Development of standard calibration equipment for the rain gauges

Gang-Wook Shin*, Sung-Taek Hong, Dong-Keun Lee

* Korea Institute of Water and Environment, KOWACO, Daejeon, Korea
(Tel: +82-42-860-0413; E-mail: gwshin@kowaco.or.kr)
(Tel: +82-42-860-0418; E-mail:sthong@kowaco.or.kr)
(Tel: +82-42-860-0410; E-mail: dongkeun@kowaco.or.kr)

Abstract: Because the rain gauges of tipping bucket type can easily use the digital signal, the rain gauges are widely used for the meteorological observation. In general, the resolution of rain gauges of tipping bucket type can be categorized by the 0.1mm, 0.5mm, and 1.0mm classes. But, the error of the tipping bucket rain gauges is made by the intensity of rainfalls and is expected to make the standard calibration method for error measurement. Thus, we developed the hardware of standard calibration facility for rain gauges by weighing measurement method and proposed the standard procedure by rainfall intensity in this study. Also, we calculated the error for the rainfall intensity and obtained useful result through the proposed calibration method.

Keywords: Rain gauge, Calibration, Rainfall, Tipping bucket

1. INTRODUCTION

WMO(World Meteorological Organization) recommends the standard for the measurement methods and equipments of the rain gauges used to measure rainfall among equipments for meteorological observation.[1]

To measure the amount of rainfall, various rain gauges, which are tank type, weighting type and load-cell type etc, are now developed. But tipping bucket type gauges are widely used for the meteorological observation because of simplicity of the system.[2]

The tipping-bucket rain gauges are classified according to resolution-0.1mm, 0.2mm, 0.5mm and 1.0mm types. The 0.1mm and the 0.2mm type gauges are used for observation of weather. But the gauge for basin operation are mainly used 1.0mm type rain gauge.[3]

These tipping-bucket gauges should be applied by selection of gauge type in order to minimize error according to rainfall intensity. But it is not easy for obtaining the exact error factor in accordance with rainfall intensity. Because the inertia of tipping bucket varies according to rainfall intensity, the rainfall loss breaks out.

Thus, this study developed the standard calibration facility to measure error characteristic of rain gauges by rainfall intensity and standardized the procedure to upgrade the accuracy of calibration. Using the developed facility, this paper presents a fitting rain gauge by test result and provides the compensation value to improve the data quality of rainfall.

2. THEORY

2.1 Tipping Bucket Rain Gauges

The amount of rainfall mean the height of rainwater at fixed space, and the rain gauge is to simply measure the height using equipment. The structure of tipping-bucket rain gauges consists of rain receptor, tipping bucket and pulse sensor such as fig.1. The diameter types of receptor are 200mm, 227.5mm, and 447.2mm but, 200mm type among various types is mostly used at field. The tipping-bucket mean a tool to measure the amount of rain when the height of rainwater is 1 mm at rain receptor area. The two buckets discharge the rainwater one after another when the buckets are filled with rainwater. The rain gauges records the number of discharge.

![Fig. 1. Tipping Bucket Rain Gauge](image)

2.2 Principal of Calibration

The calibration method of rain gauges is that generally compare a volume of rainwater by cylinder with tipping number by automatic pipette. This method should calibrate a cylinder or an automatic pipette because of using calibrated tools. But calibration method using mass measurement does not need the calibration of volume tools and has merit of directly measuring by weighting machine and is a method that is improved the accuracy.

The calibration using mass measurement method, first, installs the precision balance on balance table to free from vibration influence, puts a water vessel on the precision balance, discharges the water in vessel using peristaltic pump to rain gauges, converts mass change by weight machine into the amount of rainfall, and compare the amount with tipping number of rain gauges.

Mass of water will be obtained amount of rainfall by the volume that is measured using calibrated standard weight such as Eq. (1).

The parameters used at Eq. (1) are expressed as follow.

\[ m_1 \]: Balance value before discharged (g)
**3. Standard Calibration Facility**

3.1 Configuration

The developed facility for calibration of rain gauges is composed of a water container, a precision weighting machine, a balance weight, two peristaltic pumps, a controller, environment sensors, and a data acquisition equipment.

The main functions of the facility could be presented as follows. First, the facility can be automatically set for calibration test by initial data. And to measure the uncertainty variation by the amount and intensity of rainfall, it can control the amount of water according to test time. The facility can compare the applied water with the measured data of rain gauge. Using the standard calibration facility, the uncertainty calculation for rain gauge can include the environment factors, which are weight, temperature, operation time, measurement iteration number, humidity, and pressure.

Fig. 2 shows the configuration of standard calibration facility.

Fig. 2. Standard Calibration Facility for rain gauges

3.2 Detailed Structure

(1) Water vessel and precision balance

The object of water vessel is to keep the water for calibration of rain gauges and the structure consists of 235mm for diameter, 300mm for height, respectively. And maximum amount for calibration is up to 13㎘.

The precision balance as main equipment at standard calibration facility is made by Mettler Toledo Co. and it has the characteristics of 16100g for maximum capacity, 0.1g for resolution.

Fig. 3. Water vessel and precision balance

Fig. 4. Standard weight
(3) Peristaltic pump and Controller

Two peristaltic pumps were equipped at standard calibration facility to provide water to rain gauges from water vessel and to fill up water in water vessel.

One pump can apply maximum 150 ml/min to rain gauges and change the rainfall intensity. The other pump operates to keep the water in vessel and applies maximum 300 ml/min to the water vessel.

Table 1. Characteristics of peristaltic pump

<table>
<thead>
<tr>
<th>Item</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow Capacity</td>
<td>0.9 ~ 600 ml/min</td>
</tr>
<tr>
<td>rpm Range</td>
<td>15 ~ 125 rpm</td>
</tr>
<tr>
<td>Max Torque</td>
<td>0.7 ~ 2.7 (Max 6.5) kg/cm</td>
</tr>
<tr>
<td>Voltage</td>
<td>220 V</td>
</tr>
<tr>
<td>Fuse Rating</td>
<td>2.0/250</td>
</tr>
<tr>
<td>Motor Type</td>
<td>Magnet DC</td>
</tr>
<tr>
<td>Motor Size</td>
<td>25 W</td>
</tr>
<tr>
<td>Temp. Operating</td>
<td>0 ~ 40</td>
</tr>
<tr>
<td>Interface</td>
<td>RS 232 interface, Adjustable flow rate</td>
</tr>
</tbody>
</table>

(4) Environment instrument and data acquisition equipment

All measurement for calibration is realized by the data acquisition PC and controller, and the controller controls input/output signal transmitted from each sensor such as Fig. 6.

Table 2. Characteristics of thermometer

<table>
<thead>
<tr>
<th>Item</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>-183.00 0 ~ 850.00°C</td>
</tr>
</tbody>
</table>
| Resolution| 0.001°C : -183.000 ~ 100.009°C  
            | 0.01°C : 100.01°C ~ 850.00°C |

Environment instrument is to calibrate the air density by measuring temperature, humidity and pressure. And Fig. 3 shows the characteristics of environment instrument.

Table 3. Environment Instrument

<table>
<thead>
<tr>
<th>Item</th>
<th>Range</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp.</td>
<td>Sensor 1: -40 ~ 60°C</td>
<td>0.1°C</td>
</tr>
<tr>
<td></td>
<td>Sensor 2: -50 ~ 200°C</td>
<td>0.1°C</td>
</tr>
<tr>
<td>Humidity</td>
<td>0 ~ 100% rH</td>
<td>0.1% rH</td>
</tr>
<tr>
<td>Pressure</td>
<td>225 ~ 1125hPa</td>
<td>0.1hPa</td>
</tr>
</tbody>
</table>

4. Standard Calibration Procedure

4.1 Program

A program was developed to operate standard calibration equipment of rain gauge using Microsoft Visual C++.

There are the functions of the program; First, the data is automatically obtained according to standard calibration procedure. Secondly, the program calculates uncertainty in measurement by precisely collecting data such as mass, water temperature, operation time of peristaltic pump, number of measurement frequency, temperature of interior, humidity, pressure, and more, which are necessary to calculate uncertainty from standard calibration equipment. Thirdly, the program provides the results according to the form for output when the calculation for uncertainty in measurement is...
completed. Fourthly, the equipment saves the achieved data and automatically functions to produce files after calculating the uncertainty, or during or after measurement.

Fig. 7 shows the initial screen of this program to operate standard calibration equipment, which allows to confirm tipping time of tipping-bucket rain gauge and measurement data on real-time.

Fig. 7. The initial screen of standard calibration equipment

4.2 Procedure

Fig. 8 shows the developed standard calibration procedure of rain gauge in this study. Therefore, execute calibration according to the flow map in fig. 8 for rain gauge calibration.

First, we set initial parameters for measurement such as the quantity of needed water, tipping counter number, measure number, rainfall intensity, and file name for data saving, and more.

We start the measure procedure after filling up the experiment vessel with the water quantity set before for measurement by operating the peristaltic pump, then measure the overall mass of water filled up in the vessel and the vessel itself, and provide water to rain gauge for calibration using the peristaltic pump.

This system measures the mass of discharged vessel after tipping, and saves the environment data such as temperature of water and air, humidity, pressure, and more.

And it measures the water temperature, the environment, and mass of vessel whenever the bucket is tipped in this way, so the quantity of discharge on tipping bucket and tipping count can be compared. Also, it waits for about 10 seconds to stabilize scale-indicating-value once the change of tipping bucket is completed just as the frequency set before is completed. Then read the scale value, load standard weight, and measure the scale sensitivity.

After unloading the weight, it calculates the scale sensitivity by compensating the scale drift by calibrating the scale-indicating-value.

Fig. 8. The standard calibration procedure of rain gauge

5. Measurement Test

This study made experiment about the error property of 1.0mm tipping bucket rain gauge for developed standard calibration facility. After setting the providing amount of rain quantity to 120㎖/min for pump A, the tipping bucket is set to change 20 times. Table 4 shows environmental measurement data such as vessel mass, temperature, humidity, pressure, and more other than data of measurement over 20 times of repetition and measurement date. It took 6.5833 minutes to measure, and the amount of water used in measurement was in total 638.1g.

Table 4  1.0㎜ rain gauge test data(I)
The sensitivity is calculated first using the weight to get a reverse sensitivity concerning total precipitation. First of all, to get the value for rainfall time concerning measurement value, the first change procession of table 5. Also, the rainfall intensity concerning measurement calculates rainfall for an hour using the overall rainfall 20.431 mm and continuing time of rainfall 6.68 minutes; 20.431 mm × 60 min. / 6.5833 min = 186.209 mm /hr. The average rainfall per bucket through the formula above is 1.022 mm, and the correction amount of tipping bucket is 0.022/1 × 100 % = 2.2 % with the error of 0.022 mm. The rainfall intensity needs to be measured with modification since the rain gauge has certain errors according to the rainfall intensity. This experiment measured in rainfall intensity of 125 mm/h to compare with the value for 186 mm/h. Table 6 is the comparison of errors with 125 mm/h and 186 mm/h, and fig. 9 is the change of error according to the rainfall intensity.

Table 6. The error rate of rainfall intensity

<table>
<thead>
<tr>
<th>Rec.Sen. (g/div.)</th>
<th>Rain strength (mm/h)</th>
<th>One bucket (mm)</th>
<th>Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>125</td>
<td>1.000839</td>
<td>125</td>
<td>1.05</td>
</tr>
<tr>
<td>186</td>
<td>1.000855</td>
<td>186</td>
<td>2.16</td>
</tr>
</tbody>
</table>

The sensitivity is calculated first using the weight to get a precise error for the measurement value of rain gauge concerning total precipitation. First of all, to get the value for sensitivity; First, in order to obtain a reverse sensitivity

- Stabilized value of balance(after 20 change) : 4550.2 g
- Balance (after loading the weight) : 7659.6 g
- Balance (after unloading the weight) : 4550.4 g
- Balance : 7659.6 - (4550.2 + 4550.4)/2 = 3109.3 g
- Mass of weight : 3111.96 g

The sensitivity using the measurement value above is 3111.96/3109.3 = 1.000855 g/div.. Air density uses formula

\[ \rho_w = \frac{m}{S \times 8.0} \]

where 
- \( \rho_w \) is the water density (g/cm³)
- \( m \) is the mass of water (g)
- \( S \) is the sensitivity (g/div.)

By applying the value below using formula (1) to get the bucket precipitation for each time concerning measurement value, the first change precipitation is 0.941 mm.

- \( m_1 = 5188.2 \) g
- \( m_2 = 5158.8 \) g
- \( S = 1.000855 \) g/div.
- \( \rho_w = 0.99603 \) g/cm³
- \( \rho_A = 8.0 \) g/cm³
- \( \rho_A = 0.0011729 \) g/cm³
- \( t = 28.7 \) °C
- \( D = 20 \) cm

The calculation of per rainfall is values on the right procession of table 5. Also, the rainfall intensity concerning measurement calculates rainfall for an hour using the overall rainfall 20.431 mm and continuing time of rainfall 6.68 minutes; 20.431 mm × 60 min. / 6.5833 min = 186.209 mm/hr. The average rainfall per bucket through the formula above is 1.022 mm, and the correction amount of tipping bucket is 0.022/1 × 100 % = 2.2 % with the error of 0.022 mm. The rainfall intensity needs to be measured with modification since the rain gauge has certain errors according to the rainfall intensity. This experiment measured in rainfall intensity of 125 mm/h to compare with the value for 186 mm/h. Table 6 is the comparison of errors with 125 mm/h and 186 mm/h, and fig. 9 is the change of error according to the rainfall intensity.

Figure 9. The change of error rate of rainfall intensity

As can be seen in fig. 9, the error can be achieved as mentioned below with rainfall intensity of 100 mm/h if error property is set in linear according to the increase of rainfall.
Error = 0.018133 × 100 – 1.220142  
= 0.59%  
(5)

Therefore, the rain gauge in this study has 0.59% error possibility in rainfall intensity of 100 mm/h.

6. CONCLUSIONS

This study developed standard calibration facility that can analyze the error property of rain gauge and equipment calibration. Also, the calibration procedure of rain gauge is standardized by developing the standard calibration procedure using the standard calibration facility. An error property test is executed concerning 1.0mm tipping-bucket rain gauge using such calibration facility and procedure. As a result, it shows 1.05% error possibility in rainfall intensity of 125 mm/h, and 2.16% error possibility in rainfall intensity of 186 mm/h. It also shows real rainfall by correcting 0.0105mm correction value with rainfall intensity of 125mm/h, and 0.0216mm with rainfall intensity of 186 mm/h. Through the results of experiment, the error property is 0.59% in case of representative rainfall intensity of 100 mm/h.

Using this way, the standard calibration facility and the procedure are allowed to know the precise calibration factor of tipping-bucket rain gauge according to the rainfall intensity.

REFERENCES