Establishment of New Air Velocity Standard in NIM

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Abstract：New air velocity standard facility is established at NIM. The facility is constituted of wind tunnel with outlet diameter of 200mm and LDA that works as standard to calibrate anemometer. In the velocity range of（0.2～30）m/s, the velocity stability and the deviation of velocity distribution along profile are both less than 0.35%. To realize traceability of LDA the spinning-disc is developed. The wire with diameter of 5μ is mounted on the edge of spinning disc to simulated tracing particle in air flow. The calibration results and analysis suggest that the expanded uncertainty of fringe spacing is evaluated to be: U_{rel}<0.3%，k=2.

Key word：Air velocity　Calibration　LDA　Spinning disc　Wind tunnel　Uncertainty

1. Introduction

Anemometer is used widely in the fields of atmospheric monitoring, indoor ventilation, and aerospace industry. To solve the problem of anemometer calibration it is the tusk for national metrology institute to establish air velocity standard. In china Pitot tube is taken as primary standard for a long term, however its accuracy could not meet the requirement of application recently. At NIM new air velocity standard is established not only to realize the traceability of m/s but also calibrate the anemometer with higher accuracy.

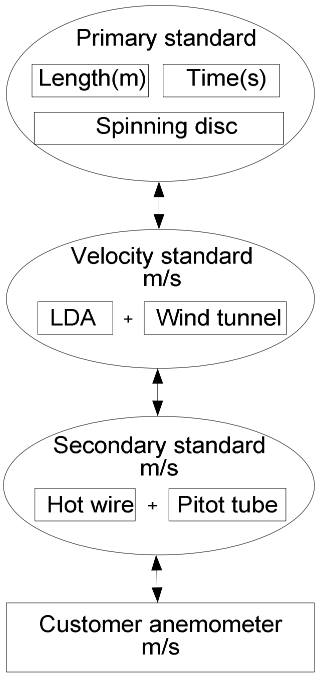

Figure 1 Chain of traceability at NIM

The chain of traceability at NIM is showed as figure1. The open-channel wind tunnel with outlet diameter of 200 mm provides air flow measured. A commercial LDA is taken as reference meter to calibrate anemometer. The spinning disc system is developed to make the value of LDA be traceable to m and s of SI unit. Considering the calibration efficiency the secondary standard includes hot wire meter and Pitot tube. Pitot tube is expected to work in the range of （5~30）m/s for its unsatisfying accuracy in the low velocity period. Hot wire is used to cover the range of (0.2~5)m/s. In this paper the secondary standard is not discussed because the stability of anemometers is under investigation.

2. Design & experiment

2.1 Spinning disc facility

Spinning disc facility is popular to be employed to calibrate LDA. Particle or wire running with spinning disc is able to generate Doppler signal. The calibration layout is showed as figure 2.

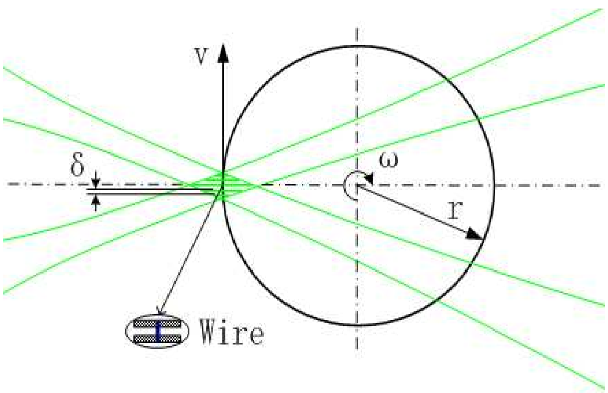

Figure 2 the calibration layout for LDA

At NIM the wolfram wire of 5μ diameter is stick on the edge of spinning disc. The velocity of spinning disc can be provided by:

$$v_s = r \cdot \omega = \pi \cdot f \cdot d \qquad (1)$$

Where, r is radius of spinning disc, ω is angular velocity, f is spinning frequency, d is diameter of spinning disc. v_s could be traceable to m and s by the calibration of d and f. The Photo of spinning disc to calibrate LDA is showed as figure 3.

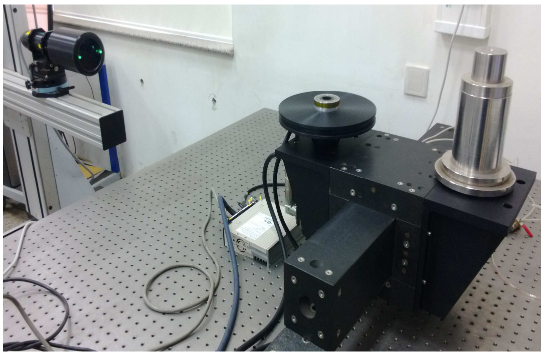

Figure 3 Photo of spinning disc to calibrate LDA

The servo motor drives spinning disc rotating with different velocity the range of which could cover (0.5~30)m/s. The diameter of disc is measured by coordinator machine and angular velocity is measured by circle angle encoder. When fine wire cross the measuring volume formed by two beams the velocity measured by LDA should be:

$$v_{LDA} = \frac{\lambda}{2\sin(\theta/2)} f_D^{wire} = \delta \cdot f_D^{wire} \qquad (2)$$

Where, λ is laser wavelength, θ is crossing angle of two beams, f_D^{wire} is Doppler frequency that is measured by LDA, δ is fringe spacing. If $v_{LDA} = v_s$, according to formula (1) and (2):

$$\delta = \frac{\pi \cdot f \cdot D}{f_D^{wire}} \qquad (3)$$

With the calibration result of δ, the reference value of air velocity can be calculated by:

$$v_{NIM} = \delta \cdot f_D \qquad (4)$$

f_D is Doppler frequency generated by air flow.

There is gradient distribution of fringe spacing in the measuring volume. The wire is used to scan measuring volume to determine the fringe spacing at different position along light axial. As figure 3 showed the spinning disc with servo motor is mounted on the air-float table together. The spinning disc can be driven by step motor to move with resolution of 0.1mm. By this way the wire is able to scan the whole measuring volume. The wavelength of commercial LDA is 514.5nm, and focal length is 800mm. The crossing angle of two beams is $\theta = \arctan(\frac{39.07}{2\times 800})$. The fringe spacing in the center of measuring volume can be calculated to be 5.325 μm in theory.

The calibration experiment is conducted at different velocity. The results of fringe spacing are showed as figure 4.

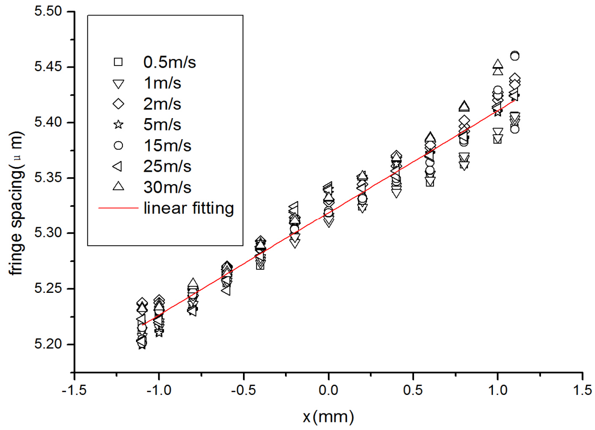

Figure 4 Fringe spacing at different velocity

The mean value of fringe spacing at each velocity is showed as figure 5.

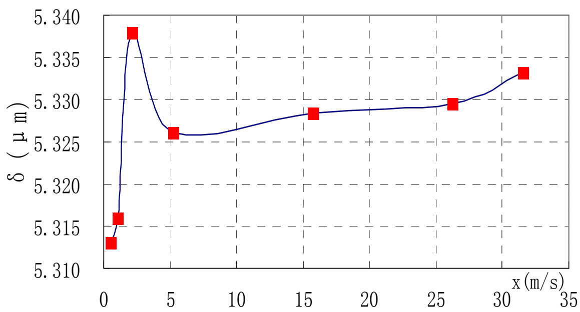

Figure 5 Fringe spacing at different velocity

To estimate the accuracy of velocity measurement of LDA the deviation between indicating velocity and reference velocity is calculated. The maximum of deviation is 0.24% at 0.5m/s. The deviation at each velocity is showed as figure 6.

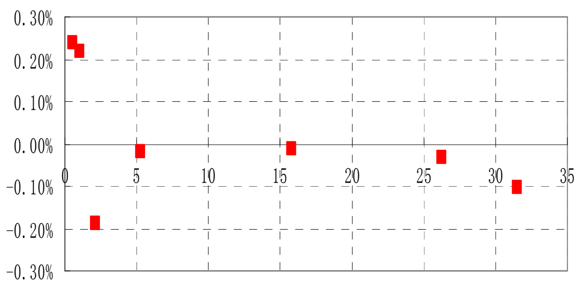

Figure 6 Velocity deviation of LDA

Gaussian distribution of light intensity in the measuring volume is helpful to determine the scanning position. The distribution of light intensity at velocity of 15m/s is showed as figure 7.

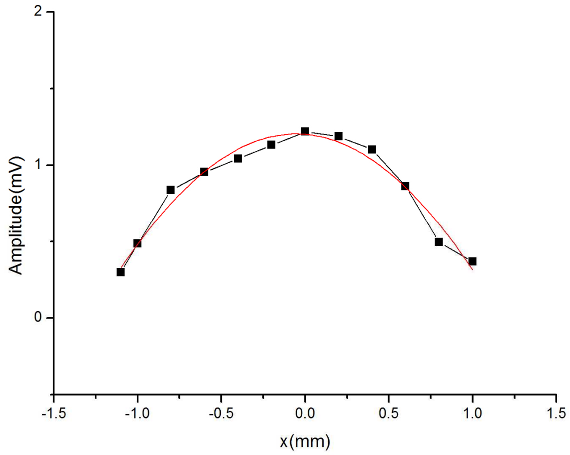

Figure7 Light intensity Gaussian distribution in the measuring volume

The results above suggest that the fringe spacing in measuring volume is between 5.216 μ m and 5.422 μ m. The maximum of relative bias is about 4%. The mean value of all measurements is 5.318 μ m that is very closed to 5.325 μ m of theoretical value. The mean value of fringe spacing can be accepted due to excellent linearity of fringe spacing. For the case of bad linearity the light intensity distribution in the measuring volume has to be considered as weight factor to calculate the mean value of fringe spacing.

2.2 Wind tunnel

Open-channel wind tunnel is taken for design due to the cost and space in the room. The diameter of nozzle outlet is designed to be 200mm. As figure 1 showed hot wire and Pitot tube working as secondary standard are calibrated by LDA. The size of both these two sensors is small enough so that there is no serious blockage effect is produced. The contraction of nozzle with Vischinski shape curve is 9:1. The total length of wind tunnel is 6.8m. The honeycomb mounted in the inlet and 4 layers of nets regulate the flow and shatter the swirls produced in the upstream. The axial fans at downstream drives air flow.

Air velocity distribution along flow axial is measured. The results at different velocity are showed as figure 9(a). On the base of test the probe

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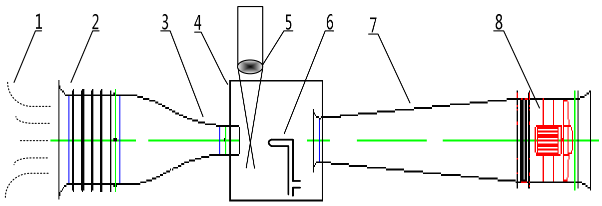

1. Tracing particle 2.Setting chamber 3.Nozzle

4. Test section 5.LDA 6.MUT 7.Diffusor 8.Axial fan

Figure 8 the sketch of Open-channel wind tunnel

9(a).On the base of test the probe under test is mounted at the position of 100mm away from nozzle outlet. To evaluate the specification of wind tunnel both flow profile and stability are measured by LDA. The measurement of velocity distribution along flow axis is helpful to determine the position of anemometer under test. The test results are showed as figure 9(b) and 9(c).

By the result of figure 9(a) the test section is determined at the position of measuring volume that locates at position of 50mm away from nozzle outlet. The test results suggest the standard deviation of flow profile within the range of (-70mm, 70mm) is less than 0.35%, and the stability in 30 minutes is also less than 0.35%.

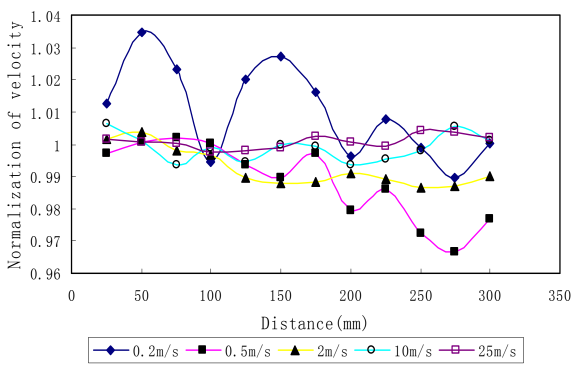

Figure 9(a) Velocity along flow axial

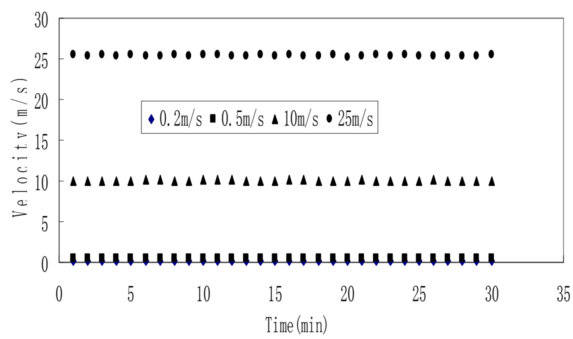

Figure 9(b) Velocity stability

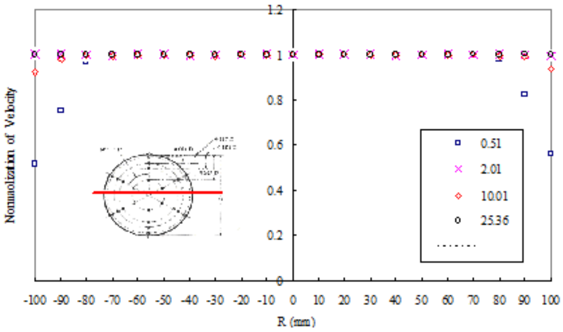

Figure 9(c) Flow profile (at 50 mm away from nozzle)

3. Uncertainty evaluation

According to formula (4) the uncertainty of v_{NIM} is determined by measurement of fringe spacing δ and Doppler frequency f_D .

1.Fringe spacing δ

δ can be calculated by formula (3). The uncertainty of spinning velocity *f*, diameter of disc *d* and f_D^{wire} has to be investigated.

A type uncertainty of *f* is estimated to be 0.05% that is due to the stability of spinning disc. B type uncertainty is 0.025% that comes from upper standard of spinning velocity.

The static diameter *d* is measured by coordinator machine with repeatability of 0.05%. B type uncertainty is estimated to be 0.01mm/200mm=0.005%. Considering the gap of bearing to be 0.01mm, the uncertainty is about 0.005%. The maximum distortion of wire is considered to be 0.02mm that produces the uncertainty of 0.01%. Therefore the B type uncertainty of dynamic diameter is combined to be 0.0115%.

A type uncertainty of f_D^{wire} is mainly produced by spinning stability that is about 0.05%. B type uncertainty is estimated to be 0.001%.

2. f_D

The repeatability of f_D is 0.2%. B type uncertainty is same as f_D^{wire} of 0.001%.

When real air flow is measured turbulence makes the repeatability get worse. For this reason the uncertainty of v_{NIM} has to be increased by about 0.2%. The evaluation of uncertainty budget is showed as figure10.

Figure 10 Uncertainty budget

Uncertainty		Type A (%)	Type B (%)	u_{rel}^{c} (%)
$u(\delta)$	$u(f)$	0.05	0.025	0.056
	$u(d)$	0.05	0.0115	0.052
	$u(f_D^{wire})$	0.05	0.001	0.05
$u(f_D)$		0.20	0.001	0.2
$u_{rel}^{c}(\delta)$				0.091
$U_{rel}^{c}(\delta), k=2$				0.18
$u_{rel}^{c}(v_{NIM})$				0.22
$U_{rel}^{c}(v_{NIM}), k=2$				0.44

4. Conclusion & discussion

New air velocity standard facility is established at NIM. The facility is constituted of wind tunnel with outlet diameter of 200mm and LDA that works as standard to calibrate anemometer. In the velocity range of（0.2～30）m/s, the velocity stability and the deviation of velocity distribution along profile are both less than 0.35%. To realize traceability of LDA the spinning-disc is developed. The wire with diameter of 5μ is mounted on the edge of disc to simulated tracing particle in flow. The calibration results and analysis suggest that the expanded uncertainty of LDA measurements is evaluated to be U_{rel}<0.3%， k=2.

In this paper wire is used to generate Doppler signal, however, the light scattering of wire is different of tracing particle because there is intensity gradient of light in the measuring volume at any direction. The influence is expected to be analyzed and investigated.

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