Measurement 48 (2014) 149–154

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Measurement of volume change induced by a bulging of a diaphragm inside a differential type capacitance diaphragm gauge

Kenta Arai *, Hajime Yoshida, Tokihiko Kobata

National Institute of Advanced Industrial Science and Technology (AIST), National Metrology Institute of Japan (NMIJ), AIST 3, Umezono, Tsukuba 305-8563, Japan

ARTICLE INFO

Article history:
Received 8 July 2013
Received in revised form 6 September 2013
Accepted 31 October 2013
Available online 9 November 2013

Keywords:
Vacuum
Diaphragm gauge
Volume measurement
Bulged volume
Maximum bulged volume

ABSTRACT

A diaphragm gauge measures differential pressure by bulging of a thin diaphragm inside a metal housing. A volume change induced by its bulging is evaluated for a full scale 133 Pa CDG (differential type) by using Boyle's law. It was observed that below its full scale, the bulged volume is proportional to the pressure as predicted by the elastic theory. The ratio of the bulged volume to the pressure is obtained to be 0.000131 ml/Pa with an uncertainty of 1.4% ($k = 1$) at a line pressure of about 100 kPa. The bulged volume is increased with an increase of the differential pressure above 133 Pa. At a differential pressure of 40 kPa, the diaphragm is seemed to be touching to a guard electrode and the corresponding maximum bulged volume is estimated to be 0.18 ml.

1. Introduction

Both a differential type and an absolute type diaphragm gauges (DGs) are widely used in not only many industries but also the vacuum science and metrology because of its high sensitivity and its independency of gas species. Both type DGs consist of two rooms separated by a thin diaphragm [1]. According to the elastic theory, a displacement of the diaphragm at its center, w, is proportional to the differential pressure P applied to the diaphragm, as given by

$$w = \frac{3a^4(1-\nu^2)}{16Eh^3}P, \tag{1}$$

where a, h, ν, and E are radius, thickness, the Poisson ratio and the Young modulus of the diaphragm, respectively. In case of a capacitance diaphragm gauge (CDG), bulging of a diaphragm is sensed by change in capacitance between the diaphragm itself and an electrode. That electrode also serves as a guard to prevent a damage of the diaphragm in case of over pressure [2].

A volume change induced by the bulging of the diaphragm (hereafter, it calls as a bulged volume δV_{DIA}) is obtained by using Eq. (1) and given by,

$$\delta V_{\mathrm{DIA}} = \frac{\pi a^6(1-\nu^2)}{16Eh^3}P. \tag{2}$$

Thus, the bulged volume depends on the applied pressure to the diaphragm. This feature of the bulged volume is one of the uncertainty component for both a static expansion method [3], in which the exact volume ratio among chambers are required, and a constant volume type flow meter [4], in which a flow rate is derived from the pressure rise rate of the constant volume chamber against the time. However, it is difficult to measure the bulged volume, since the diaphragm is inside the metal housing of the gauge.

In this study, the bulged volume of a diaphragm against the differential pressure in a differential type CDG (full

* Corresponding author. Tel.: +81 29 861 6826; fax: +81 29 861 4379.
E-mail addresses: kenta-arai@aist.go.jp (K. Arai), hajime-yoshida@aist.go.jp (H. Yoshida), tokihiko.kobata@aist.go.jp (T. Kobata).

0263-2241/$ - see front matter
http://dx.doi.org/10.1016/j.measurement.2013.10.042

scale: 133 Pa) was measured by using the Boyle's law at a line pressure of about 100 kPa. As a result, the bulged volume had a linear response against the differential pressure within the three times of its full scale. The slope of the bulged volume against the pressure was evaluated. The bulged volume was reached at its maximum at the differential pressure of 40 kPa, 300 times of its full scale.

2. Experimental setup

An experimental setup is shown in Fig. 1. Both ends of a differential type CDG (G_1, test gauge, full scale (FS): 133 Pa) were connected to chambers A and B, respectively. Those chambers were also connected via valve #1. Chamber A was connected to chamber C (inner volume: about 6×10^{-3} m^3) via a cramped metal capillary type leak artefact as a gas flow rate restrictor. Chamber B was connected to chamber D via valve #3. Chambers C and D were connected to a turbo molecular pump and a gas cylinder, respectively. The pressures in chamber B and C were measured by a resonant silicon pressure gauge (G_2, FS: 130 kPa, resolution: 0.0001 kPa) and a digital pressure gauge (G_3, FS: 500 kPa), respectively. Chambers A and B, CDG G_1, and the leak artefact were set in a thermostatic chamber to stabilize the temperature of the system within 1 mK for 30 min. Gauge G_2 was set at the outside of the chamber due to its size. The connection line to gauge G_2 was covered with water gel packs to decrease the fluctuation of the temperature. Eight ball bearings, whose diameter were 14.288 mm, were used to fill the inside of chamber D. Temperatures of the experimental setup were measured by four calibrated platinum thermal resistances with a digital multi meter. Nitrogen gas was used as a gas medium for the experiments. Leak rate of the whole system was below 10^{-10} Pa m^3/s measured by the pressure rise method. A typical pressure in chamber D was below 10^{-4} Pa after the 30 min evacuation, when valve #3 was closed.

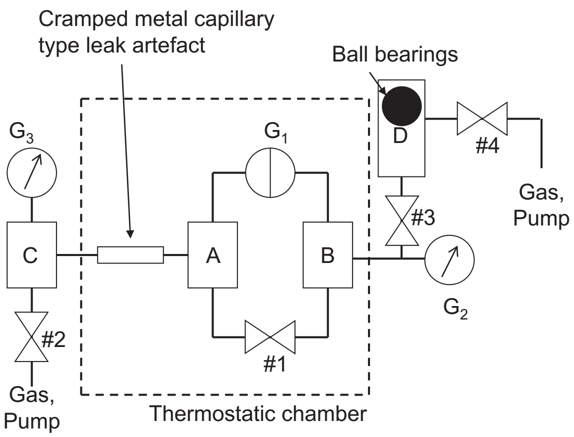

Fig. 1. Schematic diagram of an experimental setup. A, B, C, and D: Chambers. G_1: differential type capacitance diaphragm gauge (target gauge, full scale: 133 Pa), G_2: resonant silicon pressure gauge (FS: 130 kPa), G_3: digital pressure gauge (FS: 500 kPa), #1, #2, #3, #4: valves.

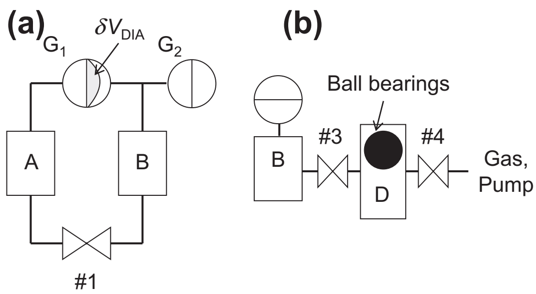

Fig. 2. Concept illustrations (a) for the measurement of the bulged volume, δV_{DIA}, of the diaphragm inside a capacitance diaphragm gauge, and (b) for the measurement of a chamber volume including pipes, an inner volume of a gauge and others. Assignments for chambers and valves are same as shown in Fig. 1.

3. Experimental principles

3.1. Measurement of bulged volume

A concept illustration for the measurement of the bulged volume, δV_{DIA}, is shown in Fig. 2(a). Two closed vacuum systems are connected via a valve and a differential type CDG (test gauge). One system consists of chamber A, a pump and a gas cylinder. Another consists of chamber B and a pressure gauge. When the valve connecting two systems is opened, pressures in both chambers A and B are equivalent at, P_{Bi}, and the differential pressure on the CDG, P_{AB}, is 0 Pa. After closing the valve, the pressure in chamber A increases, as a result, the differential pressure, P_{AB}, also increases and the diaphragm is bulged towards the chamber B. Then, the volume of chamber B is decreased by the bulged volume, δV_{DIA}. Based on the Boyle's law, the relation of pressures in chamber B before and after the increase of the pressure in chamber A is given by,

$$P_{Bi} V_B = P_{Bf}(V_B - \delta V_{DIA}), \tag{3}$$

where P_{Bf} represents the pressure in chamber B after the increase of the pressure in chamber A. The bulged volume δV_{DIA} is, then, given by,

$$\delta V_{DIA} = \left(1 - \frac{P_{Bf}}{P_{Bi}}\right) V_B. \tag{4}$$

The obtained volume, however, will include the volume reduction inside a valve, δV_{VAL}, caused by the position change of the valve from the open position to the close one, since it is difficult to distinguish the pressure change due to the bulged volume from that due to the position change. Thus, the obtained volume by Eq. (4) is a sum of the bulged volume, δV_{DIA}, and the volume reduction in a valve, δV_{VAL}, and then, Eq. (4) is changed to

$$\delta V_{DIA} + \delta V_{VAL} = \left(1 - \frac{P_{Bf}}{P_{Bi}}\right) V_B. \tag{5}$$

3.2. Volume measurement of chamber B including pipes and other accessories

An exact volume of chamber B including pipes, the inside volume of gauges, and others is required for the