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THE CEM LASER INTERFEROMETER MERCURY MANOBAROMETER

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Abstract – A laser interferometer mercury manobarometer (Fig. 1) has been designed and manufactured. It works from 1 kPa up to 130 kPa (gauge, absolute and differential modes) with line pressure up to 500 kPa. The uncertainty budget depends on the range and working mode. In absolute mode the expanded uncertainty ranges from 0.13 Pa up to 0.42 Pa.

Keywords : pressure, manobarometer

1. INTRODUCTION

The development of a pressure standard based on Pascal's and Torricelli's experiments started in 2000. After analyzing different prototypes of other NMI's, NPL prototype model was chosen as a starting point. Its main features were: columns at different heights, height difference measurement using laser interferometry against floating retro-reflectors and temperature control. In the end, the column has been tested with satisfactory results.

2. DESCRIPTION

The CEM laser interferometer mercury manobarometer works from 1 kPa up to 130 kPa (gauge, absolute and differential modes) with line pressure up to 500 kPa. Its main features are:

a) Granite structure.
b) Two 304 stainless steel tubes of 110 mm inner diameter and 750 mm length.
c) Temperature control.
d) Height measurement using laser interferometry against floating retroreflectors.
e) Wavelenghth compensation.
f) Automated operation.
g)

2.1. Structure

The manobarometer structure is totally made of granite. The supports of the mercury tubes are located on a granite base (2 x 1.6 x 0.2) m³. A U-shaped structure, which is mounted on the base, supports a triangular table, where the interferometry system is installed on, and two supporting tables, where wave compensators are located. All these tables are adjustable to allow appropriate levelling.

It has been installed placed on a concrete foundation with the same area, which is independent of the building, with the purpose of minimizing external vibrations.

Fig. 1. Laser interferometry mercury manobarometer

2.2. Temperature

In order to ensure a temperature of 20ºC all over the mercury volume, controlled temperature water flows inside a closed circuit around the columns. A thermostatic bath and a pump are used to control the water temperature. The temperature and its stability are measured by means of two PT25 and eight PT100. All of them are distributed evenly at different heights.

The highest contribution to the uncertainty for temperature is due to its instability. The maximum instability is smaller than 20 mK, so that an uncertainty contribution of 3.6×10^{-6} P can be assumed.

2.3. Mercury Density

The mercury comes from our country and it has been purified by distillation. Equation 1 was taken from the

Supplementary Information of ITS 90 [1] to determine mercury density:

$$\rho(t_{90},\frac{p}{2}) = \frac{\rho(t_{90},p_0)}{\left[1 + A(t_{90} - 20^{\circ}C) + B(t_{90} - 20^{\circ}C)^2\right]}\frac{1}{\left[1 - \chi(\frac{p}{2} - p_0)\right]} \qquad (1)$$

where:
A = 1.812 0 x 10^{-4} ºC^{-1}, B = 8 x 10^{-9} ºC^{-2}, χ = 4 x 10^{-11} Pa^{-1}, p_0= 101 325 Pa and ρ(20 ºC, p_0) = 13 545,854 kg·m^{-3}.

After studying the experimental values according to [2] a contribution to the uncertainty of 3.0 x 10^{-6}·ρ(20 ºC, p_0), k = 2, can be assumed.

2.4. Pressures in reference and measuring columns

Pressure inside the reference column is required to be measured in absolute and differential modes. In differential mode a pressure balance, which has been previously calibrated in gauge mode with the own mercury column and in absolute mode a 133 Pa full-scale capacitance diaphragm gauge (CDG) are used.

In absolute mode the CDG zero adjustment prior to the reference pressure measurement is required. In order to perform this adjustment a turbomolecular pump and an ionization gauge are used.

The final pressure in absolute mode inside the reference column is 0.5 Pa. This value was chosen to guarantee that the pressure value in the reference pressure column is higher than the mercury vapour pressure. In order to reach this pressure the turbomolecular pump and a mass flow controller are used. This value instability is ± 0.1 Pa.

Figure 2 shows the operation scheme of the reference pressure regulation system.

The pressure in the measuring column is controlled by means of pressure controllers, which can also generate pressure in the reference column in differential mode.

2.5. Gravitational acceleration

The gravitational acceleration have been measured with uncertainty below 0.6 x 10^{-6}·$\boldsymbol{g}$, k =2.

2.6. Height value

The height difference between mercury levels is measured using laser interferometry against floating retroreflectors.

As the Edlen compensation is only valid when the propagating environment is air close to atmospheric conditions, two laser trackers have been located in auxiliary columns in the same environmental conditions as the columns that contain the mercury. Figure 3 shows the length measurement system configuration. The wavelength can be adjusted under vacuum or atmospheric pressure conditions.

The floats are made of steel and tungsten carbide. They have an external diameter of 100 mm and an approximate mass of 1200 g.

In contrast to [3] a centring effect of the floats on the top of the mercury has been observed. This is, the 100 mm-diameter floats remain centred inside the 110 mm-diameter tubes and the laser beam maintains its way in spite of pressure variations.

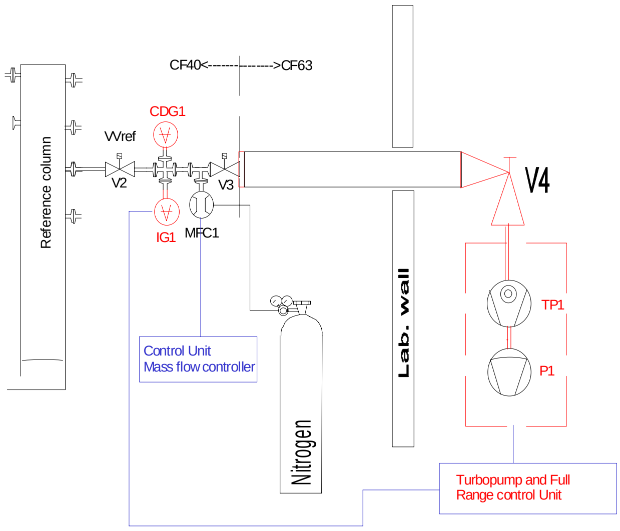

Fig. 2. Absolute mode. Reference pressure control system

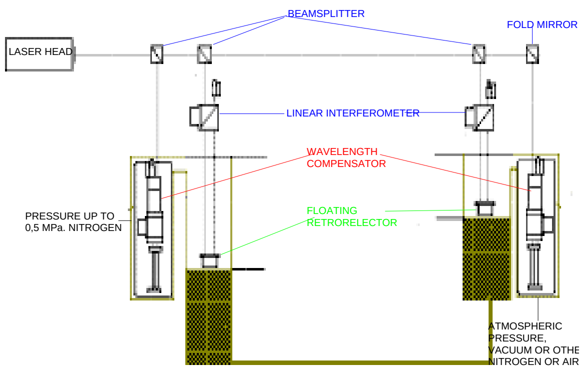

Fig. 3. Length measurement system

On the other hand, a correction in the height measurement is required due to the float immersion depth variation in the mercury with pressure. This effect only takes place in the measuring column because the reference column remains the same during the whole measurement process.

The float immersion depth variation depends on the pressures in the reference and measuring columns and the float geometry. Its value together with the influence due to the superficial tension on the float is determined experimentally; the correction is obtained by means of the variation with pressure of the interferometry system indication when both columns are communicated. The function is not a straight line due to the float geometry. The Figure 4 shows the experimental result and the float geometry can be appreciated in Fig. 5.

The uncertainty contribution for length measurement is 0.43 µm, so that an uncertainty contribution of 0.06 Pa can be assumed.

2.7. Mode of operation

Finally, in order to calculate the pressure, equation (2) can be applied in absolute mode:

$$P_{mc} = \rho(t_{90}, \frac{p}{2}) g_l (\Delta h + \delta h) + P_{rc} \qquad (2)$$

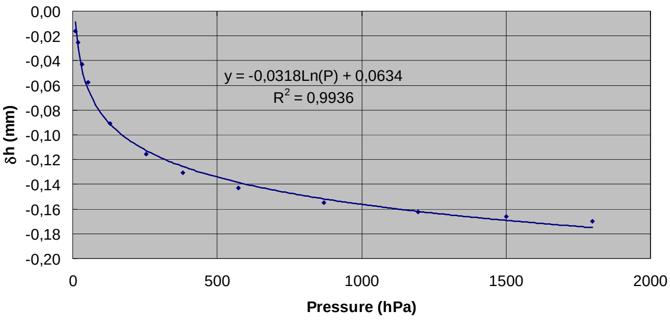

Fig. 4. Immersion depth and superficial tension corrections

Fig. 5. Float

where P_{mc} is the measured column pressure, $\boldsymbol{g_l}$ is the gravitational acceleration, Δh is the height, *idc* is the immersion depth correction and P_{rc} is the pressure in the reference column.

The manobarometer has been completely automated, but it also can work manually.

2.8. Uncertainty analysis by GUM method

Table 1 shows the uncertainty budget at 130 kPa when the GUM [4] is applied to equation (2).

Quantity *Xi*	Estimate xi	Standard uncertainty *u(xi)*	Unit	Probability distribution	Sensivity coefficient *ci*	Uncertainty contribution *ui(y)*
Hg density	13545,813	0,0112	$kg\cdot m^3$	Rectangular	9,60	1,08E-01
Drift Hg density	0	7,82E-03	$kg\cdot m^3$	Rectangular	9,60	7,51E-02
Temperature	20,02	0,0025	ºC	Normal	-2,36E+01	-5,89E-02
Temperature stability	0	0,0058	ºC	Rectangular	-2,36E+01	-1,36E-01
Pressure	1,30E+05	15	Pa	Normal	-2,60E-06	-3,90E-05
Pressure drift	0	17	Pa	Rectangular	-2,60E-06	-4,51E-05
Gravity	9,799485	9,80E-07	m/s^2	Rectangular	1,33E+04	1,30E-02
Gravity (Short term stability)	0	2,83E-06	m/s^2	Rectangular	1,33E+04	3,76E-02
Lenght	980	5,00E-05	mm	Rectangular	1,33E+02	6,64E-03
Lenght (Long term stability)	0	5,77E-05	mm	Rectangular	1,33E+02	7,66E-03
Float immension depth + superficial tension	0,165	0,000029	mm	Rectangular	1,33E+02	3,83E-03
Residual pressure	0,500	1,25E-03	Pa	Normal	1,00E+00	1,25E-03
Residual pressure (Long term stability)	0	7,22E-04	Pa	Rectangular	1,00E+00	7,22E-04
Residual pressure stability	0	0,058	Pa	Rectangular	1,00E+00	5,77E-02
Repetibility	0	0,0002	mm	normal	1,33E+02	2,65E-02
					u(P)	0,21 Pa
					U(P)(*k* =2)	0,42 Pa

Table 1. Uncertainty budget

2.9. Uncertainty analysis by Monte Carlo method

Figure 6 shows the probability density distributions when the values of the Table 2 are applied to equation (2) by means of both, Monte Carlo and GUM methods. Monte Carlo calculation has been performed with 300000 samples.

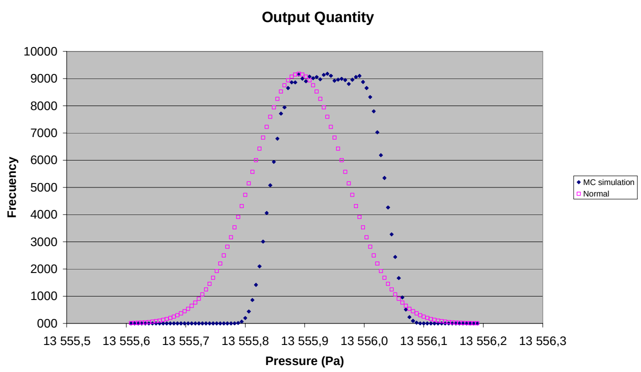

Fig. 6. Probability density functions.

Monte Carlo calculation shows that the resulting probability density function is not normal. This is a consequence of having two rectangular distributions as predominant.

3. CONCLUSIONS

A laser interferometer mercury manobarometer has been developed. It works from 1 kPa up to 130 kPa (gauge, absolute and differential modes) with line pressure up to 500 kPa. The uncertainty budget depends on the range and work mode. In absolute mode the expanded uncertainty ranges from 0.12 Pa up to 0.42 Pa.

REFERENCES

[1] Supplementary Information for the International Temperature Scale of 1990, Sèvres, BIPM,1990, 117p.

[2] H. Bettin and H. Fehlauer, "Density of mercury – measurements and reference values", *Metrologia*, vol. 41, nº.2, pp. S16-S23, April 2004.

[3] C. R. Tilford, "Three and a half centuries later – The moderm art of liquid-column manometry", *Metrologia*, vol. 30, nº.6, pp. 545-552, April 1993/194

[4] Guide to the expression of uncertainty in measurement. JGCM 100:2008.

Total number of Monte Carlo events	100000					
Input Quantity: Define el valor medio del parámetro			**Uncertainty:** Define la amplitud del valor del parámetro:			**Funcion de distribución**
Name	Value	Unit	Name	Value	Unit	
Hg density	13500,000	kg·m³	u_Hg density	1,94E-02	kg·m³	RL64_Rectangular semi-width
Drift Hg density	0,00E+00	kg·m³	u_Drift Hg density	1,35E-02	kg·m³	RL64_Rectangular semi-width
Temperature	2,00E+01	ºC	u_Temperature	2,50E-03	ºC	RL64_Gaussian standard deviation
Temperature stability	0,00E+00	ºC	u_Temperature stability	1,00E-02	ºC	RL64_Rectangular semi-width
Pressure	130000	Pa	u_Pressure	1,50E+01	Pa	RL64_Gaussian standard deviation
Pressure drift	0,00E+00	Pa	u_Pressure drift	3,00E+01	Pa	RL64_Rectangular semi-width
Gravity	9,799485	m/s²	u_Gravity	9,80E-07	m/s²	RL64_Rectangular semi-width
Gravity (Short term stability)	0	m/s²	u_Gravity (Short term stability)	4,89974E-06	m/s²	RL64_Rectangular semi-width
Lenght	980	mm	u_Lenght	0,00005	mm	RL64_Gaussian standard deviation
Lenght (Long term stability)	0	mm	u_Lenght (Long term stability)	0,0001	mm	RL64_Rectangular semi-width
Float immension depth + superficial tension	1,65E-01	mm	u_Float immension depth + superficial tension	5,00E-05	mm	RL64_Rectangular semi-width
Residual pressure	0,5	Pa	u_Residual pressure	1,25E-03	Pa	RL64_Gaussian standard deviation
Residual pressure (Long term stability)	0	Pa	u_Residual pressure (Long term stability)	0,00125	Pa	RL64_Rectangular semi-width
Residual pressure stability	0	Pa	u_Residual pressure stability	1,00E-01	Pa	RL64_Rectangular semi-width

Table 2. Input to Monte Carlo calculation.