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Characterization of LPM diving-bell manometer

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Abstract

This paper presents characterization of diving-bell manometer in the gauge pressure range from -1.0 up to 3.0 kPa in the Croatian national pressure laboratory - Laboratory for Process measurement (LPM), located at the Faculty of Mechanical Engineering and Naval Architecture (FSB), University of Zagreb.

The work points out comparison of two independent methods for diving-bell effective area determination i.e. determination based on dimensional measurements as well as determination of the effective area by a pressure comparison method.
The dimensional measurements were performed in the Croatian national length laboratory, also at FSB.

Determination of the effective area by the pressure comparison method was performed in LPM using a Physikalisch-Technische Bundesanstalt (PTB) Rosemount pressure transducer previously calibrated in PTB Braunschweig.
From the results it can be seen that the difference in the effective areas obtained with the two independent methods is very small compared to the estimated effective area measurement uncertainties.

Keywords: Diving-bell manometer, effective area, measurement uncertainty

1. Introduction

The Laboratory for Process Measurement (LPM) at FSB Zagreb is developing and maintaining national pressure, temperature and humidity standards. The performance of those standards is adjusted to the ratio of available resources and the calibration needs in Croatia.

In the low pressure range from -1.0 up to 3.0 kPa The LPM gauge working standard is diving-bell manometer traceable to PTB pressure standard. In order to improve diving-bell calibration capabilities double effective area determination was performed.

The pressure laboratory from the Physikalisch-Technische Bundesanstalt (PTB), Germany helped LPM in the establishment and characterization of this measurement system.

1.1 Theoretical Basis and System Design

The pressure, p_e, generated by a diving-bell manometer operating at its reference level is given [1] by:

$$p_e = \frac{\left[\sum_i \left[m_i \cdot \left(1 - \frac{\rho_a}{\rho_{mi}} \right) \right] \right] \cdot g}{A_0 \cdot \left[1 + 2 \cdot \alpha \left(t - 20 \right) \right]} \tag{1}$$

where A_0 is the effective area at the reference temperature, g is the local acceleration due to gravity, ρ_a, ρ_{mi} *are the* density of surrounding air and the density of the weights, m_i is the individual mass value of i-th weight applied on the bell, α is the linear thermal expansion coefficient of the bell and the cistern, t is the measured temperature of the bell during its use.

1.2 Metrological Characterization of The Standard

Characterization of LPM diving-bell assumed calibration of mass set, determination of local acceleration due to gravity, determination of diving-bell effective area and determination of other characteristics as weights density, tilt error analysis etc.
Since the most influencing quantity in overall pressure uncertainty is uncertainty of effective area, it has been measured twice, described in the following paragraph.

1.3 Determination of Effective Area From Dimensional Measurements

Dimensional measurements of inner and outer bell diameters, D_R, D_i *i* D_Z, as well as inner diameter of cistern containing the sealing liquid D_a, were performed for two pairs of orthogonal diameters (I-I, and II-II) at three different heights 1, 2 and 3, as shown in Figure 1. Difference in heights was 10 cm. Dimensional measurements were performed in Croatian national length laboratory at FSB. Outer bell diameter, D_R was measured at threecoordinate measuring device, and other diameters were measured by comparative method using universal measuring device with reference ring standard of 49,9988mm.

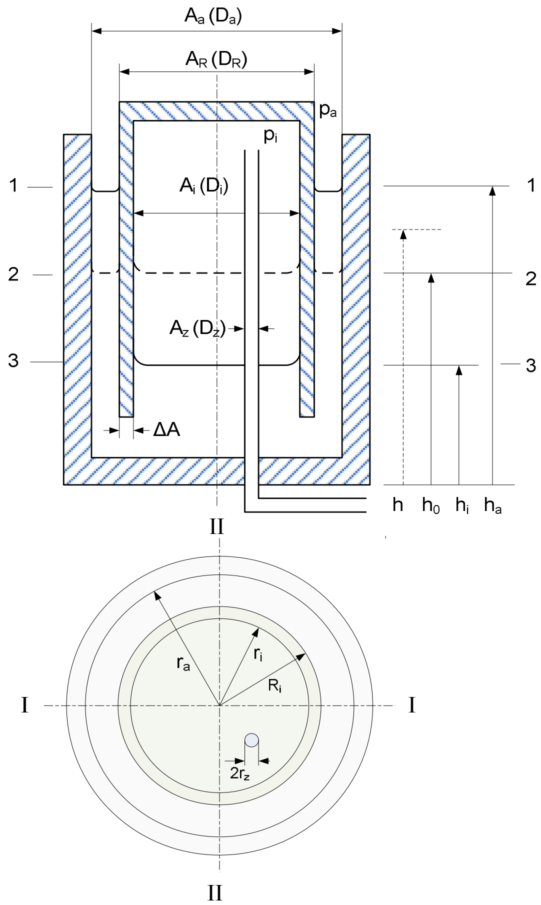

Figure1: Cross-sections of diving-bell manometer for dimensional measurements

Each diameter measurement was repeated five times. Average values with measurement uncertainties are given in Table 1.

Table 1: Average diameter measurement results

Level	D_a			D_Z	
	I-I	II-II	U (*k*=2)	II-II	U (*k*=2)
	mm	mm	mm	mm	mm
1-1	197,51	202,25	0,05	7,986	0,010
2-2	198,11	201,12	0,05	7,973	0,010
3-3	198,85	200,07	0,05	7,979	0,010

Level	D_R			Di		
	I-I	II-II	U (*k*=2)	I-I	II-II	U (*k*=2)
	mm	mm	mm	mm	mm	mm
1-1	160,002	159,854	0,020	159,470	159,104	0,020
2-2	159,852	159,583	0,020	158,871	159,095	0,020
3-3	159,911	159,867	0,020	158,821	159,061	0,020

Effective area from dimensional results was calculated according to [2]:

$$A_e = A_i + \Delta A \cdot \frac{A_i - A_z}{A_R + A_i - A_z} \qquad (2)$$

With areas $A_i = \pi \cdot r_i^2$; $\Delta A = \pi \cdot \left(R_i^2 - r_i^2\right)$; $A_z = \pi \cdot r_z^2$ i $A_R = \pi \cdot \left(r_a^2 - R_i^2\right)$

depicted on Figure2.

Each area was simply calculated as the average of all dimensional data from corresponding average diameters. Uncertainty of each area was calculated as the root mean square of the sum of the squares of the shape deviation and uncertainty contributions of diameters. Uncertainty due to shape variation was calculated as standard deviation of each diameter divided by the square root of the number of points. Expanded uncertainty was estimated as Type B combined uncertainty [3], calculating sensitivity coefficients derived from equation (2) and multiplying it by coverage factor *k*=2.

1.4 Determination of Effective Area by Comparison Method

The experimental determination of effective area has been performed between 0 and 1,23 kPa in four measurement cycles by direct comparison with Rosemount pressure transducer, transported from PTB. Pressure was calculated as linear change of voltage output signal U_{min}= 0,4 up to U_{max}=2 V which is representing pressure from p_{min}=0 up to p_{max}=1,6 kPa.

Voltage drop across fixed resistor was measured with digital multimeter (DMM) as shown in Figure2.

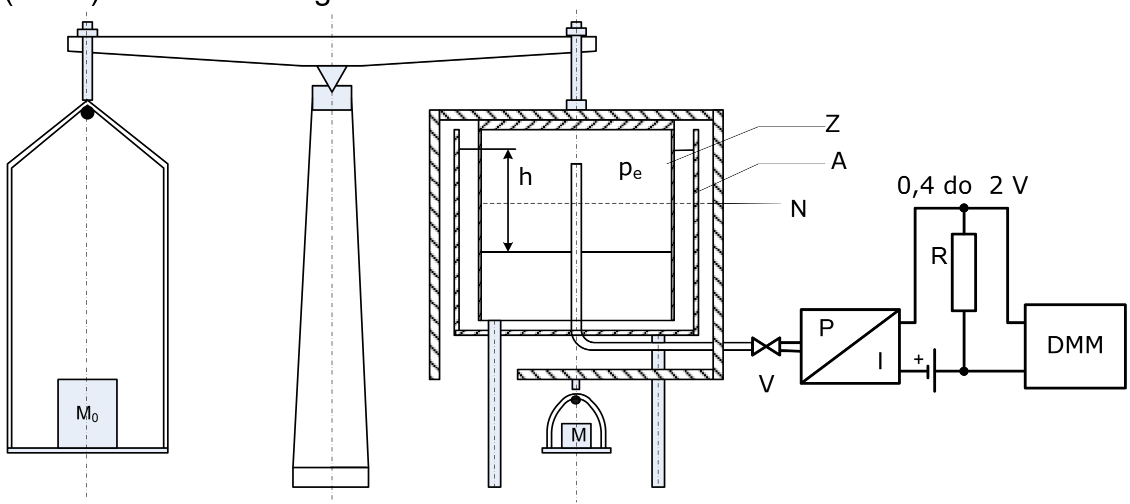

Figure 2: Calibration set-up for diving-bell manometer:
N-reference level; Z-bell, A-cistern

Zero pressure effective area was determined from measured pressures and masses m_i as:

$$A_e = \sum_i \left[m_i \cdot \left(1 - \frac{\rho_a}{\rho_{m_i}} \right) \right] \cdot g \,/\, \left[p_e \cdot \left[1 + 2 \cdot \alpha \cdot (t - 20) \right] \right] \qquad (3)$$

Expanded measurement uncertainty was estimated according to standard PTB procedure.

2. Results

Results of diving-bell effective areas calculated by different methods with estimated measurement uncertainties are given in Table 2.

Table 2 : LPM and PTB effective area results

Method	Laboratory (year)	A_0 (cm^2)	$U(A_0)$ (k=2) (cm^2)	$(U(A_0)/A_0)\cdot 10^{-6}$ (ppm)
comparison	PTB (2005)	199,950	0,063	315
dimensional	LPM (2005)	199,968	0,150	750

Figure 3 presents diving-bell calibration history including ''old'' PTB calibration result from 2000 year.

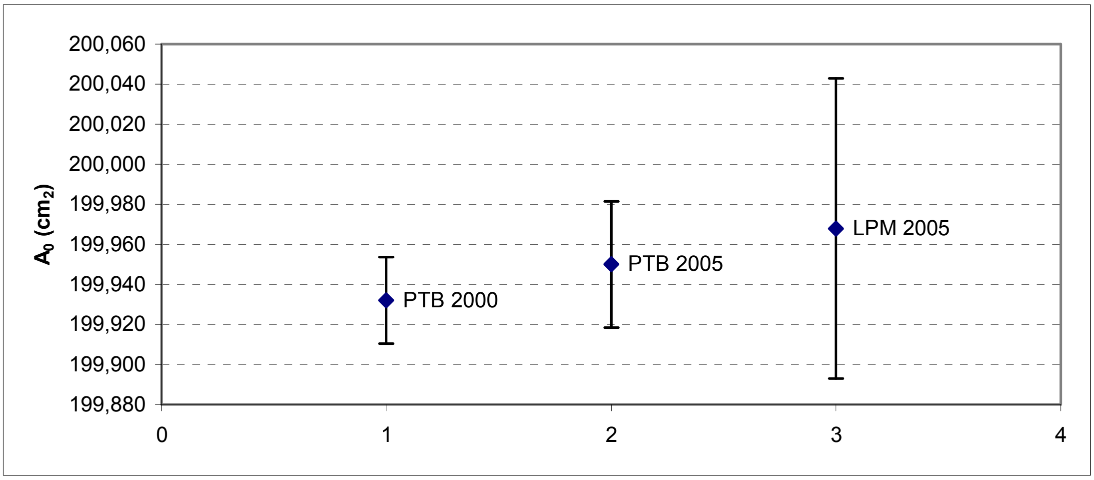

Figure 3 : LPM diving-bell calibration history

Following table presents effective area results assuming PTB result (A_{0PTB}) as reference and calculating deviation E_n, normalized with respect to the evaluated measurement uncertainty.

$$E_n = \frac{A_{0LPM} - A_{0PTB}}{\sqrt{\left(U(A_0)_{PTB}{}^2 + U(A_0)_{LPM}{}^2\right)} \tag{4}$$

Table 3. Deviation of A_0 from the PTB results

Results		Deviation	Measurement uncertainty (k=2)		
A_0 cm^2	$A_{0\,PTB}$ cm^2	A_0-A_{0PTB} cm^2	U_{LPM} cm^2	U_{PTB} cm^2	En
199,968	199,950	0,018	0,150	0,063	0,11

3. Conclusions

Diving-bell metrological characterization procedure has been described. From the results it can be seen that the difference in the effective areas obtained with the two independent methods is very small compared to the estimated effective area measurement uncertainties. Big measurement uncertainty of LPM dimensional method is consequence of high shape variations.

References

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