Insertion Depth Effect for Vane Anemometers

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Abstract

In this paper we show that velocity indication of a vane anemometer in a wind tunnel can significantly and non-trivially depend on length of the part of the anemometer's mounting rod which is exposed to flow – the so-called insertion depth. The insertion depth dependencies for four vane anemometers with various dimensions are presented. For a small size vane anemometer with a propeller diameter of 22 mm, for example, a change of the insertion depth by 10 cm can cause a reading variation by up to 5 % - a value which is an order of magnitude larger than a typical expanded uncertainty of calibration in wind speed laboratories of national metrology institutes. Therefore, this effect has important consequences for selection of transfer standards for interlaboratory comparisons, since each participant can have a different insertion depth value, and also for the calibration practice where possible differences between the insertion depth of the user and the calibration laboratory should be taken into account.

1. Introduction

In former interlaboratory comparisons between air speed calibration laboratories using vane anemometers as transfer standards mismatch of calibration curves has been often observed even for small size anemometers leading to a question what is the origin of the discrepancy and what kind of interactions, besides the blockage effect, can influence the anemometer reading when the anemometer is installed in wind tunnels with various sizes of a test section.

One of the possible causes of the discrepancies is a flow pattern in surroundings of mounting rods of the anemometers which evolves with changing length of the part of the anemometer mounting exposed to air flow – the anemometer insertion depth. Such effect has been already reported in case of thermal anemometer in [1, 2] where a changing anemometer error was obtained when the anemometer was gradually inserted deeper into a wind tunnel test section. Similar dependencies have been observed also for cup anemometers in [3].

In this paper we investigate the insertion depth dependencies for four vane anemometers with various dimensions and shapes of the vane frame and mounting support. We show that the velocity indication of the anemometers as a function of the insertion depth vary within several percent and it is not monotonous as in case of the thermal anemometer reported in [1, 2] and the cup anemometer reported in [3]. The flow behind one of the anemometers is visualised using paper flags showing non-monotonous pressure drop evolution behind the mounting rod leading to air suction from behind the vane. In conclusions important consequences for a calibration practise and interlaboratory comparisons are drawn.

2. Tested vane anemometers

Four vane anemometers have been tested for the insertion depth dependencies, namely: a) Testo 0635 9540 (Fig. 1), b) Schiltknecht MINI (Fig. 2), c) Schiltknecht MACRO (Fig. 3) and d) Testo 0635 9340 (Fig. 4). The selected anemometers differ in the vane diameter, in shape of a frame where the vane is mounted, in shape and thickness of the support tube (handrail) of the vane frame and in diameter of the mounting rod which is connected to the handrail and fixed to a construction of a wind tunnel. Basic dimensions of the selected probes are summarised in Tab. 1. Here the vane frame diameter is outer diameter of the frame where the vane is mounted, vane frame depth is the length of the frame in direction of an air flow, handrail diameter is a diameter or range of diameters of the support tube of the vane frame, probe length is a length from the top of the vane frame to bottom of the handrail and mounting diameter is a diameter of the mounting rod.

Table 1: Dimensions of the anemometer probes and mounting

vane probe type	Testo 0635 9540	Schilt. MINI	Schilt. MACRO	Testo 0635 9340
vane frame diam. (mm)	16	22	85	107
vane frame depth (mm)	16	28	80	43
handrail diam. (mm)	8-16	15	15	12-24
probe length (mm)	170	170	235	263
mounting diam. (mm)	10	12	12	10

The Testo probes have been installed using an original telescopic mounting rod provided by Testo with diameter of the narrowest segment of 10 mm (Fig. 5). The

Schiltknecht probes have been installed using an aluminium pipe with 12 mm diameter connected to the bottom screw of the probe (Fig. 6).
Measuring unit MiniAir20 was used for the Schiltknecht probes, Testo 400 was used for the smaller Testo probe (0635 9540) and Testo 445 was used for the larger Testo probe (0635 9340).

Figure 1: Testo 0635 9540 probe

Figure 2: Schiltknecht MINI probe

Figure 3: Schiltknecht MACRO probe

Figure 4: Testo 0635 9340 probe

Figure 5: Telescopic mounting rod used for the Testo anemometers

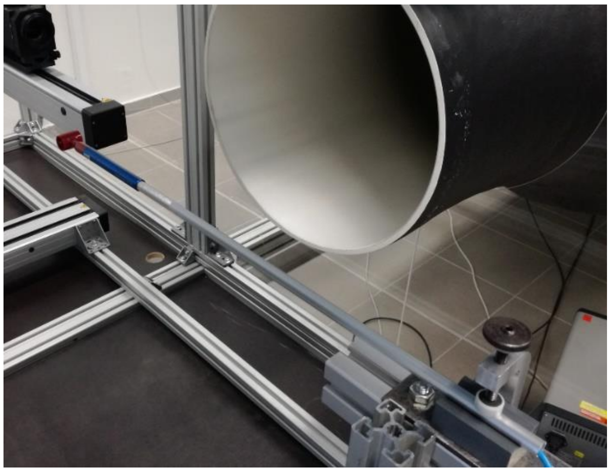

Figure 6: Mounting rod used for the Schiltknecht anemometers

3. Method of measurement – equipment used

The insertion depth dependencies of the vane anemometers have been measured using a wind tunnel of CMI, which is a closed wind tunnel with open test section and circular nozzle with diameter of 45 cm (Fig. 7). The wind tunnel is equipped with LDA system as an air velocity reference. The tested anemometers have been installed with centre of a probe placed 31.5 cm behind the wind tunnel nozzle outlet, which is a position in the middle of the test section between the outlet and suction nozzles. In vertical direction the probes have been installed always in the middle height of the outlet nozzle. In horizontal transversal direction the anemometers have been shifted and their indication has been recorded for various insertion depths.
We define the insertion depth d of an anemometer probe as a distance of the centre of the anemometer probe (axis of vane) from intersection of the anemometer's mounting rod with a prolonged inner wall of the wind tunnel nozzle (see Fig. 8). In the CMI wind tunnel with the nozzle diameter of 450 mm the velocity indicated by the anemometers have been measured for a range of the insertion depths from 60 mm to 390 mm with a step of 15 mm. The measurement has been repeated for five nominal air velocities 2, 5, 8, 12 and 20 m/s.
In order to exclude variations of the anemometer indication which are caused by inhomogeneity of the air velocity field in the wind tunnel, the air velocity field in the empty test section have been measured using LDA in the same positions as used for the tested vane anemometers. The result of this measurement is shown in Fig. 9 where the quantity dv on the vertical axis is defined as relative percentual deviation of air velocity $v(d)$ in a position corresponding to the insertion depth d from a velocity in the test section centre v_c ($= v(d)$ with $d =$ 225 mm), i.e.

$$dv = \frac{v(d) - v_c}{v_c} \times 100.$$

The expanded uncertainty of the data points in the Fig. 9 following from repeatability of the measurement is below 0.1 % for velocities 8 m/s and higher, 0.2 % for 5 m/s and 0.3 % for 2 m/s. As we will see later the velocity variations in Fig. 9 in the empty test section are order of magnitude smaller than the variations in indication of the vane anemometers, however, the data in Fig. 9 will be used to remove the air flow inhomogeneity from the insertion depth dependencies of the vane anemometers.

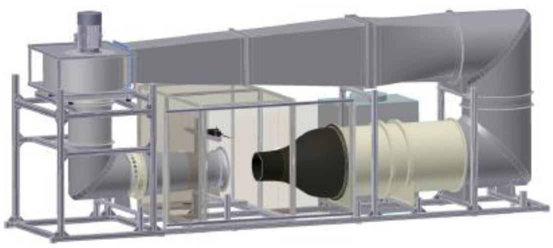

Figure 7: Wind tunnel of CMI

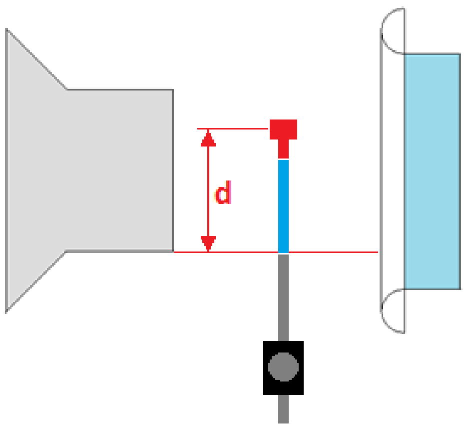

Figure 8: Definition of the insertion depth *d*

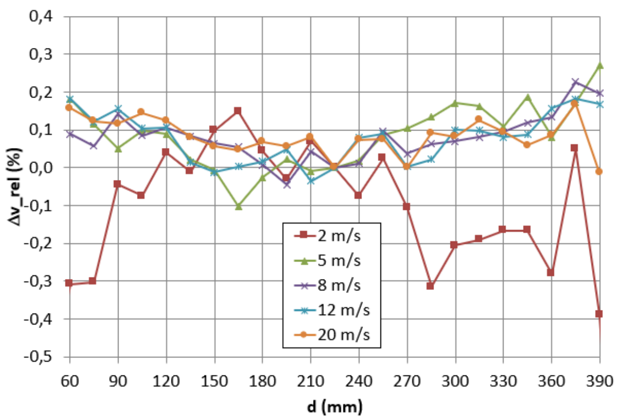

Figure 9: Transversal velocity profiles in the empty wind tunnel represented as percentual deviation from the velocity value in the centre of the test section (d= 225 mm). The expanded uncertainty of the data points given by the repeatability of the measurement is below 0.1 % for velocities 8 m/s and higher, 0.2 % for 5 m/s and 0.3 % for 2 m/s.

To shift the anemometers in the transversal direction in the wind tunnel a mounting construction has been used as shown in Fig. 10. The construction enables to shift the anemometers in prescribed direction avoiding changes in their inclination with respect to the air stream. The shift is performed manually and the anemometer position *d* is determined using a 500 mm calliper with expanded uncertainty below 0.5 mm.

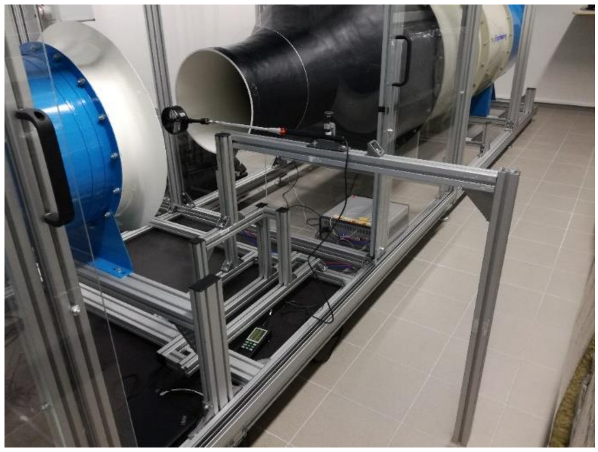

Figure 10: Construction for shifting the anemometers

4. Measured insertion depth dependencies

The measurement for each anemometer and each velocity set in the wind tunnel consisted from the following steps: a) install a vane anemometer with a proper angular alignment with respect to the air flow and set the zero position of the insertion depth measurement system, b) set the LDA position to a point which is normally used for anemometer calibrations (10 cm behind the nozzle, 10 cm from the nozzle wall), c) set a required velocity value in the wind tunnel, d) move the tested anemometer to the centre of the test section (*d* = 225 mm) and read the LDA velocity value (60 s average), e) move the tested anemometer to the lowest insertion depth (*d* = 60 mm) and read the velocity indicated by the anemometer (average from 20 readings during 60 s period), f) shift the anemometer with increment of 15 mm and read the velocity indicated by the anemometer (average from 20 readings during 60 s period) for each position, g) after each 4-5 increments return the anemometer to the centre (*d* = 225 mm) and read the LDA velocity value (60 s average).

The purpose of the LDA measurements is to determine a reference value of the velocity in the wind tunnel and its stability during the period when the tested anemometer is shifted from one side of the test section to the other. Therefore, six repeated LDA measurements are taken equally distributed during the whole measurement period. The reason why the tested anemometer is moved to the centre of the test section always when the LDA record is taken is that the anemometer position itself influences the velocity field in the wind tunnel and therefore also the LDA reading. This holds especially for the large size anemometers. Therefore, to eliminate this effect and to be able to evaluate the air velocity stability from the LDA data, the tested anemometer is placed always to the same position when LDA velocity is measured.

We denote v_{LDA} average of the six repeated LDA measurements. A reference velocity $v_{REF}(d)$ for each position of a tested anemometer is then determined as a velocity of air in empty test section in the position d when the velocity in the position where LDA is placed for calibrations is v_{LDA}, i.e., it is given as

$$v_{REF}(d) = v_{LDA} + (v_c - v_{cal}) + (v(d) - v_c)$$

where $v(d) - v_c$ is the correction discussed in the section above (given by Fig. 9 in %) and $v_c - v_{cal}$ is an additional correction given by velocity difference in empty test section between the centre of the test section and the position where LDA is placed for calibrations. This correction is determined by LDA measurement and it does not depend on d.

The relative percentual error of a meter under test (MUT) is then defined as

$$E(d) = \frac{v_{MUT}(d) - v_{REF}(d)}{v_{REF}(d)} \times 100.$$

In this error as a function of the insertion depth the velocity profile of the empty test section is subtracted by definition of $v_{REF}(d)$.

The errors as functions of the insertion depth measured for the four vane anemometers are shown in Figs. 11-14. We see various curve shapes for different anemometer types with errors varying by several percent. These variations are much larger than variations of the background velocity field (Fig. 9), therefore, they must be caused by the anemometer interaction with the air stream. The error variations with the insertion depth are larger for the two small anemometers Testo (16 mm) and Schiltknecht MINI compared to the large size anemometers Schiltknecht MACRO and Testo (107 mm). This indicates that the effect is caused mainly by different type of interaction than, e.g., the blockage effect which is more significant for larger meters. As discussed in [1, 2] for thermal anemometers the effect is probably caused by flow structures in the neighbourhood of the mounting rod. In the next section we discuss an experiment which gives an additional insight to the physical background of the effect.

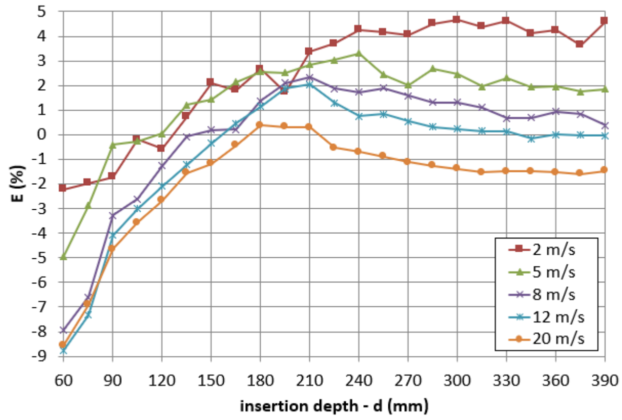

Figure 11: Velocity measurement error as a function of the insertion depth - Testo 0635 9540 (16 mm). Expanded uncertainties: 3 % for 2 m/s, 1.3 % for 5 m/s, 0.8 % for 8 m/s, 0.6 % for 12 m/s and 0.4 % for 20 m/s. Test section boundaries (prolonged nozzle walls) are located at d= 0 mm and d= 450 mm.

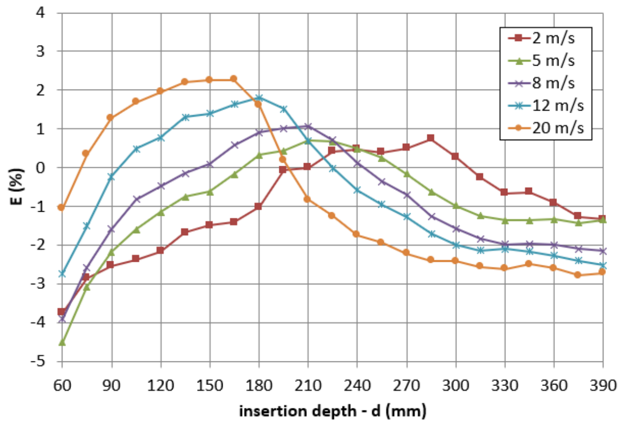

Figure 12: Velocity measurement error as a function of the insertion depth – Schilknecht MINI. Expanded uncertainties: 0.5 % for 2 m/s, 0.4 % for 5 m/s, below 0.3 % for 8 m/s and higher. Test section boundaries (prolonged nozzle walls) are located at d= 0 mm and d= 450 mm.

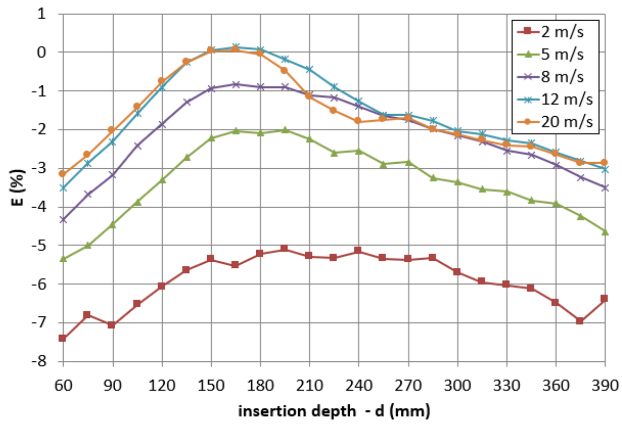

Figure 13: Velocity measurement error as a function of the insertion depth – Schiltknecht MACRO. Expanded uncertainties: 0.5 % for 2 m/s, 0.4 % for 5 m/s, below 0.3 % for 8 m/s and higher. Test section boundaries (prolonged nozzle walls) are located at d= 0 mm and d= 450 mm.

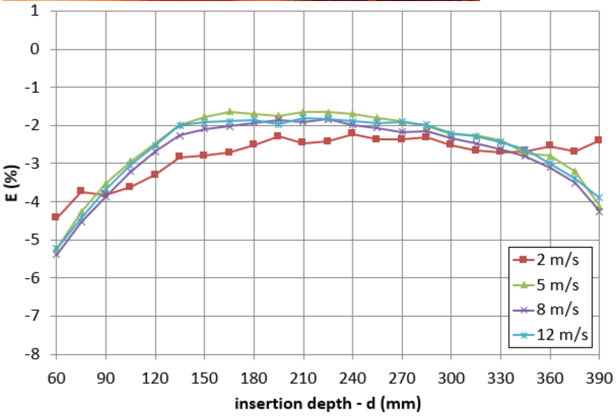

Figure 14: Velocity measurement error as a function of the insertion depth - Testo 0635 9340 (107 mm). Expanded uncertainties: 0.4 % for 2 m/s, below 0.3 % for 5 m/s and higher. Test section boundaries (prolonged nozzle walls) are located at d= 0 mm and d= 450 mm.

5. Physical background of the effect

To see how the flow around the anemometers is affected by the mounting rod and the handrail a simple experiment with paper flags has been performed. In this experiment two paper flags have been fixed to the downstream side of the MACRO probe as shown in Fig. 15. A velocity of 8 m/s has been set in the wind tunnel, the anemometer has been moved to positions with various insertion depths and the inclination of the flags has been observed. The result is shown in Fig. 15. We see a non-monotonous behaviour corresponding to the curves on Fig. 13. For small insertion depth both flags are aligned with the wind tunnel axis, when the insertion depth is increased the flag at the mounting side of the probe turns towards the mounting rod, at certain position around d = 195 mm the inclination of the flag reaches its maximum and then, increasing the insertion depth further, it returns to the direction aligned with the wind tunnel axis.

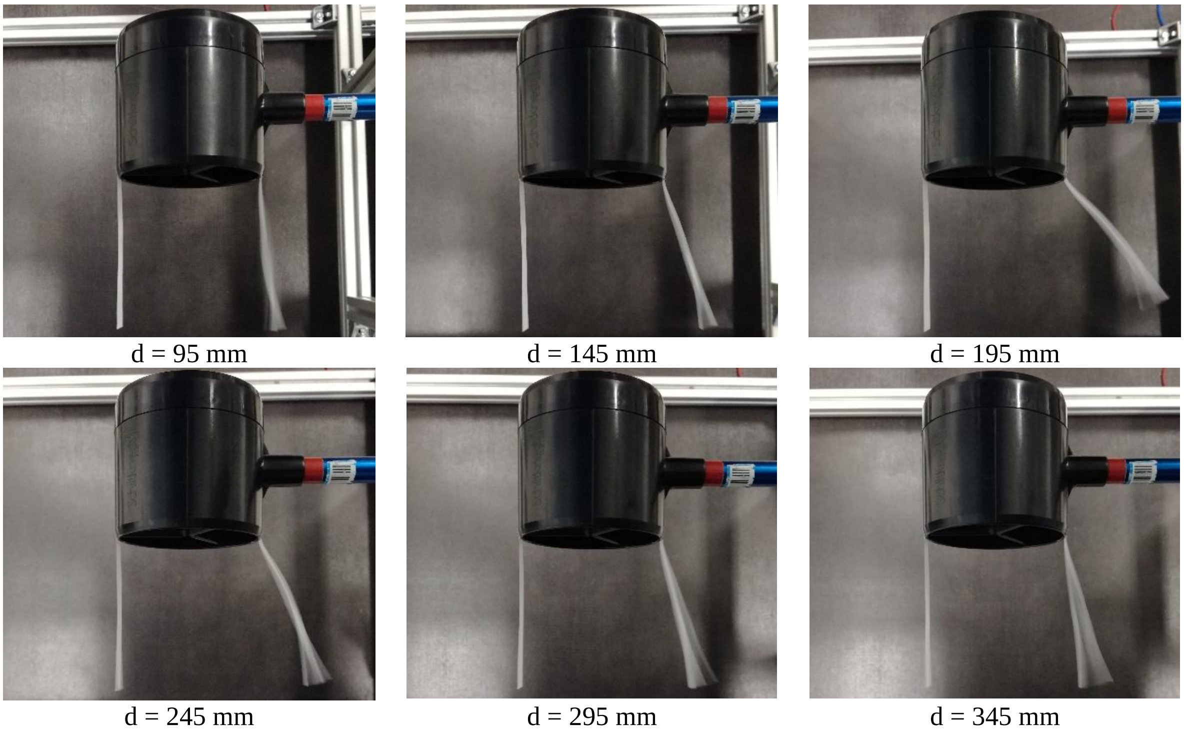

Figure 15: Flow visualisation behind the Schiltknecht MACRO probe using paper flags at various insertion depths *d*.

The result of this experiment shows that the insertion depth effect is probably caused by flow patterns in the neighbourhood of the mounting rod and the handrail of the anemometers. A pressure drop is created behind the mounting tubes which sucks air from behind the vanes affecting their rotational speed and the anemometer reading. This pressure drop depends non-trivially on how long part of the mounting tubes is exposed to air flow. An attempt to explain the dependence of flow pattern around a finite cylinder on its insertion depth was done in [1, 2] and references therein based on a CFD modelling of flow around the finite cylinders. However, the non-monotonous behaviour of the flow pattern is not explained by this approach leaving an open space for further research.

7. Conclusions

We found that velocity indication of vane anemometers significantly depends on length of the anemometers' mounting rod exposed to air flow – the so-called insertion depth. For example, for small size vane anemometers with a vane frame diameter of 16 mm to 22 mm a change of insertion depth by 10 cm can cause a reading variation by up to 5 % - a value which is an order of magnitude larger than a typical expanded uncertainty of calibration in wind speed laboratories of national metrology institutes.

This fact has several implications for quality management and calibration practice. First, the vane anemometers, and especially the small ones, are often used as reference meters in accredited air speed laboratories and these reference meters are calibrated by NMIs. If the calibration is performed with an insertion depth which differs from the insertion depth when the anemometer is in use, bias of several percent in the anemometer error can be obtained by NMI leading to biased reference value of the user's air speed laboratory.

If the vane anemometers are used as transfer standards for interlaboratory comparisons deviations can be expected even for small vane anemometers coming from the insertion depth effect if diameters of test sections of the participating wind tunnels are different. Therefore, in order to eliminate the unwanted anemometer – wind tunnel interactions during intercomparisons, a selection of small size anemometers with a sensing element shifted upstream from a mounting rod is preferable.

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