The Largest Water Flowrate Calibrating Device in China

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Abstract   Along with the increasing of bore of magnetic flowmeter day by day, if the flowrate calibrating device used for large flowrate still adopts the traditional principle of high potential tank, steady head , the disadvantages of high investment, high power comsumption etc. will be manifested. To overcome the above mentioned problems, the Shanghai Welltech Automation Co. Ltd. constructed the large water calibrating device which adopted the principle of variable head dynamic volumetric comparison method. This device needs low power consumption and less investment. It can calibrate the water flowmeter with maximum diameter DN3000 (and can be extended up to DN3800) and maximum flowrate 25000 m^3/h. The total uncertainty of the device is 0.037% (k=2, p=0.95).

The thesis stated the system, working principle, calibration method, uncertainty analysis of the device and the utilization of electronic scale within this device to trace the measuring value.

Keywords: Variable head dynamic volumetric comparison method, calibrating device

1. Preface

In order to transfer flowrate or test their accuracy, most flowmeters(e.g., electromagnetic flowmeter, turbine flowmeter, volumetric flowmeter and coriolis mass meter) must be calibrated for their actual flowrate on flowrate   calibrating device.

Flow calibration system can be divided into two categories: primary calibrating device and transfer calibrating device according to their traceability system. Transfer calibrating device which transfer the flowrate from master flowmeter, is simple and needs less investment; but the flowrate of master flowmeter still needs to be transferred from other primary calibrating device so the accuracy of such transfer calibrating device is relatively lower. Primary calibrating device uses fundamental measurements of length (derivable to volume) or mass and time to derive to and display flowrate, and can provide higher accuracy; but its structure is so complicated that it needs more investment. Only some flow measurement research institutes and some fair sized flowmeter manufacturers have the capacity to build the primary calibrating device. [2]

Those middle and small primary calibrating devices need higher header tank with overflow outlet to maintain constant head so they consume more energy. If the large primary calibrating device still uses the same scheme, the energy and investment for the overflow to maintain the constant head will be far great. For example, a device with 1,000mm pipe diameter and flowrate 18,000m^3/h needs a set of pumps with capacity up to 2,200kW. [3]

In order to calibrate a DN3,000 electromagnetic flowmeter, Shanghai Welltech Automation Co., Ltd adopted a variable head dynamic volume comparison method which consumes less energy and needs less investment to build a water flowrate calibrating device with 3000mm (up to 3800mm) pipe diameter which can regulate the flowrate. This paper introduces briefly those major points like the system construction, flow range, calibration method, uncertainty analysis, etc.

2. Introduction of the variable head dynamic volume comparison method

2.1. Briefing

The pipe diameters of the device are from DN150 to DN3000 (up to DN3800), and allocated in three systems and four pipelines. The meter size, flowrate range and total uncertainty are shown in table 1.

Table 1 Major parameters

system No.	water tower volume (m³)	pipeline No.	meter size (mm)	max. flowrate (m³/h)	total uncertainty (%)
1	605	1	DN1200--DN3800	25000	0.037
2	209	2	DN400--DN1200	8000	0.028
3	68	3	DN300--DN400	2000	0.037
		4	DN150--DN250		

2.2. System construction

The three systems are of same principle. Now take No.1 pipeline as example. The schematic diagram is shown in Fig. 1.
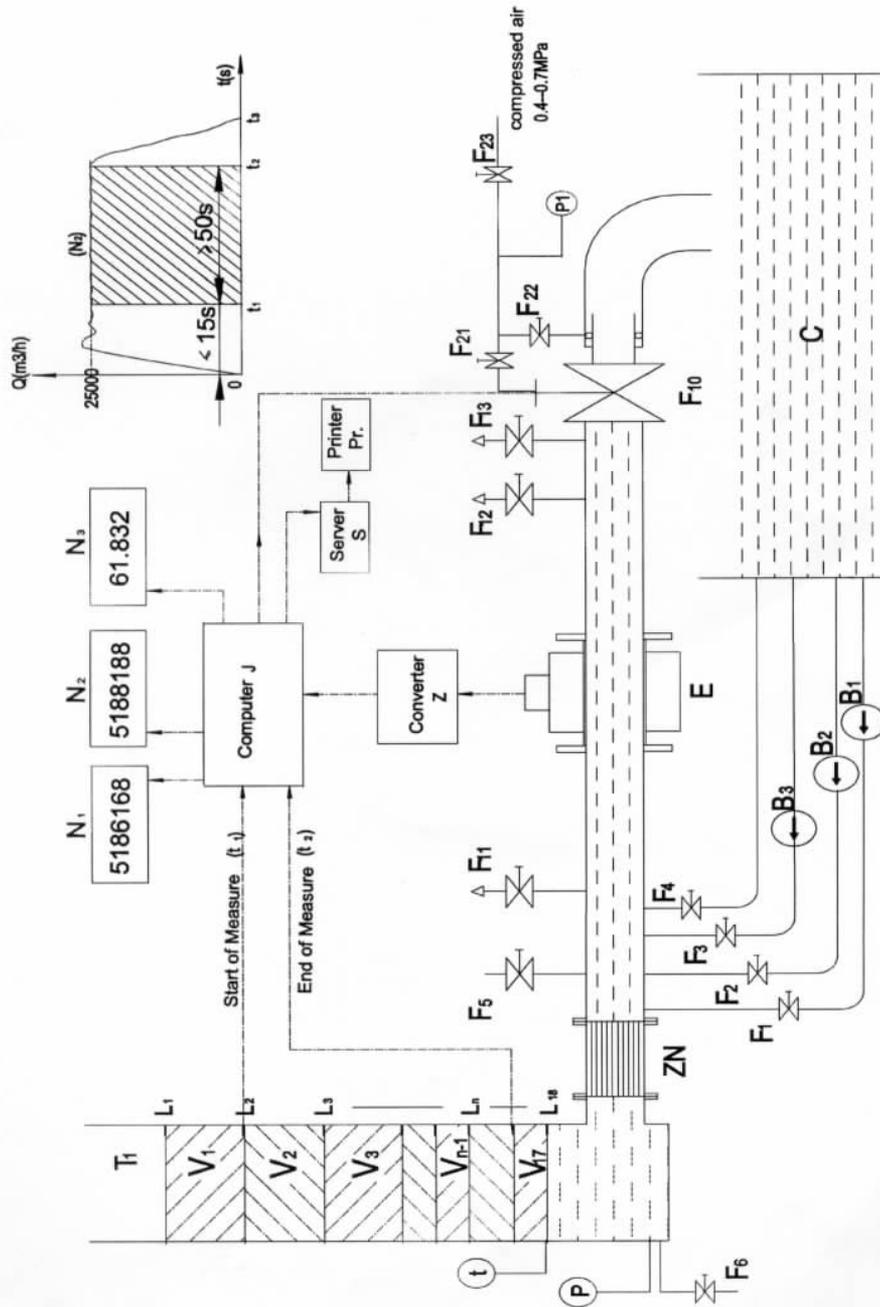

Fig.1

T_1 — Water tower i.e. the working tank, height 31.5m, volume 605m^3;

L_1~L_{18} — Level Detectors;

t — Temperature transmitter, to correct the volume of working tank;

P — Pressure transmitter, to measure water level in the tower;

ZN — Flow straightener;

C — Water reservoir;

B_1/B_2/B_3 — Pumps;

F_{10} — Flow regulating valve;

F_4/F_6 — Drainage valves;

F_5 — Connection which connects to the transfer system for tracing volume;

F_{11}/F_{12} — Automatic air exhaust valves;

F_{13} — Manual air exhaust valve;

N_1 — Accumulator, which displays the volume measured by the flowmeter;

N_2 — Accumulator, which displays the volume got from the tank;

N_3 — Timer, which displays the measuring time;

E — The flow transmitter under calibration;

P_1 — Pressure gauge;

F_{21}/F_{22}/F_{23} — Air valves。

3. Working principle

1) Install the flowmeter to be calibrated and connect the leads, turn off F_{10}, F_4, F_5, F_6, turn on B_1/B_2/B_3 to fill water to the tower until the required height of water level is reached; turn off B_1/B_2/B_3, turn on F_{13} to exhaust the remaining air and then turn off.

2) Set the parameters of flowmeter and control system.

3) Turn on the computer to control F_{10} through PID or other means to make the flowrate reaches to the set value, and keep it constant.

4) When the level reaches set point (L_2), L_2 actuates and starts N_1/N_2/N_3 simultaneously and the measuring is started (t_1).

5) When the level reaches (L_{16}), L_{16} actuates and N_1/N_2/N_3 are stopped simultaneously and the measuring is ended (t_2). During the time between t_1 and t_2, the cumulative volume passed through the flowmeter is $V = \sum_{n=2}^{15} V_n$. The average instant flowrate is $Q = \dfrac{V}{t_2 - t_1}$, where V_n is got from the certified report issued by the Shanghai Institute of Measurement and Testing Technology (SIMTT).

6) Error calculation

$$\delta = \frac{Q_1 - Q}{Q} \times 100\% \qquad Q_1 = \frac{V_b}{t_2 - t_1}$$

, where V_b is the volume measured by the flowmeter, Q_1 is the average instant flowrate measured by the flowmeter.

4. Calibration method

4.1 Construction of the transfer system for tracing volume

In Fig.2, F_9 is the flow adjusting valve; SW is the flow diverter; C_1/C_2 are the containers on the electronic loadcell scales. F_7/F_8 are the drainage valves; W_1/W_2 are the reading on the loadcell scales.

4.2 Principle of the transfer system of the electronic loadcell for tracing volume

Testing method for V_1, V_2.V_n which are the volumes between every two adjacent level detectors is same. Now describe the testing method for V_1 as example.

Use the high accurate loadcell scale to trace the weight. First, use the electronic loadcell scale to weigh the water between two adjacent level detectors L_1 and L_2, then calculate the volume between these two adjacent level detectors according to water density.

Operating procedure:

a) Turn off F_{10}, F_4, F_5, F_6 in Fig.1, and turn on B_3 to fill the working tank T_1 up the required level, and then turn off B_3;

b) Turn on F_5 and adjust F_9 to the stipulated flowrate; switch the SW so the water flows to C_1; turn on F_7, turn off F_8, and clear W_2;
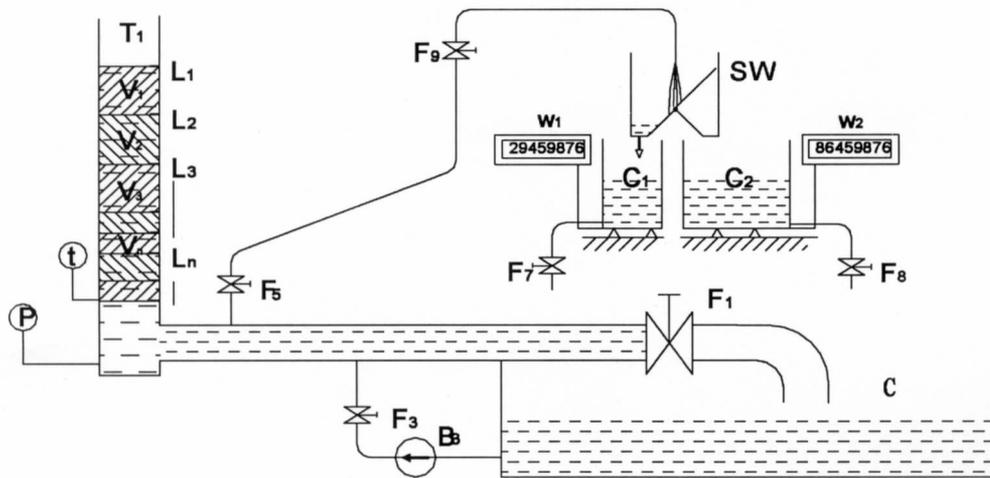

Fig. 2

c) When the level descends to the first level detector L_1, L_1 actuates so SW switches to C_2, and water flows to C_2. Simultaneously the remaining water in C_1 drains off; turn off F_7 and clear W_1;

d) When the water weight W_2 in C_2 reaches the stipulated value, SW switches to C_1 ;

e) During the time that water flows into C_1, record W_2 and follow the formula (1) [see 4.3.2.b] to calculate volume A_1 according to the clean water density got from a table which relates to the water density and temperature. Then turn on F_8 and drain off water in C_2, turn off F_8 and clear W_2, wait for next measuring;

f) After repeated the above procedure k times, volumes $A_1…A_2$ were got. When the level decends to L_2, this detector actuates and SW switches. The measuring of $V_{1,1}$, the volume between level detectors $L_1 \sim L_2$,

was completed $V_{1,1} = \sum\limits_{k=1}^{k} A_k$ where k is the number

of weighing done by the electronic loadcell scales.

Then start the measuring of $V_{2,1}$, the volume

between level detectors $L_2 \sim L_3$;

g) Through repeating the steps a)~f) for j times $V_{1,2}$ $V_{1,3} --- V_{1j}$ were got;

h) Calculate the relative uncertainty of type A per-formula (4) in 4.4.2.2.

4.3 Error source analysis

There are two forms to express the flowrate: instantaneous flowrate and total cumulative quantity. The form of instantaneous flowrate is $Q=V/t$.

The form of total cumulative quantity is $Q=\int Qdt$

The above two forms involve two variables V and t.

The error sources existed during the calibrating of these two variables will be discussed respectively according to the operating procedure of the transfer system in 4.2.

4.3.1 Error sources

  a) Error from electronic loadcell scale
  b) Air buoyancy effect
  c) Density variation effect
  d) Error from flow diverter SW
  e) Error from the timer
  f) Dynamic effect of the level detector

4.3.2 Transfer coefficient of error sources

a) Transfer coefficient of electronic loadcell scale error

$$V = \frac{w}{\rho},$$

w — Reading of electronic loadcell scale

ρ— Water density

$$\Delta V = \frac{\Delta w}{\rho}$$

$$\frac{\Delta V}{V} = \frac{\Delta w}{w}$$

So the transfer coefficient $f_1 = 1$

b) Transfer coefficient of air buoyancy effect

$$m = M - \frac{M\rho_0}{\rho} = M\left(1 - \frac{\rho_0}{\rho}\right)$$

$$M = \frac{m}{\left(1 - \dfrac{\rho_0}{\rho}\right)}$$

$$V = \frac{M}{\rho} = \frac{m}{\rho - \rho_0} \quad ----------------(1)$$

m — Reading of electronic loadcell scale

ρ — Water density

ρ_0 — Air density

M — Mass after the correction of buoyancy

V — Volume corresponding to M

$$\frac{\partial V}{\partial \rho_0} = \frac{m}{\left(\rho - \rho_0\right)^2}$$

$$\frac{\Delta V}{V} = \frac{\Delta \rho_0}{\left(\rho - \rho_0\right)} \cong \frac{\Delta \rho_0}{\rho} \quad -------------(2)$$

Coefficient $f_2 \cong 1$

c) Transfer coefficient of water density error

$$\frac{\partial V}{\partial \rho} = -\frac{1}{\rho - \rho_0} \cdot \frac{m}{\rho - \rho_0}$$

$$\frac{\Delta V}{V} = -\frac{\Delta \rho}{\left(\rho - \rho_0\right)} \cong -\frac{\Delta \rho}{\rho} \quad ---------(3)$$

Coefficient $f_3 \cong -1$

The following measures were adopted for the device:

(1) Before the SIMTT calibrates every section of the working tank T1,clean down the water reservoir,replace the water by clean tap water.

(2) Build the reservoir under the ground. Keep it clean.The variation of water temperature should be kept within $2°$ during calibration.

(3) The variation of water density caused by the temperature variation is corrected by the computer automatically, so the error of density of water can be neglected.

d) Transfer coefficient of volume of working tank

$$V_n = \overline{V_n} + \Delta V_n \qquad \frac{\partial V_n}{\partial \Delta V_n} = 1 \qquad \frac{\partial V_n}{\partial \overline{V_n}} = 1$$

Coefficient $f_4 = 1$

e) Transfer coefficient of error from flow diverter SW

According to formula (4) and (5) in JJG 164-2000, the relative uncertainty is proportional to Δt_i , so its transfer coefficient $f_5 = 1$

f) Transfer coefficient of timer error

$$Q = \frac{\sum V_n}{t}, \frac{\partial Q}{\partial t} = -\frac{\sum V_n}{t^2}$$

$$\frac{\Delta Q}{Q} = \frac{-\dfrac{\sum V_n}{t^2} \cdot \Delta t}{\dfrac{\sum V_n}{t}} = -\frac{\Delta t}{t}$$

Coefficient $f_6 = -1$

4.4 Calibration items and uncertainty calculation

4.4.1 Calibration of electronic loadcell scale

The electronic loadcell scale is calibrated by SIMTT, and the calibration report gives the uncertainty u_1.

4.4.2 Calibration of the volume of working tank

4.4.2.1 Calculation for every section's volume of the working tank

The data matrix got from the description of measuring procedure in section 4.2 is

$$
\begin{matrix}
V_{1,1} & V_{1,2} & V_{1,3}.....V_{1,j} \\
V_{2,1} & V_{2,2} & V_{2,3}.....V_{2,j} \\
. & . & . \quad . \\
. & . & . \quad . \\
V_{n,1} & V_{n,2} & V_{n,3}....V_{n,j} \\
. & . & . \quad . \\
. & . & . \quad . \\
V_{17,1} & V_{17,2} & V_{17,3}...V_{17,j}
\end{matrix}
$$

The volume of every section is measured for m times and take the average as the volume of the section.

$$\overline{V}_n = \frac{1}{m}\sum_{j=1}^{m} V_{n,j} \qquad j = 1,2,.........m$$

4.4.2.2 Relative uncertainty of Type A

$$s_1 = \frac{1}{\overline{V}_n \sqrt{m}} \sqrt{\frac{\sum_{j=1}^{m}(V_{n,j} - \overline{V}_n)^2}{m-1}} \times 100\% ---(4)$$

m is the number of measurement, $m \geq 6$.

$\overline{V}_n$ is the volume measured under the water temperature t and it should be converted to a volume at the calibrating temperature $t = 20$ °C

$$V_t = V_{20}\left[1 + 33.5 \times 10^{-6}(t-20)\right] -------(5)$$

V_t : The volume at temperature t

V_{20} : The volume at temperature $20\ ℃$

4.4.3 Calibration of water diverter

Follow the calibration method of flowmeter in JJG164-2000, Verification Regulation of Liquid Calibrating Facilities, to calculate the relative uncertainty of typeA, s_2, and the relative uncertainty of type B, u_2.

4.4.4 Calibration of timer

Follow the calibration method of timer in JJG164-2000, to calculate the relative uncertainty of type A, s_3, and the relative uncertainty of type B, u_3.

4.4.5 Calibration method of dynamic effect of level detector

Follow the calibration method of dynamic effect of level detector in JJG164-2000, to calculate the uncertainty u_4

4.5 Total uncertainty of the device

The uncertainties $s_1, s_2, s_3, u_1, u_2, u_3, u_4$ are independent from each other.

a) Cumulative quantity comparison method

$$u_c = \sqrt{s_1^2 + s_2^2 + u_1^2 + u_2^2 + u_4^2} ------(6)$$

b) Instantaneous flowrate comparison method

$$u_c = \sqrt{s_1^2 + s_2^2 + s_3^2 + u_1^2 + u_2^2 + u_3^2 + u_4^2} --(7)$$

5 Total uncertainty of the device

a) Cumulative quantity comparison method

$$U = Ku_c = 2\sqrt{s_1^2 + s_2^2 + u_1^2 + u_2^2 + u_4^2}$$
$$(K = 2, \quad P = 0.95) ------------(8)$$

b) Instantaneous flowrate comparison method

6 Calibration result

The four pipelines were calibrated by SIMTT, and the total uncertainties are listed in table 1. Now take pipeline 1 as example to show how to combine the relative uncertainties to reach a total uncertainty:

a) Relative uncertainty of electronic loadcell scale

$u_1 = 0.00015\%$

b) Relative uncertainty of the working tank volume

$s_1 = 0.0155\%$

c) Relative uncertainty of the flow diverter

$\sqrt{s_2^2 + u_2^2} = 0.0070\%$

d) Relative uncertainty of the dynamic effect of level detector =0.00698%

e) Relative uncertainty of the timer

$$\sqrt{s_3^2 + u_3^2} = 0.003\%$$

$$U = Ku_c = 2\sqrt{s_1^2 + s_2^2 + s_3^2 + u_1^2 + u_2^2 + u_3^2 + u_4^2}$$
$$= 2\sqrt{0.0155\% + 0.00015\% + 0.0070\% + 0.003\% + 0.00698\%}$$
$$= 0.037\% \quad (K = 2, \quad P = 0.95)$$

7.Conclusion

The calibrating device of water flowrate based on the variable head dynamic volume comparison method was built by the Shanghai Welltech Automation Co., Ltd. It consists of 3 systems, 3 water towers, and 4 pipelines. It can calibrate the electromagnetic flowmeter and other kinds of water flowmeter with meter size from DN150 to DN3800, and the maximum flowrate can reach up to 25,000m^3/h. The total uncertainty ≤0.037%.

Reference

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