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Twin-Piston Pressure Balance For Measurement And Uncertainty Evaluation Of Differential Pressure Digital Transducer

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Abstract

Pressure measurement plays significant role in development of various instruments and in industry. Pressure measurement, its control and accuracy are always attraction of scientist. There are many devices for the pressure measurement like U-tube manometer, Bourdon tube/Dial gauge, Dead weight tester. The present study focused on the precise generation of differential pressures with static pressure range in 0 MPa to 50 MPa using twin pressure balance in hydraulic mode. The metrological characteristics of a differential pressure digital transducer were evaluated.

Keywords: Metrology, Uncertainty, Dead Weight Tester (DWT), Digital transducer, Twin pressure balance

I. Introduction

Pressure and its measurement are quite complex. A reliable instrument is required to measure pressure precisely and accurately [1, 2]. Depending on mode of measurement, there are different kind of pressure. Pressure which exists in air free space is known as absolute pressure or actual pressure at a point. When pressure exerted by fluid on the wall of the container with respect to the pressure of surrounding medium is gauge pressure. Example: Air plans, cars, weather instrumentation. Pressure which is measured related to atmospheric pressure known as differential pressure, Reference pressure may have any value except zero. When gauge, absolute and differential pressure are measured then they are said to be in gauge, absolute and differential mode respectively. For the calibration of devices and maintain the primary standard directly or from the basic fundamental units, pressure is derived from length mass and time. Now a days, there are many devices to measure pressure such as barometer, manometer, gauge, dead weight tester [3, 4]. Dead weight tester (DWT) has brought a revolutionary change in the calibration of devices. DWT is piston cylinder type primary standard measuring device. It is used to measure pressure generated by gas or liquid and for calibration of pressure gauge over a wide range of pressure.

The pressure measurement is in terms of fundamental unit, force and area. A piston is fitted within a cylinder. A force is applied in terms of mass in a gravitational field on piston and fluid under the piston get pressurized in equilibrium. It is generally used to calibrate pressure gauges, sensors, transmitters and transducers. On the basis of their applications, DWT is divided as hydraulic and pneumatic mode for the calibration of pressure instruments. In hydraulic mode, oil is used as fluid while in pneumatic mode air is used. It measures pressure nearly equal to 10,000 bars with accuracy of 250 ppm. DWT has many advantages such as simple in construction, easy to use, widely used for the calibration, testing and adjustment of huge range of pressure measurement instrument.

In the present study the combination of two dead weight tester (Twin pressure balance) is used for the measurement of differential pressure. Twin Pressure balance increases the pressure measurement and calibration range of instrument. Pressure with larger diameter create low pressure while with smaller diameter generate higher pressure. Thus, it provides two different cross-sectional area in single piston cylinder arrangement and hence it provide the flexibility to generate pressure in wide range (low to high) with single mass load. The calibration of DWT is accredited to international system of units through National metrology institutes (NMI) [5,6]. The NMI plays an important role for sustainability of existing devices and also for the development of new devices.

II. Working principle

Dead weight tester is based on the principle of Pascal's law. In an experiment, twin pressure balance (Model 55614, Desgranges & Huot, France) available at NPL, Delhi, India is used for calibration of test pressure gauge shown in figure 2. The whole arrangement consists of Oil reservoir, pipeline (through which oil flows), pressurization chamber and the gauge under test is fix on the top of pressurization Chamber. Sebacate oil is used as fluid in dead weight tester. The oil flows from the reservoir to the pressurization chamber and air is removed with the help of vacuum pump. The presence of air will create non-uniform pressure which results in inaccurate results. When the system is consisting of oil and is air free then the pressure gradually increases in pressurization chamber. The pressure in piston cylinder arrangement is balanced with an equal amount of force is exerted by the weights which is mounted on the cylinder. The sum of the pressure values mention on the weights is operated on the gauge which is under test and the corrections can be done by using small weights. The schematic diagram of experimental setup is shown in figure 1 [7–10].
The pressure (in Pa) generated by Dead weight tester is obtained by equation (1) [11,12].

$$P = \frac{\Sigma_i m_i \, .g\, (1- \rho_a/\rho_i) + \gamma C}{A_0\, (1+b_1 p_n+b_2 p_n^2)\, [\, (\alpha_c+ \alpha_p)\, (T - T_r)]} \pm \Delta p \qquad (1)$$

m_i=Mass of the weight, ρ_a = Density of air at laboratory condition, ρ_i = ith weight Density, γ = Surface tension of fluid, C = Circumference of the piston emerging out from the fluid ,A_0= Piston – cylinder's effective area at Zero pressure, α_c& α_p = Thermal expansion coefficients of cylinder's and piston's material ,T = Assembly temperature, T_r = Temperature at which A_0 is referred b= Effective area's pressure Coefficient , Δp = It is head correction in term of pressure (where $\Delta p = [(\rho_f – \rho_a) .g. H]$,In this equation, H depicts height difference between two dead weight tester's reference level and (ρ_f) is transmitted fluid density.

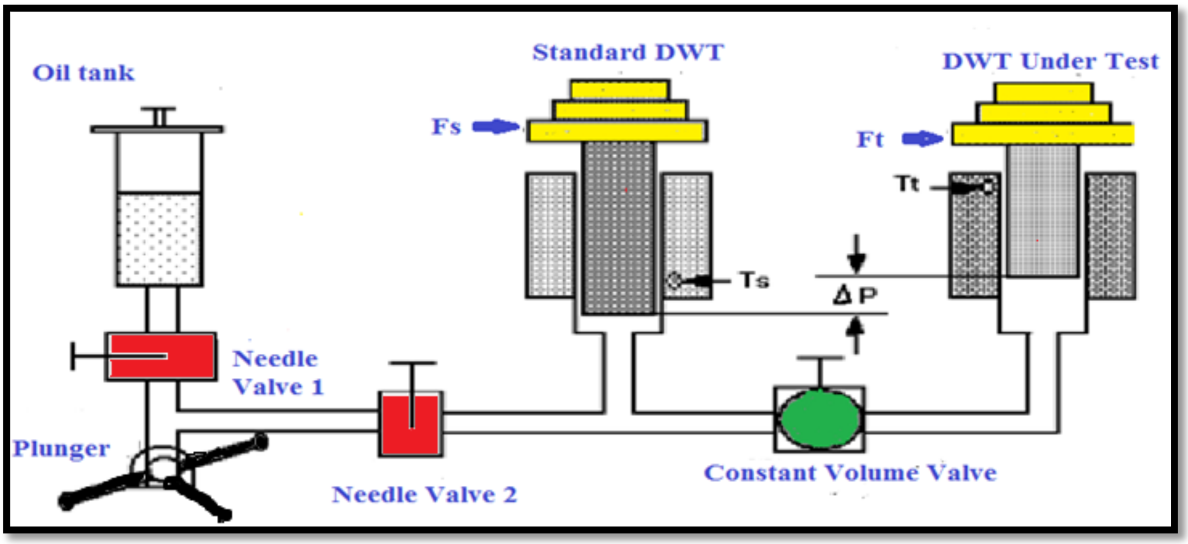

Figure 1*: Experimental setup for the calibration of DWT*

In the experiment the combination of two dead weight testers (Twin-Pressure balance) to calibrate the digital transducer. After connecting the digital gauge to the electric network, warm up time of 30 minutes is provided to it. Leakage testing is done by applying the maximum pressure (50 MPa) for 10 minutes before the experiment starts. The reading of differential pressure by the gauge is taken in increasing and decreasing order at different pressure points [13-16].

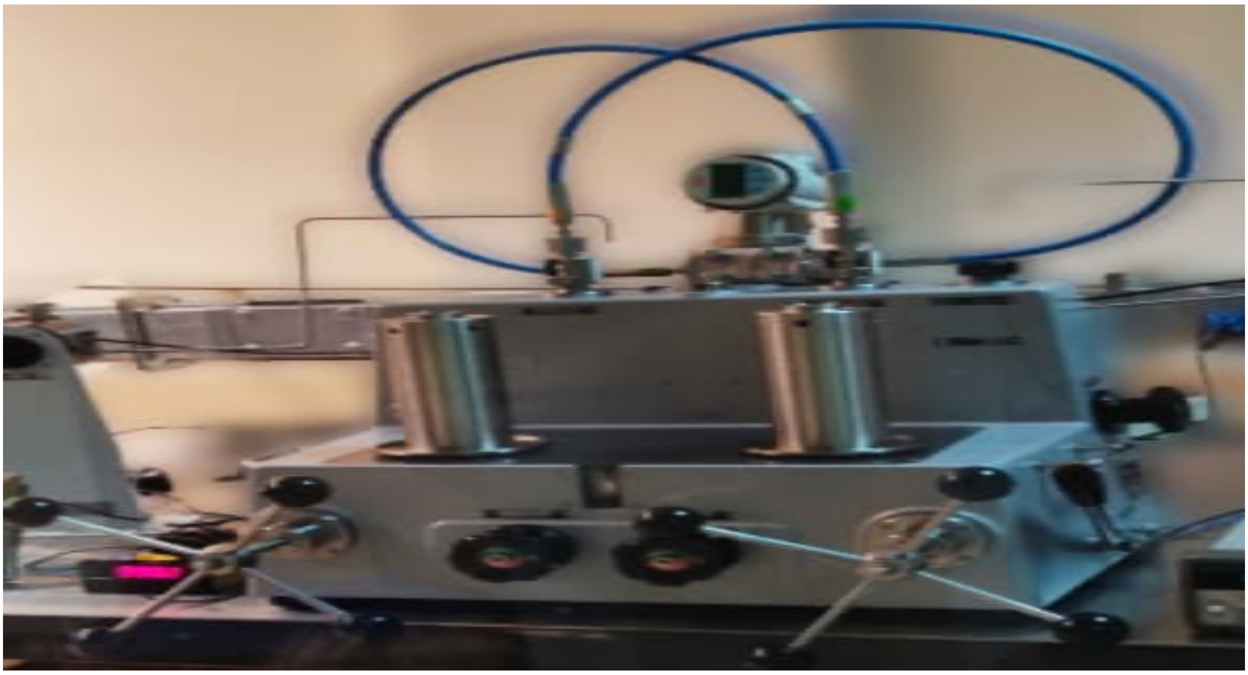

Figure 2: *Pictorial view of experimental setup for the calibration of digital transducer*

III. Calculation

Data is recorded for differential pressure against different values of static pressure and constant line pressure (10 MPa). The nominal differential pressure by twin pressure balance is nearly same as shown by digital transducer. The differential pressure output of twin pressure balance is given by equation

$$\Delta P_r = P_{reference\ 1} - P_{reference\ 2} \quad (2)$$

During the calibration of gauge by twin - pressure balance, the measurement uncertainty is established in accordance to "JCGM 100: 2008 - GUM 1995 with some small corrections - Guide to the expression of uncertainty in measurement –measured data evaluation - First edition September 2008".
The digital gauge error is evaluated by subtracting the differential pressure recorded by twin pressure balance and differential pressure shown by transducer. For digital gauge calibration, the error is given by the expression

$$E(P) = \Delta P_g - \Delta P_r \quad (3)$$

E (P) = Digital gauge error.
ΔP_g = magnitude value depicted by gauge., ΔP_r = magnitude value measured by twin pressure balance.
The error values obtained with the help of equation 3 are depicted in table 1 at different static pressure of 1, 30 and 49 MPa.in increasing and decreasing cycle.

Table.1: *Instrument errors*

ΔP (MPa)	Error (in MPa)		
	For Static Pr. 1 MPa	For Static Pr. 30 MPa	For Static Pr. 49 MPa
Increasing Cycle			
0	0.000108	0.001368	2.60E-05
0.5	0.000861	0.001742	7.34E-05
1	0.00021	0.003318	0.001719141
2	0.000829	0.004774	0.003363619
Decreasing Cycle			
2	0.000932	0.002379	0.003632561
1	0.000737	0.003219	0.001299314
0.5	0.000228	0.001984	0.000983811
0	0.000508	0.001241	5.46E-05

IV. Results and Discussion

The figure 3 shows the error as the function of pressure. From the figure concluded that the errors are contained within the interval 0.000025959 MPa-0.004774 MPa. This value shows the resolution of the digital gauge.

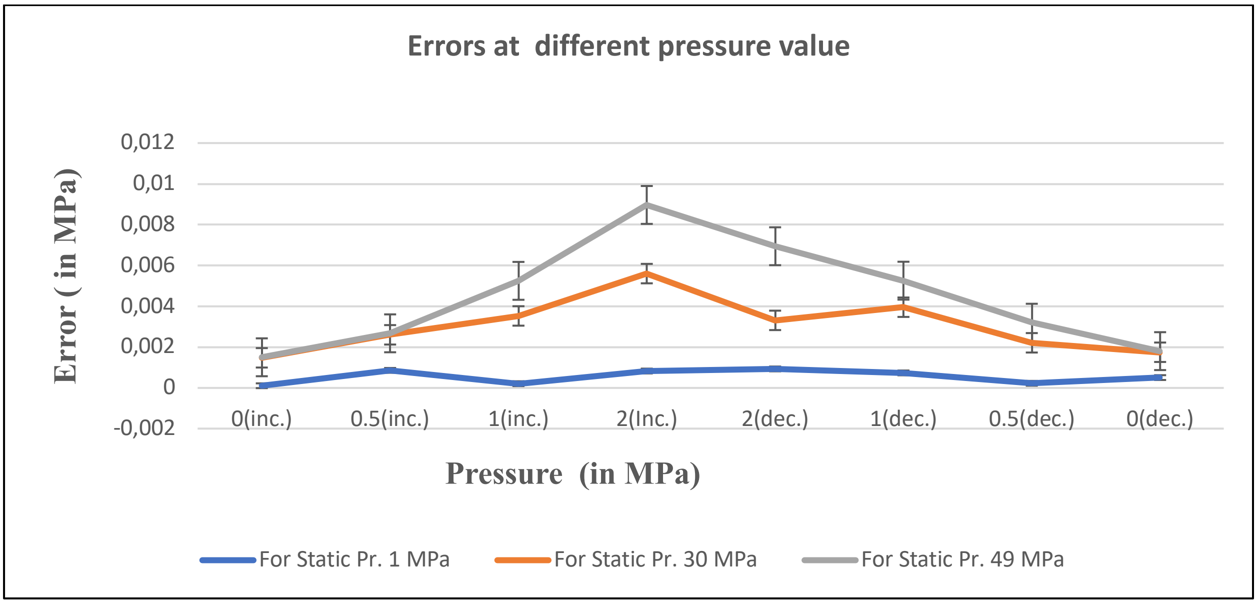

Figure 3: *Plot for digital gauge error*

The above graph between error and pressure plays an important role for the evaluation of calibration quality. The calibration is called as control calibration if the error lies within the minimum acceptable limit.

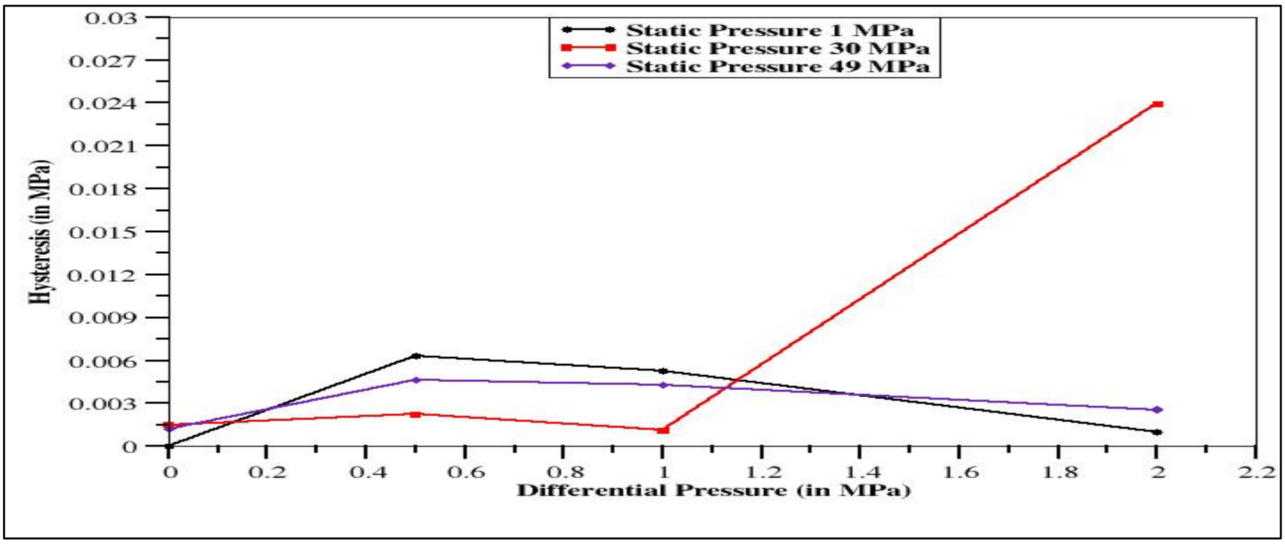

Figure 4: *Plot for the hysteresis of the transducer*

Hysteresis in the measurement is defined as the difference between corresponding values of pressure in increasing and decreasing orders in the pressure cycle. The hysteresis is plotted for the three static pressure points operating up to full range of 49 MPa (shown in Figure 4). For more precise measurements, the transducer may be used either in increasing or decreasing order of pressures. The maximum hysteresis error is 0.02395 MPa at static pressure 30 MPa i.e. 0.079 % of the full scale which is very minimal in this pressure range.

Reproducibility defines as the closeness of results which is obtained by following the same procedures but under different experimental conditions.

Table 2 shows metrological characteristics of twin- pressure balance: maximum percentage error, hysteresis and reproducibility. The values in the table 2 are in the relation with the amplitude of the measuring range of digital gauge.

Table.2: *Maximum % error, hysteresis and reproducibility*

Maximum % error	0.019
Hysteresis %	0.079
Reproducibility %	0.0667

Table 3 shows the expanded uncertainty (U) of the transducer with the respective coverage factors 2 for the 95% confidence level. The value of uncertainty comes out to be the same for the different values of static pressure at the same value of pressure.

Table.3: *Expanded uncertainty*

Pressure (in MPa)	Coverage factor (k)	Uncertainty (in MPa)
0	2	9.67304E-06
0.5	2	1.10346E-05
1	2	1.22581E-05
2	2	1.42707E-05

V. Conclusion

- A new methodology to be applied for differential pressure measurement using twin pressure balances is proposed. Error values obtained by transducer are lies within the range 0.000025959 MPa - 0.004774 MPa. Which is quite small and shows the best results. The calibration uncertainty varied from 9.67304E-06 MPa to 1.42707E-05 MPa.
- During performance evaluation and calibration process, it is found that the hysteresis loss is very low i.e., 0.079 % of the full scale and reproducibility is also minimal 0.0667% of the full scale. Therefore, the transducer works well within reasonably good accuracy for high pressure range which is less than 1% of the full scale.
- This study concludes that the Twin -Pressure balance can be used as a Primary standard for differential pressure measurement.

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