Journal of Inventive Engineering and Technology (JIET)
ISSN: 2705-3865
Volume-4, Issue-2, pp-73-82
www.jiengtech.com
Research Paper Open Access

Design and Performance Evaluation of a Pressure Gauge Calibration Apparatus

[1]Okolie Paul Chukwulozie, [2]Oluwadare Benjamin Segun, [3]Lazarus Tari Lokoja, [4]Okolie Uchenna Onyebuchi, [5]Chikelue Edward Ochiagha

[1]Department of Mechanical Engineering, Nnamdi Azikiwe University, Awka, Nigeria.
[2]Department of Mechanical Engineering, Ekiti State University, Ado Ekiti, Ekiti State.
[3]Nigerian Air Force Base Oko, Benin City, Edo State.
[4]Electronics Development Institute (ELDI) Awka Capital Territory Anambra State.
[5]3Series Premium Nigeria Limited Awka, Anambra State, Nigeria

[1]Corresponding Author: pc.okolie@unizik.edu.ng

ABSTRACT: *This paper presents the design and performance evaluation of a pressure gauge calibration apparatus using a Dead-Weight Testing method. Dead-weight tester was designed using solid works. Materials such as stainless steel, brass, plastic, glass and wood with corrosion resistant were used for the fabrication. The apparatus was tested using water of known specific gravity of 998kg/m^3 or approximately 1g/cm^3 as pressure medium and set of known weights (including that of the piston = 1.0194kg) as the input data. The actual reading (cylinder pressure), Gauge reading (gauge pressure), Absolute Gauge error, and % Gauge error were recorded. Graph of cylinder pressure and gauge pressure were plotted and a straight line graph with a slope of 0.85 was obtained, indicating linear proportionality. The graph of the absolute gauge error and the gauge pressure also gave a positive slope showing that the error increases as the gauge pressure increases. But, at point (47.53kPa, 8.53kPa), the curve shows negative slope and later returns to positive slope. The graph of the percentage error verses gauge pressure gives a negative slope, showing that values with smaller applications of pressure in the cylinder yielded a higher Fig. of % relative error. Considering the relationship between the experimental results analyzed on the pressure gauge and the actual results being measured by adding weight to the cylinder, a calibration of the system can be conducted.*

.

KEYWORDS*:* *pressure, piston, calibration, thrust, force, bourdon tube*

Date of Submission: 19-11-2023 Date of acceptance: 22-11-2023

I. INTRODUCTION

Pressure is the force exerted (thrust) perpendicularly on the surface of a body (solid, liquid or gas) per unit area over the entire region in which the force is distributed. It can be expressed as the ratio of the force to the area over which the force is acting. The pressure intensity at any point in static or moving fluid can be measured using various types of pressure measuring instruments called pressure gauges.

Electromechanical pressure gauges are essential for pressure measurement and control in various industrial applications, and also for pressure calibration. Although pressure balances are the first choice as reference devices for pressure calibration because of their high resolution and long- and short-term stabilities, expertise is necessary to operate them correctly and efficiently. To make pressure calibrations easier, high-accuracy electromechanical pressure gauges are becoming more commonly used as reference devices (H. Kajikawa and T. Kobata , 2014)).

When pressure gauges are used as the reference device, several characteristics should be evaluated in advance including repeatability, hysteresis, long-term shift, and environmental effects. We have been focusing on the time-dependent behavior of pressure gauges and the effect of pressurization on the outputs (H. Kajikawa and T. Kobata (2010); Hiroaki Kajikawa, Tokihiko Kobata (2016)).
As there are different types of pressure, there also exist variety of measurement methods, which can be classified according to pressure measurement principles, method of operation and the type of output (digital or analog). The types of pressure gauge include commercial pressure gauges, industrial pressure gauges, process pressure gauges, low pressure gauges, high precision test gauges, seal gauges and absolute pressure gauges (Saiful et al., 2016). Analog pressure gauges are often built with bourdon tube, diaphragm or capsule with indicators which are usually have a pointer and a pressure scale. There are also digital pressure gauges that have numeric pressure indication instead of an analog pointer.

Pressure gauges are very common instruments in the process industries and are used to measure the pressure of liquid or gaseous materials by calculating the force it exerted at a steady state and can be calibrated easily. The gauge displays the difference between the pressure in the area being measured and that (ambient pressure) of the surroundings, called the gauge pressure. The absolute or total pressure of the area is the sum of the pressure difference measured by the gauge and the atmospheric pressure. Gauges being mechanical devices and as with any process measurement device are prone to the risk for it to drift due to mechanical stresses (Kedar, A. U & Surendra, P., 2015). As the measuring instrument is used extensively, the factory setup of the internal components changes. Consequently, calibration at a regular interval is necessary to ensure that the device gives correct pressure readings.

Calibration is a method mostly used by research laboratories and companies for quality and reliability enhancement. It compares the instrument under analysis to a higher standard. These labs develop their procedures to standardize and control the calibration (Hiroaki, K., 2016). Calibration means checking the pressure gauge readings against a very accurate device. That is, comparing the instrument under analysis to a higher standard. As with any measurement device, pressure gauges need to be calibrated at regular intervals to ensure they are accurate (Hiroaki, K., 2016).. Calibration of pressure gauge can be done using diaphragm tube, capsule tube or Bourdon tube pressure gauge. The performance of the pressure gauges of this type varies widely, not only as a result of their basic design and materials of construction but also because of the conditions under which it was used.

II. MATERIALS AND METHODS

A. Material Selection

Materials used in this study were chosen carefully according to their purpose in calibration of pressure gauge using deadweight tester. Good material selection facilitates good project value (performance). Satisfaction of three basic requirements such as; service requirement, fabrication requirement and economic requirement are needed (T. Kobata, 2005). To fulfill the requirements the following factors were considered; Cost of material, mechanical properties, environmental and service conditions, weight, availability and workability.

B. Design Considerations

In the design and fabrication of the pressure gauge calibration apparatus, the bourdon tube pressure gauge was selected due to its high sensitivity and high selection pressure gauge range (0-200) kPa. They are employed due to their reliability, compactness, low cost and ease of use. The c**o**mponents of Apparatus are; cylinder, piston, piston plate, pressure gauge, transparent tube, transmission, medium, deadweights, base, overflow hose, control Valve, fluid Reservoir and gauge stand.

Table 1 Materials for the Components and Factors Considered

S/N	Component	Material	Factors considered
1	Column	Stainless steel	Durability, high thermal and pressure resistance, high corrosion resistance, availability, shape workability, cost
2	Piston and piston plate	Stainless steel	Workability, cost, fracture toughness, corrosion resistance, availability, shape.
3	Deadweight	Steel	Size, hardness, weight and shape
4	Transparent tube	Plastic	Safety, less expensive, less fragile
5	Pressure gauge	Digital pressure gauge	Readability, Sensitivity, scale range, durability, accuracy, environmental condition, reliability, cost effective, ergonomics
6	Nut	High carbon steel	High strength in tension and shear
7	Base	Wood	Cost, availability, appearance, durability
8	Fluid Reservoir	Plastic	Corrosion resistance, cost
9	Hose	Rubber	Corrosion resistance, flexibility, length
10	Control Valve	Brass	Leakage, corrosion resistance, versatility, heat absorbance, strength
11	Gauge stand	Mild steel	Rigidity, strength, machineability
12	Pressure media	Water	Availability, density, viscosity, pressure range, cost, safety

C. Construction

At this stage, work is done on the different parts that form the system to bring them to a suitable shape and size required for the design. The process for fabrication includes marking out operation, metal casting operation, cutting operation, drilling operation etc.

a) Marking out operation: This operation involved setting off dimensions and punching out points on the metal we used for the hollow cylinder, piston, columns, base plate using the punch tool. Marking out is necessary as it aids us during cutting, shaping, drilling and riveting operation.

b) Cutting operation: this process involves cutting of the metal by following the marked out dimensions. Appropriate clearance were given where necessary especially the precision clearance between the cylinder and piston making it sufficient air tight. The equipment or machines used in this process include the steel rule, bench vice, hack saw, drilling, boring and lathe machines. This operation involved reducing the cross sectional area of the marked out materials, it includes cutting out the required size for the base plate, cylindrical columns, and piston. This operation was done with both manual and electric powered machines.

c) Drilling operation, holes are drilled in the components to serve a purpose such as the base plate hole that allows the locking of the cylindrical columns, bourdon gauge stand by the use of nuts. It secures them to the base plate.

Fig. 1: Drilling operation

d) Boring operation:

This process involves the use of boring tool to make cross sectional hole in the component. The process serves to create hole on both the cylindrical column and the bourdon tube stand. Proper clearance was ensured between the piston and the cylindrical column during the operation.

Assembling: This process consists putting together of all individual elements or parts that have been worked on to form the system. This stage involves the screwing operation and finishing operation.

a) Screwing operation: This operation involves securing components to the body of the base plate by the use of nuts or screw such as bolting the cylindrical column and the bourdon stand to the base plate.

b) Finishing operation: This operation involves the lubricating process, the cleaning process, the painting process.

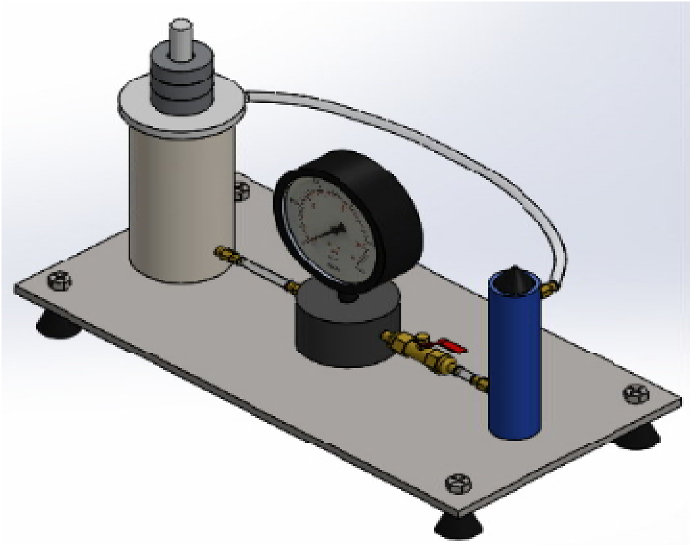


Fig. 2: Dead Weight Pressure Tester (finished work)

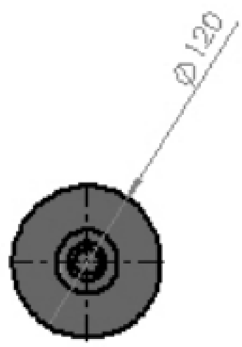
D. Principle of Operation

The pressure is generated by the deadweight which is placed on the cylinder. The generated pressure is transmitted to the piston and then to the transmission medium. The deadweight serves as the input device to the system. The initial input force from the deadweight is accounted for by taken note of its reading on the bourdon tube pressure gauge. The total weight is then read from the bourdon tube

E. Design Analysis and Calculation

This covers the arithmetic evaluations and calculations involve in various in determining the sizes of the parts and other parameters such as forces, pressure, volume, etc as related to the project. The analysis and synthesis of the various parts are done to calculate dimensions, forces and other numerical factors influencing the part.

F. Calculation for Area of the Piston



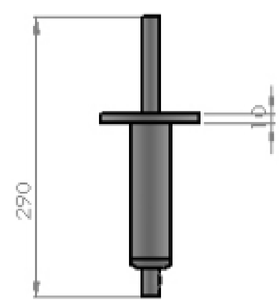


Fig. 3 a. Piston **b. Piston Plate**

- Area of the piston surface

Taking the diameter of 32.5mm

Applying the area of a cylinder for the piston diameter

$$A = \frac{\pi d^2}{4} \quad (1)$$

Where d = diameter of the piston in mm, $\pi = 3.142$

A = $\pi \times 32.5^2$

A = 829.5768 $mm^2 = 8.295768 \times 10^{-4} m^2$

G. Calculations for the Force Applied on the Pressure Media

Let the known weight used be at interval of 1kg and the weight of the piston plate be $m_0 =$ 1.0194kg

Hence, the total force applied on the fluid in the cylinder is gotten as;

$F_0 = m_0 \times g = 1.0194 \times 9.81 = 10N$

$$F_1 = m_1 \times g = 2.0194 \times 9.81 = 19.81N$$

$$F_2 = m_2 \times g = 3.0194 \times 9.81 = 29.6203N$$

$$F_3 = m_3 \times g = 4.0194 \times 9.81 = 39.4303N$$

$$F_4 = m_4 \times g = 5.0194 \times 9.81 = 49.2403N$$

$$F_5 = m_5 \times g = 6.0194 \times 9.81 = 59.0503N$$

H. Calculations for Pressure Exerted by the Piston on the Fluid

Pressure $P = \frac{F}{A}$ 2

Force $(F)_n = m_n \times g$

Where g = acceleration due to gravity = 9.81m/s^2

M = mass of the known weight N = number of times the mass placed.

Therefore, the total pressure (true pressure) exerted on the fluid in the cylinder is given as;

$$P_0 = \frac{F_0}{A_0} = \frac{10}{8.29577 \times 10^{-4}} = 12.054kN/m^2$$

$$P_1 = \frac{F_1}{A_0} = \frac{19.81}{8.29577 \times 10^{-4}} = 23.879kN/m^2$$

$$P_2 = \frac{F_2}{A_0} = \frac{29.6203}{8.29577 \times 10^{-4}} = 35.705kN/m^2$$

$$P_3 = \frac{F_3}{A_0} = \frac{39.4303}{8.29577 \times 10^{-4}} = 47.53kN/m^2$$

$$P_4 = \frac{F_4}{A_0} = \frac{49.2403}{8.29577 \times 10^{-4}} = 59.36kN/m^2$$

$$P_5 = \frac{F_5}{A_0} = \frac{59.0503}{8.29577 \times 10^{-4}} = 71.18kN/m^2$$

I. Calculation for Gauge Error

Gauge Error = True Pressure – Gauge Pressure

When mass of 1.0194kg was applied; Gauge Error = 12.05 – 10 = 2.05kPa

When mass of 2.0194kg was applied; Gauge Error = 23.88 – 19 = 4.88kPa

When mass of 3.0194kg was applied; Gauge Error = 35.71 – 29 = 6.71kPa

When mass of 4.0194kg was applied; Gauge Error = 47.53 – 39 = 8.53kPa

When mass of 5.0194kg was applied; Gauge Error = 59.36 – 51 = 8.36kPa

When mass of 6.0194kg was applied; Gauge Error = 71.81 – 62 = 9.18kPa

Gradient = $\frac{\Delta y}{\Delta x} = \frac{39-19}{47.53-23.88}$ = 0.845666 = 0.85

Where;

True pressure = pressure applied on the fluid in the cylinder

Gauge pressure = pressure reading on the pressure gauge

J. Calculation of %Gauge Error

% Gauge Error = $\frac{Gauge\ Error}{Gauge\ Reading}$ x 100

At mass of 1.0194kg: % Gauge Error = $\frac{2.05}{10\ kPa}$ x 100 = 20.54

At mass of 2.0194kg: % Gauge Error = $\frac{4.88kPa}{19\ kPa}$ x 100 = 25.68

At mass of 3.0194kg: % Gauge Error = $\frac{6.71kPa}{29\ kPa}$ x 100 = 23.12

At mass of 4.0194kg: % Gauge Error = $\frac{8.53kPa}{39\ kPa}$ x 100 = 21.87

At mass of 5.0194kg: % Gauge Error = $\frac{8.36kPa}{51\ kPa}$ x 100 = 16.38

At mass of 6.0194kg: % Gauge Error = $\frac{9.18kPa}{62\ kPa}$ x 100 = 14.80

III. RESULTS AND DISCUSSIONS

A. Performance Tests

The use of the piston, weights with the cylinder and water as the pressure medium (fluid) generated a measurable reference pressure, p:

P= F/A (Pascal)

Where, F = mg

F is the force applied to the liquid in the calibrator cylinder

M is the total mass (including that of the piston = 1.0194kg)

A is the area of piston

The area of the piston is expressed in terms of its diameter (0.01767m), d as: $A = \pi \frac{d^2}{4}$ 3

The pressure generated on Bourdon type pressure gauge due to weight applied on piston is recorded corresponding to every incremental weight on piston. After completing the experimental work, the pressure recorded at Bourdon type pressure Gauge is compared with actual pressure generated at cylinder due to incremental weight.

B. Input Data

The input data required for computation of cylinder reading and gauge reading and finally computing error in pressure gauge are diameter of Piston to get the area on which weight is applied. Secondly to get variation in pressure reading, various set of weight are required. For this experiment weight in 1kg multiple are applied on weight tester. The input showing diameter of piston, Area of piston, Total mass is shown in Table 2.

Table 2: Input Data

S/N	Piston Diameter (m)	Area (m^2)	Total Mass (kg)
1	0.0325	0.00082958	1.0194
2	0.0325	0.00082958	2.0194
3	0.0325	0.00082958	3.0194
4	0.0325	0.00082958	4.0194
5	0.0325	0.00082958	5.0194
6	0.0325	0.00082958	6.0194

C. Computation and Result

The calibration of the pressure gauge using a dead weight tester was carried out; Based on the experimental results obtained a deviation in the calibrated reading was compared to the theoretical values. Therefore applied load/weight is directly proportional to the obtainable pressure gauge calibration meter readings

Table 3 shows actual reading, Gauge reading, Absolute Gauge error, and % Gauge error. The slope between actual reading and gauge reading is found to be 0.85.The Fig.4 shows the relation between actual reading and recorded gauge reading, while Figs.5 and 6 show relation between Gauge Error and Gauge pressure.

Table 3: Results

S/N	Cylinder Pressure (kN/m^2)	Gauge Pressure (kN/m^2)	Absolute Gauge Error	% Gauge Error
1	12.05	10	2.05	20.54
2	23.88	19	4.88	25.68
3	35.71	29	6.71	23.12
4	47.53	39	8.53	21.87
5	59.36	51	8.36	16.38
6	71.18	62	9.18	14.80
Slope	0.85			
Equation	Y = 0.85x			

D. **Graphical Relationship**

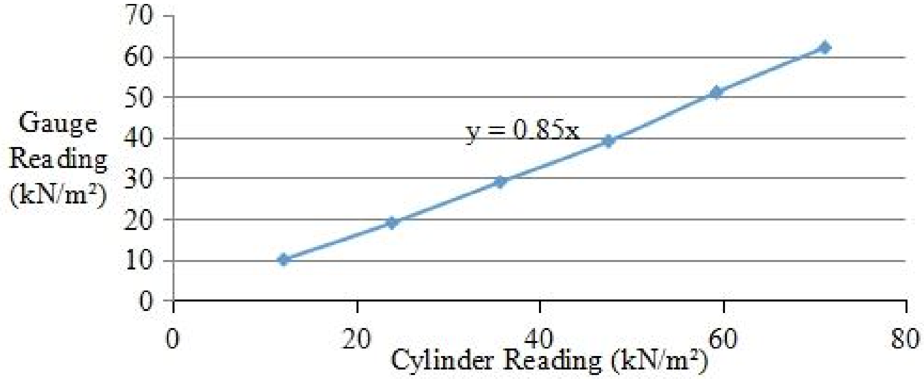


Fig 4: Graph of Gauge Pressure versus True Pressure

Fig. 4 is a graph demonstrating the relationship between the pressure in the cylinder and the gauge reading on the manometer. There is a linear relationship between the values, true pressure and gauge pressure plotted on the x and y axis respectively. The equation for the relation is expressed as y = mx

Where; y = gauge pressure; k = slope = 0.85; x = true pressure

The pressure measured by the pressure gauge is directly proportional to the value of the pressure exerted by the load on pressure media and the gauge reading increase as the magnitude of the load increases. That is, the effect of the load on the fluid is directly proportional to the amount of the load applied.

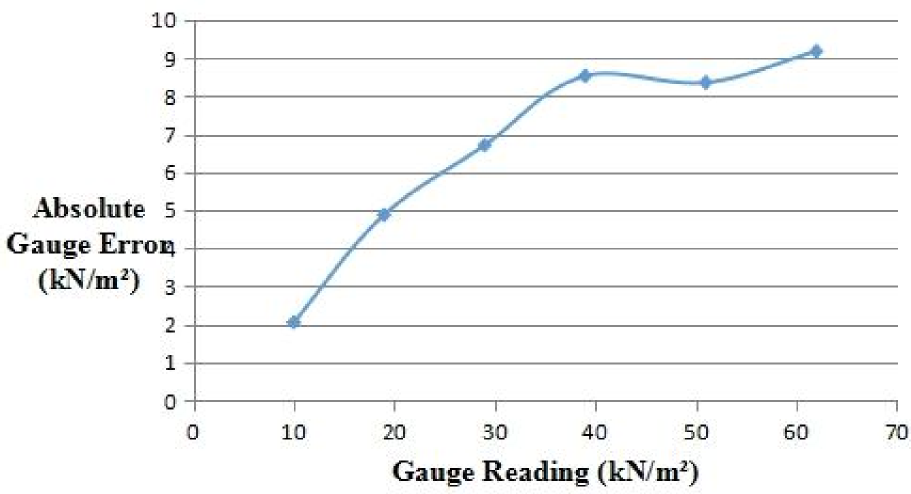


Fig 5: Absolute Gauge Error verses Gauge pressure Curve

Fig. 5 is a graph demonstrating the relationship between the absolute gauge error and the pressure reading on the gauge. The absolute error in this experiment juxtaposes the value of the data that should be obtained and the value of the data that is being measured by the system being used. The curve moves upwards from left to right showing that the error increases as the gauge pressure increases to point (47.53kPa, 8.53kPa). From point 4 to 5, the curve shows negative slope and positive slope from 5 to 6.

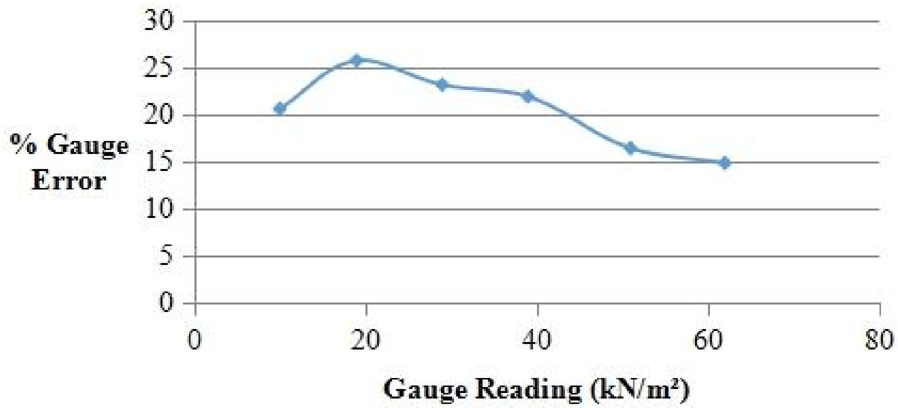


Fig 6: % Gauge Error verses Gauge pressure Curve

The relative % error values of the data collected shows, by percent, how close or far away the values obtained by the instrument were close the actual value that was measured by the gauge. The curve is not uniform. It demonstrates both upward and downward-sloping power equation. The relative error was highest at point 2 when the gauge pressure was 19kPa which is close to its lowest and decreases as the cylinder pressure increases. The values of these plots follow a traceable trend; however, they are not as similar as the data displayed in the gauge reading versus pressure in cylinder graphs because the values vary a bit more.

IV. CONCLUSION

The provision of pressure gauge calibration apparatus in the Mechanical Engineering Laboratory through the design and fabrication of the pressure gauge calibration apparatus solves the problem of calibrating the drifted pressure gauges in the school laboratories. It also helps students to perform some pressure related experiment required by their course of study. The analysis of the perspective of value engineering in the design and construction of a pressure gauge calibration apparatus solves the problem of incurring unnecessary expenditures in the design and fabrication of the bourdon tube pressure gauge thereby reducing cost and increasing the value for the manufacturer and/or their customers. The use of less expensive and locally source materials and elimination of complicated but maintaining a detailed design aid in reducing the total cost of production. The gauge measures pressure between 0.01kg to 200kPa with because of the application of value engineering in the design and fabrication.

References

Hiroaki, K. (2016) Pressure Gauge Calibration applying D.A.O. pressurization to reference gauge. *Journal of Engineering* 2(3). 125-127.

Hiroaki, K. (2016) Pressure Gauge Calibration applying D.A.O. Pressurization to reference gauge. *Journal of Engineering* 2(3). 125-127.

Hiroaki Kajikawa, Tokihiko Kobata (2016). Pressure gauge calibration applying 0-A-0 pressurization to a reference gauge ACTA IMEKO ISSN: 2221-870X *Volume 5, Number 1, 59-63*

Kajikawa H. and T. Kobata (2014), Reproducibility of calibration results by 0-A-0 pressurization procedures for hydraulic pressure transducers, Meas. Sci. Technol., 25 015008.

Kajikawa H. and T. Kobata (2010), Effects of pressurization procedures on calibration results for precise pressure transducers, Meas. Sci. Technol. 21, 065104.

Kedar, A. U & Surendra, P. (2015). Determining Measurement Uncertainty Parameters for Calibration. *The International Journal of Engineering And Science (IJES)* 4(11). 01-10.

Kobata T.(2005) Characterization of quartz Bourdon-type high-pressure transducers, Metrologia 42 pp. S235-S238.

Saiful et al (2016) Estimation of Error in Bourdon type pressure Gauge using Dead Weight Tester. *Journal of Computing Technologies* 39(5). 2278 – 3814.