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Study on the influence of installation angle on pitot tube in wind tunnel

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Abstract

Pitot tube is a standard instrument commonly used in wind speed measurement, which generally needs to be used in conjunction with wind tunnel. On the premise that the pitot tube coefficient is determined and the performance of other related supporting equipment (digital pressure gauge, temperature and humidity sensor) is stable, it is found that the horizontal installation angle of pitot tube in the wind tunnel will have a significant impact on the measurement of wind speed. This paper designs an experimental method for this kind of phenomenon, summarizes the experimental data, and analyzes the possible impact of this kind of phenomenon on wind speed traceability, in order to improve the accuracy and effectiveness of pitot tube wind speed measurement.

1. Introduction

Pitot tube is a kind of instrument used to detect the pressure, wind speed and air volume of gas (liquid) in the pipeline. It is widely used in scientific research and teaching, environmental protection, pipeline ventilation, energy management and so on [1]. The pitot tube can be used to trace the wind speed source of EPF, V_0[2] and other calculation coefficients in *GB/T51366-2019 Standard for Building Carbon Emission Calculation* approved by the Ministry of housing and urban rural development.

Pitot tube has the advantages of simple structure, convenient operation and high accuracy. When the pitot tube is used as the main standard to transfer or trace the value of wind speed measurement equipment, a wind tunnel is also required to provide a stable flow field. When the anemometer is calibrated in the wind tunnel, it is found through experiments that when the horizontal installation angle of the pitot tube changes, even if the change is small, it will have a certain impact on the measurement of wind speed.

This paper designed a targeted experiment with the horizontal installation angle of L-type pitot tube as a single variable. Under the condition of ensuring the stability of temperature, humidity, atmospheric pressure and air density in the experimental environment, the included angle between the axis of the pitot tube total pressure hole and the longitudinal geometric axis of the wind tunnel is taken as the only variable, a series of experiments are carried out, and the experimental results are analyzed to make inferences.

2. Experimental part

2.1 Experimental principle

The principle of pitot tube measuring wind speed (shown in Figure 1) is based on Bernoulli equation. When an ideal fluid flows uniformly parallel to a stationary object, assuming that one of the streamline collides with the object, where the fluid bifurcates, it becomes a stagnation point [3].

The Bernoulli equation of the fluid at stagnation point A is:

$$\frac{P_t}{\rho}+0=\frac{P_S}{\rho}+\frac{V^2}{2} \quad (1)$$

Thus, the flow velocity at this point is:

$$V=\sqrt{2\frac{P_t-P_s}{\rho}}=\alpha\sqrt{2\frac{\Delta P}{\rho}} \quad (2)$$

Where P_t is the total pressure, P_S is the static pressure, ρ Is the air density, ΔP is the differential pressure measured by the digital pressure gauge. α Is the calibration factor of pitot tube.

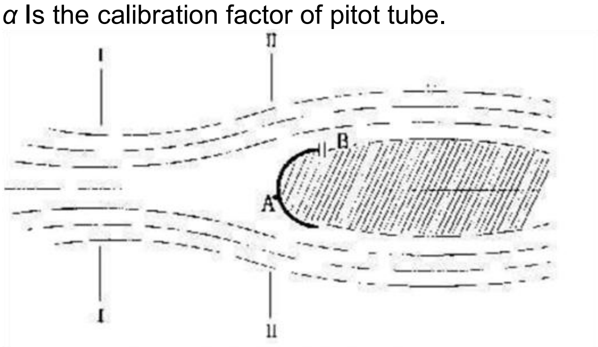

Figure 1 Schematic diagram of pitot tube

2.2 *Experimental design*

2.2.1 Experimental influencing factors

When the pitot tube measures the wind speed, it will be affected by various factors such as temperature, humidity and atmospheric pressure. In order to reduce the influence of such factors as far as possible, the laboratory environment with relatively stable temperature and humidity shall be selected and the test shall be conducted in a fixed period of time in order to reduce the influence of factors such as air density change (refer to CIPM-2007 formula) on the test.

2.2.2 Experimental scheme

TPL-06-300 standard pitot tube produced by Kimo company was used in the experiment, and the pitot tube coefficient was 0.998. The experimental flow field is provided by the DHS-500×500/830×830-Ⅷ annular low-speed wind tunnel.

According to the previous experience of L-type pitot tube (as shown in Figure 2) installed in the wind tunnel, it is generally appropriate that the included angle between the axis of the pitot tube's total pressure hole and the longitudinal geometric axis of the wind tunnel should not exceed ± 3 °.At the beginning of the experimental design, it was assumed that the angle was adjusted at an interval of 0.2 °. After actual measurement, it was found that the included angle was adjusted at an interval of 0.2 °. The resulting wind speed change was too small to be observed. When 1 ° is used as the change, the wind speed changes obviously, and the adjustment is easy to realize.The experiment starts when the included angle between the axis of pitot tube total pressure hole and the longitudinal geometric axis of the wind tunnel is 0 °. The variation of experiment interval is 1 °, and the total variation is 20 °. During each change, the fan frequency shall be fixed and 12 wind speed measurements shall be conducted to eliminate the possible abnormal wind speed values (maximum and minimum), and the remaining wind speed values shall be taken as the final measured values.

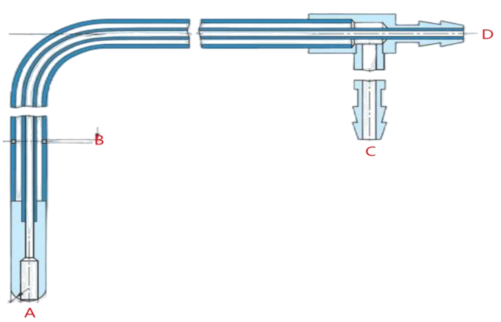

Figure 2 L-type pitot tube

(A: total pressure hole, B :static pressure hole, C :static pressure outlet pipe, D : total pressure outlet pipe)

2.2.3 Angle adjustment

There are many ways to adjust the pitot tube and measure its angle change. Through experiments, it is found that there are two ways that are relatively easy to implement.One is to measure with universal angle ruler, magnifying glass and plumb line. Before each adjustment, make a mark in the wind tunnel, fix the universal angle ruler, and use a magnifying glass to observe the rotation angle of the hanging plumb on the pitot tube on the universal angle ruler. This method is suitable for small experimental sites.

The second method is to fix the laser lamp above the pitot tube exposed to the wind tunnel, and the spot of the laser lamp should be as small as possible. A vertical plate with scale shall be set at the same horizontal plane as the laser lamp at a distance from the wind tunnel. The angle can be controlled according to the distance that the light spot passes on the vertical plate.

If the radius is R, the perimeter is C, and the center angle is A, then the formula of the circle perimeter is C=2 π R, and the formula of the chord length corresponding to the center angle is L=2Rsin (A/2). When R=4000mm, the arc length corresponding to every 1 ° is 69.813mm, and the chord length corresponding to every 1 ° is 69.812mm. The difference between the two can be ignored, that is, every time the spot passes 69.8mm, we think that the included angle changes by 1 °.

2.2.4 Wind speed point selection

According to the requirements for the allowable error of L-type pitot tube coefficient in *JJG518-1998* verification regulation of pitot tube [4]: when the wind speed is (10 ~ 25) m/s, it shall not exceed 0.01. Moreover, the annular low-speed wind tunnel used in the experiment has good stability when the wind speed is around 25m/s (under the condition of fixed frequency, the hourly wind speed fluctuation does not exceed 0.03m/s), so 25m/s wind speed point is selected for the experiment.

3 Experimental results and analysis

3.1 Experimental result

Table 1 Wind speed measurement results when the included angle is 0 °.

Calibration wind speed point	Temperature(°C)	RH (%)	Atmospheric pressure(hPa)	Air density (kg/m³)	Average dynamic pressure of 10 measurements(Pa)	Measured blast velocity(m/s)
25m/s	23.33	62.24	998.72	1.173	364.25	25.005
	23.35	62.07	998.69	1.173	364.76	25.024
	23.38	61.91	998.67	1.173	364.78	25.026
	23.38	61.83	998.66	1.173	364.68	25.023
	23.40	61.75	998.68	1.173	364.09	25.003
	23.42	61.56	998.66	1.173	364.43	25.015
	23.43	61.44	998.63	1.173	364.21	25.009
	23.45	61.31	998.61	1.173	364.16	25.008

	23.46	61.22	998.63	1.173	364.53	25.021
	23.47	61.11	998.62	1.173	364.07	25.005
	23.49	61.02	998.60	1.173	364.39	25.017
	23.50	60.94	998.61	1.173	364.02	25.005
Maximum wind speed(m/s)					25.026	
Minimum wind speed(m/s)					25.003	
Wind speed final measured value(m/s)					25.013	

Table 2 Wind speed measurement results when the included angle is 1°.

Calibration wind speed point	Temperature(°C)	Humidity(%RH)	Atmospheric pressure(hPa)	Air density (kg/m³)	Average dynamic pressure of 10 measurements (Pa)	Measured blast velocity (m/s)
25m/s	23.43	60.30	998.45	1.172	364.51	25.020
	23.58	59.47	998.42	1.172	363.96	25.007
	23.60	59.34	998.43	1.172	364.15	25.014
	23.61	59.23	998.45	1.172	364.22	25.017
	23.62	59.17	998.45	1.172	364.26	25.019
	23.62	59.09	998.45	1.172	364.20	25.016
	23.65	58.82	998.47	1.172	364.31	25.021
	23.65	58.72	998.49	1.172	364.31	25.020
	23.67	58.62	998.49	1.172	364.08	25.013
	23.69	58.57	998.49	1.172	363.83	25.006
	23.68	58.54	998.49	1.172	364.17	25.017
	23.69	58.46	998.49	1.172	364.21	25.019
Maximum wind speed(m/s)					25.021	
Minimum wind speed(m/s)					25.006	
Wind speed final measured value(m/s)					25.016	

Table 3 Summary of final measured values for 0 ° to 20 ° wind speed

Included angle(°)	Wind speed final measured value(m/s)	Included angle(°)	Wind speed final measured value(m/s)	Included angle(°)	Wind speed final measured value(m/s)
0	25.013	7	25.066	14	25.128
1	25.016	8	25.075	15	25.130
2	25.024	9	25.085	16	25.130
3	25.032	10	25.094	17	25.120
4	25.041	11	25.104	18	25.108
5	25.049	12	25.113	19	25.098
6	25.056	13	25.122	20	25.088

3.2 Result analysis

According to Table 1, Table 2 and Table 3, the final measured value of wind speed shows an increasing trend when the included angle changes from 0 ° to 15 ° and decreases from 16 ° to 20 °. The line chart is shown in Figure 3:

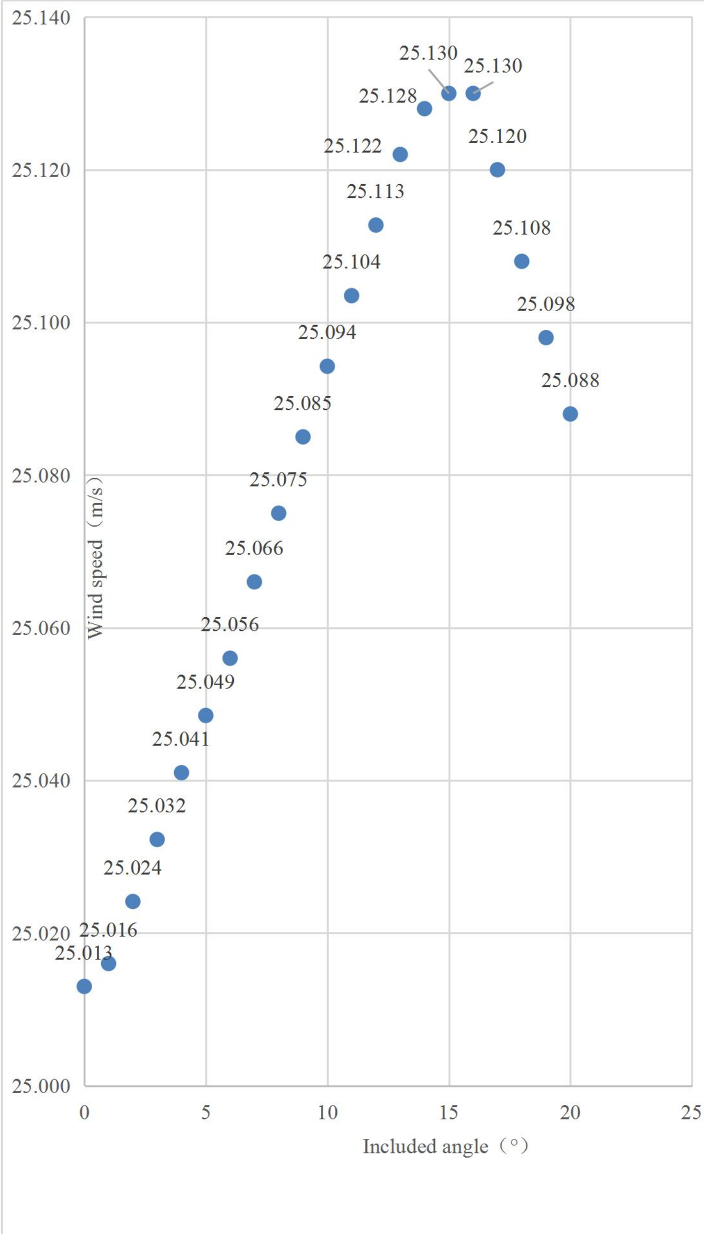

Figure 3 Comparison diagram of included angle and wind speed

Due to the structural limitation of the annular wind tunnel, there is a certain air flow deflection angle, so the measured wind speed is nearly constant when the included angle is 15 ° and 16 °.According to these 21 sets of data, it can be concluded that when the deflection angle of pitot tube sensor head is 15 °, the wind speed measured by pitot tube is the closest to the actual wind speed in the flow field. In other words, when the pitot tube deviates from the wind tunnel pipe axis by a certain angle, the measured value closer to the actual wind speed can be measured [5].

The variation of measured value of wind speed per 1 ° change is shown in Figure 4.

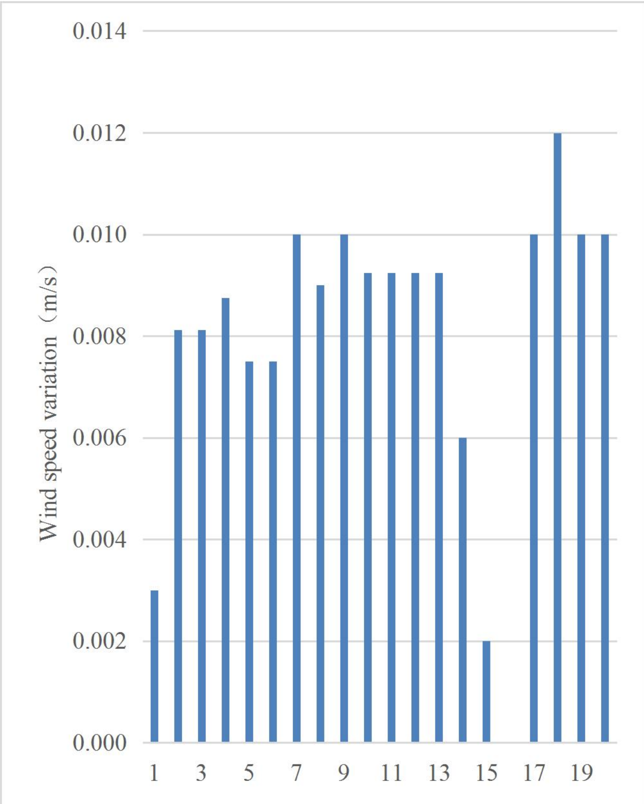

Figure 4 Schematic diagram of variation of wind speed measured value

It can be seen from the figure that at the 25m/s wind speed point, the measured value change of wind speed caused by every 1 ° change of included angle is mostly concentrated in the range of 0.008m/s ~ 0.01m/s, and the relative change is about 0.03% ~ 0.04%.

4 Conclusion and exploration

When the above tests are carried out in a low-speed annular wind tunnel using an L-shaped pitot tube, the following conditions will exist:

(1) The change of the included angle between the axis of the pitot tube total pressure hole and the longitudinal geometric axis of the wind tunnel will affect the wind speed measurement, and the amount of influence is related to the change of the angle.

(2) Generally, the installation method that makes the axis of pitot tube total pressure hole parallel to the longitudinal geometric axis of the wind tunnel can not obtain good wind speed measurement results. It should be adjusted according to the inherent characteristics of the wind tunnel and pitot tube used.

(3) In this experiment, the ratio of the blockage area of pitot tube to the cross-sectional area of working section is not greater than 0.02, so the pitot tube has little disturbance to the wind tunnel flow field. Another pitot tube of the same manufacturer and type with a coefficient of 0.997 is used to carry out verification experiments. It is confirmed that the above effect also exists in the influence of angle on wind speed measurement. Therefore, the influence of "position error"[6] caused by different pitot tube static pressure hole structure is eliminated.

(4)During the calibration of wind speed measuring instruments, it is inevitable to touch the pitot tube and cause position changes.In case of similar situations, if no effective adjustment is made, the resulting error will be multiplied by the traceability chain and transmitted to the measuring instruments for work, which will have a lot of impact on production, work and life. In order to ensure reliable traceability of measurement value, positioning marks shall be made between the wind tunnel and pitot tube, and the marks shall be used for resetting; Or the pitot tube position commissioning test shall be carried out to ensure that the wind speed measurement is accurate and effective.

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