Uncertainty Evaluation of Wind Speed Sensor in Automatic Weather Station

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Abstract—Uncertainty is a description of the degree of uncertainty of measurement results affected by measurement errors. This article completes the repeatability test of the verification results according to "JIG (Meteorology) 004-2011 Automatic Weather Station Wind Speed and Direction Sensor Verification Regulations". The author establishes a mathematical model to determine the source of uncertainty, calculates the uncertainty components item by item, and completes the analysis of the verification results of the anemometer standard device. This helps to ensure the reliability of the observation data of the meteorological wind speed sensor.

1. INTRODUCTION
Measurement uncertainty [1] is "a parameter that characterizes the dispersion of the measured value reasonably assigned to it and is related to the measurement result". This means that the degree of doubt or uncertainty about the credibility and validity of the measurement results is a parameter that quantifies the quality of the measurement results. Uncertainty evaluation is extremely important to ensure the accuracy of meteorological observation data. Yang Bo [2] et al. and Zeng Tao et al. [3] and Chen Tao et al. [4] analyzed the uncertainty of the verification results of the wind speed sensor of the automatic weather station. However, they did not evaluate the measured wind speed equation, or did not consider the influence of temperature, humidity, and air pressure on the flatness of uncertainty. Han Yuting et al. [5] used the portable three-cup wind speed as a model to calculate the uncertainty evaluation. Therefore, according to the wind speed calculation equation of "JIG (Meteorology) 004-2011 Automatic Weather Station Wind Speed and Wind Direction Sensor Verification Regulations", the influence of temperature, humidity, and air pressure on the uncertainty of wind speed is studied, and the detailed calculation process is given. In this way, the uncertainty evaluation of the wind speed sensor of the automatic weather station is realized.

2. MATHEMATICAL MODEL, VARIANCE AND SENSITIVITY COEFFICIENT
During the verification of the wind speed sensor, the standard wind speed value is calculated according to formula (1):

\[ v = 1.278K_P \sqrt{P \cdot \frac{\xi}{K_p}} \]

In the formula: \( P_v \): the actual wind pressure value measured by the digital micromanometer (unit: Pa);
\( r \) : Density correction coefficient of the working fluid of the micromanometer (when the working fluid is distilled water, \( r = 1 \))

\( \xi \) : Pitot tube coefficient;

\( K_e \) : Micromanometer coefficient (when second-class micromanometer is used, \( K_e = 1 \));

\( K_P \) : Air density correction factor.

(1) In the formula

\[
K_P = \sqrt[3]{\frac{1013.25(273.15 + t)}{288.15(P - 0.378\,we)}}
\]

\( t \) : Temperature in the flow field, °C;

\( u \) : Humidity in the flow field, %RH;

\( P \) : Ambient atmospheric pressure, hPa;

\( e_w \) : The saturated vapor pressure when the flow field temperature is \( t \) °C, hPa.

What is given in the verification is the relative error value of each verification point, and the formula for calculating the indication error is:

\[
\Delta \nu = \nu' - \nu
\]

Among them: \( \Delta \nu \) : the indication error value of the measured wind speed sensor at a certain point;

\( \nu' \) : The value of the measured wind speed sensor at this point.

\( \nu \) : Standard wind speed indication.

In formula (1), \( \Delta \nu \), \( \nu \), and \( \nu' \) are independent of each other, and the sensitivity coefficient can be obtained:

\[
c_1 = \frac{\partial \Delta \nu}{\partial \nu} = -1, \quad c_2 = \frac{\partial \Delta \nu}{\partial \nu} = 1
\]

So:

\[
u_r^2 = u_r^2(\nu) + u_r^2(\nu')
\]

3. UNCERTAIN SOURCE

A. Uncertainty component introduced by repeatability;

B. Relative uncertainty component introduced by the reading resolution of the tested sensor;

C. The uncertainty component introduced by the micromanometer;

D. The uncertainty component introduced by the Pitot tube;

E. The uncertainty component introduced by the air density correction factor;

4. UNCERTAINTY EVALUATION

4.1. Class A Uncertainty Evaluation

4.1.1. Standard uncertainty component introduced by repeatability

In the verification of the wind speed sensor, the repeatability of the meter under test is evaluated by the repeatability of the error of the measured value. For the wind speed sensor numbered FS10.0230, the measured data under the wind speed test point with 15m/s data is shown in Table 1, and the corresponding type A standard uncertainty is calculated.
### TABLE I. REPEATABILITY MEASUREMENT (UNIT M/S)

| Testing Frequency | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   |
|-------------------|------|------|------|------|------|------|------|------|------|------|
| Wind Speed Value  | 14.97| 14.95| 14.99| 15.03| 14.95| 15.02| 14.97| 15.02| 15.01| 14.96|
| Average Value     |      |      |      |      |      |      |      |      |      | 14.99|
| Experimental standard deviation |      |      |      |      |      |      |      |      |      | 0.03  |

The relative standard uncertainty introduced by repeatability is:

\[
u'(v) = \frac{0.03}{15} \times 100\% = 0.2\%
\]

### 4.2. Type B Uncertainty Evaluation

#### 4.2.1. Relative uncertainty component introduced by the reading resolution of the sensor under test

The sensor being inspected is in the range of 0.1m/s~30m/s, the resolution is 0.1m/s, the half-width of the interval is 0.05m/s, and it is processed according to the uniform distribution, so the relative standard uncertainty introduced by the reading resolution is:

\[
u'(v) = \frac{0.05}{\sqrt{3}} \times 100\% = 0.19\%
\] (4)

Since the relative standard uncertainty component introduced by the reading resolution is smaller than the standard uncertainty component introduced by the repeatability, the relative uncertainty component introduced by the repeatability is used to calculate the composite uncertainty.

#### 4.2.2. Uncertainty component introduced by micromanometer

The verification result of the digital micromanometer is 0.02 level. According to the "JJG875-2005 Digital Manometer Verification Regulations", the maximum allowable error of the 0.02 level digital micromanometer is: ±0.02*full scale. Since the measuring range is 2500Pa, the maximum allowable error of the digital micromanometer is ±0.5Pa, and the 15m/s verification point is used for calculation. The error value of a single verification point obeys a uniform distribution, and the inclusion factor \(k = \sqrt{3}\) is taken. Therefore, the relative uncertainty component introduced by the digital micromanometer is:

\[
u_r(P_v) = \frac{0.5/\sqrt{3}}{P_v} \times 100\%
\]

The differential pressure corresponding to a wind speed of 15m/s is 118.58Pa, and the corresponding

\[
u_r(P_v) = \frac{16.7}{118.28} \times 100\% = 0.14\%
\] (6)

#### 4.2.3. Uncertainty Component Introduced by Pitot Tube

The pitot tube used in this verification device is L-type, and the coefficient of L-type pitot tube should be between 0.99 and 1.01. Calculated according to the verification data given by the Chinese Academy of Metrology, so the relative uncertainty component introduced by the Pitot tube is:
\[ u_r(\xi) = 0.29\% \]

4.2.4 Uncertainty Component Introduced by Air Density Correction Factor

4.2.4.1. Mathematical Model of Air Density Correction Coefficient

Let \( K_p = \frac{1}{\sqrt{\rho}} = \rho^{-\frac{1}{2}} \) get \( u_r(K_p) = \sqrt{\left(\frac{1}{2} u(\rho)\right)^2} = \frac{1}{2} u_r(\rho) \)

Because \( K_p = \frac{1013.25(273.15 + t)}{288.15(P - 0.378ue_u)} \), so we get:

\[ \rho = \frac{288.15(P - 0.378ue_u)}{1013.25(273.15 + t)} = 0.28 \frac{(P - 0.378ue_u)}{T} \quad (7) \]

Among them: \( T = 273.15 + t \).

4.2.4.2 Highlight All Author and Affiliation Lines

Derive the humidity \( u \) from the formula (7):

\[ d\rho = -0.28 \times \frac{1}{T} \times 0.378e_u du \quad (8) \]

When \( e_u \) increases, the coefficient of \( du \) increases, and the temperature \( T \) decreases, so the coefficient of \( u \) also increases. Therefore, in the calculation, conservatively select values for \( e_u \) and \( T \) to maximize the absolute value of \( du \) the coefficient to simplify the calculation. Because the laboratory environment temperature is at \((0 \sim 30)\,\text{°C}\), the highest value of temperature \( T \) is 303.15K and the lowest value is 273.15K. At the same time, the value of \( e_u \) is 303.15K, which is 4242Pa, and the lowest value of \( T \) is 273.15K.

The maximum allowable error of the experimental room temperature humidity sensor verification is \( \pm 8\% \text{RH} \). According to the uniform distribution, the humidity standard uncertainty can be obtained as 4.62\%RH. Put the above value into the equation (8) to obtain \( d\rho = -0.00076\,\text{kg/m}^3 \), which is introduced by humidity \( \rho \). The standard uncertainty component of the measurement result \( u_u(\rho) = 0.00076\,\text{kg/m}^3 \).

4.2.4.3 Uncertainty Caused by Temperature

Derive the temperature \( T \) from the formula (7):

\[ d\rho = -0.28 \times (P - 0.378ue_u) \times \frac{1}{T^2} \times dT \quad (9) \]

In order to maximize the absolute value of the \( dT \) coefficient, \( P \) is 1100kPa, the relative humidity \( u \) is 0, and the lowest value \( T \) is 273.15K. The maximum allowable error of the laboratory temperature and humidity sensor verification is \( \pm 0.2\text{K} \). According to the uniform distribution, the temperature can be introduced the standard uncertainty of is 0.11K, and the above value is inserted into the formula (9) to obtain \( d\rho = -0.00045\,\text{kg/m}^3 \), the standard uncertainty component of the measurement result introduced by the temperature \( \rho \) is \( u_r(\rho) = 0.00045\,\text{kg/m}^3 \).

4.2.4.4 Uncertain Component Introduced by Air Pressure

Derivation of the air pressure \( P \) from equation (7):
\[ d\rho = 0.28 \times \frac{1}{T} \times dP \] (10)

In order to maximize the absolute value of the \(d\rho\) coefficient, the lowest value of \(T\) is 273.15K, and the maximum allowable error of laboratory air pressure sensor verification is 30Pa. According to the uniform distribution, the standard uncertainty introduced by the temperature is 17.32Pa. Bring the above value into (10). In the formula, get \(d\rho = -0.00017\text{ kg/m}^3\), the standard uncertainty component \(u_p(\rho) = 0.00017\text{ kg/m}^3\) of the measurement result introduced by the air pressure \(\rho\).

### 4.2.4.5. Air Density Uncertainty Calculation

The standard uncertainty of \(\rho\) measurement results can be calculated according to the following formula:

\[ u(\rho) = \sqrt{u_r^2(\rho) + u_t^2(\rho) + u_p^2(\rho)} \]

Bring in and calculate: \(u(\rho) = 0.0009\text{ kg/m}^3\), the air density in the standard state is 1.29kg/m3, so the relative standard uncertainty component introduced by \(\rho\) is:

\[ u_r(\rho) = \frac{0.0009}{1.29} \times 100\% = 0.07\% \]

So \(u_r(K_p) = \frac{1}{2}u_r(\rho) = 0.035\%\)

### 4.3. Synthetic Standard Uncertainty

Since \(v = 1.278K_p\sqrt{P_r\xi K_e} = 1.278K_pP_r^{\frac{1}{2}}\xi^{\frac{1}{2}}\sqrt{r}\), where \(r\) and \(K_e\) are constants, so

\[ u_r(v) = \sqrt{\left(\frac{1}{2}u_r(P_r)\right)^2 + \left(\frac{1}{2}u_r(\xi)\right)^2 + (u_r(K_p))^2} \]

Calculated: \(u_r(v) = 0.16\%\), calculate \(u_r(\Delta v) = \sqrt{u_r(v)^2 + u_r(v)^2} = 0.26\%\) at the same time.

### 4.4. Extended Uncertainty

Under the confidence probability of \(p_{95}\) and the inclusion factor \(k=2\), the expansion uncertainty \(U_{95}(\Delta v) = k \times u_r = 2 \times u_r\) is calculated according to the following formula, \(U_{95}(\Delta v) = 0.52\%\).

### 5. Conclusion

This paper establishes a mathematical model based on the wind speed calculation equation of "JJG (Meteorology) 004-2011 Automatic Weather Station Wind Speed and Wind Direction Sensor Verification Regulations", and gives the source of uncertainty. This article analyzes and calculates the influences one by one, and aims to provide a reference for the uncertainty assessment of wind speed sensors in automatic weather stations. In addition, it can be seen from the calculation process in this paper that the uncertainty introduced by the Pitot tube and the micromanometer has a greater impact on the measurement results, and other factors have relatively small effects on the results. Therefore, a qualified standard device must be used in the verification work.

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