

# The BEV/E+E Elektronik Air Speed Reference

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## Abstract

The paper presents a detailed description of the calibration equipment and procedure of the new Austrian reference laboratory for air speed in the range from 0.04 m/s to 40 m/s.

Calibrations of pitot tubes, rotating wheel, vane, ultrasonic, and thermal anemometers are made as comparison measurements with a Laser Doppler Anemometer (LDA) in a homogenous reproducible wind tunnel flow.

The new calibration procedure takes interactions between different types of probes and the air flow reference into account. The influence of the probe on the flow profile is determined and considered in the calibration setup as well as in the uncertainty budget.

Finally, the uncertainty budget for the calibration process is described. Participation in international comparison projects has proved the traceability of the claimed CMC entries.

## Introduction

The globalization of industries and markets has been one of the main driving forces to explore traceability in metrology. Therefore, international standard agencies have been defining more and more restrictive rules relating to the needs of quality control and industries. In the field of air speed, the range of calibration needs is quite wide and covers spans from about 0.04 m/s for clean rooms and natural air convection flows up to more than 40 m/s for high wind speeds, ventilations, and industrial flow measurements.

The calibration of anemometers requires the combination of the metrology of air speed and of the know-how of flow mechanics of different instruments under test.

The major task is to ensure traceability for a large diversity in measurement principles, such as thermal anemometers, Prandtl tubes, ultrasonic, rotating wheel, and vane meters, subsequently with different geometrical shapes that influence the flow in specific ways.

E+E/BEV has been designated to build a new Austrian standard for air speed to cover this range of air speeds with a high level of traceability.

This paper presents the Austrian solution for calibrating anemometers by using a combination of an accurate reference meter, low turbulence wind tunnels, and a calibration procedure which deals with the requirements of most air speed meters on the market.

## Facilities

### Wind tunnels

The calibration procedure for air speed requires a homogenous, reproducible, and low turbulent flow. To cover the whole measurement range, this flow is produced by two different wind tunnels.

In a range from 0.3 up to 40 m/s, a closed loop wind tunnel (Göttingen style) is used (Figure 1).

This wind tunnel has a round open horizontal test section with a diameter of 0.255 m. The contraction has a ratio of 4 and a length-diameter ratio of 1. In combination with a honeycomb and several screens, the wind tunnel produces turbulence values between 0.15 and 0.5% in 90% of the test section.

The return section of the wind tunnel is isolated. A specially designed low turbulence heat exchanger regulates the temperature inside

the tunnel. The test section is housed in a closed chamber to avoid thermal exchange with the ambient air conditions.

This way the temperature of the air flow can be controlled in a range of 5 to 80 °C.

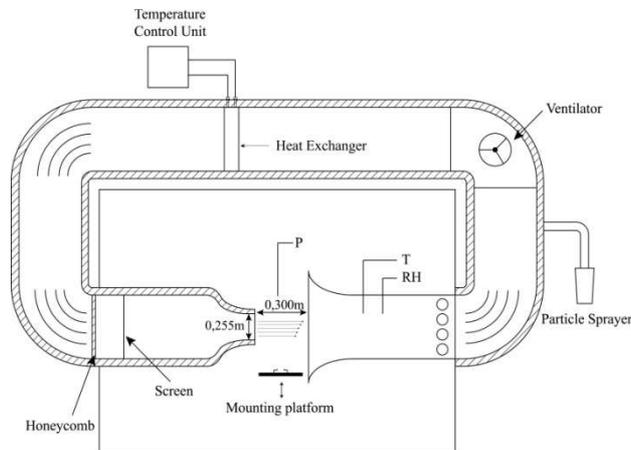


Figure 1: BEV/E+E wind tunnel for air speeds of 0.3-40 m/s

In order to enable calibrations as low as 0.04 m/s, a unique low-air speed wind tunnel has been developed (Figure 2). This open loop wind tunnel (Eiffel style) has a vertical closed test section with a square of 0.25 m.

The combination of a specially designed contraction with several screens and honeycombs produces a very homogenous flow profile with turbulence values from 0.15 to 0.8 % with air speeds 0.15 m/s up to 2 m/s; below 0.15 m/s the turbulence values are below 1.5 %. In order to provide light scattering particles, required for the LDA measurements, a particle sprayer produces oil droplets of DEHS with an average diameter of 1 µm. The particles are mixed with the air flow at the closed loop wind tunnel in front of the ventilator, and at the flow inlet side of the low air speed wind tunnel.

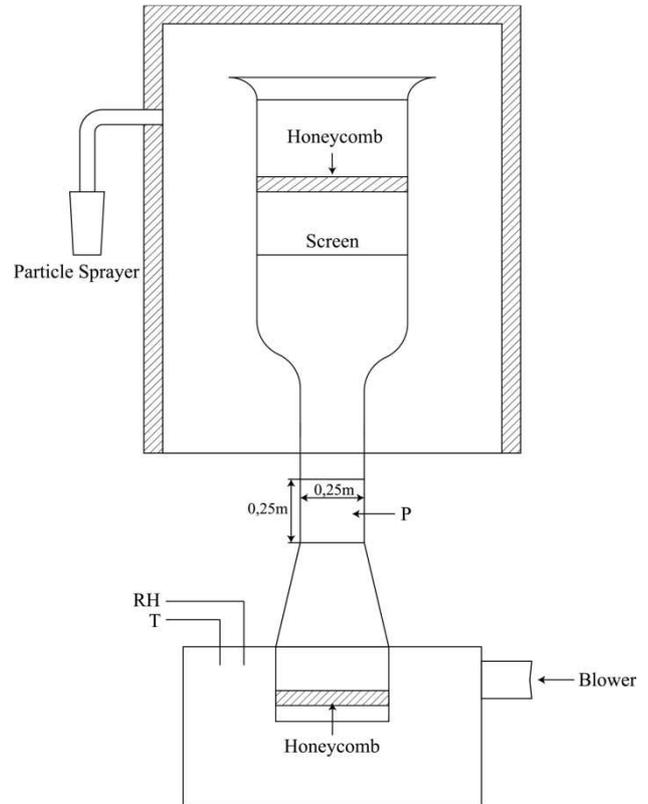


Figure 2: BEV/E+E low air-speed wind tunnel, 0.04-2 m/s

### Primary Reference Standard – LDA

The primary standard for air speed is a Laser Doppler Anemometer (LDA).

An LDA actually measures the speed of small particles moving with the air through its measurement volume.

A laser beam is split into two beams in a plane and then interfered at a small intersection angle by using a transmitting focus lens. At the intersection point this results in a pattern of interference fringes.

Particles moving through this measurement volume backscatter light as they pass the bright fringes. On passing the whole measurement volume, the particle produces a reflecting signal, the so-called burst signal.

This signal is analysed by an FFT Algorithms. Its dominating frequency, the so-called Doppler-frequency  $f_D$ , ultimately depends on the speed of the particle  $v_x$  and the mean distance  $\Delta x$  between the bright fringes of the measurement volume.

$$f_D = v_x \cdot \Delta x$$

At E+E/BEV, we use an LDA with a HeNe laser (632.8 nm) at a power of only 11 mW. The advantages of this laser type are its long-term stability and its beam characteristics, which allows for lowest uncertainties when calibrating the mean interference fringe distance.

The LDA is calibrated by the German NMI (PTB) with an uncertainty of less than 0.2%. Recent calibrations have displayed a drift of the mean interference fringe distance of less than 0.015%/year (Figure 3).

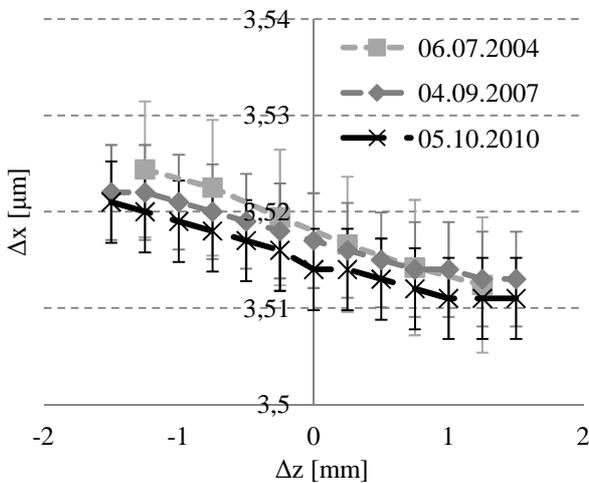


Figure 3: LDA calibration results

$\Delta z$  Distance to the center point of the LDA-measurement volume in viewing direction of the LDA

The LDA permits independent measurements of the air speed displaying very low uncertainties. Its crucial advantage, however, is that there is absolutely no influence on the measured flow.

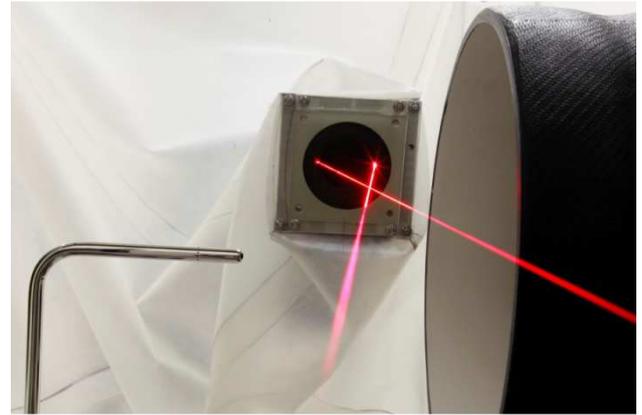


Figure 4: Photo of a calibration setup using LDA

### Calibration setup

The interactions between solid probes and the calibration flow profile make the geometrical setup one of the major boundary conditions of the calibration of air speed.

The setup is defined by the geometry of the wind tunnel (open or closed test section, dimensions, homogeneity, turbulence values) and by the geometry of the instrument under test (IUT; diameter, length, design).

Depending on its geometry, the probe blocks parts of the flow ahead.

A change of the flow profile affects the velocity around its area (blockage effect).

The dimension of the influenced area depends on the geometry of the probe, mainly on its size and flow resistance.

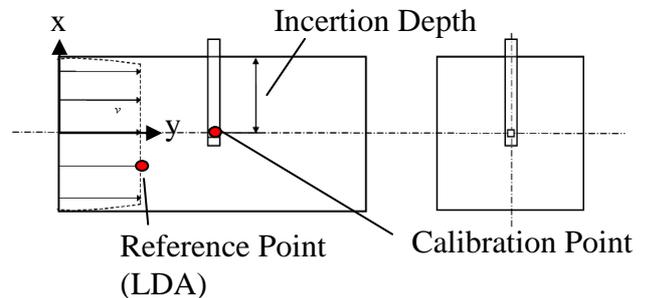


Figure 5: Calibration setup

At E+E/BEV, the calibration is performed “online”, which means that IUT and reference measure at different positions at same time. In the following step, the deviations in the flow profile between reference point and calibration point are considered by a correction factor.

To avoid deviations caused by the blockage effect, the point of reference (LDA) has to be chosen outside of the influenced area of the instrument under test

At E+E/BEV, the positions of reference and the calibration point are specifically chosen according to each geometrical type of IUT. For that reason, the influenced area (blockage area) has to be determined.

### Detection of blockage effect

With the help of a 3-D traverse system, the LDA measurement point can be chosen freely inside the whole test section. In order to determine the influence of the IUT, flow profiles are measured at a specific air speed at the status influenced and non influenced by the probe. The blockage effect of the IUT is shown by the deviation between the influenced and non-influenced flow profile (Figure 6).

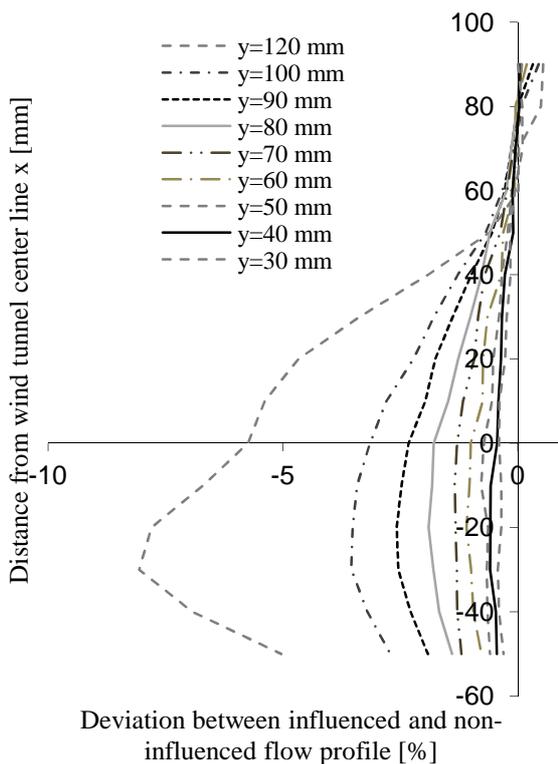


Figure 6: EURAMET P827 Ultrasonic Anemometer (Position y=150mm)

### Uncertainty calculation

The Air speed calibration system described is operated as comparison measurement of a

reference meter (Laser Doppler Anemometer) and the instrument under test.

Hence, involves the following parts:

- Uncertainty of reference
- Uncertainty of the calibration process
- Uncertainty of the instrument under test

### Uncertainty of reference

As already mentioned, the reference value is the determination of the dominating frequency of a burst signal, in combination with a calibrated mean interference fringe distance.

Calibration uncertainty of the mean interference fringe distance
Uncertainty caused by different characteristics of the measured particles
Uncertainty caused by the determination of the Doppler frequency of the scattered burst signal
Variation of the LDA measurement values
Uncertainty caused by angle misalignment

Table 1: Consideration of the uncertainty contributions to the reference air speed

The uncertainty of the reference air speed value  $v_{ref}$  can be calculated (expansion factor  $k=2$ ) as:

$$U(v_{ref}) = 0,248 \%$$

### Uncertainty of the calibration process

Uncertainty of the correction factor between the position of reference and instrument under test inside the wind tunnel test section.
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Table 2: Consideration of Uncertainty contribution to the calibration process

For most calibration setups at BEV/E+E wind tunnels, the uncertainty of the measured correction factor  $K_{ref}$  is ( $k=1$ ), as follows:

$$u(K_{ref}) = 0.0015 \text{ m/s} + 0,2\%$$

## Uncertainty of the instrument under test

Variation and reproducibility of the instrument under test
Uncertainty caused by the influence of the blockage effect on the reference point
Variations in the flow profile around the calibration point if the probe measures the velocity of a larger area of flow.
The increase in the flow in the section of the probe for the closed test section.
Influences caused by calculations of the output signal of the instrument under test (e.g. pressure correction, density corrections)

Table 3: Consideration of uncertainty contributions of the instrument under test

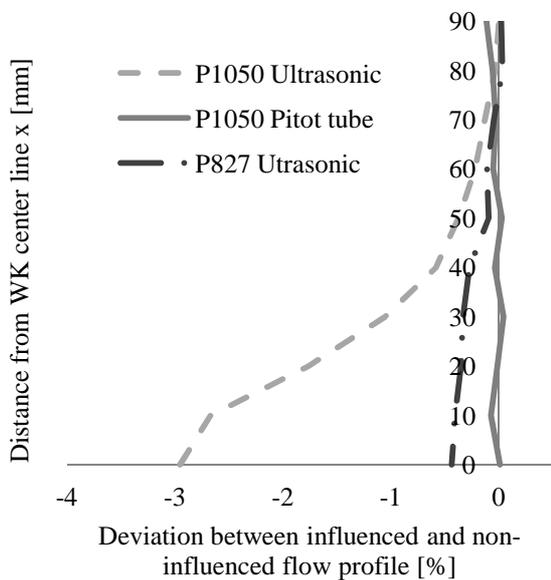


Figure 7: Influence of instrument under test, EURAMET P827 and P1050 at level of reference point

The following example may serve as illustration: For the Ultrasonic meter of the EURAMET Comparison P1050 the reference point was chosen at an 80-mm distance to the center line x (Figure 7).

The uncertainty factor considered, caused by the geometric influence of the meter, is 0.115% ( $k=1$ ).

The uncertainty for the size of the measurement volume of the meter, caused by variations in the flow profile around the calibration point, is included with 0.15% ( $k=1$ )

## E+E/BEV Uncertainty (CMC)

The ultimate uncertainty (Figure 8) of the achieved air speed of calibrations of an instrument under test without geometrical influence is provided in Figure 3, using an expansion factor of 2:

All uncertainty calculations have been made according to GUM (Guide to the Expression of Uncertainty in Measurement).

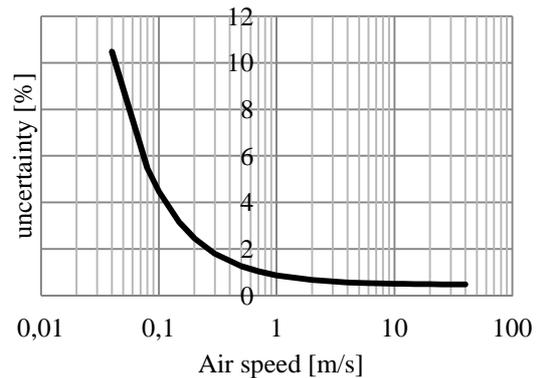


Figure 8: CMC entries of E+E/BEV calibration of air speed

## Measurement results and discussion

In order to prove traceability, the laboratory participates in frequent international comparisons, mainly under the organization of EURAMET TC Flow group.

The latest EURAMET comparisons P827 [1] and P1050 [2] concern several different meters, including the comparison of a Laser Doppler Anemometer (P827), which shows the traceability without any interference.

The ultrasonic meters (P827 and P1050) and pitot tube (P1050) represent several different geometries of meters.

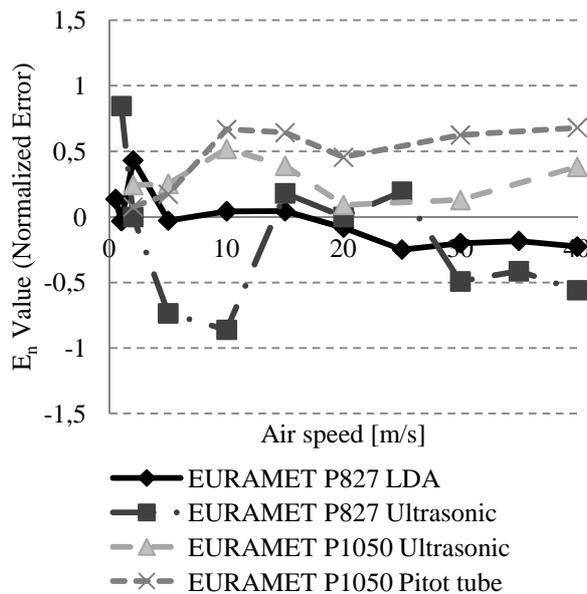


Figure 9:  $E_n$  values to the CRV of the EURAMET Comparisons P827 and P1050

Figure 9 illustrates the  $E_n$  values between E+E/BEV to the Comparison reference values (CRV) of the different comparisons.

It shows the degree of equivalence between the lab and the comparison reference value established on the results of the competing laboratories.

All values are calculated below 1, which represents the traceability of the lab in both comparison projects.

## Conclusion

A new Austrian standard for air speed in a range of 0.04m/s up to 40 m/s has been set up.

It was our objective to assure a high level of traceability for calibrations of many types of anemometers, independent of their geometry.

Comparison measurements show that it is possible to handle the calibration of different types of anemometers by considering their different geometrical influences on the flow profile in the calibration setup and uncertainty budget.

## References

- [1] Müller, H., "LDA-based intercomparison of anemometers", EUROMET Project No. 827, Draft Final Report, 2012.
- [2] Spazzini, P. G., "Comparison of Airspeed measurements at high speeds (2-50 m/s)", EUROMET Project No. 1050, Draft B Report, 2012.
- [3] Rohm, M., & Y. Cordier-Duperray, "Influence of the insertion depth on the response of a hot film anemometer in different wind tunnels", 13th international Metrology Congress, Lille 2007.
- [4] Rohm, M., H. Müller & J. Kampe, "Geometrical influences calibrating Flow-Velocity Sensors in Wind Tunnels", Fachtagung "Lasermethoden in der Strömungsmesstechnik", Rostock 2007.