# EVALUATION OF PRESSURE DISTORTION COEFFICIENT FOR 200 MPa PISTON CYLINDER ASSEMBLY


A.E.Eltawil*,S.S.Kishk*,A.M.Fawzy*,M.A.Kenawy** and M.I.Elanwar ***

* National Institute for Standards - Tersa Street, El-Haram, El-Giza
** Faculty of Women for Art, Science and Education -Ain Shams-University
*** National Research Center.- Eltahrir Street, Doki Giza



## ABSTRACT

Recently a special attention has been given to the design and metrological characteristics of pressure balance, in particular to the evaluation of pressure distortion coefficient of piston cylinder assembly effective area. In high pressure range namely above 50 MPa, a change of the effective area of piston cylinder units due to elastic distortions becomes one of the main sources of uncertainty of the measured pressure. The elastic distortion coefficient for piston cylinder unit of range 200 MPa used at National Institute of Standards (*NIS)* was measured through cross-floating experiment and calculated using the finite element analysis method *(FEA)*. The results obtained by these means (numerical and experimental) were compared for the NIS piston cylinder assembly up to 200 MPa.



**KEY WORDS:**

Pressure, Pressure balance, Distortion coefficient, Finite element analysis *(FEA)* , Cross-floating


## 1. INTRODUCTION

The pressure primary standard, that can metrologically be characterized in a complete and an independent way with reference only to the basic units of the *S.I.* system, is defined as force per unit area (pressure balance) or the height of a liquid column (liquid manometer). Pressure balances are excellent primary standards for measuring pressure with high resolution and high accuracy. A pressure balance is essentially made up of a piston cylinder assembly *(PCA)* and a system for the application of a known vertical load on the piston [1-2]. In the case of high pressure measurements because of high pressure gradient in the clearance of the *PCA* which give rise to elastic distortion that modify the *PCA* effective area. In this work it is aimed at the measurements and calculation of pressure distortion coefficient for *NIS 200 MPa* piston cylinder assembly with experimental cross floating technique and numerical method using finite element method.

## 2. Measurement of Distortion Coefficient using Cross Flow Technique

Different methods have been utilized for elastic distortion calculation and measurement; the cross floating method [1-3], and finite element calculation method [4-6] provide the lowest uncertainty. The effective area of the piston-cylinder assembly under test, as a function of pressure $A_T$(p), could be calculated using the equation

$$\frac{W_s}{A_s(p)} = \frac{W_T}{A_T(p)} \qquad (1)$$

Where, $W_S$ is the applied weights on the standard *PCA*.
$W_T$ is the applied weights on the under test *PCA*.
$A_S(p)$ is the effective area of the standard *PCA at pressure p*.

Knowing both $W_S$ and $W_T$ and using the effective area of the standard pressure balance, given in the calibration certificate, [7] $A_T(p)$ could be calculated.

1. One of the most critical problems regarding the performances of pressure balances is the determination of the effective area which is usually carried out using cross floating experiments. On using a pressure balance as standard instrument, the cross floating method is carried out at each measuring point according to the standard method specifies in [8-9]. Such calibration repeated 3 times in increasing and decreasing pressures. Set up of the cross floating experiment is shown in fig (1).

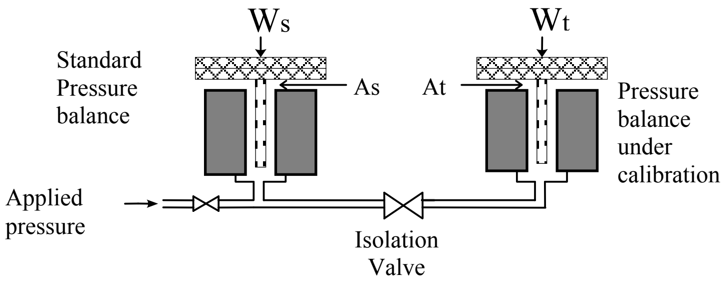


**Fig.(1)** Schematic diagram illustrating the cross floating experiment set up
From the analysis of the cross flow experimental data, three cases can arise [2]:

1. $A_t(p)$ is independent of pressure , i.e.

$$A_t(p) = A_o \tag{2}$$

Where, $A_o$ is the effective area at zero pressure

2. $A_t(p)$ is a linear function of pressure ,

$$A_t(p) = A_0(1 + \lambda P_i) \tag{3}$$

3. $A_{P_i}$ is a second order polynomial of pressure ,

$$A_t(p) = A_0(1 + \lambda P_i + \lambda^2 P_i^2) \tag{4}$$

Where, λ is the distortion coefficient of the piston cylinder.

For the first case, the effective area is simply the mean of all the determinations while in the second and the third cases $A_o$ , λ and $\lambda^2$ could be calculated from the least square fitting.

### 2.2. Distortion Coefficient Calculation using Finite Element Method

For PCA Dadson et al [2] derived a formula for the effective area depending on the geometry of the piston cylinder assembly, geometrical imperfection of the balance components and elastic distortions. The force $F$ acting on the piston cylinder was determined as:

$$F = \pi P_0 r(0)R(0) + \pi \int_{y_J}^{y_L} P(y)\left[ R\frac{\partial r}{\partial y} + r\frac{\partial R}{\partial y} \right] dy \tag{5}$$

Where, $P_o$ is the generated pressure
$P(y)$ is the pressure at the point y in the clearance
$r(0)$ and $R(0)$ undistorted radii of the piston and cylinder
$r(y)$ and $R(y)$ distorted radii of the piston and cylinder

The elastic distortion coefficient *(λ)* could be calculated according to the following formula [10]

$$\lambda = \frac{1}{P_0}\left[\frac{F}{P_0 A_0} - 1\right] \quad (6)$$

The radial displacements of the jacket surfaces of the piston and cylinder bore are calculated using the Cosmos/M *FEA* program, where the geometry of the unit and elastic properties of its material were described, the model was meshed with axi-symmetric *2D* elements using 1000 elements, and pressure loads as well as constraints were applied to the model. The pressure distribution along the engagement length as described in [11-12] was applied. As a solution, radial displacements of the element nodes lying on the generatrix of the piston and cylinder bore were calculated.

The main characteristics of our *NIS 200 MPa* piston cylinder assembly and the properties of the used oil are given in table (1)

**Table (1)** main characteristics of *NIS 200 MPa PCA*

| **Property** | **Value** | **Property** | **Value** |
|---|---|---|---|
| *PCA* type of geometry | Simple | *PCA* Material | tungsten carbide |
| Measurement range | | Young's modulus | (630 ± 30) GPa |
| Piton radius | 4 to 200 MPa | Poisson ratio | 0.218 ± 0.002 |
| Cylinder radius | 1.2486 mm | Oil used | Sebacate |
| Undistorted clearance | 1.2492 mm | Density of used oil | 913.4 |
| | 0.6 μm | Viscosity of used oil | 0.021 $Pa^{-1}$ |

## Piston cylinder modeling and geometry:

Adopting the hypothesis of axial symmetry [4], the coordinates of the principal points, those shown in figure (2) of the *NIS200 MPa PCA* are listed in table (2)

**Table (2)** coordinates of the principal points of the *NIS200 MPa PCA*

| Point | X (mm) | Y (mm) | Point | X (mm) | Y (mm) |
|---|---|---|---|---|---|
| A | 0.00000 | 47.40000 | H | 8.49400 | 36.98800 |
| B | 0.00000 | 0.00000 | I | 0.00000 | 10.00000 |
| C | 1.24863 | 0.00000 | J | 1.24863 | 10.00000 |
| D | 1.24863 | 47.40000 | K | 0.00000 | 36.98800 |
| E | 1.24932 | 36.98800 | L | 1.24863 | 36.98800 |
| F | 1.24932 | 10.00000 | M | 5.89393 | 36.98800 |
| G | 8.49400 | 10.00000 | N | 2.39400 | 10.00000 |

## 4 RESULTS AND DISCUSSION

*NIS* 200 MPa *PCA* was calibrated as described above over the range (20-200) MPa. The repeatability of the cross floating experiment against the applied pressure for the three calibration cycle is found to be less than 6 ppm that gives good indications about the performance of the cross floating experiment

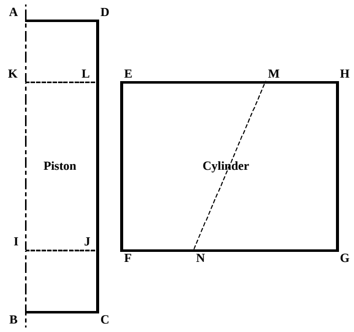


**Fig. (2)** simplified model of the *NIS200 MPa PCA*

The calculated values of the effective area at zero pressure ($A_o$) and the elastic distortion coefficient *(λ)* using experimental results and equations (1& 3) are presented in table (3).

Analysis of the uncertainties related to the calibration was obtained in accordance with the Guide for the Expression of Uncertainty in Measurements [13].

The standard uncertainties were calculated from the contributions of uncertainties originating from the measurement standard, from the calibration method and environmental conditions, as well as from any short term contribution from the object being calibrated.

**Table 3** Calibration Results

| **Parameter** | **Value** | **Uncertainty (k=1)** | **Relative uncertainty** |
|---|---|---|---|
| Effective area at zero pressure ($A_o$) | 4.90226996 $mm^2$ | 9.5 E-5 $mm^2$ | 19.4 (ppm) |
| Elastic distortion coefficient *(λ)* | 7.97 E-7 $MPa^{-1}$ | 3.1 E-8 $MPa^{-1}$ | |

### 4.2 Results of the Finite Element Method

After obtaining the redial displacements, for both piston and cylinder, a special written, Visual Basic code, software was used to solve equation (5) for redial displacements. The obtained radial displacements were used to feed a visual basic code program especially written for pressure distortion coefficient calculations *(λ)*. Calculations were made using material constants tabulated in table (1). The distortion coefficient *(λ)* as calculated was found to be 8.12E-07 $MPa^{-1}$. Comparing our results of the distortion coefficient *(λ)* obtained experimentally (cross floating method) with that obtained numerically *(FEA)* and within its expanded uncertainty.

## 2. <u>CONCLUSIONS</u>

In conclusion to this paper we found:-

i. A repeatability of less than 6 ppm has been achieved in cross flow experiment for effective area measurements.
ii. The pressure distortion coefficient *(λ)* could be calculated using commercially available finite element software with values which comply with the experimental results.
iii. Comparison between the result obtained from *FEA* and cross flow indicated that the *FEA* methods work well, quickly and accurate as well as the reliability of the proposed model. A difference of 1.85% between the two methods, which lies within the standards uncertainty of "*λ*" obtained from cross flow.

## REFERENCES


[1] Guide to the measurement of pressure and vacuum, the institute of measurements and control. HMSO, London, 1998.

[2] Dadson R.S., Lewis S., Peggs G.N.,: the pressure balance theory and practice, Teddington, UK, National Physical Laboratory, 1982.

[3] Pavese F, Molinar G F, Modern gas-based temperature and pressure measurements Eds K D Timmerhaus, A F Clark, C Rizzuto (New York: Plenum Press) pp 273-356, 1992.

[4] Buonanno G., Dell'Isola M., Iagulli G., Molinar G., High Temperatures High Pressures 31, 131-143 , 1999.

[5] Molinar G, Sabuga W, Robinson G, Legras J, Metrologia 35, 739-760, 1998.

[6] V. Fiori, Study of fluid flow in a pressure balance. BNM-LNE translation 2001.

[7] BNM-LNE Calibration certificate No. A050271/1, 2000.

[8] OIML R110, Edition (E), 1994.

[9] EAL- G26, Calibration of pressure balance, Edition 1, 1997.

[10] Sabuga W., PTB- Bericht, W-60, 1995.

[11] Woo S.Y., Lee K.H. Proceeding of the second international workshop, New Delhi, 2001.

[12] Study of pressure distortion coefficient of NIS 200MPa piston cylinder assembly, Journal of Faculty of Education Ain Shams University, 27, 2002, 257-269. M.A.Kenawy, S.S.Kishk, A.M.Fawzy, A.E.Eltawil

[13] Guide for the expression of uncertainty in measurements, 1st ed., prepared jointly by ISO/ TAG4/ WG3, IEC, OIML ,BIPM, ISO, 1993.