Static And Dynamic Calibration Of Pressure Measuring Instruments and U-Tube

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Q1. Read the static calibration of Pressure transducer experiment and explain the input, output and how do you use the result in future?

A1.

- Inputs are a constant DC voltage (16V) and pressure.
- Output is current measured in mA.

When pressure is not applied the output current will be zero since the transducer experiences zero strain so there is no strain in the resistors (which are in Wheatstone configuration) and thus the output current will be zero. But when pressure increases, the resistors are strained and thus the Piezoresistor generates some output current in mA.

The output current is then used to measure pressure.

They can be used for absolute, gauge, relative and differential pressure measurement, in both high- and low-pressure applications.

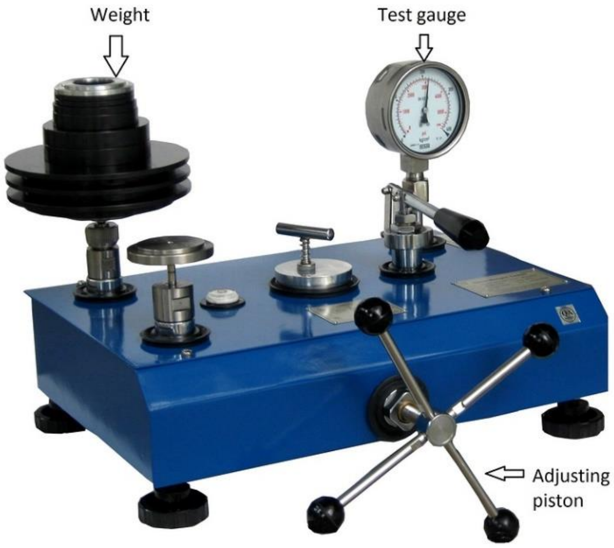
These results can be used in semiconductor strain gauges, pressure sensors, accelerometers, etc.

Q2. Explain the working principle of Bourdon gauge?

A2. The Bourdon pressure gauge operates on the principle that, when pressurized, a flattened tube tends to straighten or regain its circular form in cross-section, resulting in the deflection of the pointer which is connected to the curved portion via geared mechanism.

Q3. How will you calibrate bourdon gauge using dead weight tester?

A3.



Step by step procedure:

- Check if the adjusting piston is completely disengaged.
- Set the needle of the test gauge to zero.
- Select a weight and place it on the vertical piston.
- Turn the handle of the adjusting piston to make sure that the weight and the piston are supported freely by oil.
- Check if the vertical piston is floating freely by spinning it.
- Let the system stabilize and record the bourdon gauge reading and the weight.
- Repeat the previous steps by keeping more weights and then record the reading by decreasing the weights. Calculate the error at each gauge reading.

At each pressure reading the absolute error is,

$$Error = \ DWT\ pressure - Bourdon\ Gauge\ Pressure$$

Q4.

Q. a. What is the analogy between the dynamic calibration of U-tube manometer

and RLC experiment?

Ans. a.

2^{nd} order dynamic calibration of U-tube manometer equation :

$$\rho_m A l \frac{d^2h}{dt^2} + \frac{32\mu l A}{d^2}\frac{dh}{dt} + 2\rho_m g A h = \Delta P A \quad -(1)$$

2^{nd} order LCR circuit equation :

$$L\frac{d^2 i}{dt^2} + R\frac{di}{dt} + \frac{1}{C} i = 0 \quad -(2)$$

Comparing equation (1) and (2) we can draw analogy, i.e

$$L = \rho_m A l = \frac{\rho_m \pi d^2 l}{4}$$

$$R = \frac{32\mu l A}{d^2} = \underline{32\mu l \pi} = 8\pi\mu l$$

$$\frac{1}{C} = 2\rho_m g A = \frac{\rho_m g \pi d^2}{2}$$

In LCR circuit,

$$\text{damping coefficient} = \frac{R}{2}\sqrt{\frac{C}{L}}$$

Substituting,
$$R = 8\pi\mu l$$
$$L = \frac{\rho_m \pi d^2 l}{4}$$
$$C = \frac{2}{\rho_m g \pi d^2}$$

$$(\text{Damping coeff})_{\text{manometer}} = \frac{8\pi\mu l}{2}\sqrt{\frac{2}{\rho_m g \pi d^2} \times \frac{4}{\rho_m \pi d^2 l}}$$

$$(\text{Damping Coeff})_m = \frac{8\mu l}{\rho_m d^2}\sqrt{\frac{2}{gl}}$$

$$\boxed{(\text{Damping Coeff})_m = \frac{8\mu l}{\rho_m g d^2}\sqrt{\frac{2l}{g}}}$$

Q. b. Also extend the analogy to forced vibration. For all the three cases, list down the driving, restoring and damping mechanism.

Ans. b.

In a forced damping vibration,

The second order differential equation is:

$$mu'' + \gamma u' + ku = F(t)$$

If we compare this equation to the LCR second order equation and the U-tube manometer second order equation:

U-tube Manometer	**RLC- Circuit**	**Damped Vibrations**
Displacement(h)	Charge (Q)	Displacement (u)
Mass ($\rho A l$)	Inductance (L)	Mass (m)
Friction ($^{32ulA}/_{d^2}$)	Resistance (R)	Damping Constant (γ)
Gravitational Potential ($2\rho A g$)	1/Capacitance	Spring Constant (k)
Force (ΔP × A)	Potential difference (ΔV)	Force (F)

Force	**U-tube Manometer**	**LCR-Circuit**	**Damped Vibrations**
Driving	Inertial Force	Induced Force	Inertial Force
Restoring	Gravitational Force	Energy stored in capacitor	Spring Force
Damping	Friction	Resistance	Damping constant

Q. c. For the type of manometric fluids given in the manual calculate the theoretical damping ratio and natural frequency or time constant.

Ans. c.

Damping coefficient is given by: $\left(\xi = \frac{8L\mu}{\rho g D^2}\sqrt{\frac{2g}{L}}\right)$

Natural frequency is given by: $\omega_n = \sqrt{\frac{2g}{l}}$

Length taken = 1m

Fluid	Diameter(mm)	Damping Ratio	Natural Frequency (s^{-1})
Water	4	0.20103	4.4272
Water	6	0.08.935	4.4272
Water	8	0.05026	4.4272
Mercury	4	0.02493	4.4272
Mercury	6	0.01108	4.4272
Mercury	8	0.006231	4.4272
CCl_4	4	0.129	4.4272
CCl_4	6	0.05731	4.4272
CCl_4	8	0.03224	4.4272

Q. d. How does the system behaviour (output of the system) change for under-damped, damped and over-damped system. Draw a schematic of output for each system.

$$Damping\ Factor < 1 => Underdamped$$

$$Damping\ Factor = 1 => Ctritically\ Damped$$

$$Damping\ Factor > 1 => Overdamped$$

For Underdamped System:

- It is oscillatory.
- Amplitude decreases with time.
- There is exponential decay.

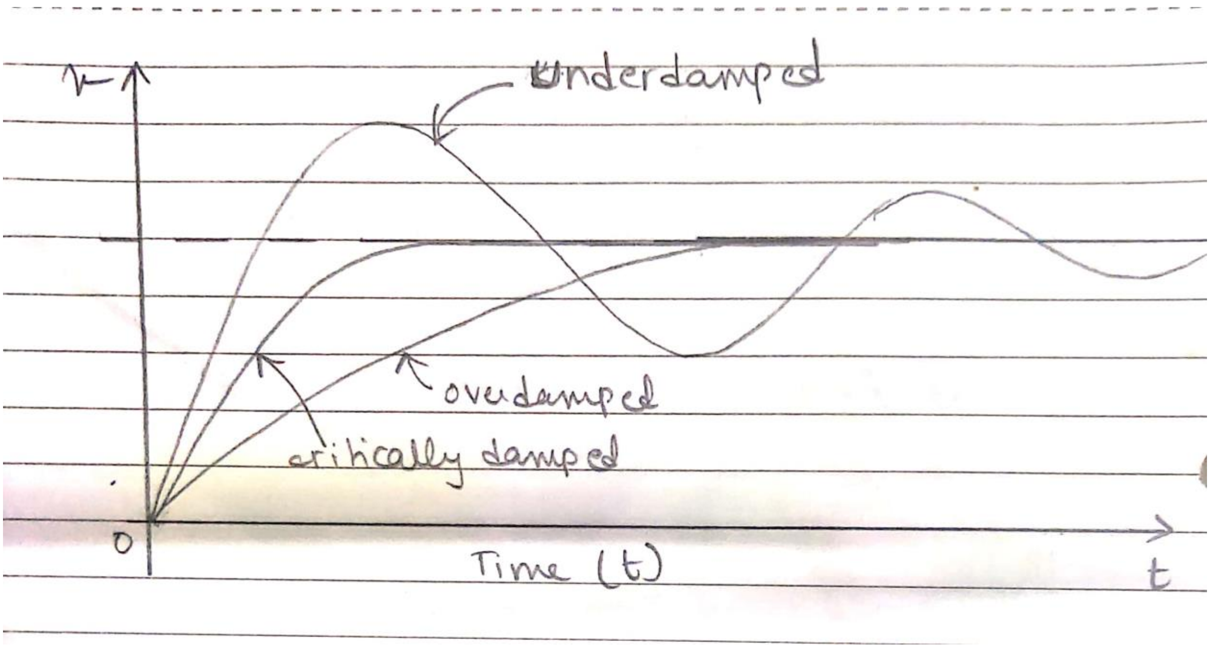
- For damping factor <= 0, system is unstable since it never returns to its equilibrium position.
- For damping factor which is positive and less than 1, system is stable since it returns back to its equilibrium position.

For Critically Damped System:

- It is not oscillatory.
- It will directly decay to 0 value (equilibrium).
- It is fastest damping system which reaches to equilibrium.

For Overdamped System:

- It is also not oscillatory.
- It will decay to a tending to 0 value.



Q. e. List down different ways to measure low-pressure, explain their working principles for any 3 and also possible sources of error.

Ans. e.

Different ways to measure low-pressure:

- Mechanical Type – McLeod Gauge
- Thermal Type – Thermocouple, Pirani Gauge, Knudsen Gauge
- Ionization Type – Hot Cathode and Cold Cathode
- Radiation Vacuum Gauge – Alphatron, Quartz Reference

McLeod Gauge:

Principle:

McLeod Gauge is based on Boyles Fundamental theorem equation.

$$p_1 = \frac{p_2 v_2}{v_1}$$

P and V refer to pressure and volume with subscripts 1 and 2 for initial and final conditions

McLeod gauges operate by taking in a sample volume of gas from a vacuum chamber, then compressing it by tilting and infilling with mercury. The pressure in this smaller volume is then measured by a mercury manometer, and knowing the compression ratio (the ratio of the initial and final volumes), the pressure of the original vacuum can be determined by applying Boyle's law.

Sources of error:

- Condensation of low-pressure gas to the liquid/solid phase may occur during the compression stage.
- Contamination by mercury vapours may occur.

Pirani Gauge:

Principle:

The Pirani gauge measures the vacuum pressure dependent thermal conductivity from the heated wire to the surrounding gas.

As gas molecules collide with the filament wire, heat is transported from the hot wire. The heat loss is a function of the gas pressure and at low pressure the low gas density and long mean free path between gas molecules provides a low thermal conductivity. At high pressure the high gas density and short mean free path between molecules will result in high thermal conductivity.

Sources of Error:

- There can be insulation resistance. Insulation Resistance refers to the electrical resistance between the sensing circuit and the metallic sheath of a resistance thermometer. It is important for the sensing element circuit to be insulated from the sheath because electrical leakage can cause an error when measuring the resistance of the sensing element.

Alphatron Gauge:

Principle:

Alphatron is a radioactive ionization gauge in which a small radium source serves as an alpha particle emitter. These particles ionize the gas inside the gauge enclosure. Number of ions is directly proportional to the gas pressure. The degree of ionization is measure by measuring the voltage output.

Sources of error:

- If the gas being measured has a very high ionization cross-section, there would be larger number of ions at a given pressure.
- Radium in equilibrium with its daughter products gives a very stable flux of alpha particles. But if there is any film of condensable vapours on the source, it will reduce the flux and change the average energy.