

Original Article



Research on Calibration Methods for Whirling and Sling Hygrometers

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Abstract:

This study introduces the measurement principle, structural types, and usage methods of whirling and sling hygrometers and compares them with laboratory hygrometers. It identifies the difficulties in calibrating these instruments. By examining how wind speed affects their measurements, this study proposes three different calibration methods for relative humidity and points out the advantages and disadvantages of each through theoretical analysis and practical calibration. This work provides valuable insights for unifying the value transfer system of whirling and sling hygrometers and guiding their calibration by metrological technical institutions.

Keywords: Whirling and Sling Hygrometers; Humidity and Temperature; Calibration; Wind Speed; Psychrometer coefficient; Forced Ventilation

1. Introduction

Whirling and Sling Hygrometers are wet-and-dry-bulb type instruments designed to measure humidity. Also referred to as hand-cranked hygrometers, they operate by inducing airflow at controlled velocities over dry-bulb and wetted-bulb sensors. Evaporation from the moistened sleeve causes the wet-bulb temperature reading to decrease relative to the dry-bulb temperature. By measuring the dry-bulb temperature and wet-bulb depression, and referencing the instrument's calibrated psychrometric scale, parameters such as relative humidity and dew-point temperature are determined. Requiring no external power, these devices are widely deployed for field measurements in meteorology, maritime navigation, and other outdoor applications.

Conventional wet-and-dry-bulb hygrometers operate under natural ventilation, typically with wind speeds ≤ 0.4 m/s at the sensing bulb^[1,7]. In contrast, whirling and sling hygrometers generate wind speeds of (2~3) m/s at the sensing bulb through rotational motion during measurement. These instruments have scales defined and converted for forced ventilation conditions^[3,11].

Maintaining natural ventilation around the sensing bulb is challenging during outdoor operations, particularly in windy environments where significant measurement deviations can occur^[1,6]. Consequently, whirling and sling hygrometers provide a more portable and accurate solution for field temperature and humidity measurements.

Based on the August-Appzohn Equation^[3,19], relatively big error in relative humidity may occur during the calibration of whirling and sling hygrometers according to the JJG 205-2005 "Mechanical Thermo-hygrometers" verification regulation^[14], primarily due to variations in wind speed at the sensing bulb^[1,2,6]. These errors compromise the accuracy of measurement results.

This study resolves these challenges by developing calibration methods for whirling and sling hygrometers' relative humidity measurements, with experimental validation confirming their accuracy and feasibility.

1 Comparison between Whirling and Sling Hygrometers and Wet and Dry Bulb Hygrometers

Whirling and sling hygrometers share structural

similarities with conventional wet-and-dry-bulb hygrometers. As illustrated in Figure 1, their configuration typically includes dry-bulb and wet-bulb thermometers, a psychrometric scale, a rotating shaft, and a water reservoir. During operation, rotating the handle drives both thermometers around the shaft at controlled

speeds, establishing stable wind conditions at the sensing bulbs. Following sustained rotation until readings stabilize, the dry-bulb and wet-bulb temperatures are recorded. Relative humidity and dew-point temperature values are subsequently determined by referencing the instrument's psychrometric tables.



Figure 1 Basic Structure of Whirling and Sling Hygrometers

According to the August-Appzohn Equation ^[3,19]:

$$U = \frac{e}{e_w} \times 100\% = \frac{e_w - AP(t - t_w)}{e_w} \times 100\% \quad (1)$$

where:

U - Relative humidity;

e - Actual water vapor pressure, in kPa;

e_w - Saturation water vapor pressure over a plane of pure water at the dry bulb temperature t , in kPa;

e_{tw} - Saturation water vapor pressure over a plane of pure water at the wet bulb temperature t_w , in kPa;

A - Psychrometer coefficient, in $^{\circ}\text{C}^{-1}$; its value is determined by the type of wet and dry bulb thermometer and the wind speed at the bulb of the wet and dry bulb thermometer ^[1,3,7];

P - Atmospheric pressure, in kPa;

$(t - t_w)$ - Difference between dry and wet bulb temperature

The primary parameter governing humidity measurement accuracy in wet-and-dry-bulb psychrometry is the psychrometer coefficient A , with ventilation speed being its dominant influencing factor ^[1,6,12]. At sufficiently high ventilation speeds (e.g., 2.5–3.0 m/s), A exhibits minimal variation across different theoretical and empirical approaches ^[3,11], effectively rendering it constant. By contrast, under natural ventilation conditions, A may vary up to twice its constant value ^[7,9].

For illustration: Consider cylindrical psychrometers at 100 kPa atmospheric pressure with dry-bulb/wet-bulb temperatures of 20.0 $^{\circ}\text{C}$ /15.0 $^{\circ}\text{C}$. At natural ventilation (0.4 m/s), $A = 0.815 \times 10^{-3} \text{ }^{\circ}\text{C}^{-1}$ yields 55.5% RH. At forced ventilation (2.5 m/s), $A = 0.662 \times 10^{-3} \text{ }^{\circ}\text{C}^{-1}$ produces 58.8% RH. This 3.0% RH discrepancy (Table 1) demonstrates the significant measurement impact of ventilation control ^[1,2,6].

Table 1 Corresponding Values of Relative Humidity at Different Wind Speeds ^[1,7]

Wind Speed (m/s)	psychrometer coefficient $A \times 10^{-3}/^{\circ}\text{C}$	Dry Bulb Temp. $^{\circ}\text{C}$	Wet Bulb Temp. $^{\circ}\text{C}$	Relative Humidity /%RH
0.2	0.988	20.0	15.0	51.8
0.4	0.815			55.5
1.0	0.718			57.6
1.5	0.695			58.0
2.0	0.684			58.3
3.0	0.673			58.5

Under natural ventilation in open environments, fluctuating wind speeds prevent reliable determination of the psychrometer coefficient A for wet-and-dry-bulb psychrometers ^[1,6]. Statistical approaches to estimate wind speed and A typically yield lower measurement accuracy ^[9]. In contrast, whirling and sling hygrometers maintain stable airflow at the sensing bulb through controlled rotation. This enables precise determination of A and consequently achieves higher measurement accuracy ^[5,11].

2 Calibration of Relative Humidity for Whirling and Sling Hygrometers

From the above analysis, it is evident that the relative humidity measured by wet and dry bulb hygrometers varies significantly under different wind speed conditions ^[1,2,6-9]. Currently, when metrological institutions carry out calibration and verification of hygrometers, digital hygrometers, and mechanical hygrometers, the accompanying equipment generally used is a temperature and humidity standard chamber. According to Clause 7.1.1.2(a) of "JJG 205-2005 Mechanical Thermo-hygrometers," the wind speed inside the chamber should not exceed 0.2 m/s, which is considered a natural ventilation state. Therefore, it is inappropriate to directly place a whirling and sling hygrometer in a temperature and humidity standard chamber for calibration ^[14,16].

The preceding analysis demonstrates significant wind speed-dependent variations in relative humidity measurements from wet-and-dry-bulb hygrometers. Current calibration practices at metrological institutions for hygrometers (both digital and mechanical types) typically employ temperature-humidity chambers. According to Clause 7.1.1.2(a) of "JJG 205-2005 Mechanical Thermo-hygrometers", chamber wind speeds must remain ≤ 0.2 m/s to maintain natural ventilation conditions. Consequently, direct calibration of whirling and sling hygrometers in such chambers is not recommended.

2.1 Calibration Process for Relative Humidity of Whirling and Sling Hygrometers

Three calibration methods for whirling and sling hygrometers' relative humidity were rigorously evaluated to determine their implementation viability and measurement accuracy ^[5,11,16].

Method 1: Manual Rotation Technique. Without modifying the temperature-humidity chamber, a metrologist manually rotates the hygrometer at specified speeds within the chamber during calibration.

Method 2: Forced-Ventilation Calibration. The chamber's wind speed is adjusted to 2 m/s ^[16]. The hygrometer remains stationary during calibration, with dry-bulb and wet-bulb temperatures recorded for subsequent humidity calculation.

Method 3: Direct Psychrometric Reading. Using an unmodified chamber (natural ventilation ≤ 0.2 m/s), the hygrometer is statically positioned. Readings from dry-bulb/wet-bulb thermometers are converted to relative humidity via the instrument's psychrometric scale.

2.1.1 Standard Instruments and Test Conditions Used in the Comparative Experiment

The device under test used in the comparative experiment was the G116C-1 type sling hygrometer produced by elcometer. When measuring humidity, the cover is removed, and the end of the core is fully immersed in water to ensure that the sensing bulb of the wet bulb thermometer is completely wetted, while the sensing bulb of the dry bulb thermometer remains dry. The core tube is pulled out from the tube until it can rotate freely. The empty tube is used as a handle, and the core tube is rotated at a speed of (2~3) revolutions per second for approximately (0.5~1.0) minutes. The readings of the wet bulb and dry bulb thermometers are then quickly taken, and the relative humidity is read on the scale according to the marked arrow.

The temperature and humidity standard chambers used for calibration are shown in Table 2. The uniformity, fluctuation, and change rate in these chambers all meet the technical requirements specified in Table 3 of JJG 205-2005.

Table 2 Temperature and Humidity Standard Chambers Used in the Comparative Experiment

No.	Name	Model	Manufacturer
A	Temperature and Humidity Calibration Chamber	HWS-IV-B	Changfeng Guozheng

B	Super Temperature and Humidity Calibration Chamber	ConST610	ConST
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Other standard instruments and the technical specifications used in the calibration are shown in Table 3.

Table 3 Other Standard Instruments and Their Technical Specifications Used in Calibration

Name	Model	Manufacturer	Technical Specifications
Precision Dew Point Meter	473SH2	MBW	Dew point temperature: $\pm 0.1^\circ\text{C}$, Temperature: $\pm 0.05^\circ\text{C}$
Hot-wire Anemometer	425	testo	$\pm(0.03 + 5\% \times \text{reading})$ m/s
Digital Barometer	622	testo	$\pm 3\text{hPa}$

2.1.2 Measurement Methods for Wind Speed in the Test Chamber and Atmospheric Pressure

Wind speed measurements ^[21] were performed with the thermal anemometer sensor oriented horizontally toward the sensing bulb position of

the stationary whirling and sling hygrometer. The sensor was positioned at the specified location, recording measurements at 30-second intervals over a 5-minute duration. The average measured wind speed was established as the resultant wind speed at the sensing bulb location (Table 4).

Table 4 Measured Wind Speeds in Temperature and Humidity Standard Chambers

No.	Measured Wind Speed at Bulb Position (m/s)					Result (m/s)
A	0.17	0.18	0.23	0.16	0.18	0.20
	0.22	0.26	0.18	0.21	0.22	
B	1.96	2.10	2.01	2.04	1.92	2.00
	1.91	2.04	1.96	1.95	2.07	

The measured wind speed in temperature and humidity standard chamber A is 0.20 m/s, and in chamber B is 2.00 m/s.

Atmospheric pressure measurement ^[18]. Laboratory barometric pressure was directly recorded using a digital barometer. The measured value was 1008 hPa.

2.1.3 Comparison of Relative Humidity Calibration

For Method 1, both the precision dew-point meter and the test hygrometer were placed in Standard Chamber A. The reference instrument was positioned proximal to the test unit without impeding rotation. The chamber was stabilized at 20.0°C and 60%RH. Following equilibrium attainment, the hygrometer was manually rotated per operational protocols until reaching target velocity (maintained for 60 seconds). Dry-bulb and wet-bulb temperatures from both instruments

were promptly recorded, with replicate measurements taken after a 5-minute interval.

For Methods 2 and 3, the precision dew-point meter and sensing bulbs of the whirling and sling hygrometer were co-located near the geometric center of the temperature-humidity chamber. The reference standard and test unit were positioned in Chambers B and A, respectively. Per "JJG 205-2005 Mechanical Thermo-hygrometers" Clause 7.3.2, the chamber was stabilized at 20.0°C and 60%RH. Following 30-minute stabilization after reaching setpoint:

Step1. Record reference instrument readings

Step2. Measure test unit's dry-bulb/wet-bulb temperatures

Step3. Repeat sequence after 5-minute interval

Experimental data are presented in Table 5. Humidity values obtained through direct scale are presented in Table 6.

Table 5 Test Data for Whirling and Sling Hygrometers

Method	Precision Dew Point Meter	Whirling and Sling Hygrometer
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	Temp./°C	Humidity /%RH	Dry bulb Temp. /°C	Wet bulb Temp./°C
1	20.22	61.37	19.8	15.0
	20.22	61.32	19.8	15.0
Average Value	20.22	61.35	19.8	15.0
2	20.08	59.98	19.8	15.0
	20.08	59.95	19.8	15.0
Average Value	20.08	59.97	19.8	15.0
3	20.17	61.36	19.5	15.5
	20.17	61.28	19.5	15.5
Average Value	20.17	61.32	19.5	15.5

Table 6 Humidity values obtained through direct scale

Method	Standard Device Reading /%RH	Direct Reading/%RH	Error/%RH
1	61.4	60	-1.4
2	60.0	60	0.0
3	61.3	66	4.7

Among the three methods, the wind speed for Method 1 and Method 2 is approximately 2 m/s, for Method 3 is about 0.2 m/s. The relative

humidity values obtained through theoretical conversion are presented in Table 7.

Table 7 Relative humidity values obtained through theoretical conversion

Method	psychrometer coefficient A $\times 10^{-3} \text{ } ^\circ\text{C}^{-1}$	Standard Device Reading /%RH	Converted Reading /%RH	Error /%RH
1	0.684	61.4	58.9	-2.5
2	0.684	60.0	58.9	-1.1
3	0.988	61.3	60.8	-0.5

2.2 Analysis of Calibration Results for Relative Humidity of Whirling and Sling Hygrometers

2.2.1 Comparative analysis of indication errors obtained through calibration

Humidity deviations between direct-scale and

theoretical-conversion approaches are -1.1%RH (Method 1 and Method 2) and -5.2%RH (Method 3), demonstrating Method 3's significant measurement variance (Table 8). The measurement results of Method 3 have seriously exceeded the tolerance limits.

Table 8 Differences between direct-scale and theoretical-conversion

Method	Error of direct-scale /%RH	Error of theoretical-conversion /%RH	Difference between direct -scale and theoretical-conversion /%RH
1	-1.4	-2.5	-1.1
2	0.0	-1.1	-1.1
3	4.7	-0.5	-5.2

2.2.2 Comparison of the correctness and operability of the results from three calibration methods

Method 1 demonstrates superior accuracy by replicating operational conditions of whirling and sling hygrometers. Method 2 achieves comparable performance through wind speed adjustment, showing negligible deviation from Method 1

while meeting calibration requirements. In contrast, Method 3 exhibits significant wind speed variance relative to Methods 1-2, substantially altering the psychrometer coefficient A and producing clinically unacceptable measurement deviations. Consequently, Method 3 is unsuitable for direct calibration of whirling and sling hygrometers.

Comparing the measurement results and operational steps, Methods 1 and 2 use direct measurement and the process relatively simple [5,11].

Method 1 requires adjusting the temperature-humidity chamber's internal wind speed to approximately 2 m/s. This necessitates calibration-grade chambers with enhanced airflow performance and strategic planning of test unit placement/quantity to ensure compliance with wind speed standards.

Method 2 requires manual rotation of the test instrument within the calibration chamber, necessitating significant internal clearance. This operational complexity – compounded by spatial constraints – underscores the need for specialized fixtures to streamline the calibration process.

Method 3 necessitates hybrid empirical-theoretical calibration for relative humidity, beginning with airflow velocity determination at wet/dry-bulb positions via measured rotation radius, followed by calculation of the psychrometer coefficient A , and culminating in theoretical derivation of relative humidity under specified conditions. This approach faces significant limitations due to non-standardized definitions of A [4,20] (lacking international/domestic consensus), which may yield divergent relative humidity values at identical dry/wet-bulb temperatures when instrument scales are undefined. Furthermore, the inability to directly obtain measured RH values, coupled with error-prone manual calculations, compromises result reliability.

3 Conclusions

This study systematically investigates the structural configuration, operational methodology, and measurement principles of whirling and sling hygrometers, establishing three novel relative humidity calibration methods through rigorous analysis of psychrometric deviations under variable wind speeds. Experimental validation at 20.0°C/60%RH demonstrated that Method 1 (manual rotation) and Method 2 (forced ventilation at 2 m/s) deliver superior accuracy ($\Delta \leq 1.1\%RH$) with operational simplicity, enabling direct calibration implementation, whereas Method 3 (empirical-theoretical hybrid) exhibited significant errors ($\Delta = 5.2\%RH$) due to non-standardized psychrometer coefficient A and computational vulnerabilities. The research

further advances metrological practice through wind velocity modeling at sensing bulbs and standardized chamber airflow measurement protocols, providing a technical foundation for enhancing value transfer systems and guiding metrological institutions to prioritize Methods 1-2 for reliable calibration of whirling and sling hygrometers.

Funding: None

Conflict of Interest: The authors declare that they have no conflict of interest.

Author Contributions: Conceptualization, Junming Zhang. and Yan Ma.; validation, Huilin Jia. and Yue Yin.; formal analysis, Huilin Jia.; investigation, Lilong Peng. and Shuaishuai Lu.; resources, Lilong Peng.; data curation, Yan Ma. and Lei Mu.; writing—original draft preparation, Junming Zhang.; writing—review and editing, Junming Zhang. and Yan Ma.; visualization, Huilin Jia.; supervision, Yue Yin.; project administration, Junming Zhang.. All authors have read and agreed to the published version of the manuscript.

Data Availability: Data available on request from the corresponding author. Ethical approval and Consent to participate This article does not contain any studies with human participants or animals performed by any of the authors. Informed consent was obtained from all individual participants included in the study.

Acknowledgements: We express our sincere appreciation to the anonymous reviewers for their valuable suggestions and the editorial team for their professional work.

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