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Establishing Primary Gas Pressure Standard facility – (0.140 to 70) bar Gas Piston Gauge at FCRI and its applications

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ABSTRACT

Physical Standards Laboratory of FCRI has commissioned and NABL accredited a Ruska Model 2465 Piston Gauge operated using ultra pure Nitrogen gas. The Ruska Gas Piston Gauge has a history of serving national standards laboratories, commercial industry and government organizations as primary pressure standard for over 40 years. This Piston Gauge is a Primary Pressure Standard in which pressure is achieved by the fundamental physical quantities –length, mass and time. The operating range of this Piston gauge is (0.140 to 70) bar – both in gauge and absolute modes. This piston gauge was used for evaluating the performance of (0.25 to 7) bar g Air Dead Weight Tester, (1 to 70) bar g Air Dead Weight Tester, (30 to 2620) mbar a Druck DPI145, (0 to 20) bar a Druck DPI145 and Beamex MC 6 multifunction calibrator of (0 to 70) bar g range. The results and analysis of the performance evaluation are presented. The achievable uncertainty level using the Ruska Piston was found to be within 0.003% of reading. This equipment will serve as a primary pressure standard for calibrating pressure instrumentation of Standards laboratories, aviation and aircraft industries, gas transmission companies, refineries and process industries, pharmaceutical, atmospheric sciences, metallurgy, human healthcare and space applications. Accurate measurement of pressure is essential in determining the gas density and also gas flow measurement applications.

KEYWORDS:

Piston gauge, traceability, dead Weight Tester, effective area of Piston Cylinder unit

1.0 INTRODUCTION:

"Maintenance of traceability of reference standards for basic parameters related to fluid flow, to the National Measurement System and Maintenance of Quality system as per relevant international standards (such as ISO/IEC 17025-2005)" is one of the main part of Quality Policy of FCRI. In order to accomplish this, Physical Standards Laboratory (i.e.,PSL) was established in 1989 along with the flow measurement facilities. PSL is one of the first NABL accredited laboratory in the country in Mechanical measurement category and today, the only single laboratory covering a wide range of parameters in the area of Mechanical Calibration covering - Length, Mass, Volume, Density, Pressure - Gauge Vacuum, Barometric Pressure, Low / Medium and High Pressure (Pneumatic and Hydraulic), Viscosity, Force, Torque etc. PSL has participated in various Proficiency Testing programmes, organized by NPL/NABL/APLAC at national and international level.

PSL is equipped with the most reliable and sophisticated state-of-the art calibration equipment and is manned by trained and experienced personnel, operated under controlled environmental conditions of temperature (20±1.0)°C, Humidity 50±10% Rh, Dust level 1,00,000 class. All the master instruments are regularly calibrated at NPL, New Delhi /International laboratories to maintain traceability. Calibration activities are carried out with established procedures in conformance with BIS / OIML/ ISO / ANSI / ASTM/ BS specifications or validated in-house procedures.

2.0 DESCRIPTION OF MASTER AND TEST INSTRUMENTS

Piston gauge is a primary standard for pressure. It establishes the relation between the applied pressure and the fundamental physical quantities as defined for pressure involving length, mass and time.

The detailed specifications of the piston gauge is as follows :
Operating range : (0.140 to 70) bar – both in gauge and absolute modes
Model(Piston-Cylinder) : 2465-729
Material of construction Piston and cylinder : Tungsten carbide
Coefficient thermal expansion of piston/cylinder : 9.1E-06 /ºC
Certified uncertainty rating : 0.0012% rdg. (12 ppm)
Long Term Stability: 1 ppm per year
Operating temperature range : 18 to 28 ºC
Working medium: The operating medium of this equipment is ultra high pure nitrogen gas.

The primary feature of the gauge is its ability to accurately reproduce its performance at the lower pressure. The low viscosity of the gas provides excellent lubrication for the close-fitting piston/cylinder assembly. Relative motion between the piston and cylinder is necessary and is obtained by an electric motor which is used to distribute the gas molecules throughout the annulus of the assembly. It is relative absence of friction between piston and cylinder walls that characterizes the performance for which the gauge is so highly respected. A second feature of the gauge is its ability to measure either absolute pressures or those referenced to the atmosphere. The gauge is equipped with a bell jar which, when placed over the weights, permits reduction of the external reference air pressure to a value of about 0.133 mbar.
The following equipment were used as Device Under Calibration (i.e.,DUC) for comparison against the Piston gauge :

(a) Budenberg Pneumatic Dead Weight Tester
Many pressure measurements below 6 bar in industry are made on gases and it is neither convenient nor practical to calibrate instruments in oil or on air using liquid columns. Following dead weight tester is easy to use and accurate and is a suitable replacement for liquid columns and oil dead weight testers for this low pressure work :

Make : Budenberg Gauge Co. Ltd., UK
Model : Fig 240
Range : (0.1 to 7) bar g

(b) Pressurements Pneumatic Dead Weight Tester
Make : Pressurements, UK
Range : (1 to 140) bar g

(c) Druck Multifunction Pressure Indicator This is a high accuracy, digital pressure indicator which combines the latest in pressure sensing technology with advanced, application oriented, processing and display facilities. Designed to satisfy a wide range of applications in general industry, meteorology, calibration laboratories, aeronautical engineering and on airfields, the DPI 145 is easily configured to the users needs.

Digital compensation applied to micro-machined silicon sensor elements provide outstanding performance over a wide range of pressures and temperatures. Resonant silicon sensors provide remarkable stability for absolute pressure measurements.

The specifications of the transducer calibrated are :
Model : Druck DPI 145
Range : (30 to 2620) mbar a
Sensor : Resonant sensor
Accuracy : 0.013% FS
(d) Druck Multifunction Pressure Indicator
Model : Druck DPI 145
Range : (0 to 20) bar a
Resolution : 0.0001 bar

Sensor : Piezo electric
Accuracy : 0.025% rdg. for 20% to 100% FS
0.005%FS for 0 to 20% FS

(e) Beamex MC6 Multifunction Calibrator
Beamex MC6 is an advanced, high-accuracy field calibrator and communicator. It offers calibration capabilities for pressure, temperature and various electrical signals.

Fig.1 Ruska 2465 Piston Gauge used for the determination of Effective Area of (0.25 to 7) bar g Air Dead Weight Tester

The MC6 also contains a full fieldbus communicator for HART, FOUNDATION Fieldbus and Profibus PA instruments. The MC6 is one device with five different operational modes.
The specifications are as follows :
Model : MC 6
Range : (0 to 100) bar g
Resolution : 0.0001 bar
Accuracy : (0.005%FS+0.0125% rdg)
Calibrated range : (0 to 70) bar g

3.0 PERFORMANCE EVALUATION OF THE DEAD WEIGHT TESTER AND DIGITAL CALIBRATORS USING RUSKA PISTON GAUGE

3.1 Procedure to determine the Effective area of Dead Weight Tester

All the test equipment i.e., the Dead Weight Tester, dead weights and its accessories along with all the master piston gauge and its accessories for thermal stabilisation. The determination effective area of the dead weight tester was done as per the procedure given in reference [2]. This involves cross floating the DUC piston against the Ruska piston gauge. Fig.1 shows a setup for the determination of effective area of Piston Cylinder Unit (i.e.,PCU) of (0.25 to 7) barg Dead Weight Tester. The measurement cycles in general

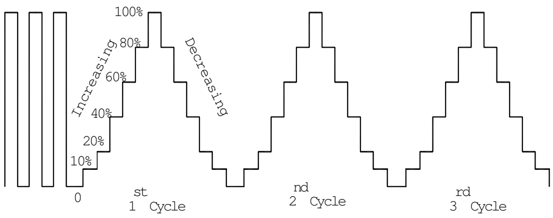

Fig.2

were followed as per Fig.2.

The reference pressure generated is determined by the following equation :

$$p_a = \frac{\left\{\Sigma\left[m_{ci}\left(1-\frac{\rho_{0a}}{\rho_0}+\frac{\rho_{0a}-\rho_a}{\rho_{mi}}\right)\right]g\right\}}{A_p(1+\lambda p)\left[1+(\alpha_p+\alpha_c)(t-t_r)\right]} \quad ...(1)$$

where,

ρ_{0a} is the conventional value of the air density, kg/m^3
ρ_0 is the conventional value of the mass density, kg/m^3
Ap is the effective area of the ref. PCU m^2
g is the local acceleration due to gravity, ms^{-2}
α_p , α_c the linear thermal expansion coefficient of the piston and cylinder °C^{-1}
λ - pressure distortion coefficient Pa^{-1}
tr is the reference temperature of the PCU, °C Σm_{ci} sum of the dead weights, piston & floating elements, kg
ρ_a is the density of air, (calculated from measured environmental parameters) kg/m^3
t is the measured temperature of ref.PCU during its use, °C
tr is the reference temperature of the PCU, °C
p – nominal pressure applied, Pa

The equation for effective area of the DUC dead weight tester is determined using the following relation:

$$A_{o-DUC} = \frac{1}{Pa} \frac{\left\{ \Sigma \left\{ m_{cti} \left(1 - \frac{\rho_{0a}}{\rho_0} + \frac{\rho_{0a} - \rho_a}{\rho_{mti}}\right) \right\} g \right\}}{(1 + \lambda_t p)\left[1 + (\alpha_{pt} + \alpha_{ct})(t_t - 20)\right]} \quad ....(2)$$

m_{cti} = the conventional mass value of each weight applied on the piston of test DWT (i.e.,DUC) including all floating elements,
ρ_{mti} = the density dead weight of the test/DUC Dead Weight Tester
t_t = the piston temperature of the test/DUC DWT
λ_t - the pressure distortion coefficient of piston-cylinder assembly of test DWT (i.e., DUC)
α_{pt}, α_{ct} the linear thermal expansion coefficient of the piston and cylinder of DUC dead weight tester °C^{-1}

3.2 Procedure to calibrate digital instruments using Piston gauge

All the test equipment comprising of the transducers, indicators and its accessories were placed in laboratory for sufficient duration along with the master piston gauge and its accessories for thermal stabilization. The transducer was switched on and was allowed to warmup for atleast 1 hour.
The calibration was done in general as per guidelines of reference [3]. Initially the transducer was pre-loaded to it full capacity and the pressure was held for a duration of atleast 30 s. The pressure is brought back to zero and allowed for at least 30 seconds. This was repeated two more times before the start of recording the readings. The readings were taken in an increasing order upto 100% and this was followed by decreasing order to 0%. Two The measurement cycles followed were in general as per Fig. 2. The pressure generated by the piston gauge is calculated using equation (1).

3.3 Sources of Uncertainty components in the performance evaluation

The values of the mass of piston, floating elements and dead weighs used and the effective area are based on the calibration certificates and the pressure generated is calculated using the equation (1). Following uncertainties are associated in the determination of the generated pressure:
- due to calibration of masses of the Piston gauge
- in the determination of the effective area of the piston -density of the mass
- air density
- in the determination of the acceleration due to gravity
- due to the thermal coefficient of expansion of the piston material
- due to the thermal coefficient of expansion of the cylinder material
- due to the temperature difference w.r.t. reference temperature
- due to sensitivity of the piston and
- due to repeatability

Sources of uncertainty while determining the Effective area of the piston using the Piston gauge are as follows :
- due to calibration of masses of the Test Dead Weight tester (DUC)

- in the determination of the acceleration due to gravity
- density of the mass
- air density
- due to thermal coefficient of expansion of the piston material
- due to the thermal coefficient of expansion of the cylinder material
- due to the temperature measured temperature difference w.r.t. reference temperature
- due to standard deviation of the Mean Effective area
- due to measured pressure
- due to repeatability

Sources of uncertainty while calibrating the digital calibrators using the Piston gauge are as follows : -

- due to generated pressure
- due to resolution of DUC
- due to zero deviation (for gauge mode)
- due to repeatability
- due to hysteresis

4.RESULTS OF PERFORMANCE EVALUATION

(a)Determination of Effective Area of (0.1 to 7) bar g Budenberg Pneumatic Dead Weight Tester

The effective area of this dead weight tester was determined by cross floating against the Ruska piston gauge. The results are given in Table 1. The mean effective area of the (0.1 to 7) bar g DWT was found to be (3.22559 x 10^{-4}) m^2 and the expanded uncertainty was (5.6 x 10^{-9}) m^2. The expanded uncertainty is of the order of 17 ppm. The effective area determined was found to be within 0.002% of the Original Equipment Manufacturer (OEM) certificate value.

(b) Determination of effective area of (0 to 70) bar Pressurements Pneumatic Dead Weight Tester

The effective area of this dead weight tester was determined by cross floating. The results are given in Table 2. The effective area determined was found to be within 0.004% of the OEM certificate value

The results are given in Table 2. The mean effective area of the 70 bar DWT was found to be (2.01916 x 10^{-5}) m^2 and the expanded uncertainty was (1.21 x 10^{-9}) m^2. The expanded uncertainty is of the order of 60 ppm. The effective area determined was found to be within 0.004% of the Original Equipment Manufacturer (i.e.,OEM) certificate value.

Table 1. DETERMINATION OF MEAN EFFECTIVE AREA OF 7 bar g PNEUMATIC DEAD WEIGHT TESTER

Sl. No.	Test (DUC) pressure bar @20^{0}C, STD g	Mean Ref. pres. (6 Trials) pr bar @20^{0}C & STD g	Mass applied on DUC Piston kg	Eff. Area DUC piston (6 trials) @20^{0}C & pr m^2	Expan. uncert. (6 trials) of mean eff. area m2	Mean Eff. Area of DUC piston @20^{0}C & pr m^2	Exp. Uncert. of DUC piston mean eff. Area m^2
1	1.90	1.90020	6.25081	3.22548E-04	5.45E-09	3.22559E-04	5.6E-09
2	2.00	2.00005	6.57982	3.22574E-04	5.61E-09		
2	4.00	4.00028	13.15972	3.22560E-04	4.93E-09		
3	5.00	5.00050	16.44967	3.22552E-04	4.94E-09		
4	6.00	6.00043	19.73959	3.22562E-04	4.79E-09		
5	7.00	7.00054	23.02946	3.22560E-04	4.88E-09		

Table 2. DETERMINATION OF MEAN EFFECTIVE AREA OF 70 bar g PNEUMATIC DEAD WEIGHT TESTER							
Sl. No.	Test (DUC) pressure bar @20⁰C, STD g	Mean Ref. pres. (6 Trials) pr bar @20⁰C & STD g	Mass applied on DUC Piston kg	Eff. Area DUC piston (6 trials) @20⁰C & pr m^2	Expan. uncert. (6 trials) of mean eff. area m2	Mean Eff. Area of DUC piston @20⁰C & pr m^2	Exp. Uncert. of DUC piston overall eff. Area m^2
1	7.00	6.99984	1.44164	2.01922E-05	1.21E-09	2.01916E-05	1.21E-09
2	21.00	20.99991	4.32481	2.01913E-05	5.08E-10		
3	49.00	48.99919	10.09107	2.01913E-05	3.92E-10		
4	70.00	69.99820	14.41585	2.01916E-05	5.15E-10		

(c)Calibration of (30 to 2620) mbar a Druck DPI 145 Pressure indicator

The calibration uncertainty is of the order of 0.01% of rdg. at the lowest pressure and 0.00` 4% of rdg. at the maximum pressure. The results are tabulated in Table 3

Table 3 CALIBRATION of (30 to 2620) mbar a DRUCK DPI 145 MULTIFUNCTION INDICATOR				
Calib. Range : (137 to 2570) mbar a				
Sl. No.	Reference Pressure p Std mbar a	Mean (of 6 trials) mbar a	M'ment devn. Δp mbar a	Expanded Uncert. U mbar a
1	137.429	137.43	0.00	0.01
2	604.004	604.03	0.03	0.05
3	953.787	953.75	-0.03	0.05
4	1187.111	1187.19	0.08	0.07
5	1420.363	1420.44	0.07	0.04
6	1754.152	1754.14	-0.01	0.07
7	1987.463	1987.44	-0.02	0.07
8	2220.788	2220.77	-0.02	0.11
9	2454.036	2454.02	-0.02	0.09
10	2570.640	2570.60	-0.04	0.11

(d)Calibration of (0 to 20) bar a Druck DPI145 Pressure indicator

The results show close agreement of indicated readings with the reference pressure. The uncertainty is of the order of 0.010%of rdg. at 0.60 bar a and 0.0025% of rdg. corresponding to 20 bar a. The results are tabulated in Table 4.

Table 4 CALIBRATION OF (0 to 20) bar a DRUCK DPI 145 MULTIFUNCTION				
Calib. Range : (0.6 to 19.95)bar a				
Sl. No.	Reference Pressure p Std bar a	Mean Value (of 6 trials) bar a	M'ment devn. Δp bar a	Expanded Uncert. U bar a
1	0.60420	0.6025	-0.0017	0.0001
2	0.95402	0.9520	-0.0020	0.0001
3	1.98824	1.9870	-0.0012	0.0001
4	4.90397	4.9035	-0.0005	0.0001
5	7.46973	7.4688	-0.0010	0.0002
6	9.91868	9.9189	0.0002	0.0003
7	12.48459	12.4841	-0.0005	0.0004
8	14.93452	14.9346	0.0000	0.0004
9	17.96579	17.9662	0.0004	0.0005
10	19.94831	19.9485	0.0002	0.0005

(e)Calibration of (0 to 70) bar a Beamex MC6 Multifunction Calibrator

The uncertainty of calibration is about 0.014% of rdg. corresponding to 7 bar g and 0.004 % of rdg. at 70 bar g. The results are tabulated in Table 5.

Table 5 Calibration of Beamex MC 6 Calibrator

Calib. Range : (0 to 70) bar g

Sl. No.	Reference Pressure p Std bar g	Mean value (6 trials) bar g	M'ment devn. Δp bar g	Expanded Uncert. U bar g
1	0.00000	0.0000	0.0000	-
2	0.95378	0.9531	-0.0007	0.0009
3	1.98754	1.9870	-0.0006	0.0009
4	4.90282	4.9021	-0.0007	0.0013
5	6.88481	6.8841	-0.0007	0.0010
6	13.88083	13.8800	-0.0008	0.0009
7	24.95864	24.9570	-0.0017	0.0013
8	34.98658	34.9867	0.0001	0.0012
9	49.91138	49.9125	0.0011	0.0016
10	59.93877	59.9407	0.0019	0.0020
11	69.96657	69.9676	0.0010	0.0026

CONCLUSION

The Physical Standards Laboratory of FCRI has enhanced its pressure calibration facilities by installing a (0.140 to 70) bar gauge/absolute Ruska 2465A Piston gauge. The performance of this equipment was assessed over its entire range in both gauge and absolute modes. The effective area of the piston of two pneumatic dead weight testers of range (0.1 to 7) bar g and (1 to 70) bar g were determined and show close agreement with OEM values. The performance evaluation of precision digital pressure instruments – Druck DPI 145 Pressure indicators of ranges (30 to 2620) mbar a and (0 to 20) bar a and Beamex MC6 multifunction calibrator of range (0 to 70) bar g was also done and results are found to be within the specifications.

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