity value that is stable over time.
- The relevant placement position of the TA is the center of the sensing element unless otherwise stated by the manufacturer.
- The alignment of the TA has to be done carefully. Manufacturer's recommendations or orientation dependence measurements have to be considered. The resulting deviations of the meter indication due to its misalignment have to be considered in the uncertainty evaluation.
- Take special care to the air flow direction sensitivity of the meter. Especially in the low flow range a horizontal air flow can give deviations from vertical air flow. The TA should therefore be calibrated in the position it is used.
- TAs are typically used for low velocities, thus closed measuring chambers are preferable to achieve low uncertainties.
- Temperature calibration of the TA can be done before the test run under stationary conditions or during the test run if an appropriate temperature reference is available.
- Sensor contamination with seeding particles that are needed for the LDA reference measurement can lead to incorrect measurement results (see reference [5], 5.2 EE75, p.7). It is mandatory to use seeding particles that do not influence TA measurement.

Prior to the calibration, the following data shall also be recorded:

- The identification parameters of the reference instrument and of all the instruments used for measuring the output signal.

- The identification parameters of the device to be calibrated. An identification number and/or serial number should be indicated on the TA.
- Insertion depth in the wind tunnel – due to the insertion depth dependence as described in Appendix 1 and in reference [6,7] or if the position of the TA deviates from the instructions in the standard procedure used for calibration.
- Performing zero adjustment of the TA, if possible – residual thermal flow in the wind tunnel has to be considered. The adjustment error gives a contribution to the uncertainty budget.

4.2 Calibration

The calibration can be performed with simultaneous or sequential measurements of the reference and the TA. At each calibration point, the following data should be recorded:

- The velocity indicated by the reference instrument (or the elements necessary for calculating the measured velocity).
- The velocity or output indicated by the TA.
- The results of the air temperature, static pressure, humidity measurements in the wind tunnel for the fluid density calculation.
- Repeatability of the reference system and the TA.
- Position of the reference meter and the TA (necessary for position correction, blockage correction and correction due to the insertion depth [6, 7]).

5 EVALUATION OF MEASUREMENT UNCERTAINTY

The principal components to be taken into account for the evaluation of the uncertainty of the calibration result for a TA are:

- Uncertainty of the reference instrument or method in the conditions of use,
- Uncertainty due to repeatability,
- Uncertainty due to the resolution of the TA,
- Uncertainty of the air density calculation [1, 2], taking into account:
  - uncertainty of the measuring instruments (temperature, pressure, humidity),
  - uncertainty of the formula used, e.g. as described in [1, 2].
- Uncertainty due to the geometrical setup of TA under test in the calibration facility (blockage effect, position correction, angular misalignment, insertion depth, horizontal/vertical flow).

The measurement procedures of the calibration laboratories should describe how the contributions to the uncertainty budget resulting from these components are determined.

6 REFERENCE INSTRUMENTS

Wind tunnel with Laser Doppler Anemometer (LDA) or Pitot Static Tube (PST), towing tank or rotating arm can be used as a reference instrument. If other reference meters are used, then this may result in higher measurement uncertainties. In any case, the evaluation of the measurement uncertainty should be done according to the “Guide to the expression of uncertainty in measurement” [3].

To get the uncertainty in the range of 0.4 % to 0.8 % (*k* = 2) for the entire calibration it is recommended to use LDA as the reference. In order to get the lowest uncertainties, the following conditions should be considered:

- Profile measurement (influence of the TA on the flow profile) and the determination of the uncertainty contribution due to the blockage effect.
- Applying position correction in case of different positions of LDA and TA.
- In the case of a sequential measurement of the reference and the TA, the stability of the test rig must be documented, or a corresponding correction must be applied.
- Alignment measurement.
- Determination of the air density.
- Determination of the insertion depth dependence and any necessary corrections due to this dependence.
- Closed measuring chambers are preferable for low velocities.

7 EXPRESSING SCOPE OF CALIBRATION

The scope declared by a laboratory for calibration of solid anemometers, especially TA, should state the following parameters:

- Measurement range, e.g. $0.5\ {}^{m}/_{s} - 40\ {}^{m}/_{s}$
- Measurement uncertainty within the entire range, e.g. $0.004\ {}^{m}/_{s} + 0.0047\ \cdot v_{reference}$
- Ambient conditions (pressure, temperature, humidity), e.g. (980.5 ± 0.5) hPa, (22.3 ± 0.5) °C, (43 ± 1) %rh
- Direction of the flow, e.g. horizontal flow
- Type of probes, e.g. hot-film anemometers

8 CALIBRATION CERTIFICATES

Together with the general requirements of the ISO/IEC 17025 standard, the calibration reports for TAs should include the minimum information as following:

- Facility description,
- Type of reference standard,
- Description of the calibration procedure or reference to internal procedure used for calibration,
- Description of the TA,
- Calibration results can be depicted either as reference and the TA value separately or as reference and deviation (Δv) between the reference and the TA or as reference and calibration coefficient, *K*.

- Measurement uncertainty
    - In the case of a TA, the stated measurement uncertainty is the uncertainty either of the calibration coefficient of TA or of the measurement of v_{TA} (see Section 5).
    - The uncertainty values should be given with a maximum of two significant digits. The excessive number of digits should be rounded according to Section 7.2.6 of reference [3].
- Additional information can be provided such as:
    - Position of the TA regarding the flow.
    - If statement of compliance with a specification is made, this should identify which specifications are met or not met.
    - Indication of any malfunctioning or anomaly detected.

9 REFERENCES

[1] Davis R.S., Equation for the Determination of the Density of Moist Air (1981/91), Metrologia 1992, 29, 67-70.

[2] Picard A., Davis R.S., Gläser M. and Fujii K., Revised formula for the density of moist air (CIPM-2007) - Metrologia 45 (2008) 149–155, Online at stacks.iop.org/Met/45/149

[3] JCGM 100:2008, Evaluation of measurement data — Guide to the expression of uncertainty in measurement.

[4] EURAMET Calibration Guide No. 24, Version 2.0 (02/2021), “Guidelines on the Calibration of Solid Anemometers, Part 1 Pitot Static Tubes”.

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[6] Mathias Rohm, Harald Müller, Jessica Kampe, 2007: Geometrical influence calibrating flow velocity sensors in wind tunnels, http://www.gala-ev.org/images/Beitraege/Beitraege%202007/pdf/42.pdf

[7] Mathias Rohm, Yvan Cordier-Duperray, 2009: Influence of the Insertion Depth on the Response of a Hot Film Anemometer in Different Wind Tunnels, https://doi.org/10.1002/9780470611371.ch8

APPENDIX A. Insertion depth dependence

Usually, the measurement results of an anemometer, like a TA, are significantly affected from its geometric installation in a wind tunnel. However, if the TA is placed at the same insertion depth (as shown in Figure 1), the calibration results in geometrically completely different wind tunnels show excellent agreement.

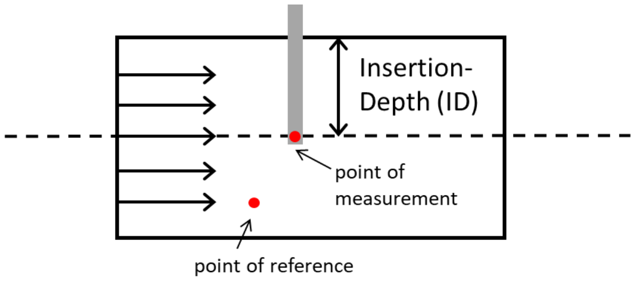

Figure 1. Definition of insertion depth of an anemometer

The observed characteristic in Figure 2 – deviation versus insertions depth – shows that the different types of wind tunnel and the different dimensions of their test section, e.g. at CETIAT and BEV/E+E, have no significant influence on the calibration result.

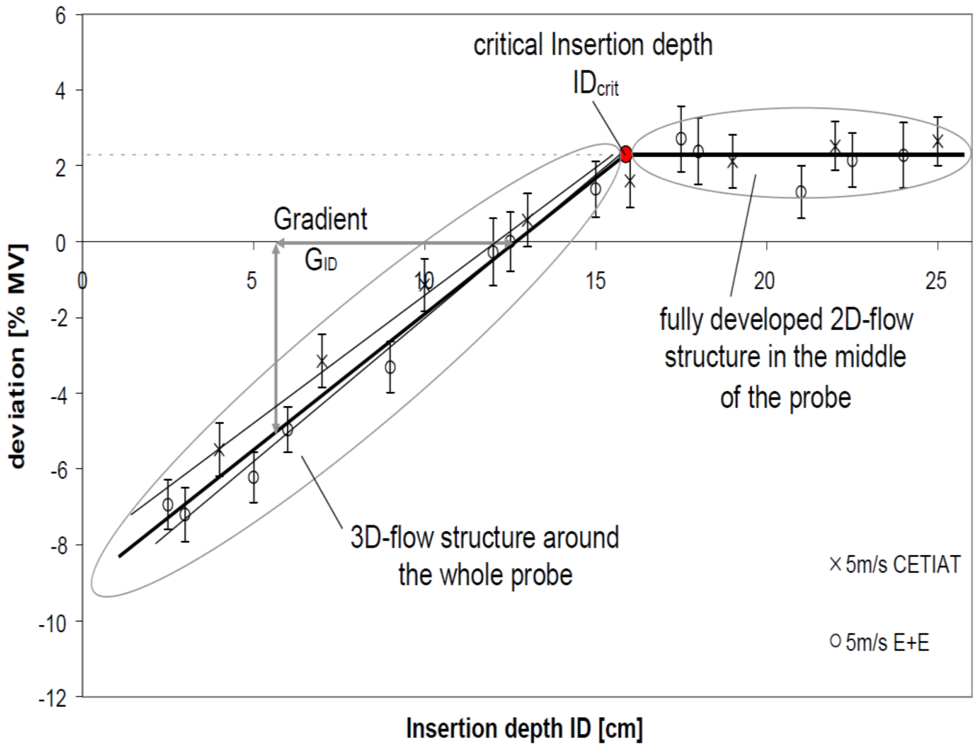

Figure 2. Typical characteristics of the anemometer in a wind tunnel by varying insertion depth

The characteristic curve in Figure 2 can be divided into two main parts. Below the critical insertion depth ID_{crit}, the flow around the whole probe is 3-dimensional. The flow around the cylinder head and the calibration result therefore depend on the insertions depth, showing an approximately linear increase with a gradient G_{ID}. Above an insertion depth of ID_{crit} a quasi-2D-flow region is developed in the middle of the probe. Thus, the calibration result is independent from the insertion depth [see reference documents]. In conclusion, a non-dimensional parameter $\left(\frac{l}{d}\right)_{crit}$ is defined, in order to determine the critical insertion depth of a given wind tunnel. (l - length of TA, d - diameter of TA, Re - Reynolds Number, δ - thickness of boundary layer)

$$\left(\frac{l}{d}\right)_{crit} = \frac{ID_{crit}}{d} = F\left(\frac{\delta}{l}, Re\right)$$

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