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PROPOSED METHOD FOR GAUGE CALIBRATION BY A SERIES EXPANSION SYSTEM AT NML –CSIR, SOUTH AFRICA

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Abstract - There are various types of series expansion systems around the world, offering high accuracy for calibration of standards. The method investigated in this paper considers a much simpler system with a higher degree of certainty in measurements. The novelty of the method does not offer a new calculation, but rather a much-simplified design   Instead of using a high number of vessels, where the gas expands into, the system is limited to only two. The uncertainties will relate only to the pressure reduction factors or volume ratios and other known external factors.

1.   INTRODUCTION

High vacuum systems require adequate calibrated vacuum gauges. A series expansion system is intended for this purpose, by creating a known low pressure that can be measured against a gauge. The method employs the isothermal expansion of a gas of known pressure that takes place between two known volumes

$$p_i V_i = ct \qquad [1]$$

Since the expansion takes place between two volumes, for an ideal gas model

$$p_0 v = p_{\exp}(v + V) \qquad [2]$$

The uncertainty of the initial pressure p_0 can be measured within a low range with piston or oil column gauges.

2.   THE METHOD AND EQUIPMENT

The device (Figure 1) consists of two interconnected vessels, one small and one large (intended as a calibration vessel). The small vessel is used as initial volume v for expansion. Its pressure can be measured against a reference gauge G; this can be chosen as 100 kPa. The interconnecting volumes δv will have to be

determined for corrections to be applied to the results. The relevant measuring points will be the odd subscripts for the pressure and a general term can be written as

For the measurement of gauge standards the process employed is described below

During the first stage the pressure p_0 contained within the volume v expands into V

$$p_0 v = p_1(v + V) \qquad [3]$$

$$p_1 = p_0 \frac{v}{v + V} = \frac{p_0}{R} \qquad [4]$$

Where R stands for volume ratio $(v + V)/v \gg 1$

The second stage consists of closing the valve [1] after the equilibrium was achieved between the two vessels, and V is vacuumed out through the valve [2]. Opening the valve [1] again, the pressure p_1 will expand back into V:

$$p_1 v = p_2(v + V) \qquad [5]$$

$$p_2 = p_1 \frac{v}{V + v} = p_0 \frac{1}{R^2} \qquad [6]$$

For the third stage, the entire sequence repeats.

$$p_2 v = p_3(v + V) \qquad [7]$$

$$p_3 = p_2 \frac{v}{v + V} = p_0 \frac{1}{R^3} \qquad [8]$$

At this point, the expansion ratio is around 10^{-4}. The relevant measuring points will be the odd subscripts for the pressure and a general term can be written as

$$p_n = p_0 \frac{1}{R^n} \qquad [9]$$

Where $n = 1, 3, 5, ...$

The expansion process involves an extra term Δ, introduced by the vacuuming the small vessel, as an intermediate stage after closing the valve [1] and the equilibrium was obtained. The gas will be expanded back into the small vessel starting from expression [4]

$$p_1 V = p_2(v + V) \qquad [10]$$

$$p_2 = p_1 \frac{V}{v + V} = p_0 \frac{\Delta}{R} \qquad [11]$$

Where $\Delta = V/(v+V) \leq 1$ is a coefficient of transition and it is related to R as

$$\Delta = \frac{R-1}{R} \qquad [12]$$

The relevant measuring points will be the odd subscripts for the pressure and a general term can be written as

$$p_n = p_0 \frac{\Delta^{m-1}}{R^m} \qquad [13]$$

The index m takes values 1, 3, 5, … and the index n 1, 2, 3, 4, …

$$p_n = p_0 \frac{\Delta^{m-1}}{R^m} \qquad [14]$$

Where $n = 1, 2, 3, \ldots$, and $m = 1, 3, 5, \ldots$

$\Delta = V/(v+V) \leq 1$ is a coefficient of transition and is related to R as

$$\Delta = \frac{R-1}{R} \qquad [15]$$

The model described can reproduce entirely the initial conditions before each measurement.

As far as the baking process is concerned, the usual method of covering the system and heating it from the outside, a different approach was used. A heating element inside the vacuum chamber heats the surface, releasing the air trapped in the non-uniformities of the wall. Alternatively, a Getter Ion Pump can be used to sputter the inside wall metal ions.

A more expensive method in processing the inner surface of the vessels is to place an amorphous metal layer. In this way any inclusion of air can be eliminated.
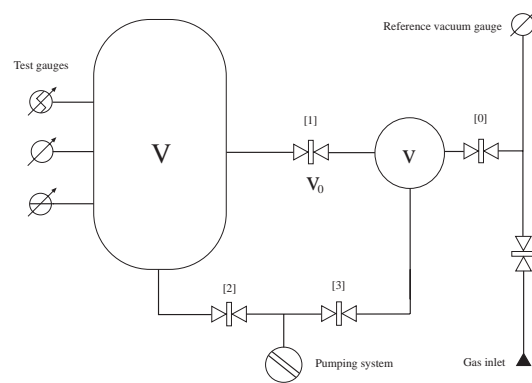

Fig.1. Schematic diagram of the proposed set up of the system

3. DETERMINATION OF THE VOLUME RATIO R, TEMPERATURE EFFECTS AND GAS PROPERTIES

In the process of calibration, the various methods for volume ratio determination can be employed, i.e. *successive expansion*, *linear gauge* or *reference gauge*.

The calibration of the system works as follows. The volume V is vacuumed and the valve [1] is opened, allowing the gas to expand. After equilibrium is established, valve [1] is closed. This represents the first stage. The volume v is refilled with gas at the same pressure of 100 kPa. The valve [1] opens and the gas expands from v into V again; this represents the second stage. The process repeats until the pressure in V builds up to a level compatible with an accurate reading, and the volume ratio can be obtained. For an nth order expansion the volume ratio is given by

$$R = \frac{1}{1 - \left(1 - \dfrac{p_n}{p_0}\right)^{\frac{1}{n}}} \qquad [14]$$

For very large n the final pressure in the large vessel converges to the initial pressure. The drift in the temperature will be responsible for the uncertainty of the volume ratio, for the reason that isothermal processes are ideal cases, therefore $1^0 K \sim 3 \cdot 10^{-3}$ of relative pressure $\Delta p / p$.

A correction of the non-ideal gas must be performed in the early stages of the process. As the gas expands, further no correction is needed.

For non ideal gas behaviour the formula [2] it is adjusted by a correction factor B" that can be taken from various charts as the Second Virial coefficient. This is a function of the type of the gas used.

$$\frac{p_i V_i}{1 + B'' p_i} = ct \qquad [15]$$

The B" coefficient has the dimension $[p]^{-1}$ and it is a function of temperature. Its value can be determined as function of Z, the real gas factor as follows:

$$B'' = \frac{1}{p}\big[Z(T, p) - 1\big] \qquad [16]$$

Temperature effects must be taken into consideration since the thermodynamic process involved is not isothermal and a drift in temperature can take place during the expansion process. The temperature changes arise from the Gay-Lussac effect.

Finally, the gas adsorption should be considered in relation to the type of gas used for expansion.

4. UNCERTAINTIES

Due to the fact that the system uses a minimal number of vessels, the uncertainties associated the measurement are also lowered significantly.

The usual uncertainty budget of the generated pressure includes
a. Initial pressure, Expansion ratio, Non-ideal gas behaviour, Temperature effects, Gas adsorption and Gad de-sorption (out-gassing).

5. CONCLUSIONS

The method described suggests that a simpler system can achieve the same results with lower uncertainties, where high accuracy is needed. The repetitive process using the same pair of vessels instead of a long system and the baking from inside the chambers simplifies the method to a minimum.
The actual system to perform the expansion was a modified two stages vacuum system.

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