

CHARACTERISATION OF 10 Pa VACUUM GAUGE USING PRESSURE BALANCE

SamYong Woo¹, In-Mook Choi, Tae Heon Yang, HanWook Song

¹ Korea Research Institute of Standards and Science, Daejeon, Korea, sywoo@kriss.re.kr

Abstract:

This paper presents an extended usage of gas pressure balances for measurements of pressure down to below 10 Pa. This pressure range is too low to measure by using commercial pressure balances. This is because their inability to operate at pressures below a limit determined by the mass of floating elements. Using a variable bell-jar pressure method developed at KRISS, we can overcome this pressure limit. Additionally, we investigated the lowest achievable pressure limit using commercial 133-Pa CDG (Capacitance Diaphragm Gauge).

Keywords: Vacuum Gauge, pressure balance, Calibration, Variable bell-jar pressure method

1. INTRODUCTION

Pressure balances are widely used in the world to establish the pressure scale from a few kPa to 1 GPa. Basically a pressure balance is a piston fitted into a matching cylinder filled with gas or oil, loaded with known weights, and rotated with respect to the cylinder to help attain concentricity of the piston in the cylinder. To extend the operating pressure range below 2 kPa, several approaches can be applied, including tilting pressure balances, twin pressure balances and a variable bell-jar pressure method. For this method to be more effective, an automatic weight loading device is necessary to load and unload various weights in vacuum. Although automated weight handling devices are commercially available, the lowest bell-jar pressure is too high (a few kilopascals) or the minimum weights available for these automated loaders are around the order of hundred grams which corresponds to a few kilopascals. In this article, we investigate the lowest pressure attainable using variable bell-jar pressure method with the help of 133-Pa capacitance diaphragm gauge.

Capacitance diaphragm gauges are well-known electromechanical vacuum sensors in which the displacement of a stretched thin metal diaphragm is detected by a capacitance measurement. They have gained widespread international popularity as high accurate vacuum gauges. In order to characterize such high accurate vacuum gauges, laser/ultrasonic mercury manometers or FPG (Force Balanced Piston Gauge, DHI) can be used. In this paper, we tried to characterize such an accurate vacuum gauge using conventional well-known pressure balance but applying advanced new methodology.

2. PRINCIPLE AND APPARATUS

The pressure P_i generated by a pressure balance under the absolute-pressure condition can be expressed as

$$P_i = \frac{(T + M_i)g}{A_e} + P_{vac} \quad (1)$$

where T is the initial tare mass including the mass of piston and mass-carrying bell. M_i is the added mass, which varies according to the pressure point. A_e is the effective area of the piston and cylinder unit, g the local acceleration due to gravity. P_{vac} is the pressure in the ambient space around the piston, and is close to zero. As we can see from this equation, changes in M_i lead to changes in the generated pressure P_i , so that some minimum pressure is necessary to balance the tare weight. This corresponds to a pressure of several kilopascals. Therefore, we cannot use the above equation to measure pressures below several kilopascals.

As a substitute, the following equation can be used to measure such low pressures.

$$P_m = \frac{(T + M_i)g}{A_e} + P_j \quad (2)$$

where P_m is the pressure generated by the pressure balance, and should remain constant during measurements. The pressure P_j is the surrounding pressure around the piston and changes according to the weight change M_i . This pressure can be varied from very low pressures. In this equation, M_j and P_j are both variables. In other words, the change in ambient pressure can be related to the change in weight on top of the piston. Here, the buoyancy correction is included in the equation.

For this purpose, a mechanism for loading and unloading the weights on top of the rotating piston is necessary. If the bell-jar had to be opened in order to exchange the weights, a long evacuation time would be necessary to re-stabilize the measurement conditions. Moreover, the consequent exposure of the piston, cylinder, and weights to the atmosphere can cause a contamination problem.

Our device is made from a commercial gas operated pressure balance manufactured by DH Instruments in USA. The pressure balance was modified, in that the glass cover that contains the vacuum was replaced by a stainless steel chamber. Fig.1 shows the appearance of the device. The chamber is cylindrical with four 2.75" ports 90° apart. One of these is used to connect three test gauges, and others are used as viewing ports to see the inside the chamber. A stainless steel upper cover plate was made with five holes

that allow rotary motion feedthroughs to connect stepping motors. The five motors are located outside the pressure balance in order to avoid heating within the bell-jar. The stepping motor rotates a screw shaft via a flexible coupling. The weight lifter connected to the screw shaft travels vertically. Each combined weight set can be moved up or down using the weight lifter. The vertical position of the weight is controlled by stepping motor controller and two photo-interrupters. The piston and cylinder units available for these measurements have nominal areas of 980 mm², so that a mass of 1 kg corresponds to a pressure of 10 kPa

For calibration of 10 Pa pressure range, weights from 100 mg to 1 g are necessary and they are made from a thin stainless steel sheet with a thickness of 0.15 mm to 0.65 mm which was folded into a cylindrical shape. The weight has holes in the top and bottom in order to load and unload it from a turn table effectively. The measurement can be performed at 10 pressure points from 1 Pa to 10 Pa in steps of 1 Pa.



Fig.1. Photo of the calibration apparatus.

3. EXPERIMENT AND DISCUSSION

An experimental set-up used for a 100 Pa vacuum gauge is identical to the experimental set up used for traditional absolute calibration method except that the vacuum gauge is attached to the bell-jar. A precise barometer (Paroscientific, Model 760-16B) was used to read and monitor the pressure generated under the piston. The step by step calibration procedure is described as follows:

3.1 First, the zero-adjustment for the vacuum gauge under test is carried out by using high vacuum pump and compact cold cathode gauge (IKR 251, Pfeiffer Vacuum). In this case, a turbo-molecular pumping system (Leybold, Model PT-50) was used.

3.2 Next, the piston is floated with all the weights loaded on top of the piston. Then, the pressure inside the bell-jar is observed. Generally this pressure is slightly higher than zero.

3.3 The monitor pressure P_m is then determined with the assumption that bell-jar pressure is essentially zero ($P_0=0$).

$$P_m = \frac{(T + M_0)g}{A_e} + P_0 \quad (3)$$

where M_0 is the initial added mass, which is determined by the pressure range of monitoring gauge.

3.4 The desired weights are removed from the top of the piston, which causes the piston move upward slightly.

3.5 Using the pressure controller, the pressure inside the bell-jar is increased until the piston returns to its previous floating position. The pressure under the piston should be identical with the monitor pressure. The indications of the vacuum gauge under test are recorded.

3.7 The test pressure P_j value around the piston is then calculated by using Eqs. (2) and (3) as follows:

$$P_j = \frac{(T + M_0) - (T + M_j)g}{A_e} \quad (4)$$

The test pressure, P_j is only related to the mass change of the applied mass, with force calculated with the local gravity, and with the effective area of the piston-cylinder assembly. Note that in order to simplify the equation (4) we assumed that effective area is constant during calibration work.

3.8 In succession, another weight is removed from the top of the piston. The same procedures from 3.5 to 3.7 are repeated.

3.9 The same calibration procedure can be used to the pressure down mode calibration, except that the corresponding weight is added instead of being removed.

The initial tare mass is around 10 kg, including the mass of the piston and the mass-carrying bell. In order to investigate the low pressure limit, we focused the pressure points from 1 Pa to 10 Pa using 133-Pa CDG (MKS, Model 626A01TDE). The measurement was done at 11 pressure points. Fig. 2 shows calibration results of 133-Pa CDG. The horizontal axis represents the generated pressure calculated from the Eq. (4) and the vertical axis represents the correction values.

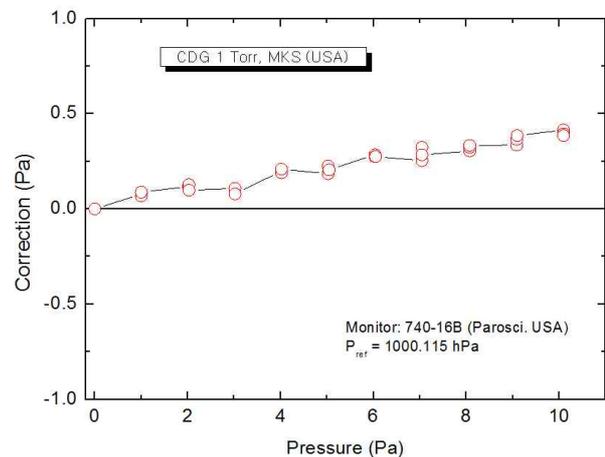


Fig.2. Calibration results of 133-Pa CDG. The calibration pressure points are restricted within 10 Pa limit.

Using this device, we can easily calibrate the built-in internal vacuum gauge inside PG7601. It has pressure range of 20 Pa. Fig.3 shows the calibration results of it.

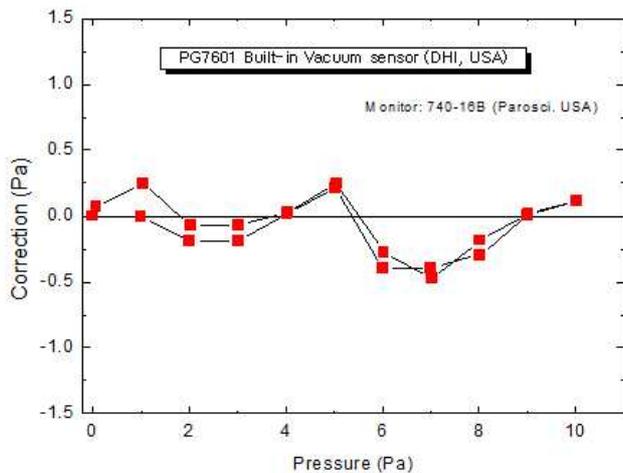


Fig.3 Calibration results of internal vacuum sensor installed in gas pressure balance, PG7601.

Fig.4 shows the calibration results of 133-Pa CDG. At 10 Pa, correction value is around 0.3 Pa. This result is in agreement with the earlier one shown in Fig.2.

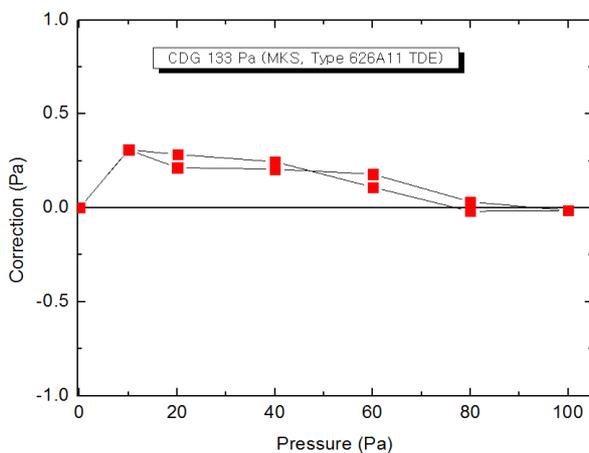


Fig.4 Calibration results of 133 Pa, absolute mode CDG.

The system performance is mainly limited by the uncertainty of the monitor pressure gauge and pressure gradient inside bell-jar chamber. Therefore, the monitoring gauge should have high performance characteristics such as high resolution, low drift and good repeatability. The quartz resonance pressure sensor is most likely gauge for this purpose. In order to minimize possible pressure gradients inside the bell-jar, we intentionally made 4 holes with a diameter of 8 mm on the side of the mass carrying bell. These holes are expected to play an important role by releasing the gas quickly inside and outside of the mass carrying bell.

4. CONCLUSION

A low pressure calibration device mounted on the base of a

gas-operated pressure balance has been developed. Using this device, we investigated the ultimate low-pressure limit attainable from gas pressure balance. The experiments show that the pressure down to 1 Pa is possible to measure using variable bell-jar pressure method. It may also be noted that one of the greatest advantages of this method is that the pressure measurements are based on the fundamental pressure definition and can be easily traceable to the national primary pressure standards with small uncertainty.

REFERENCES

- [1] C. M. Sutton et al, "Conventional pressure balances as reference standards for pressures in the range 10 Pa to 10 kPa", *Metrologia*, Vol.36, pp.517-520, 1999.
- [2] S.Y.Woo et al, "New apparatus for calibrations in the range of 2 kPa absolute pressure", *Metrologia*, Vol.42, pp.S193-196, 2005
- [3] H.W.Song, I.M.Choi, and S.Y.Woo, "Extended usages of pressure balance down to a few Pa", *MAPAN-Journal of Metrology Society of India*, Vol. 24, pp.119-124, 2009.