Investigation of Characteristics of 133 Pa CDG Using Pressure Balance

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Abstract: The purpose of this paper is to investigate the characteristics of precise low-pressure gauges such as Capacitance Diaphragm Gauge (CDG) devices in the range 133 Pa using a commercial gas-operated pressure balance. Generally the pressure balance is not adequate to calibrate such low pressure gauges as the minimum pressure to balance the tare weight corresponds to a pressure of several kilopascals. However using a variable bell-jar pressure method can overcome this difficulty. To realize this method effectively, we developed a new weight-handling device that makes it possible to add or remove weights easily. This apparatus is very useful to find the characteristics of such low-pressure gauges. Moreover, one of the greatest benefits of this method is the traceability to link directly to the gas pressure standard that is easily traceable to the national standard.

Keywords: CDG, pressure balance, characteristics.

1. INTRODUCTION

Capacitance diaphragm gauges are well-known electromechanical pressure 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 gauges. In order to characterize such accurate vacuum gauges, laser mercury manometers can be used. In this article, we introduce a calibration apparatus based on piston-cylinder technology. The minimum pressure that is necessary for balancing against tare weight, which generally corresponds to a pressure of several kilopascals, is overcome by adopting a variable bell-jar pressure method. To realize this method effectively, we developed a noble weight loading device. This device can be used to measure pressures from 10 Pa to 13.3 kPa in the absolute mode. However, we present here the calibration results only for CDG 133 Pa.

2. PRINCIPLE AND APPARATUS

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

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

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_{const} 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.

$$P_{const} = \frac{(T + M_j)g}{A_e} + P_j \quad (2)$$

where P_{const} is the pressure generated by the pressure balance, and remains constant during calibration. The pressure P_j is the ambient pressure around the piston and changes according to the weight change. This pressure can be varied from very low pressures. In this equation, M_j and P_j are variables. In other words, the change in ambient pressure can be related to the change in weight on top of the piston. 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.
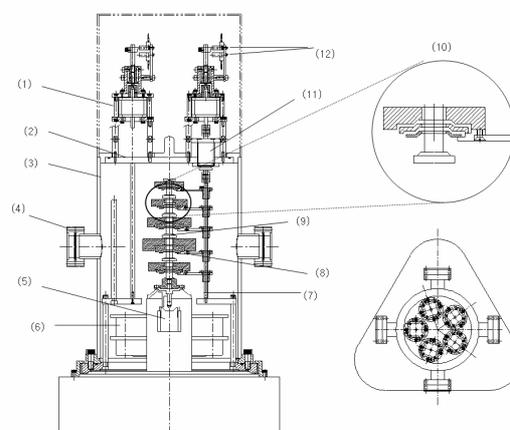

Fig. 1. New weight loading device.

This device is made for use in a commercial gas operated pressure balance manufactured by DH Instruments in USA. Figure 1 shows the details of the device with the operating mechanism. The device stores a stack of selected masses over the piston. The pressure balance was modified, in that the glass cover that contains the vacuum was replaced by a stainless steel chamber (3). The chamber is cylindrical with four 2.75" ports (4) 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 (2) was made with five holes that allow rotary motion feedthroughs (11) to connect stepping motors (1). 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 (7) via a flexible coupling. The weight lifter (8) connected to the screw shaft travels vertically. Each combined weight set (10) 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 (14). The piston and cylinder units available for these measurements have nominal areas of 980 mm^2, so that a mass of 1 kg corresponds to a pressure of 10 kPa.

Table 1. The weights for 133 Pa CDG calibration.

No.	Id.	Mass /kg	Density /(g cm^{-3})
1	1 g	0.0009996	2.71
2	2 g	0.0020009	2.71
3	4 g	0.0040029	2.71
4	8 g	0.0080040	7.89
5	3.33 g	0.0033330	2.71

The weight loading device consists of fifteen weights which cover in the range of 13.3 kPa. Table 1 shows only the masses and density values of the weights for 133 Pa calibration. The weights are in five sets. Each weight set is in three parts. The lower part is used only for 133 Pa calibration. The middle part put together with the lower part is used for 1.33 kPa calibration. The upper part put together with the lower part and the middle part is used for 13.3 kPa calibration. The mass ratios between them are 1: 10: 100. The mass ratio between the five weight sets is 1: 2: 4: 8: 3.3. Therefore, using the low range weight set, we can measure 14 pressures from 10 Pa to 133 Pa with spacings of 10 Pa.

The various sources of uncertainty associated with this calibration system are shown in the Table 2. The system performance is mainly limited by the uncertainty of the monitor pressure gauge. In order to reduce the uncertainties associated with it, smaller tare weights can be used on the top of the piston. This means that a low-pressure gauge with good performance such as a CDG can be a preference. It must be noted that one of the greatest benefits of this calibration system is that it can be easily traceable to national pressure standards.

Table 2. Uncertainties estimated for the calibration system.

Source of uncertainty	Standard uncertainty	
	$u_i(p)$	$u_i(p)/p \times 10^6$
Proportional		
Effective area of piston/cylinder		10.0
Tilt of piston/cylinder		1.3
Temperature of piston/cylinder		1.0
Additional weight		5.0
Acceleration due to gravity		0.3
Buoyancy correction		0.1
Non-proportional		
Barometer stability (short term)	0.10 Pa	
Fluctuation of applied bell-jar pressure	0.05 Pa	
Combined uncertainty (k=1)	0.11 Pa + 11.3×10^{-6} p	

3. EXPERIMENT AND DISCUSSION

A calibration set-up for 133 Pa CDG is the same as the traditional absolute calibration method except that the CDG is attached to the bell-jar and a precise barometer is used to monitor the pressure generated by the pressure balance. The calibration procedures are as follows. First, zero-adjustment for the CDG under test should be done. A turbo-molecular pumping system (Leybold, Model PT-50) was used in this experiment. After finishing zero-adjustment, all the weights are lowered on top of the piston. Then, by operating the pressure controller, the loaded piston is lifted up to its floating position. The indications of the monitor pressure gauge (Paroscientific, Model 760-16B) and the CDG under test, are read. Using equation (1), the correction values of the monitor pressure gauge are calculated. Then, the 1 g weight is removed from the top of the piston. The piston will rise slightly. Using the pressure controller, the bell-jar is filled with gas until the piston comes back to its floating position. The indications of the monitor gauge and CDG are read. Using equation (2), we can calculate the standard pressure, which is the ambient pressure around the piston. The ambient pressure P_j is only related to the mass of the applied weight and to the effective area of the piston-cylinder assembly. In succession, the 2 g weight is loaded onto, and a 1 g weight is removed from the top of the piston. Using the pressure controller, the required pressure is applied to the bell-jar until the piston comes back to its initial position. The indications of the monitor gauge and CDG are read. The same procedures are used for a subsequent calibration that is made by decreasing the weights, except that the corresponding weight is added instead of being removed. Finally, the five weights are reset onto the piston, and all the conditions are re-established.

The initial mass applied is about 9.6 kg, including the mass of the piston and the mass-carrying bell. Using this device, we calibrated a 133 Pa CDG (MKS, Model 626A01TDE) two times with a gap of one day. The calibration was performed at 14 pressures, respectively, with the measurements being made with both increasing and decreasing pressures. In figure 2, the horizontal axis is the generated pressure calculated from the equation 2 and vertical axis is the correction values. The deviation values between them, those are the negative of the correction

values, ranged from +0.25 Pa to -0.15 Pa, meaning that their relative uncertainties are within 0.25% of the full scale. This figure also shows the hysteresis of a 133 Pa CDG for different pressures. Comparatively large hysteresis values are found below 40 Pa. This seems to be caused by the difficulties of mechanical recovery of diaphragm. Figure 3 shows the calibration results of the 1.33 kPa CDG (MKS, Model 626A11TQE). For this experiment, the middle part of the weight set put together with the lower part is used as explained in section 2. Using the low and middle range weight set, we can measure 14 pressures from 100 Pa to 1.33 kPa with spacings of 100 Pa. The correction values ranged from 0 Pa to +0.15 Pa, meaning that their relative uncertainties are within 0.15% of the full scale. The correction values below 133 Pa obtained by using two different weight sets coincide well as shown in the figure.

developed. Using this device, the characteristics of commercial 133 Pa CDG were studied. The system performance is mainly limited by the stability of the monitor pressure gauge and temperature stability of CDG. In order to reduce the uncertainty associated with it, smaller tare weights for pressure balance and a temperature-controlled CDG can be used respectively. However, it should be noted that one of the greatest benefits of this device is the traceability to link directly to the gas pressure standard that is easily traceable to the national standard.

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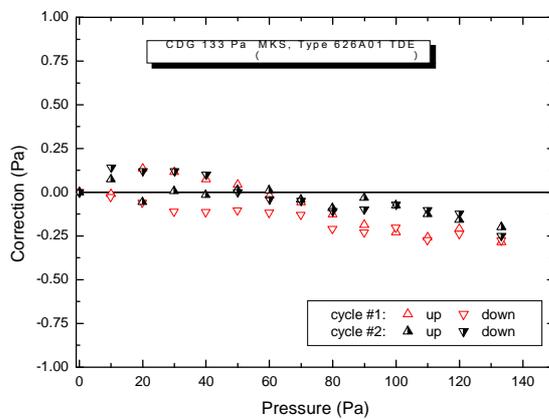
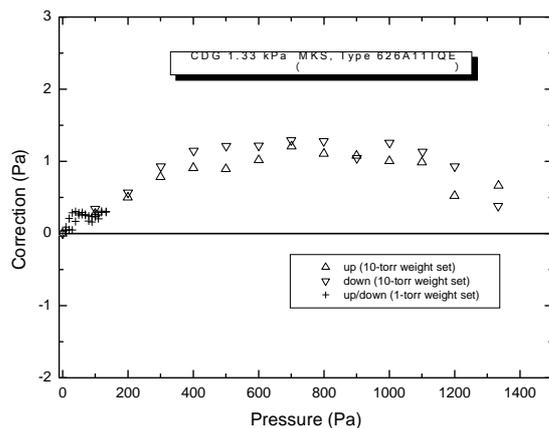Fig. 2. Characteristics of 133 Pa CDG.

Fig. 3. Characteristics of 1.33 kPa CDG. Multiple crosses represent experimental points obtained by using 133 Pa weight sets.

4. CONCLUSION

A CDG calibration device mounted on the base of a commercial gas-operated pressure balance has been