

DEVELOPMENT OF A NEW CALIBRATION WIND TUNNEL WITHIN LOW AIR VELOCITY RANGE : 0,05 UP TO 2 m.s⁻¹

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Introduction

Industrial needs for measurements of low air velocity can be classified in three categories :

- Evaluation of comfort in private or collective building (houses, offices, hospitals, schools, stores, libraries, ...) and in vehicles (cars, trucks, trains, planes, ...). Actually, the fundamental parameters to qualify comfort are air velocity, temperature and humidity.
- Control of products quality in industrial processes (clean rooms for microelectronics industries, climatic chambers for aging tests, drying chambers for food industries, ...)
- Control of equipment to ensure safety of people in hospitals, in pharmaceutical industries, in painting processes, ...

These applications require a minimum uncertainty in air velocity measurements which lead to the following evolution in air velocity metrology :

- A calibration facility which ensure the smallest calibration uncertainty as possible : The reduction of this calibration uncertainty will lead to reduce the global measurement uncertainty of process and allow to qualify industrial applications conforming to European and American standards such as EN ISO Standard 7730 « Specifications for thermal comfort conditions », 1995), ASHRAE Standard 55 (« Thermal environmental conditions for human occupancy », 1992), Federal Standard 209E (« Airborne particulate cleanliness in clean rooms and clean zones »)
- A calibration facility which can work at different temperatures, different relative humidities and with different direction of flow.

Currently, anemometers calibrations are carried out at ambient conditions (around atmospheric pressure, 20°C and ambient humidity) in a horizontal flow.

Depending on their working principle, anemometers can be very sensitive to the air flow temperature in which they are supposed to measure velocity, especially at low velocity. As working laws are complex, it is often difficult to take into account the real temperature influence on sensors in view to correct the measured value. It would be far more easy to be able to calibrate anemometers at their working temperature.

Through its influence on air properties (density, viscosity, conductivity, ...), humidity also might have an influence on air velocity measurements according to working laws of anemometers, but this influence is also difficult to take into account and very few studies have been carried out about it [1].

Concerning the direction of the flow, some studies [2] have shown (cf figure 1) that, in case of low velocity it might cause rather big measurement errors if the flow direction is not the same during calibration and use of the anemometer.

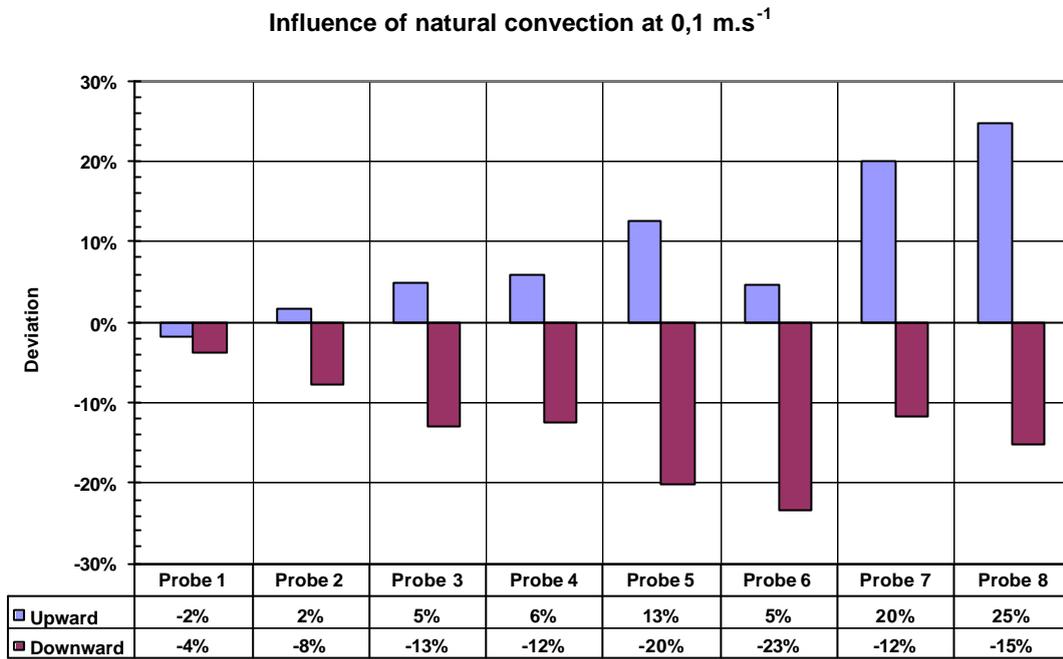


Figure 1 – Influence of the flow direction on the measurement of thermal anemometers at 0,1 m.s⁻¹

The new anemometers' calibration test rig

The previous considerations have lead us to build a new anemometers' calibration test rig with the following expected performances:

- Method of calibration : by comparison to a reference anemometer
- Reference anemometer : Laser Doppler Anemometer (LDA)
- Direction of the flow : horizontal, upward or downward
- Air velocity range : from 0,05 up to 2 m.s⁻¹
- Temperature range : from +10°C up to +50°C
- Relative humidity range : from 10% up to 90%
- Atmospheric pressure

Such a test rig is quite unusual because of the combination of low air velocity, temperature and humidity and flow direction which leads to the following problems:

- The Reynolds number is expected to be between 600 (at 0,05 m.s⁻¹) and 25000 (at 2 m.s⁻¹). This has, as a consequence, a change in the velocity profile from a parabolic profile for the laminar flow at low velocity up to a rather flat profile for the turbulent flow at high velocity. To perform calibration by comparison, a rather flat velocity profile is needed in the calibration zone to minimize the uncertainty due to its heterogeneity. So, a particular attention must be taken, at low velocity, to prevent the development of the laminar velocity profile.

- The air temperature inside the tunnel has to be as homogeneous as possible to prevent natural convection effects which could be disastrous for the flow, especially at low velocity because they would generate unwanted upward flow.
- The variation of humidity in the tunnel has to avoid water vapor condensation and induces some very strict procedures.

The general design of the test rig

To meet all the technical constraints of the project, the test rig, shown on the figure 2 below, has been built.:

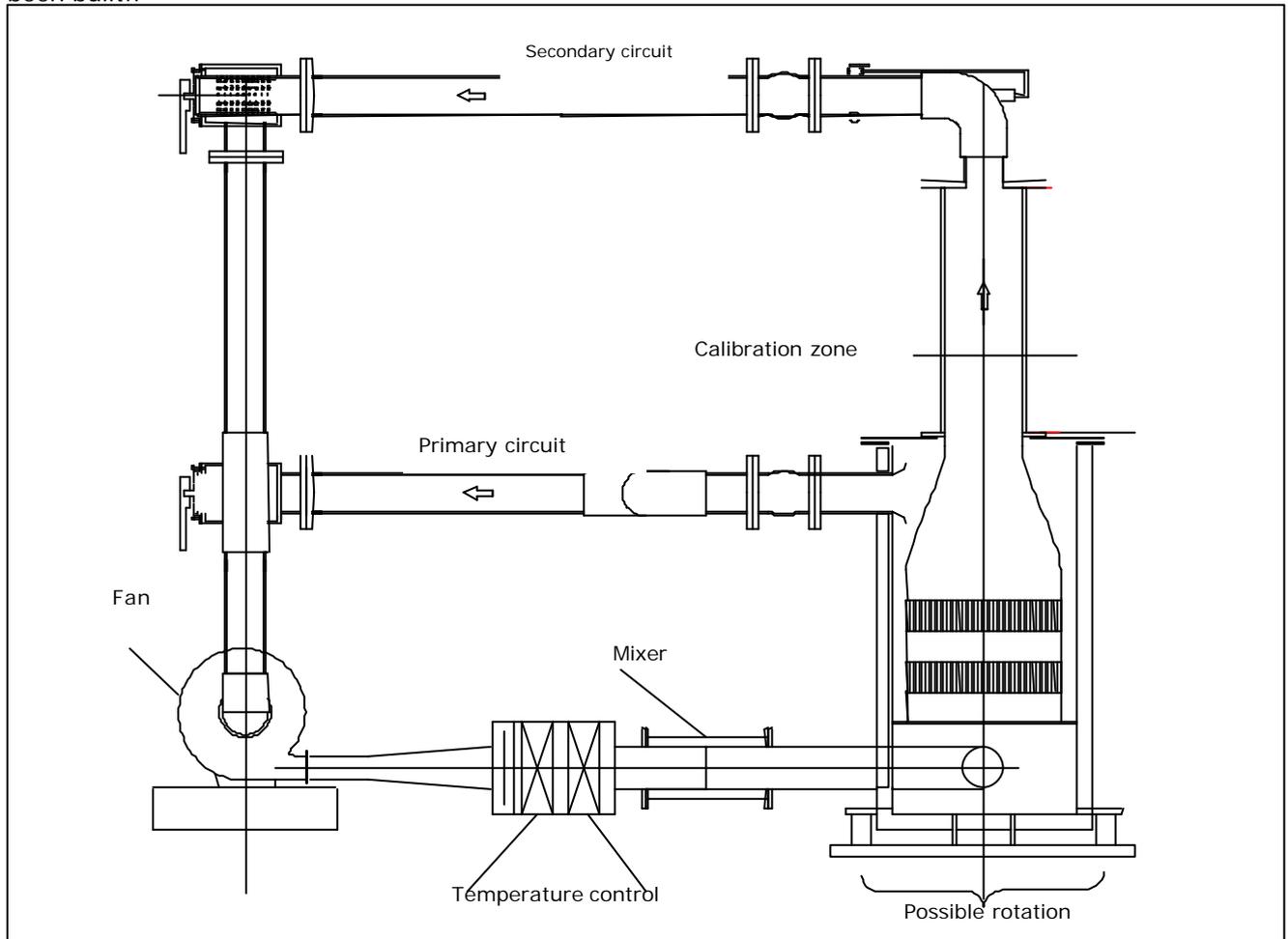


Figure 2 – General design of the test rig

As it can be shown, the test rig is composed of two circuits: the calibration zone is located in the secondary circuit in which a part of the flow is diverted from the primary circuit. The fan and the heat exchanger are located in the primary circuit. By this mean, the fan is always working at its best working point and the heat exchange is always performed at the higher flow rate as possible.

Some flexible links let rotate the secondary circuit to generate different directions of flow.

The expected performances of the test rig are the following :

- Temperature stability in time : $\pm 0.5^{\circ}\text{C}$

- Temperature stability in space : $\pm 0.5^{\circ}\text{C}$
- Turbulence intensity below 1%
- Maximum uncertainty : $\pm 0,02 \text{ m}\cdot\text{s}^{-1}$

The reference anemometer : the Laser Doppler Anemometer (LDA)

The technique is to split a laser beam into two beams and then recombine them through a small intersection angle. Since they have not the same optical path, the interaction of the electromagnetic fields of the two beams in the intersection volume results in a pattern of evenly spaced bright and dark bands. The spacing between the bright bands, i is calculated from :

$$i = \frac{\lambda}{2 \times \sin\left(\frac{\theta}{2}\right)} \tag{1}$$

where λ is the wavelength of the laser light and θ is the angle between the two laser beams.

Small particles, entrained in, and moving at the same speed as the air stream, scatter light as they pass through each bright band in the intersection volume. The velocity of the particles is then :

$$U = \frac{i}{t} = f_D \times i \tag{2}$$

where t is the average period of the pulses of the scattered light and f_D is its associated frequency.

The Laser Doppler Anemometer is shown on figure 3 below:

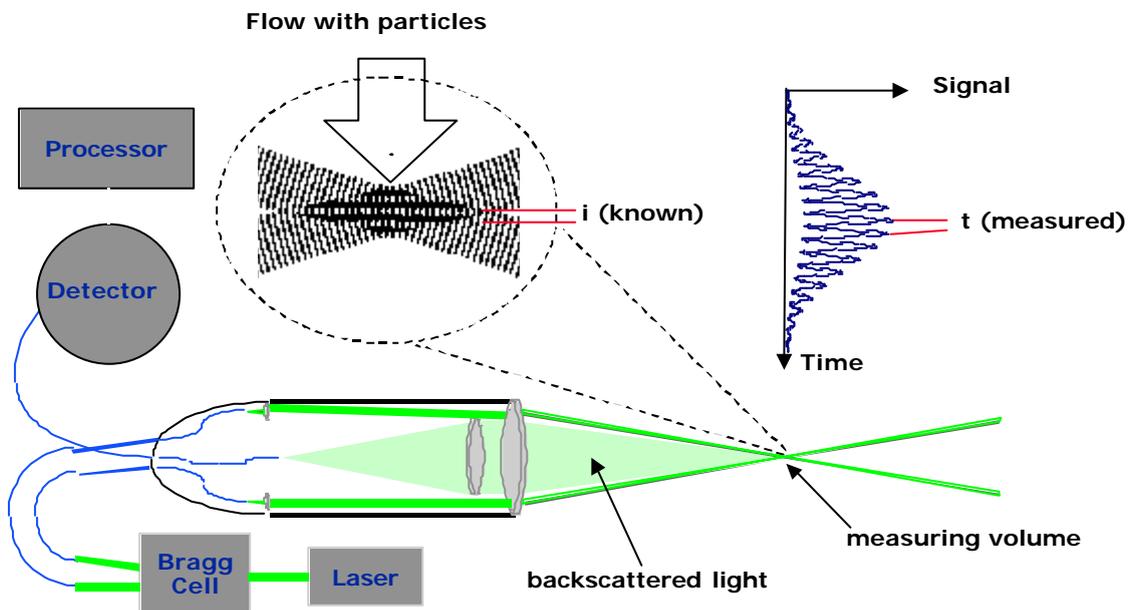


Figure 3 – Laser Doppler Anemometer 's scheme

Note that there are no negative terms in the above formula. In other words, the direction of the particle motion can not be determined by this formula. Furthermore, the measured velocity of the particle is the velocity component normal to the fringe pattern, not the actual velocity.

With equation (2), it can be seen that LDA systems are calibrated through a calibration in frequency (for f_D) and a determination of i .

There are several ways to estimate this parameter i . They are describe in [3].

The first one is referred as the "particle of known speed". A light-scattering particle is placed on the rim of a disk at a known radius. The disk rotates at a measured speed and thus, the linear speed of the particle may be calculated. The parameter i can be determined by comparing this calculated speed and the speed indicated by the LDA. Data from several hundreds measurements over the speed range of 0.15 m.s^{-1} to 5 m.s^{-1} demonstrate that the LDA is a linear instrument. The possible sources of uncertainty which have been identified are : the alignment of the laser with the axis of the cylinder, the measurement of the disk diameter, the measurement of the disk rotation speed, the measurement of f_D by the LDA software, the value of λ . In the worst case, this leads to an uncertainty of 0.06 m.s^{-1} .

The second method is referred as the "direct angle measurement". The parameter is dependent upon the wavelength of the laser beams, λ , and the intersection angle between the two beams, θ , (see Eq. (1)). If the wavelength is known accurately, the parameter i may be determined by a direct measurement of the angle with the help of a calibrated rotating plate at the center of which a mirror is placed. The possible sources of uncertainty are the following : the perpendicular alignment of the bisector of the intersection angle with the axis of the rotating plate, the uncertainty of the rotating plate, the measurement of f_D by the LDA software, the value of λ .

The authors show that the two methods are equivalent since they differ by only 0,055 percent on the fringe spacing, i . It is then established that LDA can be considered as a primary standard instrument for air velocity, characterized by two independent, fundamental methods based on the measurement of length and time in the first case and of length in the second.

Conclusions

The new test rig should respond to industrial needs because it should allow the calibration of anemometers in their working conditions, for temperature and humidity conditions as well as flow direction.

Furthermore, thanks to its characteristics such as velocity profile and associated reference anemometer, it should be considered with high metrological quality.

References:

- [1] Influence of humidity on hot-wire measurements, F. Durst et al, Meas. Sci. Technol., Vol 7, 1996
- [2] Calibration and requirements for accuracy of thermal anemometers for indoor velocity measurements, A.K. Melikov et al, EC Project MAT1-CT93-0039, 1997
- [3] New primary standards for air speed measurement at NIST, V. E. Bean and J.M. Hall, NCSL Workshop & Symposium, 1999