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A didactic experiment to evaluate the calibration of pressure gauges in low-medium vacuum range

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A didactic experiment to evaluate the calibration of pressure gauges in low-medium vacuum range

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Abstract. The present study shows a didactic experiment, carried out in the Physics Institute of the University of São Paulo, evaluating the differences among measurements of four distinct pressure gauges (Pirani, thermocouple, and two thermistors), when compared to a McLeod standard gauge, in low-medium vacuum, ranging from 10^0 Pa to 10^1 Pa. The experiment aims to evaluate the measurement differences between four distinct pressure gauges and a standard. The results show that all tested gauges presented different results, demonstrating that calibration is necessary in order to have a full understanding of the measurement results of the tested pressure gauges.
Keywords: metrology; uncertainty; vacuum

1. Introduction

Pressure measurement is an important quantity in industrial, technological and research fields. Several highly technological industries, such as micro and nano technologies, aerospace, petrochemical and pharmaceutical industries are highly demanding on pressure measurements. Similarly, the research involving particle accelerators, mass spectrometers and surface physics experiments also relies on pressure. In the industrial area, a range of processes such as hydroforming, automobile pressing, vessel production, food sterilization and water jet cleaning are pressure dependent. Moreover, there are also medical applications, as blood pressure measurement, relying on pressure accuracy for proper diagnosis.

Some of the main applications in the range from: 10^{-1} Pa to 10^3 Pa are: Drying, distillation, e-beam welding, production of gas discharge tubes, steel degassing, blood pressure measuring devices [1].

In order to measure pressure inside a chamber, there are numerous sensors and devices designed to measure at a range covering low-medium vacuum, for example thermocouples, thermistor, Mcleod, Penning, Pirani, Bayard-Alpert, Bourdon, deadweight testers and others. In low-medium range, it is worth noting the following gauges: Pirani 10^{-3} – 10^1 Pa; thermocouple 10^{-3} – 10^0 Pa; thermistor 10^{-3} – 10^1 Pa and; Bourdon 10^1 – 10^3 Pa [2].

Regardless of their range, the mentioned pressure gauges measures pressure indirectly based on distinct physical working principles. The Pirani gauge measures pressure due to the variation of heated resistance filament in a Wheatstone bridge according to the temperature inside a vacuum chamber. Similarly, the thermocouple is based on the variation of the temperature inside the chamber, and the potential difference in the thermocouple junction. Finally, the thermistor uses a variable resistance instead of a heated filament, varying as a function of the temperature [2].

Calibration is a procedure that allows identifying both accuracy and precision of measuring instruments/sensors in order to use adequately the corrections from systematic deviations as well as uncertainties. The use of corrected values of any measuring instrument and uncertainty is vital in order to have a real understanding of the results, as well as its implications.

In order to visualize the aspects, such as accuracy and precision, regarding pressure measurement, the present study describes a didactic experiment conducted in the vacuum technology course, carried out in the Physics Institute of the University of São Paulo, to evaluate the influence of calibration of different pressure gauges for low-medium vacuum measurement. The experiment compares four distinct pressure gauges using a vacuum chamber and a standard gauge, in order to compute variations between the tested gauges and the standard.

2. Methodology

The experimental setup consists of a vacuum chamber connected to an Edwards no 8 mechanical rotary pump and a Veeco diffusion pump. Four pressure gauges under test were connected, independently to the vacuum chamber, comprising a: 1-thermocouple Rochester CVC GT-100, range from (0 - 1.33) hPa; 2-Pirani CVC GP-210, range from (0-13) Pa; 3-Pirani Edwards PRE 10K, range from (0.001 - 5) hPa; and two 4/5-thermistors GT 340-A, range from (0 - 6.6) hPa.

Moreover, a liquid nitrogen trap was set up between the system and a Leybold mercury McLeod gauge, range from (0.0001-1) hPa, used as the standard pressure. A needle valve is used to vary the pressure inside the system. An overview of the setup is given in figure 1. We used a McLeod gauge as a reference since it is considered a standard in pressure measurement, as its calibration parameters rely only on geometric parameters [3-4]. Laboratory environmental conditions were ranging between (23.6 - 24.1)ºC for temperature; (64 - 66)% for humidity and; (937 ± 1) hPa for atmospheric pressure.
The procedure comprised of using mechanical and diffusion pumps to P≅1 Pa, and slowly increasing the pressure, using the needle valve, up to P≅100 Pa, to cover the full range of the tested pressure gauges.

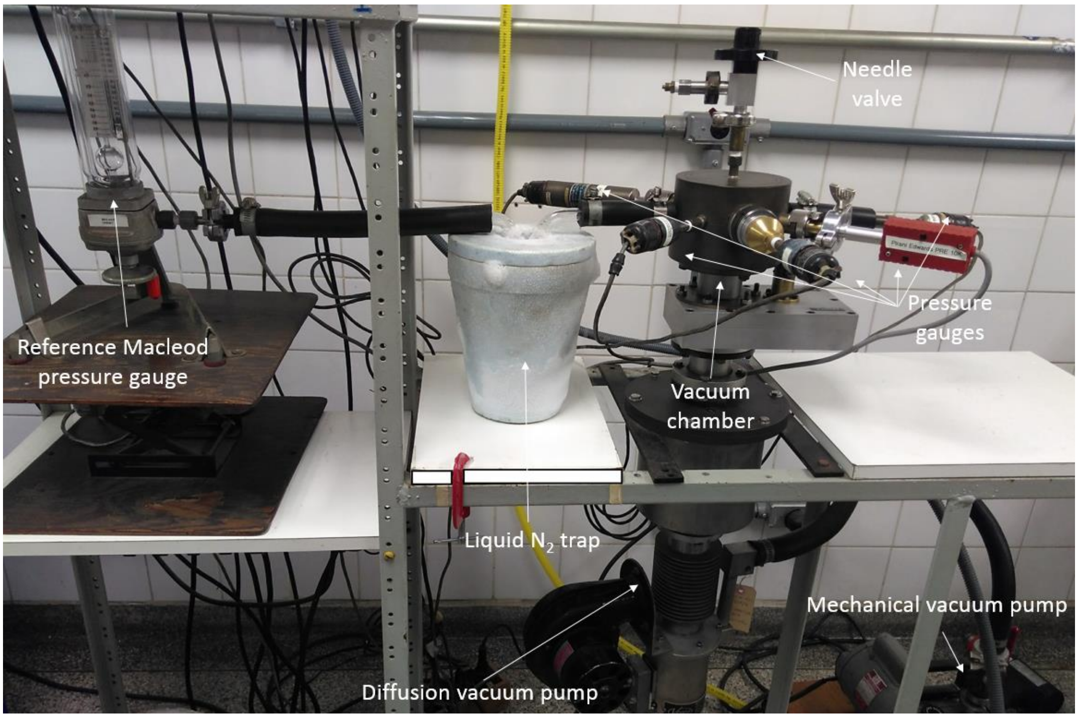

Figure 1. Overview of the experimental setup and tested pressure gauges.

Additionally, to consider uncertainty repeatability component of the pressure gauges, three distinct measurements were taken for each of the eleven measured values, totalizing 39 measurements for each tested gauge.

Finally, the expanded measurement uncertainty, for a confidence level of 95%, was computed using the variance from repeatability and resolution of the tested gauges, as well as the components from the McLeod standard regarding repeatability and resolution, according to the procedure described in the ISO GUM [5]. We only used two components of the uncertainty to simplify the experiment, since it is conducted for educational purposes.

3. Methodology

The results of the tested gauges, in comparison to a reference, McLeod mercury gauge, are given in table 1, as well as the expanded uncertainties for a confidence level of 95%. The results regards three distinct measurements considering the variance and the resolution of the tested gauges to compute the expanded uncertainty.

Table 1. Mean of three measurements in comparison to the McLeod standard and expanded uncertainty.

McLeod	1-Thermocouple	2-Pirani	3-Pirani	4-Thermistor	5-Thermistor
Mean / Pa	**(Mean ± U) / Pa**	**(Mean ± U) / Pa**	**(Mean ± U) / Pa**	**(Mean ± U) / Pa**	**(Mean ± U) / Pa**
1.1	4.2 ± 1.4	2.1 ± 1.1	2.8 ± 1.3	3.3 ± 1.2	2.4 ± 1.3
1.6	5.1 ± 1.4	3.4 ± 1.1	3.9 ± 1.3	3.7 ± 1.3	3.1 ± 1.3
2.7	6.4 ± 1.9	4.4 ± 1.3	4.7 ± 1.4	5.4 ± 1.8	4.0 ± 1.5
4.8	9.0 ± 1.4	6.4 ± 1.4	7.0 ± 1.7	7.8 ± 1.4	6.0 ± 1.4
5.6	10.6 ± 1.9	8.6 ± 1.4	7.9 ± 1.3	9.1 ± 1.2	6.9 ± 1.2
7.6	13.2 ± 2.1	12.4 ± 3.0	9.6 ± 1.9	11.2 ± 1.5	8.4 ± 1.5
14.3	21.3 ± 2.7	-	16.0 ± 3.2	23.6 ± 3.3	23.6 ± 4.1
22.0	29.3 ± 2.5	-	20.3 ± 1.6	32.9 ± 2.5	32.0 ± 2.5
32.3	42.7 ± 5.4	-	30.0 ± 4.7	51.1 ± 4.0	55.1 ± 4.7
47.7	60.0 ± 4.1	-	40.0 ± 3.2	88.4 ± 5.6	87.5 ± 7.4
93.3	93.3 ± 8.0	-	50.0 ± 5.5	200.0 ± 21.7	191.1 ± 18.8

For better visualization, the results are displayed in figure 2, regarding Pirani gauge which comprises the shorter range, from 1.0 to 13.0 Pa, and figure 3 comprising the pressure gauges in a range up to 200.0 Pa.

It is possible to observe difference among the gauges, especially for greater pressures inside the vacuum chamber, especially for values higher than 20 Pa, based on table 1 and figure 3, it is possible to observe the differences among the tested gauges, regardless the expanded uncertainty. One explanation for the difference regards on the physical working principle of the tested gauges. While both thermistor and Pirani gauges are based on the variance of resistance in a Wheatstone bright, the thermocouple is based on the potential difference in the thermocouple connection. Although the difference, the comparison to a standard allows the user proper correct them.

A second degree polynomial curve was also plotted as a calibration curve, representing the pressure as a function of the indication of the tested devices. The R2 parameter shows that a second degree polynomial curve is adequate as a calibration curve for the tested gauges in the range from 0 to 200 Pa. From the didactic perspective, it is possible to visualize the behavior of each pressure gauge as a function of the standard McLeod gauge results. Those systematic deviations shall be corrected in order to use yielded results.

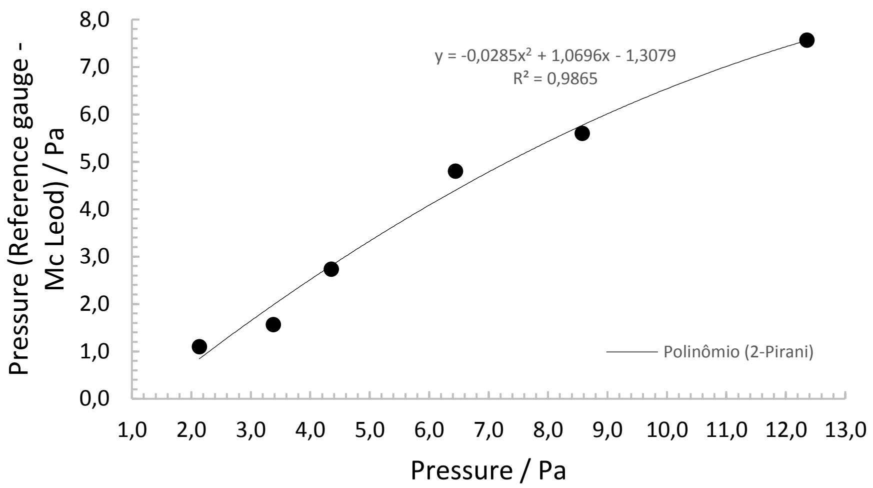

Figure 2. Results of tested pressure gauge in the range from 1.0 to 13.0 Pa.

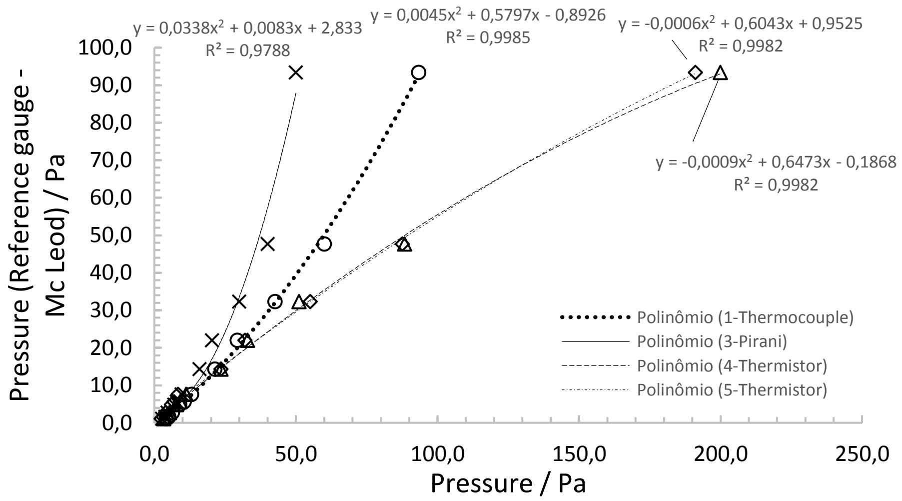

Figure 3. Results of tested pressure gauges in the range up to 200.0 Pa.

4. Conclusion

The didactic experiment conducted at the Physics Institute of the University of São Paulo allows the undergraduate students visualize how different pressure gauges, using distinct physical principles, behave in comparison to a standard device. Deviations from tested gauges can be observed, as well as the necessity for correction to avoid systematic measurement deviations. Finally, a simplified measurement uncertainty computation was also conducted to identify how the repeatability and the resolution of the tested devices influence the measurement.

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