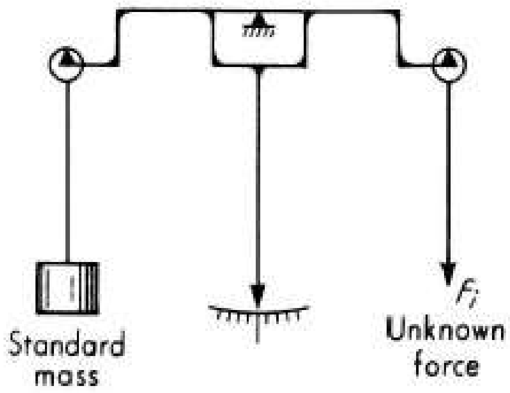
Measurement of Force, Motion, Sound, etc.

Slide 4

Most. Naznin Nahar

Analytical Balance



Analytical Balance

Analytical balances use the principle of magnetic force restoration (MFR) to measure the weight of an object:

1. **Detect the weight**

When an object is placed on the balance pan, it exerts a downward force that is detected by sensors.

2. **Generate an opposing force**

An electromagnet generates an opposing force to counterbalance the weight of the object.

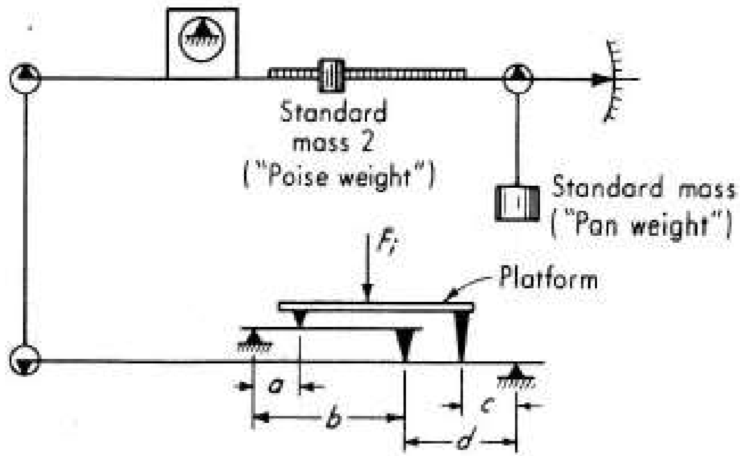
3. **Calculate the mass**

The electrical current required to generate the opposing force is proportional to the object's weight. This current is used to calculate the object's mass, which is then displayed on the balance screen.

Analytical balances are often used in educational settings, forensic science, veterinary medicine, and agricultural research.

Measurement of Force, Motion, Sound, etc.

Platform Scale



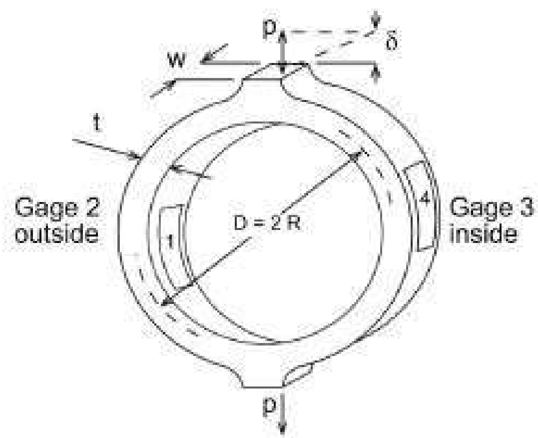
Platform Scale

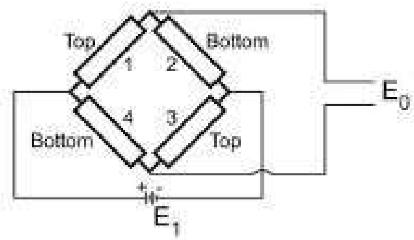
A platform scale uses load cells to measure weight by converting force into an electrical signal:

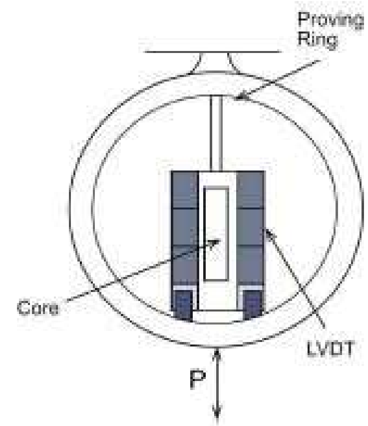
1. **Place an object on the scale**
   The object's weight compresses or stretches the load cells beneath the platform.
2. **Load cells create an electrical signal**
   The load cells bend slightly, which changes the electrical resistance of a strain gauge inside the load cell. This creates an electrical signal that's proportional to the weight being measured.
3. **Scale electronics process the signal**
   The scale's electronics process the signal and convert it into a weight measurement.
4. **Display the weight**
   The weight is displayed on the scale's screen or indicator.

Measurement of Force, Motion, Sound, etc.

Proving Ring







Proving Ring

A proving ring is a device that measures applied weight by measuring the deflection of an elastic ring when loaded along a diameter:

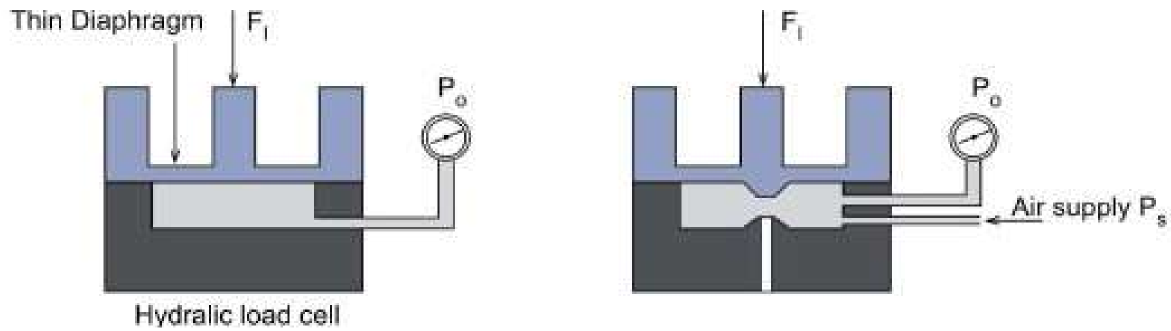
•**How it works**

•A proving ring works by applying forces to the ring through external bosses, causing the ring to deflect. The deflection is measured using a vibrating reed and a micrometer screw mounted within the ring.

Proving rings are a simple, reliable, and accurate alternative to dead-weight calibration. They are stable, long-lasting, and consume no power

Measurement of Force, Motion, Sound, etc.

Hydraulic & Pneumatic Load Cell



If a force is applied to one side of a piston or diaphragm, and a pressure, either hydraulic or pneumatic, is applied to the other side, some particular value of pressure will be necessary to exactly balance the force. This is the working principle of these instruments.

Hydraulic and Pneumatic Load Cell

Hydraulic and pneumatic load cells both work on the force-balance principle to measure weight as a change in pressure:

•**Hydraulic load cells**

•Use a piston and cylinder arrangement to convert a load into hydraulic pressure:

•A load is applied to a platform attached to a piston in a closed chamber filled with fluid.

•The piston moves and deflects the diaphragm, increasing the pressure in the fluid.

•The pressure increase is transmitted to a pressure gauge, which converts it to an electrical signal proportional to the applied force

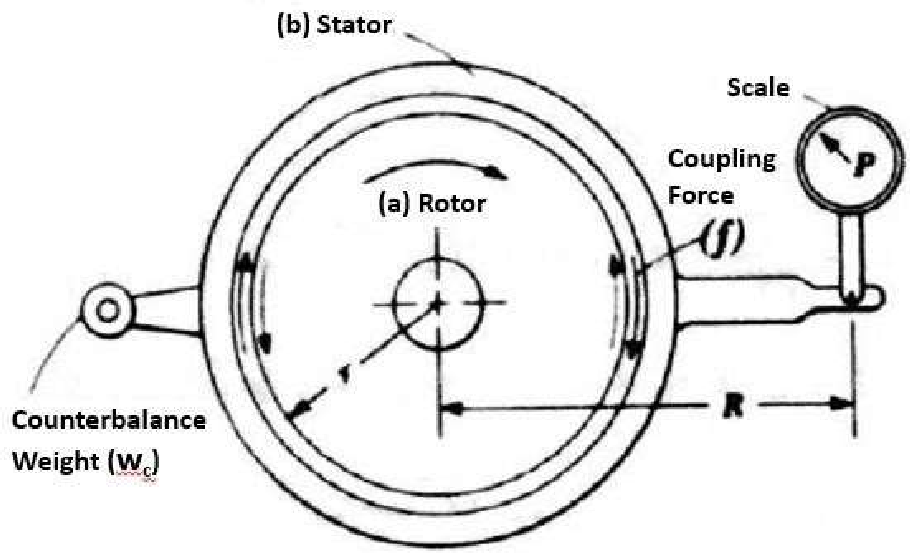
Dynamometer: Measurement of Torque and Power

Any apparatus that permits the measurement of torque and power of the engine is called a "*dynamometer*". (dyno)

There are many types of dynamometers; all operate on the principle illustrated in fig.

Here the rotor (a), driven by the engine to be tested, is coupled (electrically, magnetically, hydraulically or by friction) to the stator (b).

In one revolution of the shaft, the peripheral of the rotor moves through a distance ($2\pi r$) against the coupling force f.



Thus the work per revolution is: Work = $2\pi r f$

The external moment, which is the product of the reading p of the scale (could be a beam balance or weights) and the arm R, must just balance the turning moment $r \times f$;

i.e., $r \times f = R \times P$ therefore, Work = $2\pi RP$ where R in meters and P in Newton

So Work per minute = $2\pi RPN$ (N is engine speed in rpm)

Power is defined as the time rate of doing work, i.e. Power = $2\pi RPN$

$$Power = \frac{2\pi PRN}{1000 \times 60} \ kW$$

Dynamometer Classifications

- **Mechanical Friction type Dynamometers:** A friction band/belt is used to obstruct the rotating object. The frictional force times the radius of the rotor gives the torque.

- Water brake Dynamometers employ fluid friction and momentum transport to dissipate energy.
- Eddy Current Dynamometers: A direct current field coil and a rotor allow shaft power to be dissipated by eddy currents in the stator winding. The resulting conversion to thermal energy by joulian heating of the eddy currents necessitates some cooling be supplied, typically using cooling water.

Eddy Current Dynamometer

An eddy current dynamometer measures the torque and power of a motor or engine by using Faraday's Law of electromagnetic induction:

•**Excitation**

•A DC supply excites the stator poles, generating a magnetic field in the stator coils.

•**Rotation**

•The prime mover spins the rotor coils, which cut the stator's magnetic field.

•**Eddy currents**

•The cutting of the magnetic field induces an EMF in the rotor, which generates eddy currents.

•**Torque**

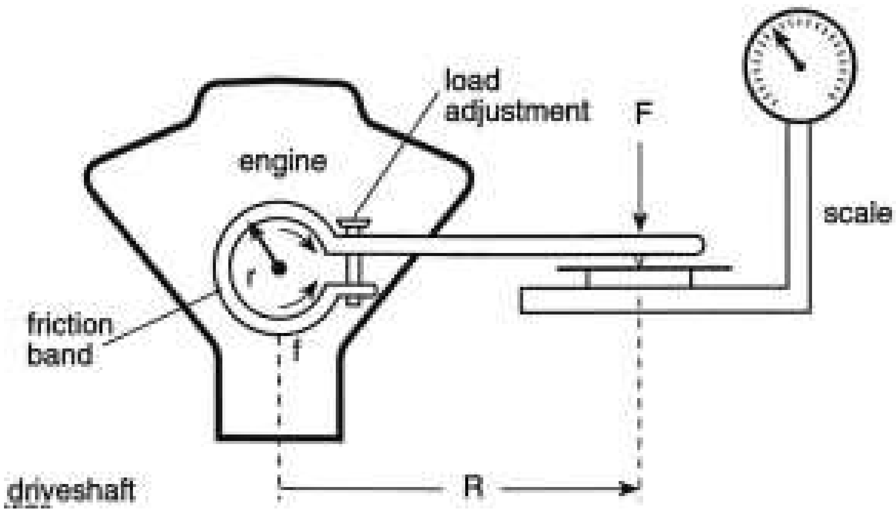
•The rotor obtains a reverse force, and the prime mover's torque keeps the speed consistent. A sensor measures the torque.

•**Cooling**

•The eddy currents dissipate as heat, so the dynamometer requires cooling.

Eddy current dynamometers are used in a variety of applications, such as mining, drilling machinery, and turbines.

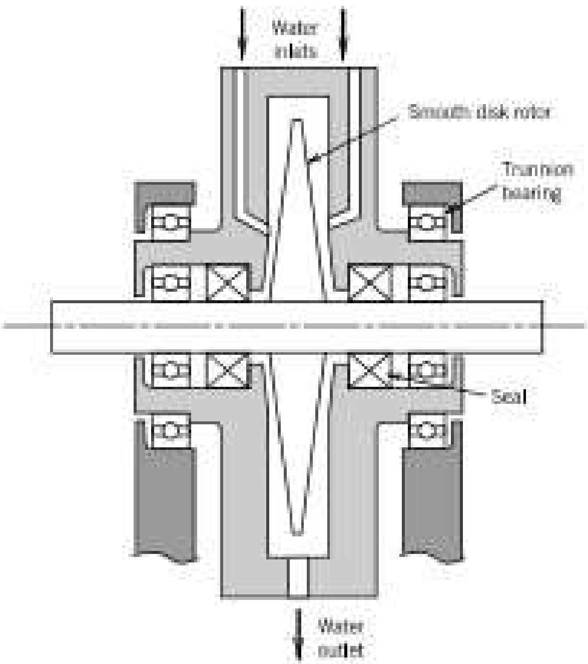
Dynamometer Classifications



- $\omega = \frac{2\pi}{60} N_{rpm}$
- torque, $\tau = FR$
- brake power, $\dot{W}_b = \tau\omega$

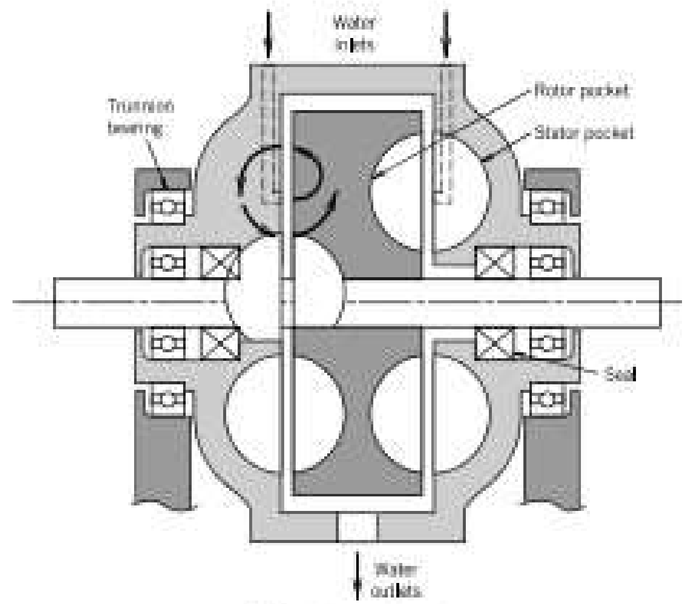
Mechanical (dry) friction type dynamometer

Dynamometer Classifications



(a) Viscous shear type

T619



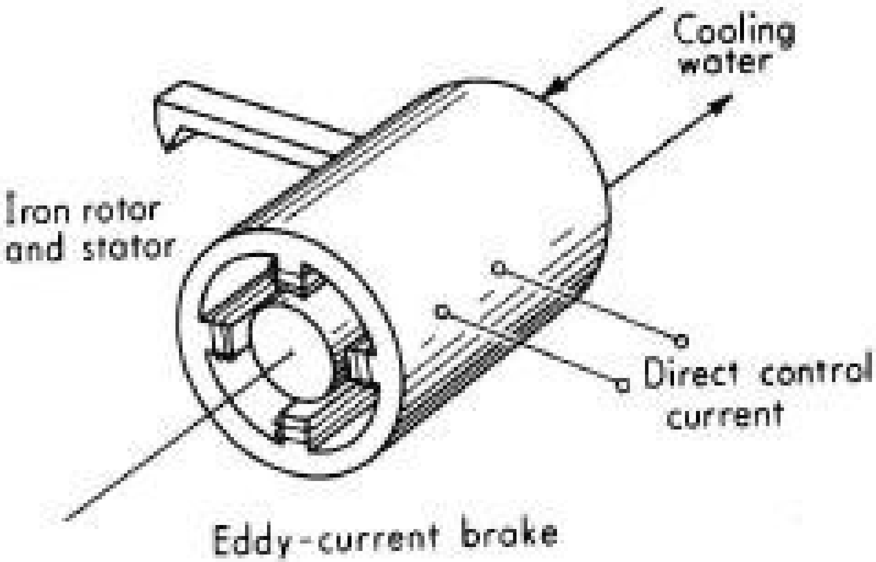
(b) Momentum exchange type

T620

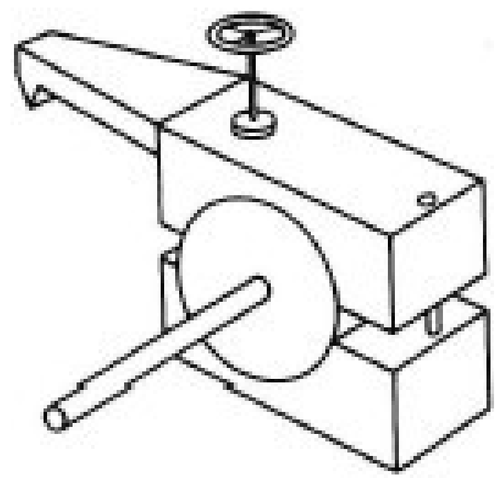
Viscous shear type brake is useful for high speeds, & agitator type unit is used over a range of speeds and loads. Water brakes may be employed for applications up to 7450 kW. The load absorbed by water brakes can adjusted using water level & flow rates in the brake.

Water-brake (hydraulic) type dynamometer

Dynamometer Classifications



Eddy-current type dynamometer



Pony brake type dynamometer

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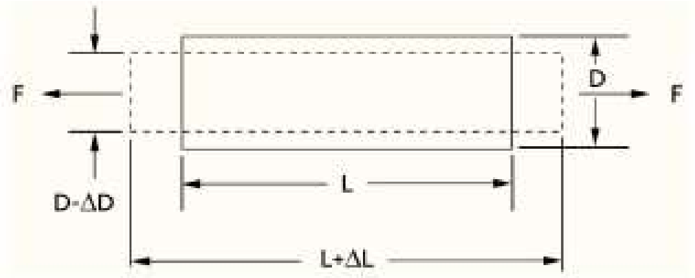
Measurement of Strain

- **Grid Method:** Some grid markings are placed on the work-piece under zero-load conditions. The deformation of the grid is used to measure the strain when the work-piece is subjected to a load. The grid may be scribed on the surface, drawn with a fine ink pen, or photoetched. The grid deformation may be measured by using: ⊙ Micrometer microscope, ⊙ Photography & ⊙ Extensometer.
- **Brittle Coating Method:** Work-piece is coated with some special coating with very brittle properties. When subjected to a load, small cracks appear in the coating. These cracks are used as an indication of the local stress level higher than some critical value. Very suitable method to determine the stresses at stress concentration points that are too small or inconveniently located for installation of strain gauges.
- **Resistance Strain Gauges:** ⊙ Metallic & ⊙ Semiconductor. Operation is based on principle that the electrical resistance of a conductor changes when it is subjected to mechanical deformation.

Measurement of Force, Motion, Sound, etc.

Resistance Strain Gauge



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$$\text{Axial strain, } \epsilon_a = \frac{\Delta L}{L}$$

$$\text{Traverse strain, } \epsilon_t = \frac{\Delta D}{D} = \frac{1}{2}\frac{\Delta A}{A}$$

$$\text{Poission's Ratio, } \mu = -\frac{\epsilon_t}{\epsilon_a}$$

- $R = \rho \frac{L}{A}$: $\rho =$ resistivity of material, $R =$ resistance
- $\frac{dR}{R} = \frac{d\rho}{\rho} + \frac{dL}{L} - \frac{dA}{A} = \frac{d\rho}{\rho} + \epsilon_a(1+2\mu)$
- $\boxed{F \equiv \frac{dR/R}{\epsilon_a} = 1 + 2\mu + \frac{d\rho/\rho}{\epsilon_a}}$: $F =$ Gauge Factor

Resistance change due to:
$\rightarrow$ Length change
$\rightarrow$ Area change
$\rightarrow$ *Piezoresistance* effect.

Resistance Strain Gauge

A resistance strain gauge, also known as an electrical resistance strain gauge (ERSG), is a sensor that measures changes in electrical resistance to determine strain.

•**Principle**

When a force is applied to a metal, it expands or contracts, which changes its electrical resistance.

•**Operation**

The gauge is attached to the surface of an object, and when the object deforms, the gauge stretches or compresses, changing its resistance.

•**Measurement**

The change in resistance is converted into an electrical signal that can be measured.

•**Arrangement**

Strain gauges are often arranged in Wheatstone bridge circuits to obtain measurable output signals.

•**Output**

The output voltage changes when the resistance of the strain gauge changes.

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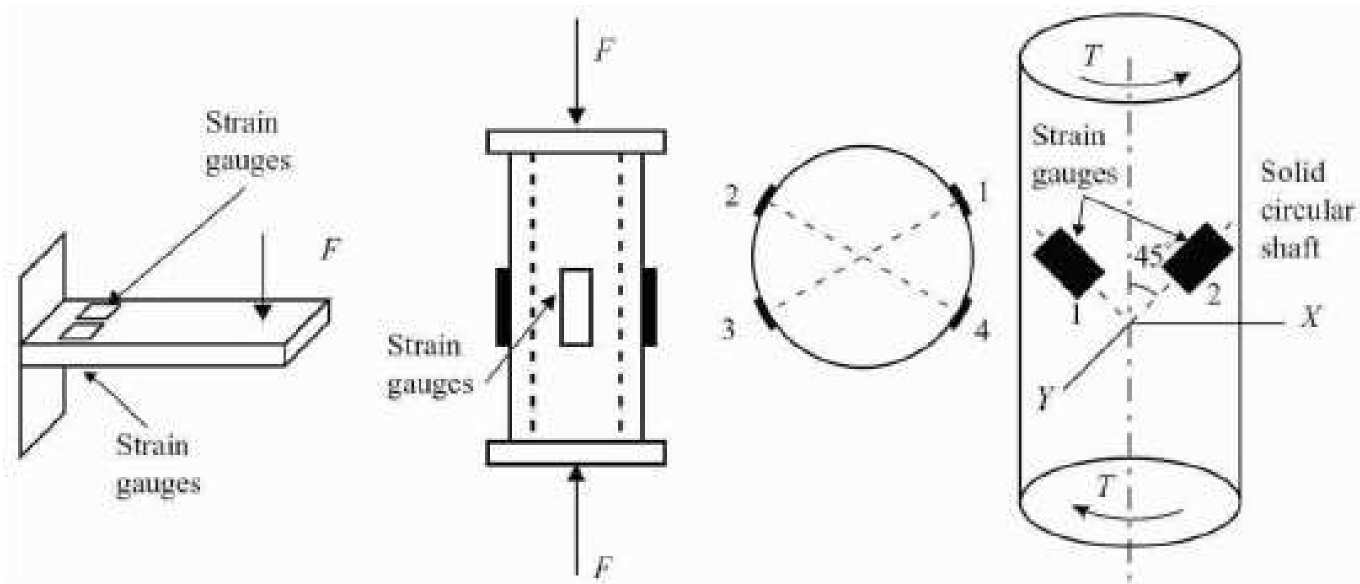

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Force & Torque measurement on a shaft or beam using strain gauges directly mounted on the part

Strain Gauge to Measure Force and Torque

Strain gauges can be used to measure force and torque by converting the force or torque into an electrical signal:

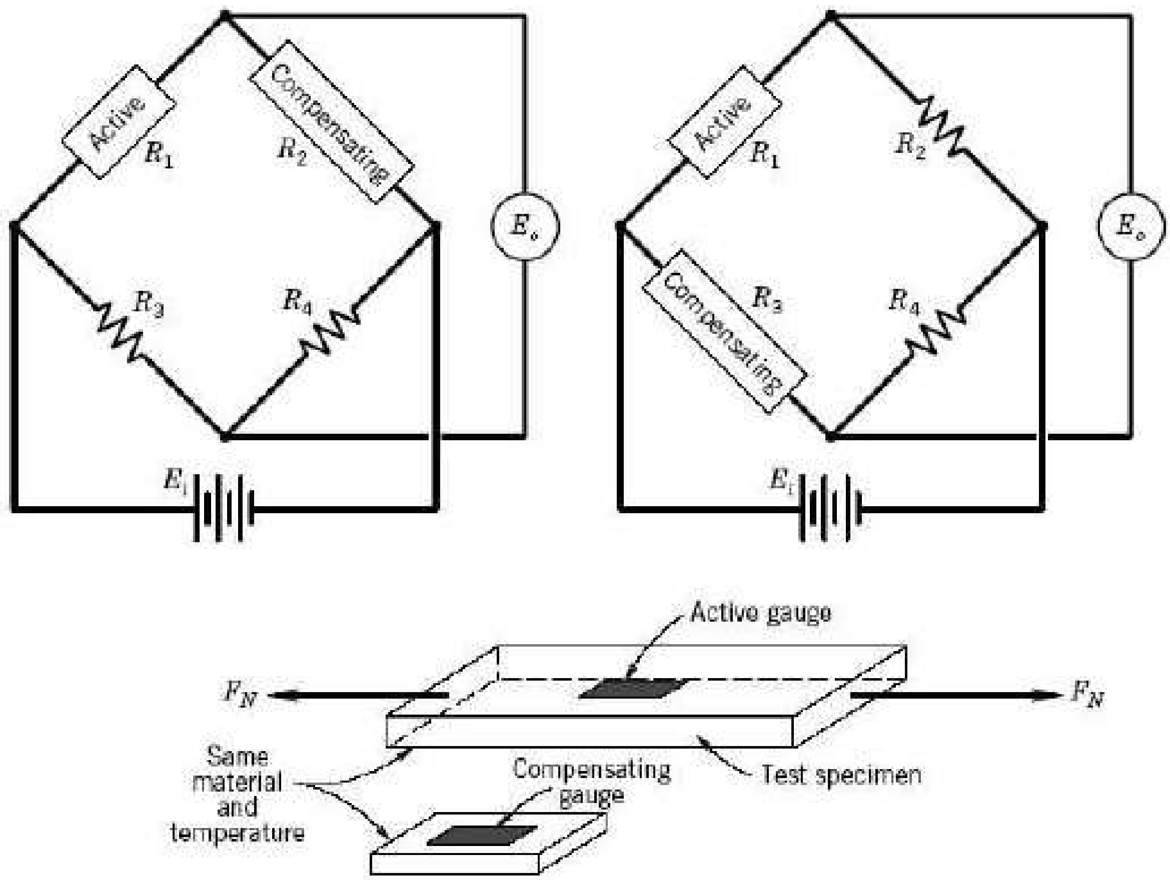
•**Torque**

•Strain gauges are mounted in pairs on a rotating shaft to measure torque. The gauges are placed at 45 degrees to the shaft axis, with one pair diametrically opposite the other. When torque is applied, the shaft twists, causing the gauges to elongate or compress. This changes the resistance in the circuit, which creates an electrical output that corresponds to the torque.

•**Force**

•Strain gauges are used to measure force by expanding and compressing in response to the applied force. The electric output signal changes in proportion to the force, which can be converted into a precise measurement

Measurement of Force, Motion, Sound, etc.



Strain gauge installation for temperature compensation

Strain Gauge to Compensate Temperature

Self-temperature-compensated (STC) strain gauges are designed to minimize the effect of temperature on strain measurements by adjusting their resistive temperature coefficient to match the linear expansion coefficient of the material being measured. This makes the apparent strain (the temperature-induced expansion of the material) close to zero

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Displacement Measurement

Most common transducers can be configured to sense displacements. However, the followings are basically displacement sensitive:

1. Resistance potentiometers
2. Resistance strain gauges
3. Variable-inductance devices
4. Differential transformers
5. Capacitive transducers
6. Piezoelectric transducers

- Variable-inductance, capacitance, piezoelectric, & strain-sensitive transducers are suitable for small displacements.
- Differential transformer may be used over intermediate ranges, say a few microinches to several inches.
- Resistance potentiometers are not as sensitive to small displacements but with no limit on the maximum.
- With the exception of the piezoelectric type, all may be used for both static and dynamic displacements.

Vibrometer

A vibrometer measures vibrations using a variety of methods, including optical interference and sensors:

•**Laser Doppler vibrometer (LDV)**

•Uses optical interference to measure the frequency difference between a reference beam and a test beam. The test beam is directed at a target, and the scattered light is collected and interfered with the reference beam on a photodetector. The voltage signal from the photodetector is proportional to the velocity of the target.

•**Vibration meter**

•Uses sensors to measure vibrations and convert them into electrical signals. A computer then converts the electrical signals into numerical values, which are analyzed to determine the vibration level.

The working principle of a vibrometer is based on the Doppler effect, which involves sensing the frequency shift of light that is scattered back from a moving surface.

Accelerometer

An accelerometer works by measuring the acceleration of an object using a variety of principles, including:

•**Piezoelectric effect**

•When a piezoelectric material, like quartz, barium titanate, or lithium sulfate, is subjected to mechanical stress, it produces an electrical charge. The charge is proportional to the force applied to the material.

•**Mass and spring**

•When an object is accelerated, the mass attached to a spring moves, which stretches or compresses the spring. The displacement of the mass is used to calculate the acceleration.

Accelerometers are electromechanical devices that are used in a variety of applications, including space stations and handheld devices

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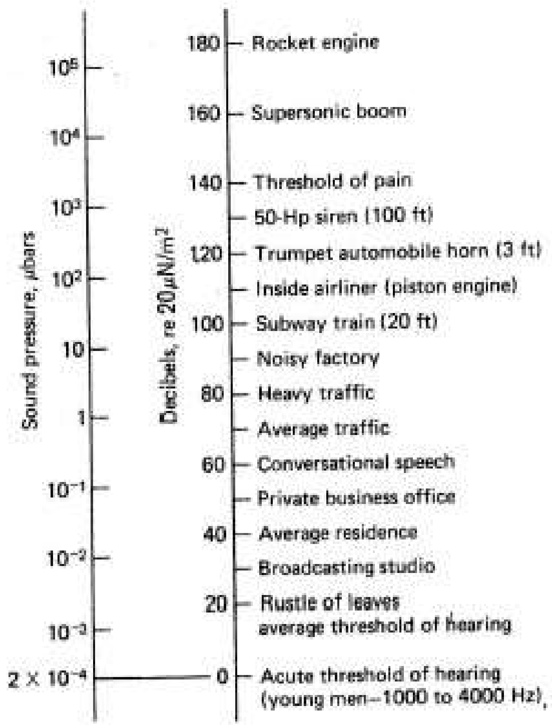
Sound Measurements

Sound intensity or pressure level is measured in decibels (dB). It is called *Sound-pressure level.*



$$SPL = 10 \log \frac{I}{I_o} = 20 \log \frac{P}{P_o}$$

$$I_o = 10^{-12} \mathrm{W/m^2}$$

$$P_o = 2 \cdot 10^{-5} \mathrm{Pa}\ (0.0002\ \mu\mathrm{bar})$$

$$SPL_{total} = 10 \log \sum_{i=1}^{n} 10^{(SPL_i/10)}$$

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Example: Two sources of equal SPL are added:

$$SPL_{total} = 10\log\left[2 \cdot 10^{(SPL/10)}\right] = 10\log 2 + SPL = 3 + SPL$$

Sound level is measured by microphones which incorporates a thin diaphragm which is moved by air acting against it. The movement of the diaphragm is converted to an electrical signal by some form of secondary transducer that provides an analogous electrical signals.