Pressure Calibration Using Precision Deadweight Piston Calibrators

By:

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Introduction

- Calibration is an important step in ensuring the accurary of process Instrumentation and measuring Devices.
- Accurate Pressure Calibration plays an important role in ensuring the integrity of the process and assuring safety in the workplace.
- An understanding of the requirements for Quality precision Calibration is needed in order to ensure that instrumentation meet acceptable standards of accuracy and safety.
- Of major concern is the use of Pressure Calibrators that are less accurate than the accuracy Grade of the Device under Test (DUT).

Calibration is Governed by the Basic Pressure Equation:

Pressure=Force/Area

- Governed by *Pascal's* Law on Hydraulic Pressure

The diagram below illustrates the law:

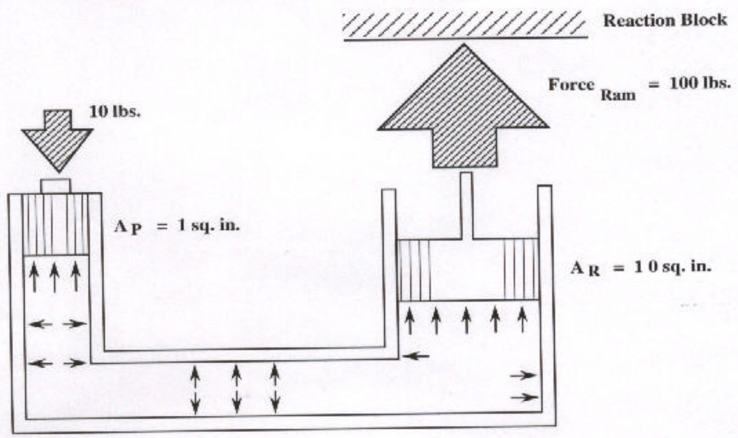


Fig. 2.0 - Hydraulic Piston Assembly

If a force of 10 lbs. is exerted on the smaller piston of A_P = 1 sq. in. the Pressure exerted everywhere within the confined container is:

$$P = \frac{F}{A} = \frac{10 \text{ lbs.}}{1.0 \text{ sq. in.}} = 10 \text{ psi}$$

The force exerted on the larger ram of A_R = 10 sq. in. is:

$$Force_{RAM} = P \cdot A$$
$$= 10 \text{ psi} \times 10 \text{ sq. in.}$$
$$Force_{RAM} = 100 \text{ lbs.}$$

Note that this Force can only develop if the ram is reacting against a resistance which in this case could be a steel block or a vehicle.

This fundamental principles is all we need to know to understand the hydraulics of Pressure Calibration.

In the RUSKA 2465 DW Piston Calibrator, the Piston has a known area and mass.

- The fundamental Law of Hydraulics Governing Pressure Calibration: *Pascal's Law*

"An external Force exerted on a unit area of a confined Liquid will be transmitted undiminished to every unit area of the interior of the Vessel"

Factors Influencing DWG Piston Calibrators

- Force
- Area
- Pressure

Influences on Force

- Mass Load
- Load Gravity
- Air Buoyancy
- Attitude

Influences on Area

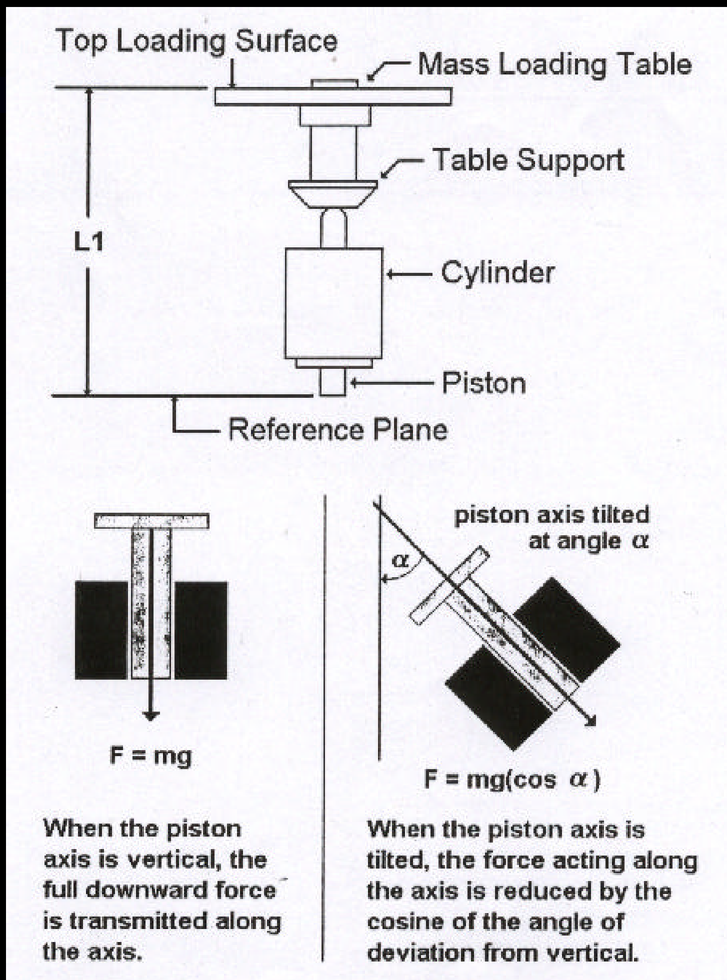
- Pressure Dependence
  - *Distortion
  - *Operating Fluid
  - *Geometric Uniformity
- Temperature

Pressure Influences

- Pressure Gradients
- Reference Plane
- Reference Pressure

Basic Pressure Equation

Pressure=Force/Area


Top Loading Surface
Mass Loading Table
Table Support
L1
Cylinder
Piston
Reference Plane
F = mg
piston axis tilted
at angle α
α
F = mg(cos α)
When the piston axis is vertical, the full downward force is transmitted along the axis.
When the piston axis is tilted, the force acting along the axis is reduced by the cosine of the angle of deviation from vertical.

In the above case, the Piston area **"A"** is replaced by the concept of **"A_{eff}"** which is a concept to consider the effect of **"f"** in the balance equation.

Thus:

$$A_{eff} = \frac{[M \cdot g] \cdot [1 - (\frac{\rho_{air}}{\rho_m})]}{\rho_{gauge}}$$

upon substitution into a series of equations;

$$A_{eff} = A \cdot [1 + \frac{f}{(M \cdot g)}]$$

and the **"f"** term is considered when A_{eff} is used.

The Concept of Effective Area "A_e"

- It must be emphasized that effective Area "Ae" exists as a concept. It does not necessarily correspond to any particular physical dimensional area of the Piston.
- It was introduced to allow two separate and distinct parameters "A_o" and "f" to be combined into one by introducing the concept from the Pressure equation:
  - $P_{gauge} = [(\{m*g\} * \{1-(P_{air}/P_m)\})-f]/A_o$.
  - The "f" parameter is to account for the viscous drag force of the gas along the annulus between the piston and the cylinder.

Accuracy Requirements for Pressure Calibration of Pressure Gauges ANSI B40.1

TABLE 1 ACCURACY GRADES

Accuracy Grade	Permission Error (+/- Percent of Span) (Excluding Friction): Lower 1/4 of Scale	Middle 1/2 of Scale	Upper 1/4 of Scale	Maximum Friction (Percent of Span)	Minimum Recommended Gauge Size (270 deg. Dial Arc)
4A	←	0.1	→	[Note (1)]	8 1/2
3A	←	0.25	→	0.25	4 1/2
2A	←	0.5	→	0.5	2 1/2
1A	←	1.0	→	1.0	1 1/2
A	2.0	1.0	2.0	1.0	1 1/2
B	3.0	2.0	3.0	2.0	1 1/2
C	4.0	3.0	4.0	3.0	1 1/2
D	5.0	5.0	5.0	3.0	1 1/2

NOTE:
(1) Grade 4A gauges must remain within specified tolerance before and after being lightly tapped.

Calibration Accuracy Requirements

- In order to satisfy requirements of *Section 6.1.2.1* of ANSI B40.1 for Calibration of Gauges, it would be necessary to use a Standard that is at least four times as accurate as the Gauge being tested.
- Thus, for accuracy Grade 4A Gauge calibration, the permissible error is 0.1% of span. In order to satisfy this requirement, the transfer standard must have an accuracy of 0.025% or better for the span being measured.

The chain of Calibration traceability is shown diagrammatically below:

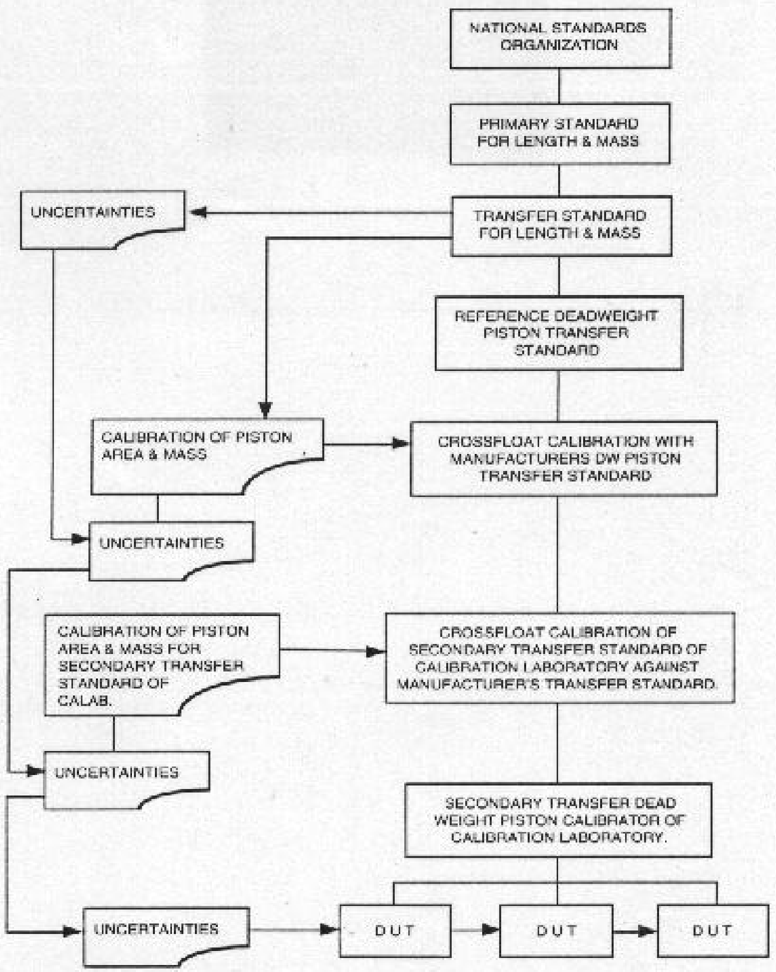


Fig. 1.0 - **Pressure Calibration Chain For Dead Weight Piston Assembly**

Chain of Calibration Traceability from Deadweight Piston Calibrators to DUT

Recommended Calibration Transfer Standards for Various Pressure Gauge Accuracy Grades

In addition to the above, for various accuracy Grades, ANSI B40.1 recommends the following Calibration Transfer Standard:

Accuracy Grade	Pressure Range	Transfer Standard
4A & 3A	As appropriate	Manometer or Piston Gage
2A, 1A, A, B, C & D	30 in Hg through 100 psi	Manometer or Piston Gage specially Calibrated Test Gage, Transducer
	Above 100 psi	Piston Gage, specially Calibrated Test Gage, Transducer

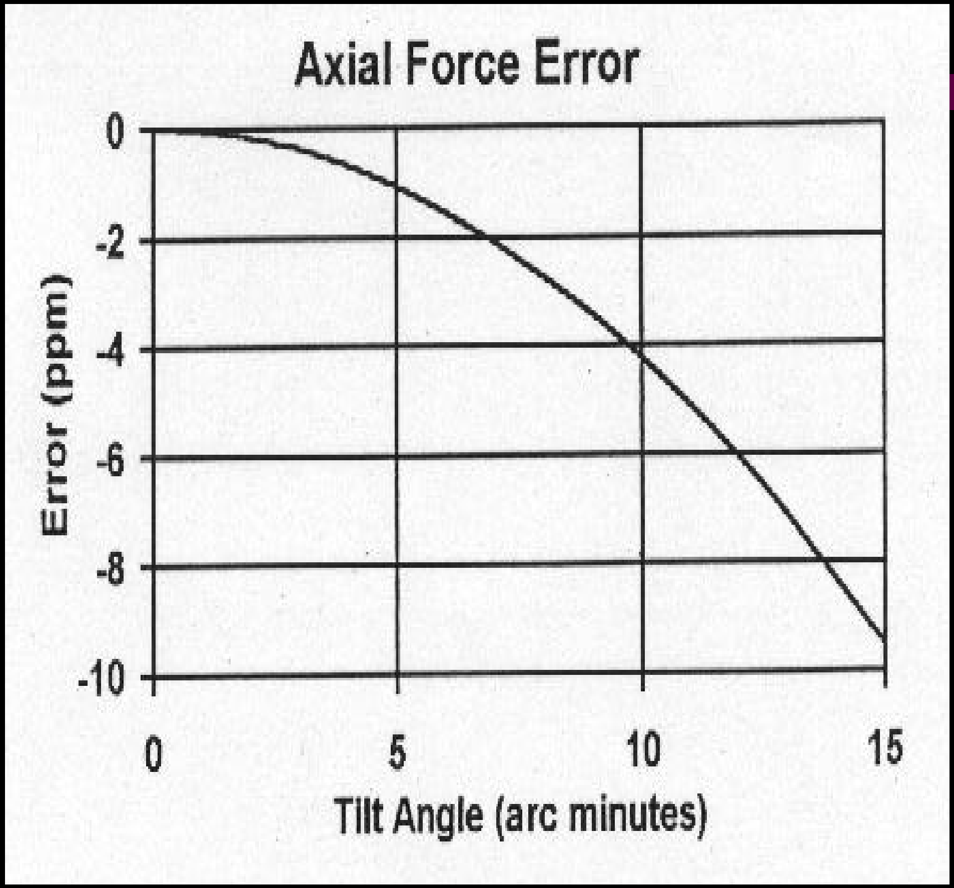
In the calibration of pressure gages, a minimum number of Test Points is also prescribed as follows:

Accuracy Grade	Minimum Number of Test Points
4A	10
3A, 2A, 1A, A	5
B, C, D	3

Note: ***The test points shall be distributed over the dial range and shall include points within 10% of the ends of the range.***

For the higher accuracy Grades Deadweight Piston Gages of sufficient accuracy would be required in order to meet ANSI B40.1.

The attitude or True Verticality of the Piston Greatly affects the accuracy of the Calibration Process.



The Chart to the left shows the effect of tilt on the accuracy of calibration.

It is therefore very important to assure that the piston is plumb or truly vertical.

Typical Setup showing Deadweight Piston Calibrator

**Nitrogen and Helium Bottles*

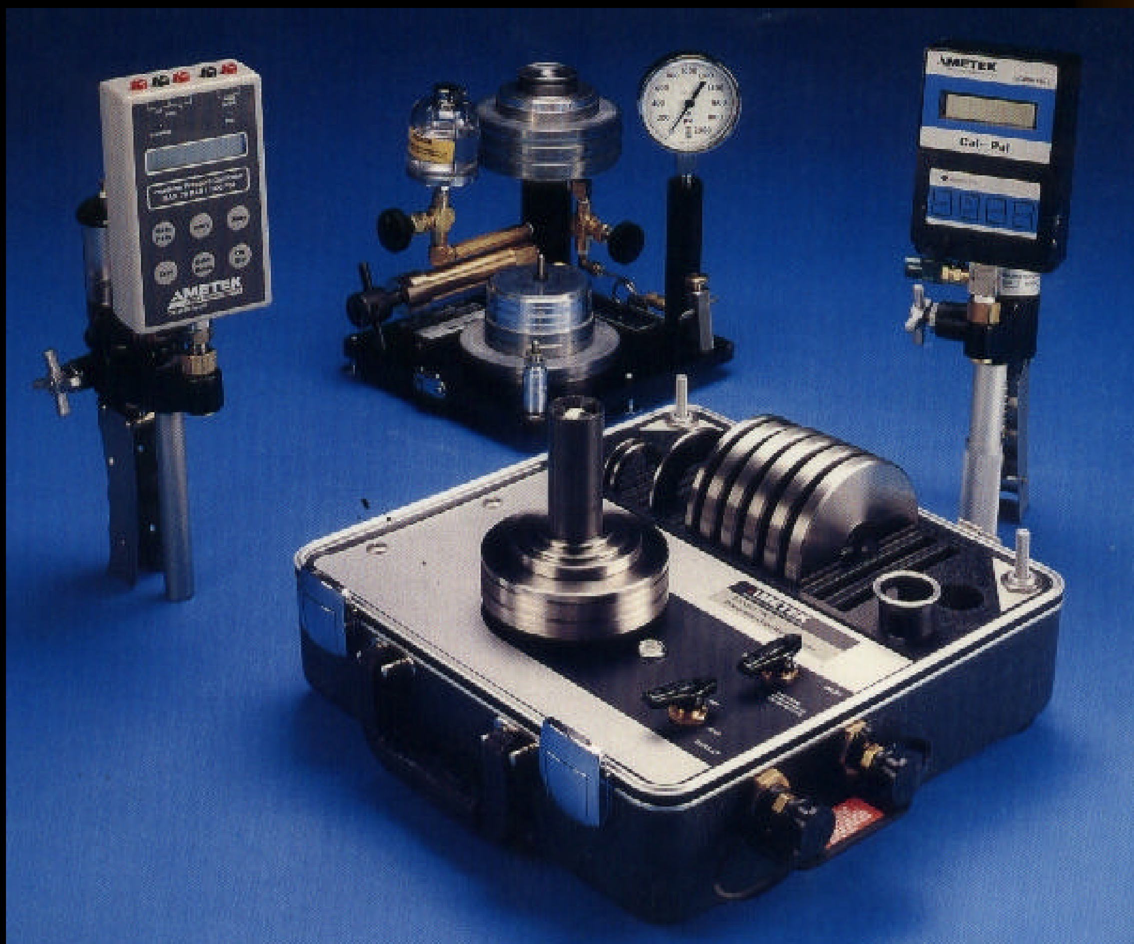
**Precision Deadweight Sets*

**High Pressure Hand Pump*

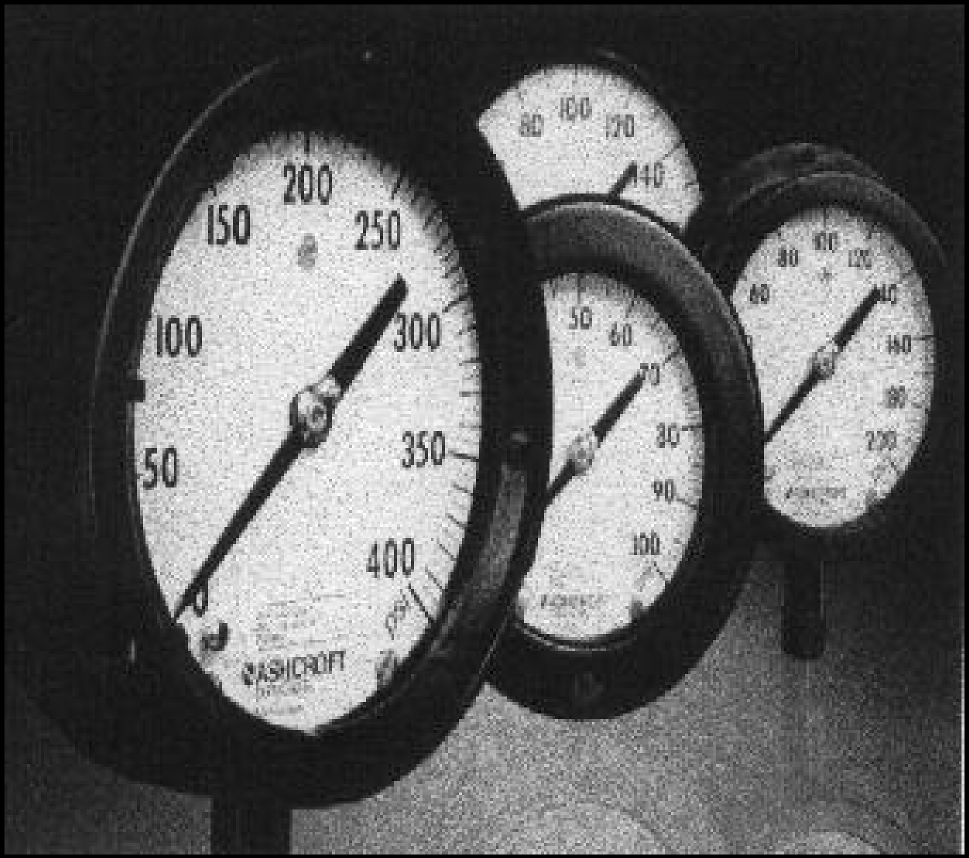
**Deadweight Piston Gauge*

Examples of DWT Piston Gauges

An Example of a DWT Piston Gauge for Secondary Transfer of Pressure



Pneumatic Electronic Pressure Calibrator for Calibration of Working Gauges and Pressure Transducers



Examples of Precision Bourdon Type Pressure Gauges

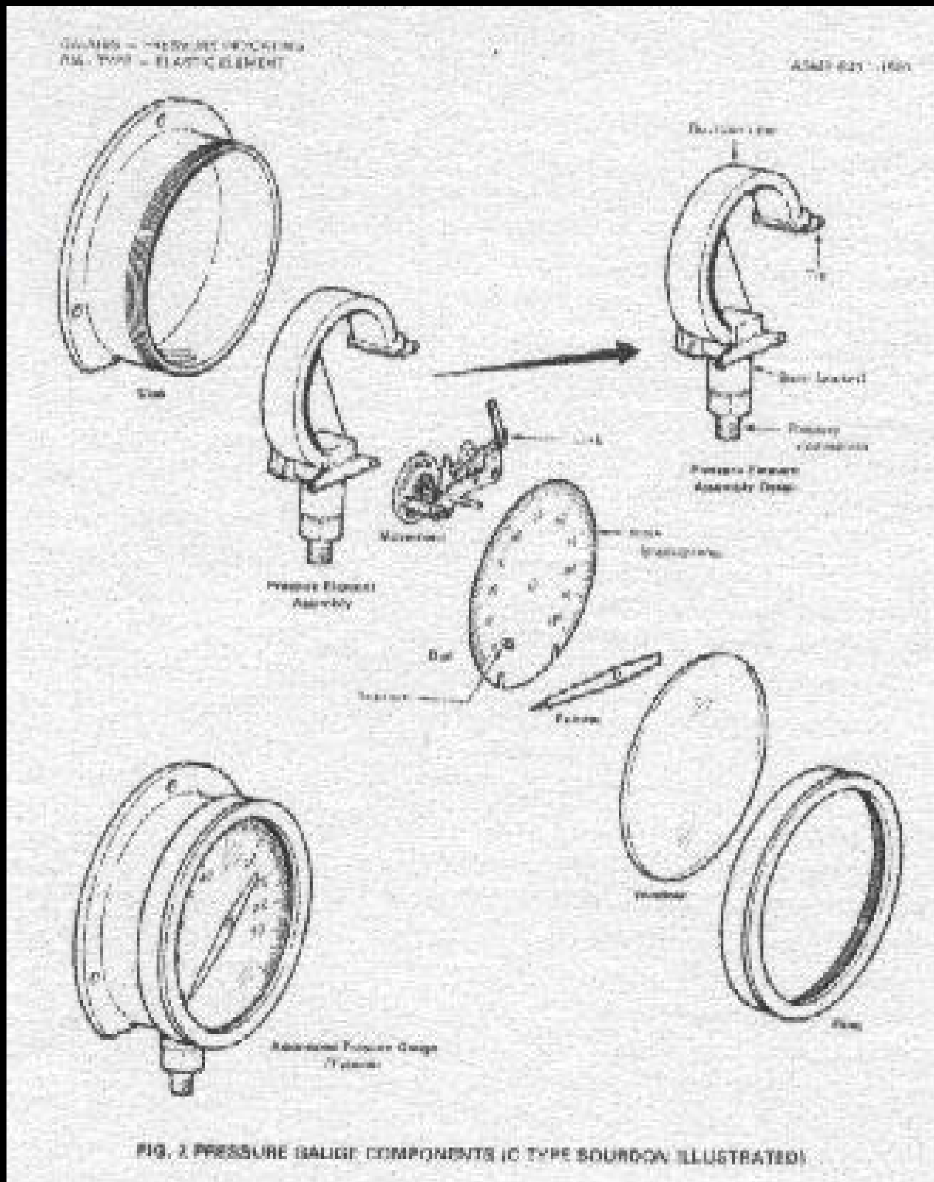


FIG. 2 PRESSURE GAUGE COMPONENTS (C TYPE BOURDON ILLUSTRATED)

The Inner workings of the Bourdon Type Gauge shows the mechanical moving parts which could go out of alignment thus requiring periodic calibration

Closure

- In closing, the following are important points to consider:
  - Pressure Calibration needs to satisfy accuracy requirements of the Device Under Test (DUT).
  - For High End precision Calibration, at normal to elevated pressures, the use of Deadweight Piston Gauges is necessary.
  - The end user needs to know the various requirements and factors likely to affect calibration so that such effects can be minimized or taken into account during the calibration process.