Establishment of Piston Devices

Wang Chi, Li Xu, Duan Hui Ming, Wang Dong Wei, Shi Zhen Dong and Meng Tao
Heat Division, National Institute of Metrology of China, No 18 Bei San Huan Dong Lu, Bei Jing, China, 100013

Abstract:

Principle, work procedure, structural features, function, test procedure and analysis of uncertainty for gas piston are introduced, the data compared with PVTt facility are given. According to the specifications, it is found that the establishment of the device is successful and some experiences for further work are accumulated.
Keywords: Piston, Gas Flow.

1. Features of Gas Piston device

High Accuracy in standard volume: the standard volume is only relative to the falling distance of the piston and diameter of the cylinder, so there are few relative influencing factors.

Good repeatability: from the principle, the repeatability is only relative to the change of cross section area, repeatability of measurement by grating, as well as deformation in seal ring, etc., and all of these factors influence little.

High inner pressure: the balancing pressure in the cylinder can be adjusted by filling compressed air into the cylinder, the max. Inner pressure of the device will be up to 200kPa (gage pressure 100kPa).

Stable flow: as the flow rate is the product of the piston's running speed and cross sectional area of the cylinder, and the piston is driven by servo motor, whose speed is easy to be adjusted and controlled during the test, so it is easy to enable the flow reach and stabilize on a fixed flow point.

Stable pressure: for the flow meter for which flowrate is proportional to the pressure difference, during the test, it is easy to achieve stable pressure in a short time by the self-balancing relationship between flow and pressure difference.

2. Working Principle

2.1 Technical specifications

The specifications achieved are:

(1) Range of flow: （0.5~150） m^3/h
Uncertainty of volume flow: U=0.05%，k=2
Repeatability: Better than 0.01%
Working pressure in cylinder: Absolute pressure 160kPa

(2) Range of flow: （0.009~0.6） m^3/h
Uncertainty of volume flow: U=0.07%，k=2
Repeatability: Better than 0.03%

2.2 System Structure

The piston-type gas flow device consists of the mechanical part, electric controlling and data-collecting part. The mechanical part is mainly composed of cylinder, piston, servo motor, speed-down part, ball screw, grating, piping, air inlet/outlet valve and base, support bracket, mounting platform and position limit -ed switch, etc. The electric controlling and data-collecting part mainly consist of the control system for servo motor and valves, the measuring and data collecting & processing system for temperature, pressure, grating, time and flowmeter signal, etc., inspection and control for piston position and valve position, computerized data processing and database, etc. (see fig.1).

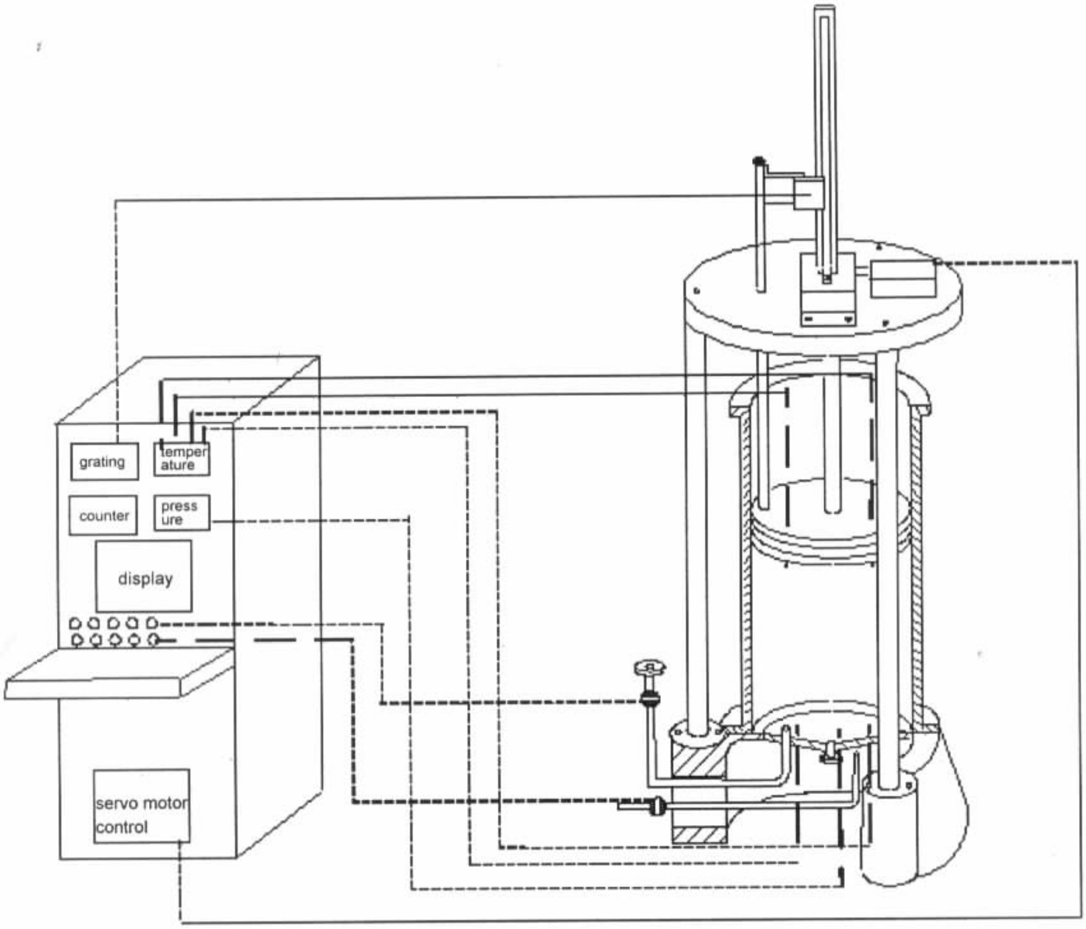

Fig. 1 Structure of the Device

2.3 Working Principle

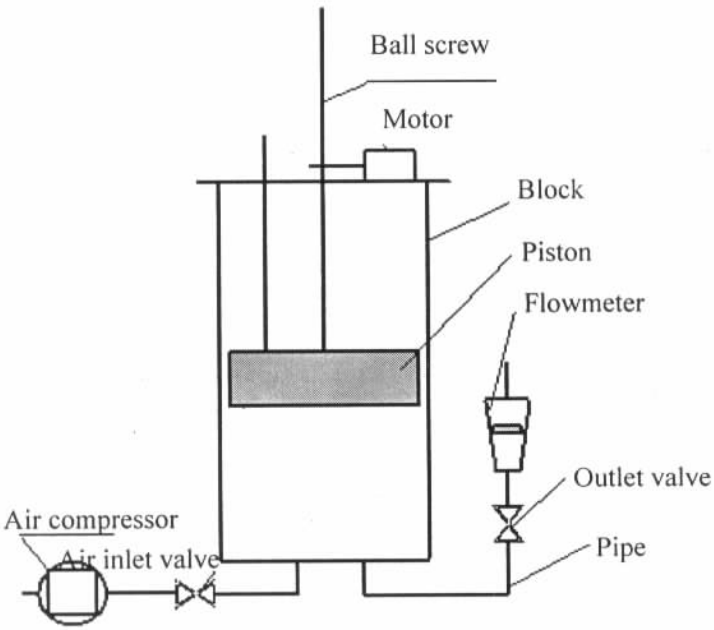

Fig. 2 Work Principle

As shown in fig.2, when the device is working, the piston moves downward, and discharges the air in the cylinder through the outlet pipe and the flowmeter. When the piston moves downward with even speed, the pressure in the cylinder will get stable gradually after rising up. It is assumed that the temperature, pressure and volume of gas during this process do not change, as the inner diameter of cylinder is known, the volume of discharged gas can be calculated for the piston running certain distance. It is taken as standard volumetric flow and is compared with the readout of the flowmeter, so the flowmeter is tested.

2.4 Mathematic model

The calculating method during the test is shown as following:

The gas volume discharged when the piston moves downward:

$$V_s = A \cdot h \qquad (1)$$

Where, A—cross sectional area of the cylinder, m^2;

h -- effective down-moved height of piston, m;

The temperature and pressure of gas in the cylinder are indicated by the average value measured from temperature sensor and pressure sensor in the cylinder, considering the influence of gas temperature and pressure in the cylinder, the volume under standard state converted from the gas volume discharged from the cylinder is:

$$V_N = V_s \frac{P_s \cdot T_N}{P_N \cdot T_s} \qquad (2)$$

Where, P_S, P_N--are absolute pressure under standard state in the cylinder, P_N=101325 Pa;

T_s,T_N -- are thermal temperature in the cylinder and thermal temperature before flowmeter respectively, T_N=297.15K.

The accumulated flow rate through the flowmeter is the gas volume discharged from the piston with correction of temperature and pressure. i.e.

$$V_p = V_s \frac{P_s \cdot T_p}{P_p \cdot T_s} \qquad (3)$$

Where, P_p -- absolute pressure before flowmeter, Pa;

T_p -- thermal temperature before flowmeter, K.

3. Mechanical Structure

The key components of piston-type gas flow device are the piston and the cylinder. It is the enclosed space formed by the cylinder and the piston that provides accurate volume for metering the flowrate. When it runs, the piston moves along the guide rod in the cylinder. While guaranteeing sealing, the product of the inner cross sectional area of the cylinder and the moving distance of piston is the standard flow rate accumulated. Therefore, the design of the device will be focused on guaranteeing the sealing between the piston and the cylinder, geometric tolerance of cylinder and dimensional tolerance, at the same time requiring the running to be stable, as well as considering the performance-to-price ratio in the machining technical condition in China.

The mechanical structure of the device consists mainly of cylinder, piston, guide rod, travel measuring system, speed-down part and ball screw system, sealing system, base and support rod, gas inlet/outlet piping and valve, etc. It is required that the overall structure of the device is reasonably designed, so the device can run smoothly. In order to make the device has good accuracy, the cylindrical contour tolerance should be guaranteed enough little for the inner circle of the cylinder. To guarantee the sealing reliable between cylinder's inner surface and sealing ring, and to reduce friction effectively, high requirement is put forward to the cylindricity and surface roughness of inner surface of the cylinder.

4 Electric Control

4.1 Function of the control system

a. We can control electrically or manually the on/off and speed of servo motor, control the on/off of the electric valve.

b. We can collect signals of temperature in the cylinder, pressure in cylinder, grating displacement, test time and flowmeter, and they are shown on the display meter, then they are input into the computer; we can receive signals from upper/lower position limit switch.

c. We can calculate the motor speed according to the preset speed, the average temperature and pressure in the cylinder, the gas volume represented by falling height of the piston, to convert the working volume into the volume before flowmeter after temperature and pressure correction with the gas state equation, and take corresponding calculation for performance of the flowmeter.

d. We can save the test data and calculation results into database for management.

4.2 Configuration of hardware

All the electric controlling devices are placed in the control cabinet, which mainly consists of five parts: electric layer, controller layer, computer layer, display meter layer and drive layer. The function of the electric layer are: power on/off, motor off; that of the controller layer are: power on/off for the controller, to control motor, manual speed signal, etc.; the computer layer is for placing the computer host and accessing various signals; and the meter layer is for placing thermometer, pressure gage, grating digital display meter and counter meter; and the drive layer is to place motor driver and DC power supply, etc.

4.3 Configuration of software

The flowmeter calibration program is measuring and controlling software compiled under Visiual Basic 5.0 version software. It achieves man-machine dialogue, automatic control, data collecting and processing for the device, and manages the test record through the self-contained Access database system of VB5.0.

5. Inspecting the Equipment

5.1 Cross sectional area of the cylinder

For the small cylinder, from the upper part of it, we measure downward two diameters vertical to each other at points 50mm, 100mm, 200mm, 400mm, 600mm, 750mm, while taking into account of the influence from thickness of oil film, the average area of 6 sections is 31396 .3 mm^2, and the standard deviation of average area is 0.007%.

As we usually use from section 2 to section 6 of the cylinder, the average value of area for section 2~6 is used for the calculation. i.e. $A=31394.4mm^2, s=0.005\%$.

For the big cylinder, from the upper part of it, we measure downward four diameters vertical to each other at points 50mm, 300mm, 600mm, 900mm, 1200mm, 1600mm, 1900mm, 2200 mm, while taking into account of the influence from thickness of oil film, the average area of 8 sections is 502645mm^2, and the standard deviation of average area is 0.0006%.

As we usually use from section 2 to section 8, the average value of area for section 2~8 is used for the calculation. i.e. $A=502643mm^2, s=0.0007\%$.

5.2 Determining of the oil-film thickness

Using a steel sheet of the same material with the cylinder, we measure its length and width by a calliper and then weigh it on a balance, smear on it some lube oil for lubricating the piston and cylinder, and scrape a Teflon tape evenly on it by simulating the piston, then weigh again the steel sheet on the balance. From the mass increment, the steel sheet area and oil density, we can work out the oil-film thickness. The oil-film thickness is determined to be 0.021mm under test.

5.3 Others

Grating precision: 1.5μm/1000mm, resolution: 0.005mm.

The readout error of temperature sensor not more than: +/-0.05℃

The readout error of pressure gage not more than: +/-0.03%

When the operation temperature is 0~60℃, the standard Uncertainty of the timer is 10^{-6}.

6. Analysis of Uncertainty

The standard volume of gas piston type device is calculated from formula (1), the analysis of uncertainty is shown as in table 1.

Table 1

S/N	Designation	Small device		Big device		Category
		Standard Uncertainty	Freedom	Standard Uncertainty	Freedom	
1	Cylinder area A	0.009%	4	0.0008%	6	A
2	Grating length h	0.005%	8	0.001%	8	B
3	Leakage	0.005%	8	0.008%	8	B
Small device: resultant standard Uncertainty from standard volume u_c=0.012% Expanded Uncertainty of standard volume U=0.024% (k=2), freedom 10. big device: resultant standard Uncertainty u_c=0.0081% Expanded Uncertainty U=0.016% (k=2), freedom 9.						

7.Stability of the Device and Comparative Test

Determine the discharge coefficient C of the critical nozzle by testing the gas piston, repeating the test after several months, so as to determine the stability of the device. Meanwhile, comparing the discharge coefficient C with that of the critical nozzle given by PVTt method, so as to determine the systematic error between devices.

7.1 Stability of the Device

The test results are shown in table 11. From the test data, one can see that totally 10 sets of data are measured in each test, the standard deviation of a single measurement is within 0.045%, the standard deviation of average value is 0.014%. Testing after 2 months, the long-term stability of the data is within 0.03%. This also indicates that under small flow rate, although the flow setting will have a poor repeatability due to adequate resolution in control signal, the repeatability of standard flow rate is better than 0.05%.

7.2 Comparative Result

The comparative results between critical nozzle and PVTt method device are: for nozzle 9905, difference between two devices is 0.24%; for nozzle 9906, difference between two devices is 0.31%. From the test we found that the humidity variation has a high influence on the measurement results, for example, if the humidity changes 1%, the difference in C coefficient will be 0.006%. In one test, the humidity variation can be up to 3%RH, and for the tests conducted at different time the humidity variation can be up to be more than 10%, therefore one have to dry the air when carrying out test on the nozzle with air. In addition to humidity, the difference in density calculation method, change in discharge coefficient caused by pressure variation will also influence the comparative results to different extent.

8. Testing on the Flow meter

Test on mass flowmeter, rotor flowmeter, roots flowmeter and turbo wheel flowmeter are taken. Without model flowmeter, pulse output and voltage output are simulated. The test result proved that the device can run normally, can realize the corresponding functions, and the data collecting, calculating and saving are correct.

9. Conclusion

9.1 The gas piston-type flowmeter has a high stability and good repeatability, as well the function necessary for a standard flow device.

9.2 The inner pressure of a gas piston-type flow device can be up to 200kPa, so as to meet the calibration of high-pressure loss flow device, especially critical nozzle.

9.3 For the principle of the device to produce flow rate being constant flow, it is to reach constant pressure by the nature of the fluid itself, therefore the adjustment of the flow point is easy to control.

9.4 It is believable that the device will play an important role in the flow rate measuring and transmitting system, especially the device has advantage in comparison between devices.