The establishment of low air speed reference facility of (0.1~1)m/s based on 83m guide trial at NIM

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In the field of Bio pharmaceutical or chip fabrication, micro air speed less than 0.2m/s has to be measured to ensure the cleanliness during the manufacturing process. In most cases micro air speed measurement could be achieved by hot wire anemometer (HWA). The linear low-speed calibration facility is developed both at INRIM and NMIJ. At NIM the low air speed reference facility is established based on 83m guide rail in 8.3m deep underground. The sensor probe is mounted on the carriage that slides with consistent speed and the sliding stroke is measured by laser interferometer accurately. With this method in the range of (0.1~1) m/s the HWA could be calibrated with the expanded uncertainty of reference speed U=5.4 mm/s, k=2. Meanwhile this HWA is also calibrated by the LDV in wind tunnel within the same speed range and the experimental procedure is designed to void the sensor probe to be polluted by scattering particles. The difference between 2 methods of calibration results is less than 30mm/s at most.

Key word: Low air speed HWA Calibration Linear guide trial LDV Uncertainty

1. Introduction

In the field of Bio pharmaceutical or chip fabrication micro, air speed less than 0.2m/s has to be measured. Usually the hot wire anemometer (HWA) is employed due to its favourable specification in low speed range. However the issue of anemometer traceability is not easy to be solved due to small Reynolds number flow in low speed. The Pitot-tube or LDV are taken as reference at most National metrology institutes. But for flow in small Reynolds number, Pitot tube could not be applied totally on ideal Bernoulli equation without viscosity correction. And it is difficult to take LDV due to particle tracing effect in low air speed, moreover there is the problem of sensor probe pollution. In 1960's NPL developed the rotating-arm facility to calibrate anemometer [1]. Laterally both at INRIM and NMIJ the low air speed calibration facility was built up and low air speed calibration was realized [2][3]. At NIM the 80m linear guide trial that is built in the 8.3m deep tunnel underground for the baseline length calibration. On the base of existing facility with interferometer and stable temperature gradient in underground space. The low air speed reference facility is established with sliding carriage on the linear guide trial. The HWA is calibrated in this facility. Meanwhile, this HWA is also calibrated by LDV in wind tunnel by considering the test procedure to void sensor probe pollution of scattering particles.

2. Facility Design

The low air speed reference facility locates in the new campus of NIM. 8.3m deep in underground the independent tunnel about 90m long is constructed. The temperature could be kept to be stable with air condition does not work. 20 pairs of pt100 and humidity senor are mounted on the wall and distributed along the 83m long guide trial to monitor the change of environment condition. In this tunnel the temperature and humidity fluctuation is less than 0.5℃and 5%RH. The natural convection could be suppressed as much as possible in this construction.

The guide trial is made of granite. Its straightness and roughness are small enough to make air-float carriage slide frequently within the whole trial range. A few of air-floating units are fixed on the bottom and of both 2 sides of sliding carriage to keep the carriage untouching the trial surface with 0.4Mpa air pressure is provided, therefore the friction does not exist in between. The linear movement is driven by a nylon wheel with step motor that is mounted on the single side of carriage.

The triangle bracket is designed to hold the sensor probe under calibration. As showing in figure2, in order to minimize the carriage-disturbing influence, the probe stays 1.5m away from the front border of carriage on the stable structure. The bracket could be moved up and down by 2 another step motors so as to confirm the height of ideal calibration position.

The movement distance of carriage is measured by laser interferometer that is calibrated. And the movement time is also traceable to reference at NIM by the way of internet timing. To isolate the calibration system away from operator, all data including motor control signal, distance, time data and the HWA output are transmitted through the wireless router. Moreover the security rig is designed in the system in case of unexpected pressure lost, motor out of control and mechanical troubles.

Figure 2 Low air speed calibration facility

Based on these design details above the carriage moves within (0.1~1) m/s of linear speed. If natural convection and secondary could be neglected the carriage speed is thought to be reference air speed to calibrate HWA.

3. Experiment and analysis

3.1 Natural convection & secondary flow

The influence of natural convection and the secondary flow have to be considered before calibration. For natural convection the HWA is tested at the different positions on the trial to achieve zero shift that is observed to be 6mm/s. As signal noise is included in this zero shift the influence of convection is less than 6mm/s. The secondary flow is considered to be caused by the movement of carriage in the round trip. In calibration trip the probe leaves the influence behind itself. For the influence by return trip of speed of 0.2m/s it has to wait for a period of time for the confirmation that the air is stable enough. For this reason the different waiting-time for each test point is temped and the HWA outputs are compared in figure 3. It takes 4 different periods of time including 2 minutes, 5minites, 11minites and 15 minutes to test in 3 speed points and there is no obvious voltage deviation among these periods of test results. The maximum change is less than 0.2%. The results suggest the waiting time more than 2 minutes is enough to neglect the secondary flow due to the return trip of carriage for the quality of data. However, we choose 8 minutes as waiting time in each stroke to ensure the calibration reliability.

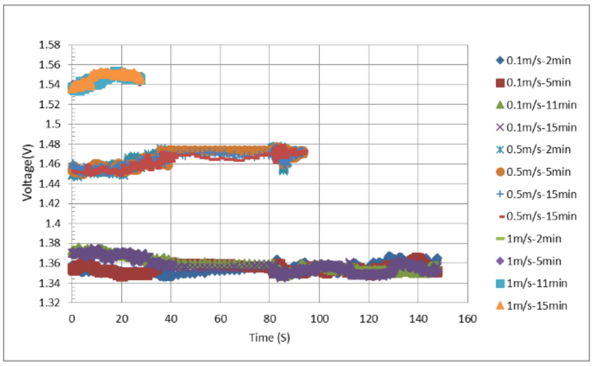

Figure 3 secondary flow influence evaluation result

3.2 Calibration results

In calibration the probe is mounted on the bracket and move along with the carriage together. The carriage is accelerated to reach configured speed. After keeping consistent speed for at least 30 s, the carriage starts to slow down till it is static. Then it returns with the speed of 0.2m/s. During this process the carriage speed and HWA output could be acquired in real time. The received data in the consistent period is used to achieve accuracy of HWA, and the data in the acceleration period is supportive to evaluate the probe's dynamic response specification.

The speed at 10 points is tested for a few times and the results of speed at 0.1m/s, 0.5m/s, 1m/s are showed in figure 4-1to 4-3. All 10 points of calibration results are showed in figure 5. As showed in figure 4, the stability of linear speed is less than 3mm/s in the consistent speed period of stroke.

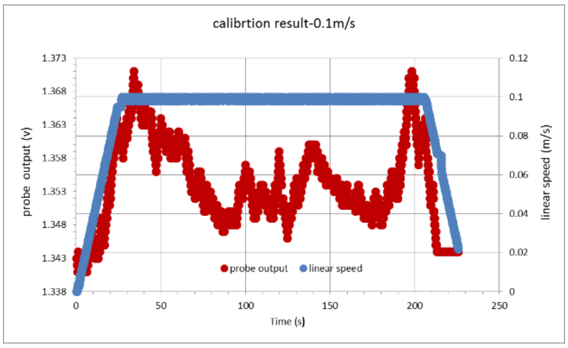

Figure 4-1 Calibration result in 0.1m/s

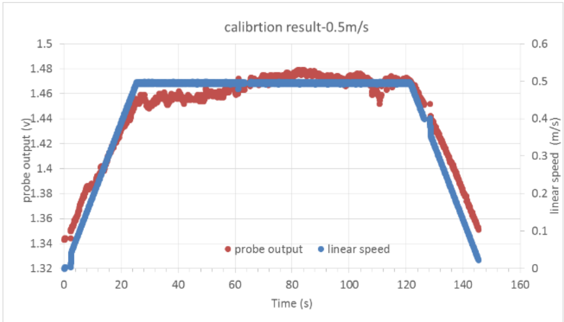

Figure 4-2 Calibration result in 0.5m/s

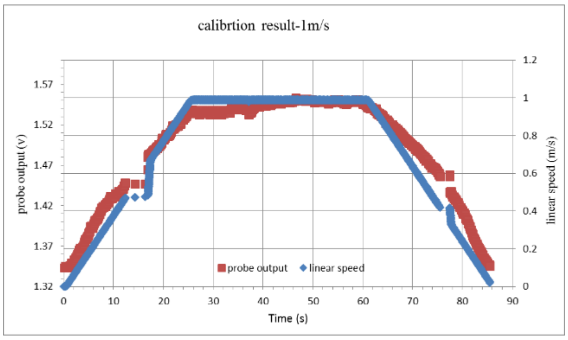

Figure 4-3 Calibration result in 1m/s

Figure 5 10 speed points of calibration results

Speed point (m/s)	Mean value of linear speed (m/s)	Standard deviation of linear speed (m/s)	Mean value of probe output voltage (v)	Standard deviation of probe output (v)
0.1	0.099	0.000	1.353	0.004
0.2	0.198	0.001	1.392	0.012
0.3	0.297	0.001	1.423	0.010
0.4	0.396	0.002	1.446	0.009
0.5	0.495	0.002	1.467	0.008
0.6	0.594	0.002	1.485	0.007
0.7	0.692	0.002	1.502	0.006
0.8	0.791	0.001	1.516	0.006
0.9	0.890	0.001	1.532	0.006
1	0.989	0.001	1.544	0.006

A few of speed defects happen in the process the reason is that there are connection gaps about 0.5mm between the granite block to disturb the movement of carriage. However it is reasonable to remove the results that do not damage the quality of calibration results significantly as a large number of satisfying data is left.

The output responses the change of linear speed and the stability is about 0.5%. In theory the static equation of HWA under calibration could be expressed as,

$$\frac{E_w^2}{R_w} = \frac{R_w - R_f}{R_f \alpha_f}(A + B\sqrt{U}) \qquad (1)$$

In this formula, U is air speed, E_w is output voltage of HWA, R_w is working resistance of hotwire in working temperature, R_f is resistance of wire in the air temperature of T_f , α_f is temperature correction coefficient. In this case, T_f =22.8 °C , $R_f = 3.38\Omega$, $\alpha_{20.3} = 0.0036$. As the working resistance of hotwire is 242 °C , R_w is calculated to be 6.03 Ω .

Then the static equation of HWA in theory is transformed to be,

$$U = 1.59E_w^4 - 5.07E_w^2 + 4.04 \qquad (2)$$

The calibration results of (0.1~1) m/s are fitted in square at least the experimental equation could be obtained by,

$$U = 14.71E_w^2 - 37.96E_w + 24.52 \qquad (3)$$

The results of formula (2) and (3) are showed in figure 6. Apparently the 2 curves are matched well. The maximum deviation is 7mm/s at the point of 0.8m/s.

The linear speed is calculated by:

$$U_{linear} = \frac{\Delta s}{\Delta t} \qquad (4)$$

Δs is the distance measured by laser interferometer. The wavelength of laser, the linearity of guide trial and air refractive index

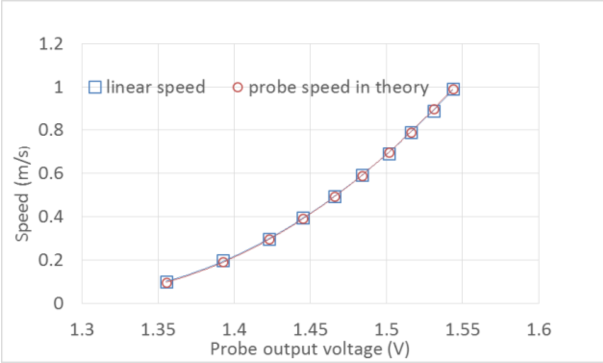

Figure 6 The calibration result-experimental result

are considered. The uncertainty of distance, $u_{rel}(\Delta s)$ is evaluated to be around 0.05%. Δt is time of stroke. The internet timing, program code delay and data transmission synchronization are considered. The uncertainty of $u_{rel}(\Delta t)$ is evaluated to be 0.1%. The expanded uncertainty of linear speed is evaluated to be in the speed rang of (0.1~1) m/s.

$$U(\mathrm{U}_{linear}) = 5.4mm/s \text{ , } k=2 \qquad (5)$$

3.3 Calibration results by LDV & analysis

The probe pollution is a problem if LDV is taken as reference. The experimental procedures are designed to solve this problem. As air in low speed of (0.1~1) m/s flows in open-channel wind tunnel in which blockage plate inserted in the diffuser in downstream.

The probe is protected by a sealing cover to wait for air speed (particles) being measured by LDV at the beginning (seeing in the figure 7). The cover will not be removed until all the particles in wind tunnel flow out of the tunnel. With the procedures the hot wire senor is calibrated by LDV. In this process the determination of LDV measurement position is based on considering the flow around the probe. And the speed deviation at different positions in axis flow is corrected.

Figure 7 The probe calibrated in wind tunnel by LDV

The air temperature in wind tunnel is 20.3°C, and the static equation in theory is expressed by:

$$U = 1.52E_w^4 - 4.95E_w^2 + 4.04 \qquad (6)$$

Similarly the experimental equation of calibration results by LDV in wind tunnel could be obtained:

$$U = 14.57E_w^2 - 38.22E_w + 25.13 \qquad (7)$$

The theoretical equation (6) and experimental equation (7) are compared to be matched well, as showed in the figure 8.

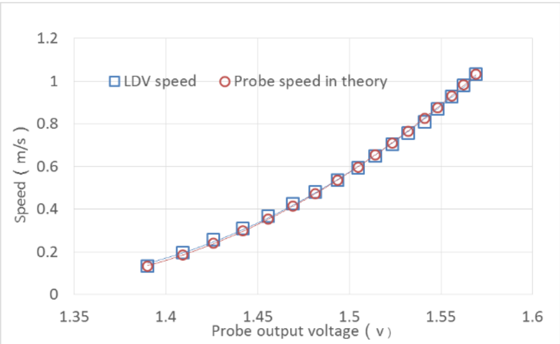

Figure 8 The probe calibrated in wind tunnel by LDV

To compare the calibration results between different methods based on the reference of linear trial facility and LDV, the air temperature has to be corrected to the consistence of 22.8℃. That means the formula (7) in 20.3is corrected to be the expression 22.8 ℃ that could be compared with formula (3) directly. The temperature correction formula is expressed as:

$$E_2 = E_1[(T_W - T)/(T_W - T_a)]^{0.5} \qquad (8)$$

In formula (8), E_2 is corrected the output voltage under temperature of T, E_1 is the output voltage under calibration temperature of T_a, T_W is working temperature. In this case $T = 22.8$ ℃, $T_a = 20.3$ ℃, $T_w = 242$ ℃, then formula (7) is corrected to be (9),

$$U = 14.90E_w^2 - 38.65E_w + 25.13 \qquad (9)$$

The calibration results of 2 different method are compared and showed in figure 9. The maximum deviation of results between 2 methods is less than 30 mm/s.

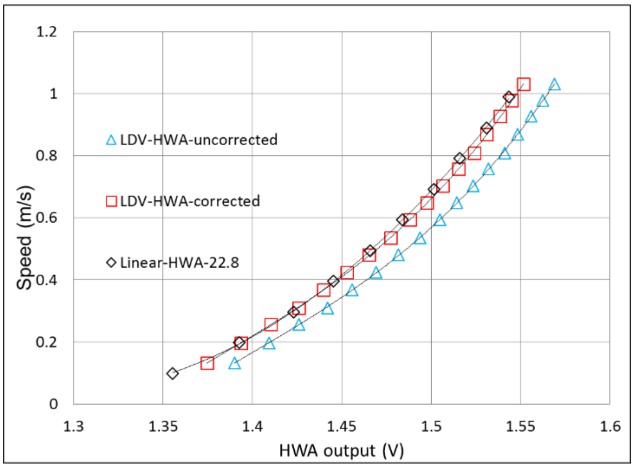

Figure 9 The probe calibrated in wind tunnel by LDV

4. Conclusion

At the speed of (0.1~1) m/s HWA is calibrated by the low speed reference facility that is built in the tunnel underground at NIM. The expanded uncertainty of reference air speed evaluated to be 5.4 mm/s, and the stability of it is about 3mm/s. It is matched well between HWA theory curve and calibration result curve with the maximum deviation of 6 mm/s at point of 1m/s. This HWA is also calibrated by LDV in wind tunnel. The calibration results suggest the difference between the 2 methods is less than 30mm/s as air temperature is corrected for HWA.

Reference

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