Measurement of the Sensitivity for Diving-bell Manometer

Jose Eduin Culma Caviedes

Instituto Nacional de Metrología, Avenida Carrera 50 # 26-55 Interior 2, Bogotá D.C., Colombia

ABSTRACT
Diving-bell manometers are devices mainly used for low-gauge measurements, with a variety of industrial and medical applications. At the Colombian *Instituto Nacional de Metrología*, a Junkalor Dessau TMG 25/1104 diving-bell manometer was subjected to sensitivity verification, with 200 mg as the discrimination threshold. Considering that this manometer works analogously to an equal arm balance, sensitivity is defined as the weight change on the balance that is needed to produce a movement larger that the smallest estimable fraction of a scale interval determined by visual interpolation component (resolution on the indicator element). Three set data points were evaluated: the first, with 20 g placed on each plate; the second, with 19.7 g on the left plate and 20 g placed on the right plate; and the third, with 20.3 g on the left plate and 20 g on the right plate. Recommendations for use of the diving bell are made and the resolution for the device was determined.

Corresponding author: Jose Eduin Culma Caviedes, e-mail: jeculma@inm.gov.co

1. INTRODUCTION

In general terms, according to Lipták [1] and Dryjańska [2], in all inverted bell pressure measuring devices, the bell is immersed into a sealed liquid. The immersion produces a vertical movement that is related to a difference of pressures between the bell's inner and outer surfaces. The bell's movement can be compared to a calibration spring or to its own weight. Depending on the reference side where pressure is measured, this device can detect absolute, positive, negative or differential pressures.

Different kinds of this type of device include single or double bells, with mercury or oil as the immersion liquid, and those designs where the bell's movement is connected to a differential pressure in a linear or square root way (Ledoux) [1]. Moreover, inverted bell pressure measuring devices are used extensively to evaluate very low pressure [2].

The diving bell manometer found at the *Instituto Nacional de Metrología* – INM (Colombian National Institute of Metrology) is a VEB Junkalor Dessau TMG 25/1104 model, made in 1982 [3]. This device has a range of measurement between − 1 000 and 1 500 Pa [4]. This range can be extended to values from − 1 000 to 3 000 Pa when Flourinert FC 40 is used as manometric liquid. Currently, kerosene is used as the operational liquid and this influences the produced pressure values obtained with this device [4].

This diving bell manometer is a single bell device, where the bell is suspended on the right the arm of an equal-arm balance (see Figure 1), weights can be placed on the both arms. According to Constantino et al. [5], small mass variations between one arm and the other are related to positive and negative pressure differentials.

Diving bell manometers, like the one found at INM, have been on the industry for a considerable amount of time. They have a variety of uses, including, but not limited to, air conditioning cost reduction, industrial leakage control and, as a result of recent quality control system implementations, serving as the standard in the calibration of other devices. They are also useful in medical equipment, pressurized rooms, and clean-room certifications because these places need a controlled atmosphere in order to offer proper working conditions and
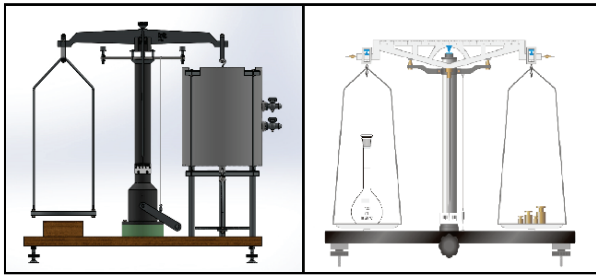
Figure 1. Similarity between a diving bell manometer and an equal-arm balance.

low infection risk [5].

However, inverted bell pressure measuring devices authentic importance is that, even considering that these devices are not traded like in the past, they can be simplified and updated to meet metrology's current needs [5]. Several articles show that they have a consistent use in different laboratories, as seen in works by Rantanen et al. [9], Ahrendt et al. [10], Perkin et al. [11] and Zvizdic et al. [12]. Most of these researchers worked on comparisons between inverted bell pressure measuring devices and other equipment used for analysing low pressure.

Nowadays there are others equipment available in the market that fulfill the Diving-Bell characteristics for low-pressure measurement. Some of the TMG 25/1104 model's characteristics, compared with similar devices can be seen in Table 1.

Inverted bell manometers are highly valued instruments and this is a reason to preserve and maintain them. Sensitivity verification is one of a series of efforts by INM toward this end.

Sensitivity is defined as the smallest weight change on the balance (it is considered that a diving-bell manometer works analogously to an equal arm balance—see Figure 1). This is necessary to produce a movement of a unit of change on the indicator element (in this particular case, the indicator needle) [13]. When the weight is on the left plate, the needle moves to the right. When the weight is on the right plate, the needle moves to the left.

In Section 2, we will discuss the methodology followed to evaluate the sensitivity in the diving-bell manometer, considering its similarity to an equal-arm balance. In the next two sections, results and conclusions will be shown.

Table 1. Comparison of measuring equipment for low pressure.

	Diving-bell manometer TGM 25/1104	Piston gauge manometer FPG8601 [6]	Low-pressure micro-manometer FCO510 Model 2 [7]	Portable commercial manometer ManoAir 100-1 [8]
Meaurement pressure range	-1 000 to 3 000 Pa [16] -1 000 to 1 500 Pa [4]	0 to 15 000 Pa	200 to 2 000 Pa	-2 000 to 2 000 Pa
Current status	Discontinued	Discontinued	On the market	On the market
Uncertainty	Not less than 0.3 Pa [16]	± 0.25 Pa + 0.003 reading percentage	-	Between ±0.05 y ±0.2 Pa
Special feature	Positive and negative pressures measurement	Reduced noise	Portability (weight is just 6 kg)	Positive and negative pressures measurement and portability
Manufacturer	VEB Junkalor	DH Instruments	Furness Controls	PCE Instruments

2. METHODOLOGY

2.1. Sensitivity analysis

For each plate, 30 observations were taken: 10 for 20.0 g, 10 for 19.7 g and 10 for 20.3 g. Certified weights were used, considering established reference parameters [14]. In total, 60 observations were taken. When weights varied in one of the plates, the other maintained a 20.0 g weight constant, following the instructions on OIML R 76-1 [15].
Three set data points were evaluated:
a) No difference: 20.0 g in both plates
b) Negative difference: 19.7 g and 20.0 g
c) Positive difference: 20.3 g and 20.0 g
These values were taken according to OIML R 76-1 [15]: "sensitivity evaluation must be done adding additional weights with a small impact in order to avoid any effects by discrimination threshold." Keeping in mind that the threshold is 200 mg, then 300 mg is a slightly higher value above this threshold.

Observations were taken following the methodology by Zvizdic *et al.* [12]. Moreover, these observations were randomized to ensure their independence.

According to its calibration certification, the diving-bell manometer is sensitive as long as a weight above 200 mg [16] produces a movement of a segment of scaling. The aim is to prove that a slightly higher weight (300 mg) can produce a movement higher than a segment of scaling. The best estimate of an analogue indicating device is determined by visual interpolation we call "AP" the number of times that the needle falls within two adjacent graduation lines [13] [17] [18]. In a practical sense, each segment of scaling was subdivided into 5 AP (see Figure 2). Accordingly, one hypothesis can be considered: the diving-bell manometer is sensitive if there is a significant difference among AP values for no difference versus AP values for positive and negative differences. In other words, if any AP value is not higher than 5 with additional weights above 200 mg, then the diving-bell manometer is not sensitive and it is not under its calibration conditional.

2.2. Statistical Analysis

Statistically, data was analyzed with a Kruskal-Wallis test, considering that their distribution was nor normal and that there are repeated values [19]. Keeping this in mind, with the Kruskal-Wallis test, it was possible to establish whether there were or were not significant differences on AP values obtained with no differences in weight and weight differences above the minimum weight defined for this diving-bell manometer sensitivity, according to its calibration certification [16].

3. RESULTS

ANOVA statistical methodology might produce unreliable outcome due to the fact that the data is about counting. This fact can affect some ANOVA characteristics such as normality and homoscedasticity. Therefore, the Kruskal-Wallis test is applied to avoid problems with these aforementioned
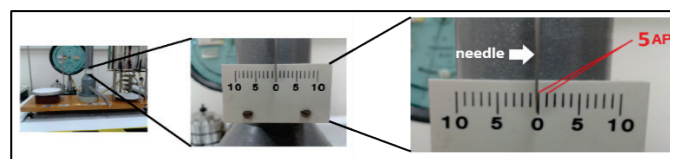

Figure 2. AP is the number of times that the needle falls within the lines.

characteristics. The null hypothesis is: Ho = The AP averages for different levels of weight variation on the left and right plate should not exceed a minimum AP value of 5.

For the left plate, obtained data (Table 4), was analyzed with R Software (Table 6), concluding the information given in (Table 2).

Moreover, this test showed that the highest AP value was for the 19.7 g level with a 6.5 average, and the lowest AP value was for the 20.3 g level with a 5.7 average.

Table 2. Kruskal-Wallis test results for the left plate.

Statistic test	$\chi^2 = 23.822$
p value	$p = 6.7 \times 10^{-6}$
Conclusion	With a 95% confidence level, it is possible to reject the null hypothesis. This means that there is a highly significant difference between average AP values for the different levels of weight variation for the left plate.

Table 3. Kruskal-Wallis test results for the right plate.

Statistic test	$\chi^2 = 25.215$
p value	$p = 3.3 \times 10^{-6}$
Conclusion	With a 95% confidence level, it is possible to reject the null hypothesis. This means that there is a highly significant difference between average AP values for the different levels of weight variation for the right plate.

Table 4. Left plate data and Kruskal-Wallis test.

Weight (g)	AP value	Range	Rm
20.0	0	1	5.5
20.0	0	2	5.5
20.0	0	3	5.5
20.0	0	4	5.5
20.0	0	5	5.5
20.0	0	6	5.5
20.0	0	7	5.5
20.0	0	8	5.5
20.0	0	9	5.5
20.0	0	10	5.5
19.7	5	11	12.5
20.3	5	12	12.5
20.3	5	13	12.5
20.3	5	14	12.5
19.7	6	15	19.5
19.7	6	16	19.5
19.7	6	17	19.5
20.3	6	18	19.5
20.3	6	19	19.5
20.3	6	20	19.5
20.3	6	21	19.5
20.3	6	22	19.5
20.3	6	23	19.5
20.3	6	24	19.5
19.7	7	25	27.5
19.7	7	26	27.5
19.7	7	27	27.5
19.7	7	28	27.5
19.7	7	29	27.5
19.7	7	30	27.5

For the right plate, obtained data (Table 5), was analyzed with R Software (Table 7), concluding the information provided in (Table 3).

Moreover, this test showed that the highest AP value was

Table 5. Right plate data and Kruskal-Wallis test.

Weight (g)	AP value	Range	Rm
20.0	0	1	5.5
20.0	0	2	5.5
20.0	0	3	5.5
20.0	0	4	5.5
20.0	0	5	5.5
20.0	0	6	5.5
20.0	0	7	5.5
20.0	0	8	5.5
20.0	0	9	5.5
20.0	0	10	5.5
19.7	5	11	16.0
19.7	5	12	16.0
19.7	5	13	16.0
19.7	5	14	16.0
19.7	5	15	16.0
19.7	5	16	16.0
19.7	5	17	16.0
19.7	5	18	16.0
19.7	5	19	16.0
20.3	5	20	16.0
20.3	5	21	16.0
19.7	6	22	24.0
20.3	6	23	24.0
20.3	6	24	24.0
20.3	6	25	24.0
20.3	6	26	24.0
20.3	7	27	28.5
20.3	7	28	28.5
20.3	7	29	28.5
20.3	7	30	28.5

Table 6. Kruskal-Wallis test data from left plate.

Weight (g)	$\bar{r}$	$\bar{r}_i$	$\bar{r}_i - \bar{r}$	n_i	$n_i(\bar{r}_i - \bar{r})^2$
19.7	15.5	23.6	8.1	10.0	656.1
20.0	15.5	5.5	-10.0	10.0	1000.0
20.3	15.5	17.4	1.9	10.0	36.1
H			21.834		
Correction			0.916		
H'			23.822		
p value			6.715E-06		

Table 7. Kruskal-Wallis test data from right plate.

Weight (g)	$\bar{r}$	$\bar{r}_i$	$\bar{r}_i - \bar{r}$	n_i	$n_i(\bar{r}_i - \bar{r})^2$
19.7	16.0	17.8	1.8	10.0	32.4
20.0	16.0	6.0	-10.0	10.0	1100.0
20.3	16	25.2	9.2	10.0	846.4
H			22.887		
Correction			0.907		
H'			25.215		
p value			3.345E-06		

for the 20.3 g level with a 6.2 average, and the lowest AP value was for the 19.7 g level with a 5.1 average.

4. CONCLUSION

Considering that both plates have significant differences and it is possible to conclude that the diving-bell manometer is sensitive due to the fact that the AP values on the plates are always higher than 5.0 AP when weights slightly heavier than 200 mg were placed on the plates. On average, for the left plate, the highest AP values were 6.5 AP while for the right plate the highest values were 6.2 AP.

The sensitivity of 300 mg is equivalent to a pressure of 0.15 Pa, however as the lowest measuring uncertainty for the diving-bell manometer is 0.3 Pa, then the contribution of the sensitivity must be included in the uncertainty budget of the diving-bell manometer.

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