Experimental Investigation to Calibrate Pitot-tube by LDA

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Abstract： Pitot -tube is widely used to measure the air velocity. The coefficient α must be calibrated to correct the measurement result. LDA (laser Doppler anemometer) can be applied to calibrate Pitot-tube to acquire the coefficient α. During the process, the calibration result is influenced by the flow round the probe of Pitot-tube and air velocity distribution deviation in long axis. The experiments are conducted to evaluate or correct this influence. The results show (1) the calibration results will be different due to the interference of probe mounted in flow field. So, the proper measurement position for LDA is required to reduce the influence as much as possible. (2) The air velocity distribution deviation that is inherent along axis also influences the result of calibration coefficient α. This influence can be corrected by actual measurement.

Key words： Air velocity; calibration; Pitot -tube; LDA

1. Introduction

As conventional anemometer Pitot-tube is used widely due to simple principle and reliable structure. After discreet calibration Pitot-tube could be taken as reference meter with accuracy of 0.5% to calibrate other type of anemometer such as hot wire, wheel or ultrasonic meter. The calibration coefficient α of Pitot tube is employed to correct the result calculated by Bernoulli's equation. In early experiments the annular-tunnel in NPL is used to calibrate Pitot-tube at low Renolds Number. The critical nozzle is also used as reference to obtain the stable gas flow for calibration of Pitot-tube in real gas flow. In the past decades LDA is applied as reference in national metrology institutes for its high accuracy of about 0.2%. Moreover, the existing flow field does not be disturbed with non-intrusive optic method by LDA. The traceability of LDA could be conducted by spinning-disc with that the unit of m/s is traceable up to SI of length (m) and time (S). Recently LDA with calibration results by spinning-disc is essential condition to be participant for new CCM.FF-K3. In 2011 New reference air velocity facility is established at NIM. The facility with LDA and wind tunnel woks as reference to calibrate the anemometer. The experiments in this paper are conducted to determine the calibration method for Pitot-tube.

2. The computation of coefficient

The local velocity of a fluid in a steady flow without transverse velocity gradient or turbulence at Reynolds numbers, v, based on the internal diameter of the total pressure tapping, greater than 200 is given by the expression

$$v_p = \alpha(1-\varepsilon)\sqrt{\frac{2\Delta p}{\rho}} \tag{1}$$

in which (1 − ε) is a compressibility correction factor. In a liquid, ε = 0 so that no compressibility correction is required, but in a compressible fluid at low Mach numbers the factor (1 − ε) may be determined by the relationship

$$(1-\varepsilon) \approx [1-\frac{1}{2\gamma}\frac{\Delta p}{\rho}+\frac{\gamma-1}{6\gamma^2}(\frac{\Delta p}{\rho})^2]^{\frac{1}{2}} \tag{2}$$

where

γ is the ratio of specific heat capacities;

ρ is the local density of the fluid;

Δp is the differential pressure indicated by the Pitot tube;

α is the calibration factor of the Pitot tube

Additionally when Pitot tube is used the Renolds number should be more than 200 that is equal to

$$\Delta p \geq \frac{2\times10^4}{\rho}(\frac{\mu}{\alpha d_i})^2 \tag{3}$$

μ is μ is the dynamic viscosity of the fluid;

d_i is the diameter of the total pressure hole of the Pitot tube;

To calibrate Pitot tube the measurement result of LDA is used as reference value:

$$v'_p = (1-\varepsilon)\sqrt{\frac{2\Delta p}{\rho}} \qquad (4)$$

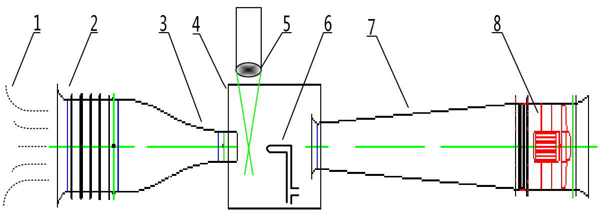
Then the calibration coefficient of Pitot tube:

$$\alpha = \frac{v_{LDA}}{v'_P} \qquad (5)$$

3. The calibration experiments

3.1 Air velocity facility

The commercial LDA is taken as reference and the expanded uncertainty is expected to be less than 0.3% (k=2) that depends on the calibration result by spinning-disc. The open-channel wind tunnel with subsonic nozzle of 200mm provides stable flow at different velocities the range of which is (0.2~30) m/s. The test results suggest that both the standard deviation of velocities along flow profile and the stability at different velocities less than 0.3% within 30 minutes. The MPE of differential pressure meter is 0.02%FS, and the pressure rang is (0~2500) Pa. The arrangement of calibration of Pitot tube is showed in figure 1.



(1)Tracing particle (2) Setting chamber (3) Nozzle (4)Test section (5) LDA 6.Pitot-tube (7) Diffuser (8) Axial fan

Fig.1 (a) Arrangement of calibration experiment

Fig.1 (b) Photo of calibration experiment

The pitot-tube probe is mounted in the downstream axis of subsonic nozzle for calibration experiments those are conducted at 3 different velocities including 5m/s, 10m/s and 15m/s. The coefficient α is calculated by formula (5). Generally the uncertainty of calibration result is effected by a few budgets including uncertainty of LDA, pressure measurement and air density measurement those determine the calibration uncertainty. Except for above, during the process of calibration the pitot probe disturbs the existing flow field and flow around the Pitot-tube produce the trouble at measurement position of LDA that is difficult to be located. Another problem is the velocity deviation along axial that also influence the calibration results while the velocity at different position is measured by reference or meter under test in the flow field. The experiments in this paper are employed to find the measurement position of LDA in the disturbed flow, and the deviation produced by position difference is expected to be evaluated and corrected. The 2 pitot-tubes with diameter of 6.5mm are employed, and the diameter of total pressure hole is 2.5mm.

3.2 Experiments on flow around the probe

The jet coming out of sub-sonic nozzle flows around Pitot-tube under test. The air velocity will decrease while the flow is approaching the probe. At the location in the upstream of the pitot-tube probe the air velocity is reduced to be zero where the static pressure increases to be maximum value. The measurement volume crossed by two beams of LDA is required to be located in the upstream of probe where the flow was not disturbed. To avoid the influence above the reasonable position of cross section formed by LDA has to be determined. However, the existing standard deviation produced by wind tunnel itself is hidden in the velocity change caused by flow around the pitot probe. To clarify this change the existing standard deviation at flow axial is defined as σ that is taken as criterion to determine the measurement position for LDA.

The measurements start with center of nozzle outlet and be conducted with every step of 25mm within 300mm along long axial. The experimental results are shown in figure 2. The standard deviation $\sigma_{\max}$ is less than 0.4% at 3 velocities of 5m/s, 15m/s, 30m/s.

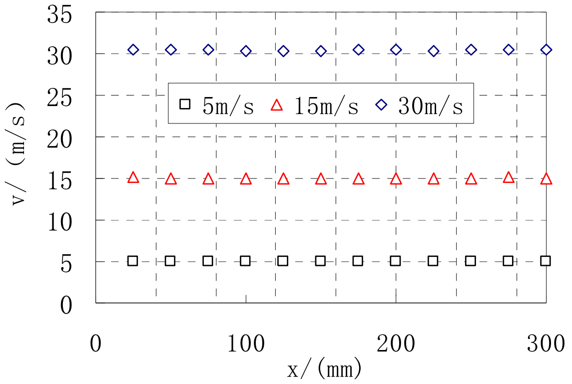


Fig.2 velocity distribution without probe in flow

To predict the influence on the upstream of Pitot tube Fluent is employed to calculate the velocity distribution around the probe. The velocity of coming flow is supposed to be 15 m/s and CFD simulation result is showed in figure 3. As it is expected the velocity is being decreased gradually when it is closed to total pressure hole. At the position of 20mm far away from the probe the velocity is reduce by 1%. Another meaningful result is that the air is accelerated along the tube contour but the flow happens to separate near static pressure hole. The separation is considered to influence the measurement of static pressure, namely in theory measurement result of Pitot tube. It is believed this effect is also a budget to calibration coefficient α .

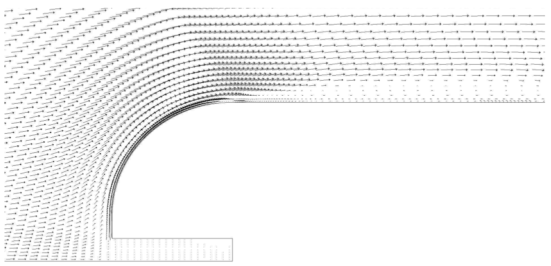
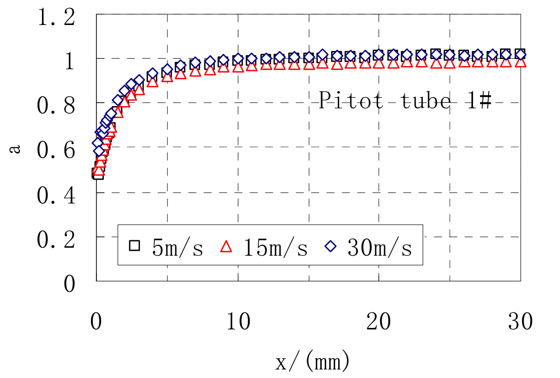
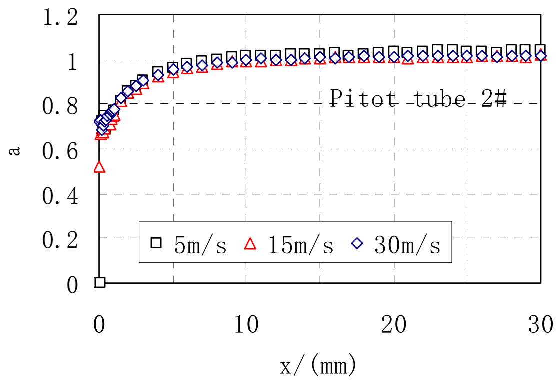


Fig.3 CFD calculation result of flow field around probe

In practical test Pitot tube is mounted 70 mm away from nozzle outlet. With each step of 1mm along axial the air velocity in the upstream of probe is measured by LDA. Both 2 Pitot tubes behave the similar specification that is shown in figure 4. It is obvious that the velocity gradient is almost same at 3 different velocities. This result means it is no need to change the position cross section in practical calibration. If σ_{max} , namely 0.4% is taken as criterion the influenced flow field is different for 2 probes. For Pitot tube 1# within 20mm upstream of probe the gradient is more than 0.4%, and further position away from the probe could be defined the region not effected by flow around the Pitot tube under test. However for Pitot tube 2# analogous position exists 13mm away from the probe.



a. The result of Pitot tube 1#



b. The result of Pitot tube 2#

Fig.4 Calibration coefficient α in upstream of probe

With experimental results above the measurement position of LDA has to be located at the position not influenced by flow around probe. Similarly the flow around other type of anemometers also influence the calibration results but at different Renolds number that depends on the size of meter under test. To achieve the satisfying accuracy this influence has to be avoided as much as possible by the same experimental procedures. Additionally within the range of (5~30) m/s the position difference could be neglected. This is helpful to maintain calibration efficiency.

3.3 The correction for axial deviation

The measurements in figure2 reveal that there is velocity deviation at different position along axial.

This deviation is involved in calibration result, however, could be corrected by the experiments. To make the correction the Pitot tube is taken out from test section. And then LDA is employed to measure the velocity at the position at which probe locates. The correction coefficient c_{LDA} is calculated by:

$$c_{LDA} = \frac{v_{LDA-MUT}}{v_{LDA-reference}} \qquad (6)$$

$v_{LDA-MUT}$ is the velocity at the position of probe, $v_{LDA-reference}$ is the velocity of LDA position. Then α can be corrected by:

$$\alpha = \frac{v_{LDA} \cdot c_{LDA}}{v'_p} \qquad (7)$$

The experimental results are showed in figure5. the measured velocities is normalized to be "1". c_{LDA} is equal to 0.997 that means α is corrected by 0.3%.

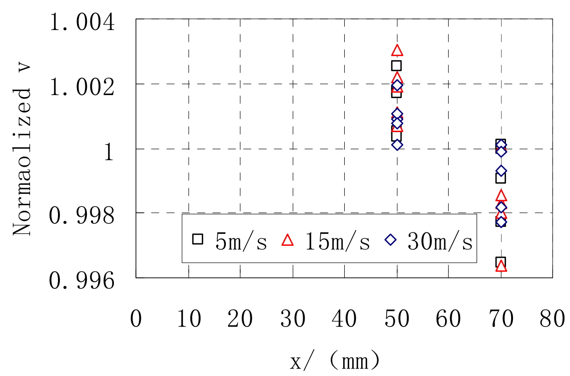


Fig.5 velocity deviation in different position along long axis without probe in flow

4 Conclusion & discussion

The experiments are conducted to evaluate or correct the influence due to the flow around the probe and velocity deviation along axial. The results suggest that (1) for Pitot tube in this paper the measurement position of LDA has to be located in the upstream 20mm away from the probe at least. Moreover, it is no need to change the measurement position of LDA within the range of (5~30) m/s. (2) the existing velocity deviation in the flow field influences the final calibration coefficient to be 0.3% that can not be neglected. The simple correction is offered in this paper. However, the correction value maybe over evaluated as maximum deviation is employed in calculation.

The experiments in this paper could be employed not only for Pitot tube calibration but for other type of anemometers such as wheel meter, hot wire, etc.

The computation formula of calibration coefficient α is on the base of hypothesis that assumes the gas is incompressible, non-viscosity and no transverse flow. For this reason α is considered to be produced by the turbulence and boundary layer closed to the wall of probe, and these two things could be defined as function of Renolds number. Therefore the further research focuses on building up the relationship between α and Renolds number in theory.

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