Model Study on the volume of the gas discharged by high accuracy bell prover

Organization： Institute of Metrology of Hebei Province

Reporting person： XING,JINGFANG

Zhaozhou bridge, It has been built for more than 1400 years.

ancient city wall of zhengding county,
general secretary xi jinping got his political start here

the night view of shijiazhuang,

Catal-
ogue

1. Source of the paper

This paper is based on the 0.1 class 2000L standard bell prover of gas flow which is the provincial highest measurement standard established by our institute. The research subject of this device is from the provincial science and technology special project of hebei province.

2. Bell prover overview

Bell prover is a kind of metering standard equipment which is used calibrate and test the gas flow meter with gas as the medium. Many countries have studied and established it as a reference device for low-pressure gas flow.

Radius Measuring Instruments	height measuring Instruments	Grade and Calibration Method of Bell Prover
diameter ruler thickness meter	steel ruler	low accuracy whole segment calibration
inside diameter micrometer	altimeter	
	encoder	
laser interferometer	grating ruler	high accuracy segment calibration
special device developed	laser interferometer	

The main factor affecting the uncertainty of flow measurement of bell prover is the internal volume,whichis obtained by measuring the radius and height.

3. The concept of volume coefficient

After calibrating, the specific relationship between the inner radius and the height is obtained, which is called the volume coefficient of the bell, with $r = f(h)$.

The volume coefficient model is different between whole section calibration and section calibration.

4. Commonly used volume coefficient model

Volume coefficient model with low accuracy level bell prover

When the whole section of the bell is calibrated, the structure of the bell is considered to be an ideal cylinder.

The inner radius of the upper, middle and lower sections are measured, the average radius $\bar{r_i}$ was used as the measurement result.The volume coefficient is a constant, with $f(h) = \bar{r_i}$.

The displacement measuring mechanism installed on the bell prover measures that the bell is lowered from position h_{begin} to position h_{end}. Drop height difference is $\Delta h = h_{\text{end}} - h_{\text{begin}}$.The volume of gas discharged by the bell falling is $V = \pi f(h)^2 \cdot \Delta h$.

Because $f(h)$ is the constant, the volume of the gas discharged is only related to the height difference and has nothing to do with the starting and stopping position of the bell.

4. Commonly used volume coefficient model

Volume coefficient model with high accuracy level bell prover

For high accuracy level, the influence of processing accuracy and deformation during transportation on the inner volume of the bell prover should be considered.

In this case, the radius corresponding to different heights of the bell are inconsistent, so it is necessary to calibrate the bell piecewise to obtain the radius in different height difference sections, and the volume coefficient is a piecewise function,

$$f(h) = \begin{cases} \overline{r_{1i}}, & h_0 \le h < h_1 \\ \overline{r_{2i}}, & h_1 \le h < h_2 \\ & \vdots \\ \overline{r_{ni}}, & h_{n-1} \le h < h_n \end{cases}$$

h: the height of the bell;

n: the number of segments;

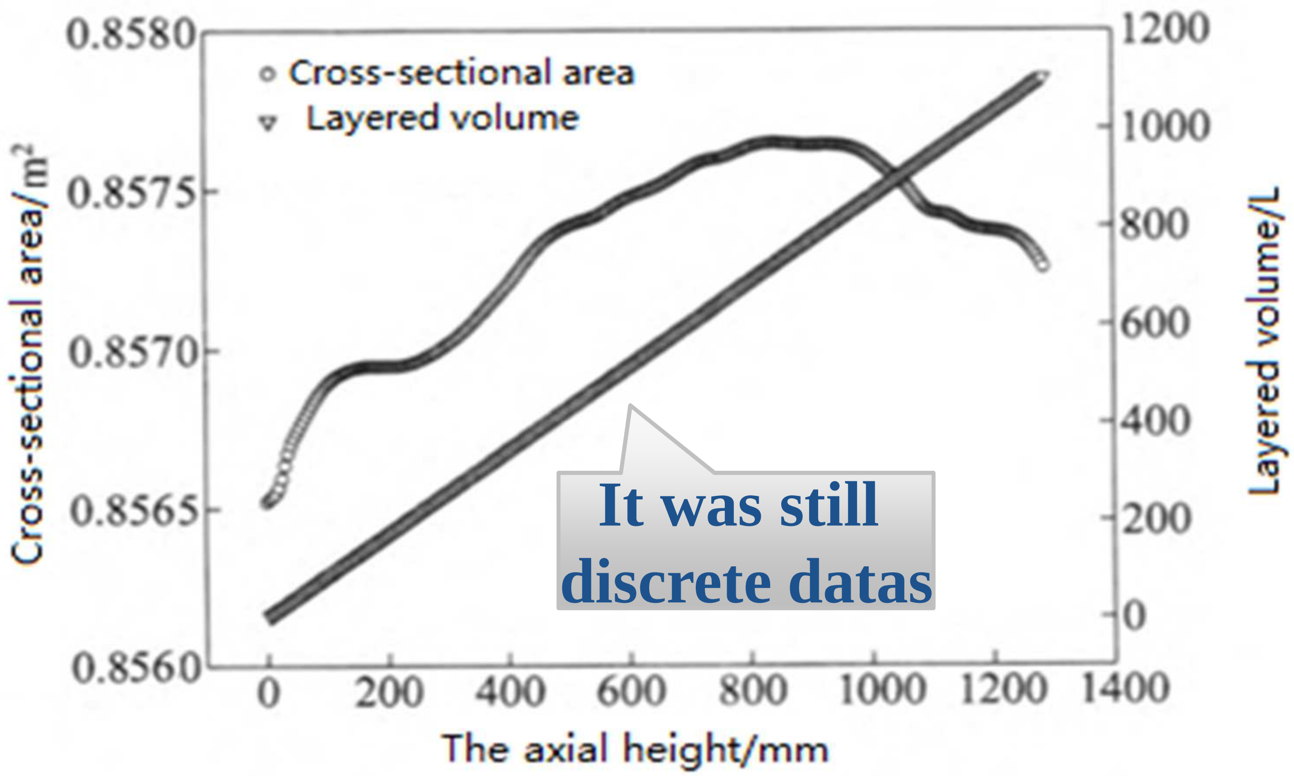
i: the number of measurements within each segment.

$V = \pi f(h)^2 \cdot (h_{\text{end}} - h_{\text{begin}})$, It can be seen that the descending position of the bell should be considered when the bell is used in sections.

4. Commonly used volume coefficient model

an example of the volume coefficient model with high accuracy level bell prover

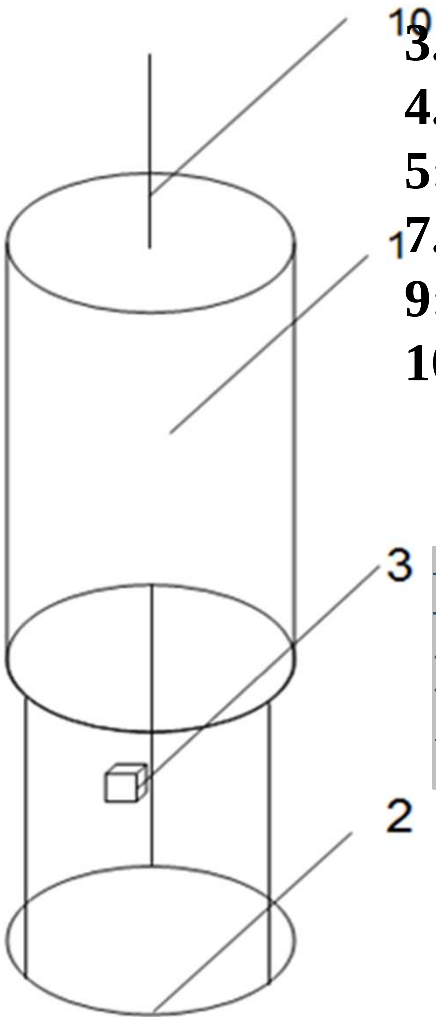
The 1000L bell prover datas measured by Shanghai metrology institute with the special device developed.



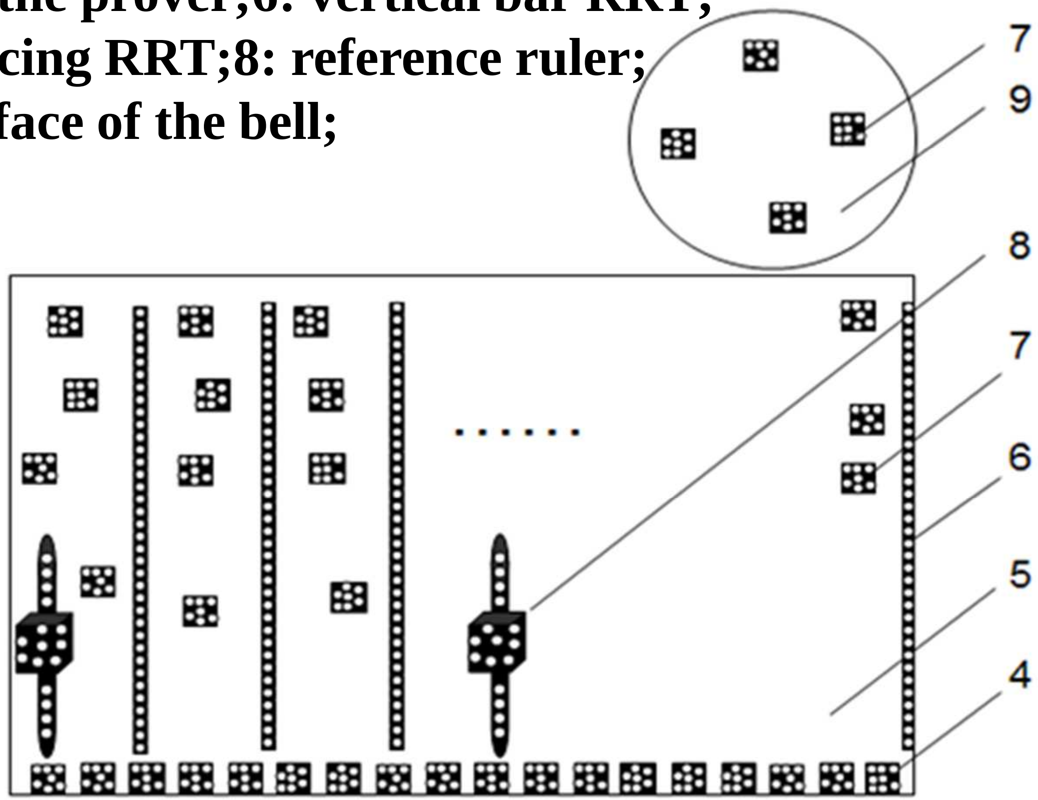
Distribution of axial cross section area

5. The volume coefficient model of this paper

1: bell prover;2: bottom support (self-developed);
3. Measuring camera;
4. Reference datum photographic mark (RRT);
5: inner wall of the prover;6: vertical bar RRT;
7. Irregular splicing RRT;8: reference ruler;
9: inner top surface of the bell;
10: wire rope.



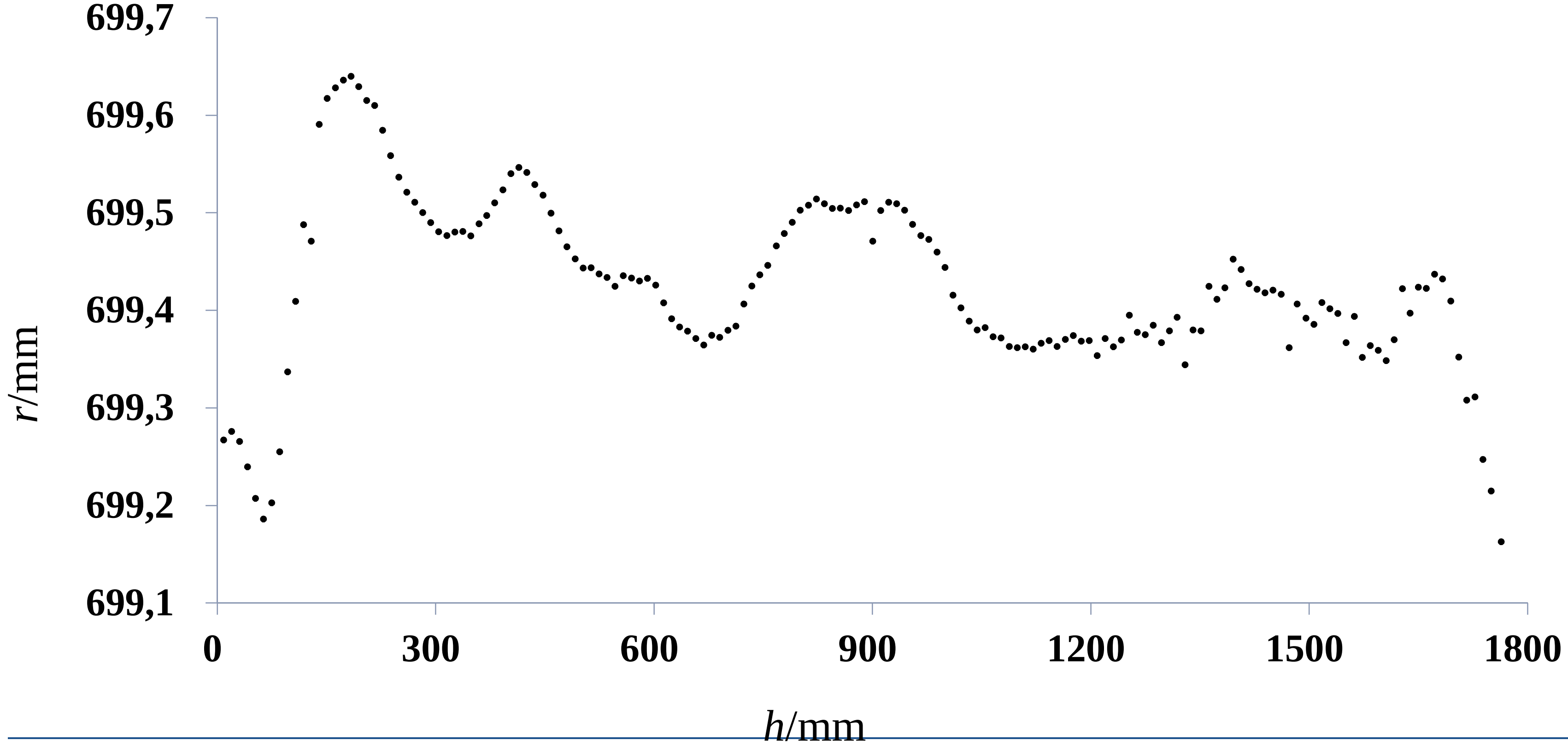
More than 100 photos were taken



Using Photography to measure the inner radius of the bell prover

5. The volume coefficient model of this paper

The cross-section radius of 160 different heights at 11 mm intervals in the range of 1800 mm of axial height is obtained with V-star software and the two-dimensional array of heights and radius is formed,which is （h_i，r_i）.



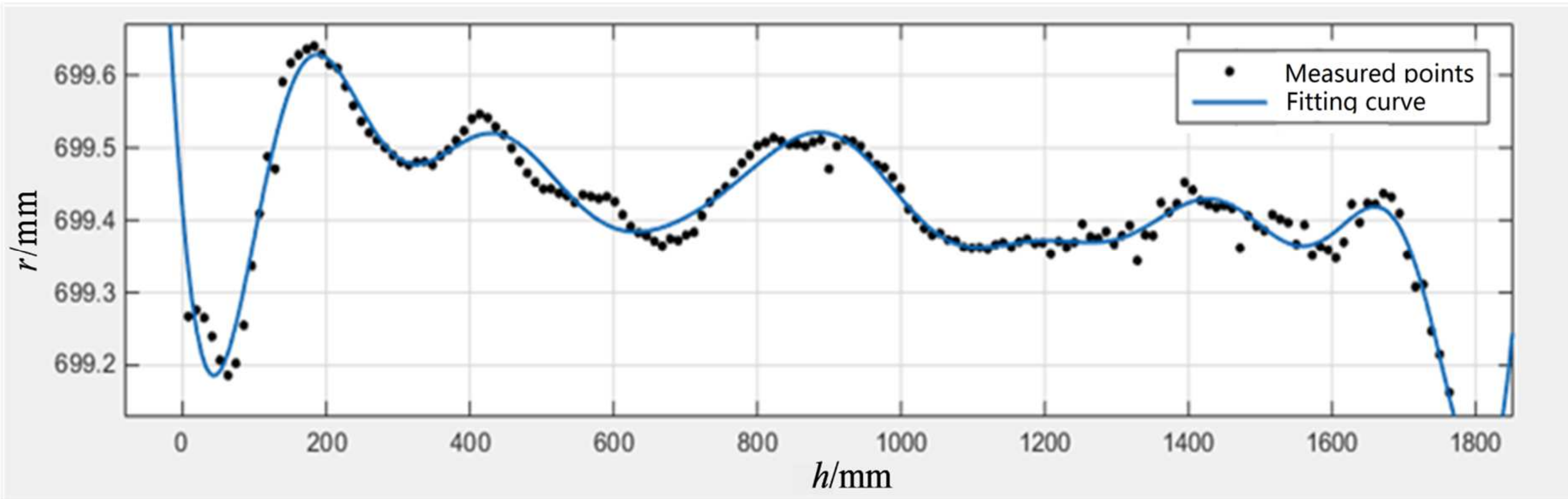
5. The volume coefficient model of this paper

Matlab software was used for curve fitting of two-dimensional array.

After analysis and comparison of fitting error, it was determined to adopt eight-time Fourier fitting curve. Its mathematical model is the next:

$$r = f(h) = a_0 + \sum_{k=1}^{8} [a_k \cos(k\omega h) + b_k \sin(k\omega h)]$$

a_0, a_k, b_k are the Fourier coefficients, ω is fundamental frequency.

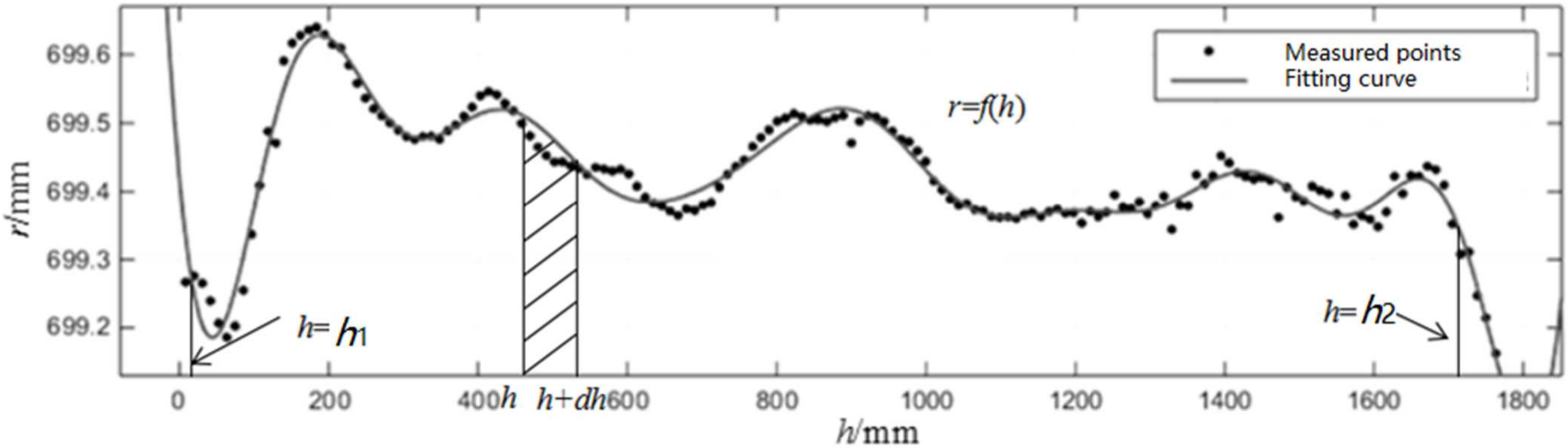


6. Actual volume of gas discharged from the bell prover

The above volume coefficient model is a continuous function, which can be calculated by definite integral to obtain the gas volume at any height of the bell, as shown in formula below:

$$V = \int_{h_1}^{h_2} \pi r^2 dh = \int_{h_1}^{h_2} \pi [f(h)]^2 dh$$

h_1 is the height measured by the displacement measuring mechanism (Here is the grating ruler) before the bell descends, h_2 is the height after the bell descends.



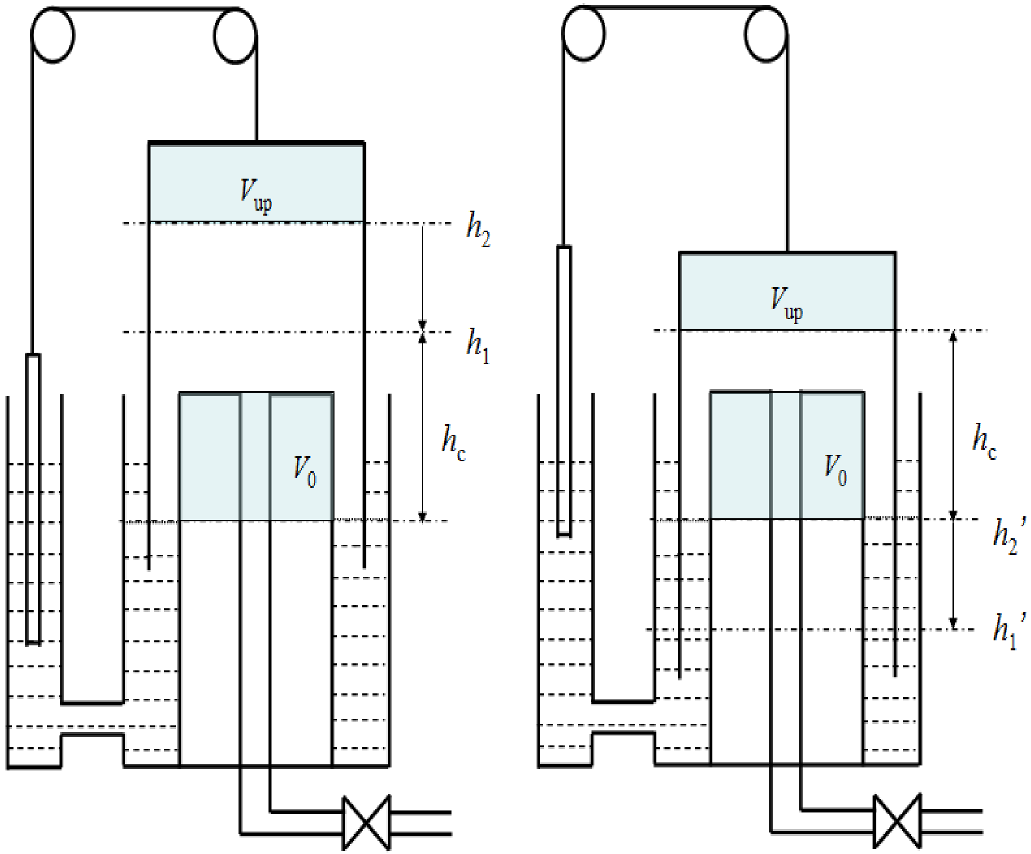
6. Actual volume of gas discharged from the bell prover

The bell prover has a liquid level balancing mechanism, the liquid level remaining unchanged during the bell descending process.

The difference between the reading head and the internal liquid level is h_c.

The bell descends to discharge gas,the actual height corresponding to the volume of the gas is h_1'(h1 prime) to h_2', however,the height measured by the grating ruler is h_1 to h_2. Where, $h_1' = h_1 - h_c$, $h_2' = h_2 - h_c$.

The volume of the gas in the bell at the initial position is V_1,and at the final position is V_2.



$$V_1 = V_{up} + \pi \int_{h_1}^{h_2} f^2(h)dh + \pi \int_{h_1'}^{h_1} f^2(h)dh - V_0$$

$$V_2 = V_{up} + \pi \int_{h_2'}^{h_2} f^2(h)dh - V_0$$

6. Actual volume of gas discharged from the bell prover

During this descent, the volume of the gas discharged from the bell is:

$$V_D = V_1 - V_2$$

$$= \pi \int_{h_1}^{h_2} f^2(h)dh + \pi \int_{h_1'}^{h_1} f^2(h)dh - \pi \int_{h_2'}^{h_2} f^2(h)dh$$

$$= \pi \int_{h_1}^{h_2} f^2(h)dh + \pi \int_{h_1'}^{h_2'} f^2(h)dh + \pi \int_{h_2'}^{h_1} f^2(h)dh$$

$$-\pi \int_{h_2'}^{h_1} f^2(h)dh - \pi \int_{h_1}^{h_2} f^2(h)dh$$

$$= \pi \int_{h_1'}^{h_2'} f^2(h)dh = \pi \int_{h_1-h_c}^{h_2-h_c} f^2(h)dh$$

Definite Integral property

It can be seen that the grating ruler measures the desending height ,the actual volume of the gas discharged is equal to the volume corresponding to desending height translated downward by h_c.

7.Conclusion

the volume of gas dischaged

low accuracy bell prover — Not ∝ → the starting and stopping position of the bell

high accuracy bell prover — ∝ → the starting and stopping position of the bell

high accuracy bell prover — ∝ → h_c

during the processing of the bell prover → there is no transverse weld in the height section of the actual discharged

in bell prover calibration:
- the height of the actual discharged
- Not the height indicated by the grating ruler

Thank you for your attention!

XING JINGFANG
Phone：15032153761
Email：xjfhbjl@126.com