

Cochin University of Science and Technology



Assignment

On

Force Measurement , Torque Measurement and Multiple Lever system

Course Title: Metrology and Instrumentation

Submitted by:

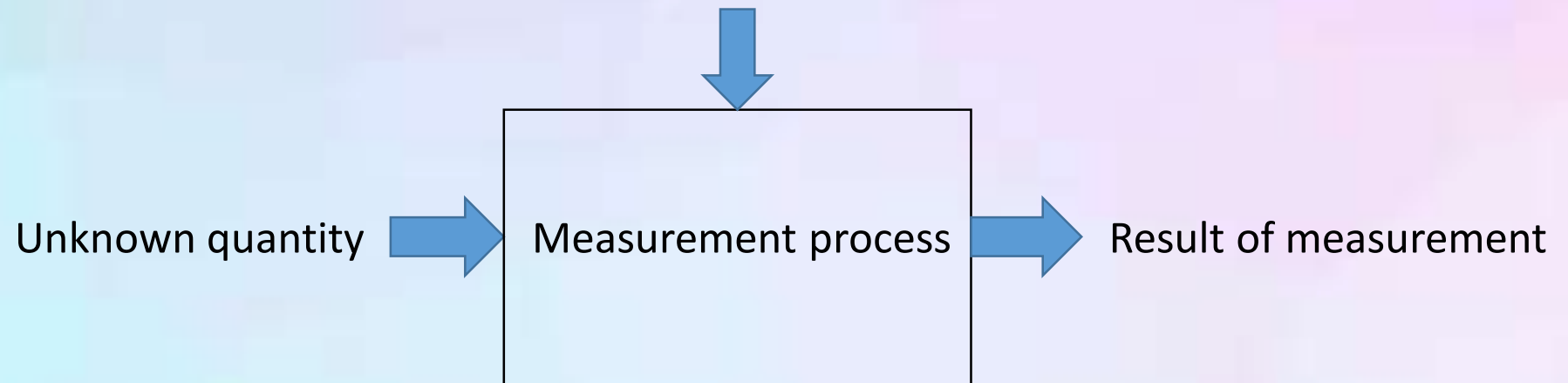
Anandhu Suresh

Mechanical Branch- SEMESTER-4(A-BATCH)

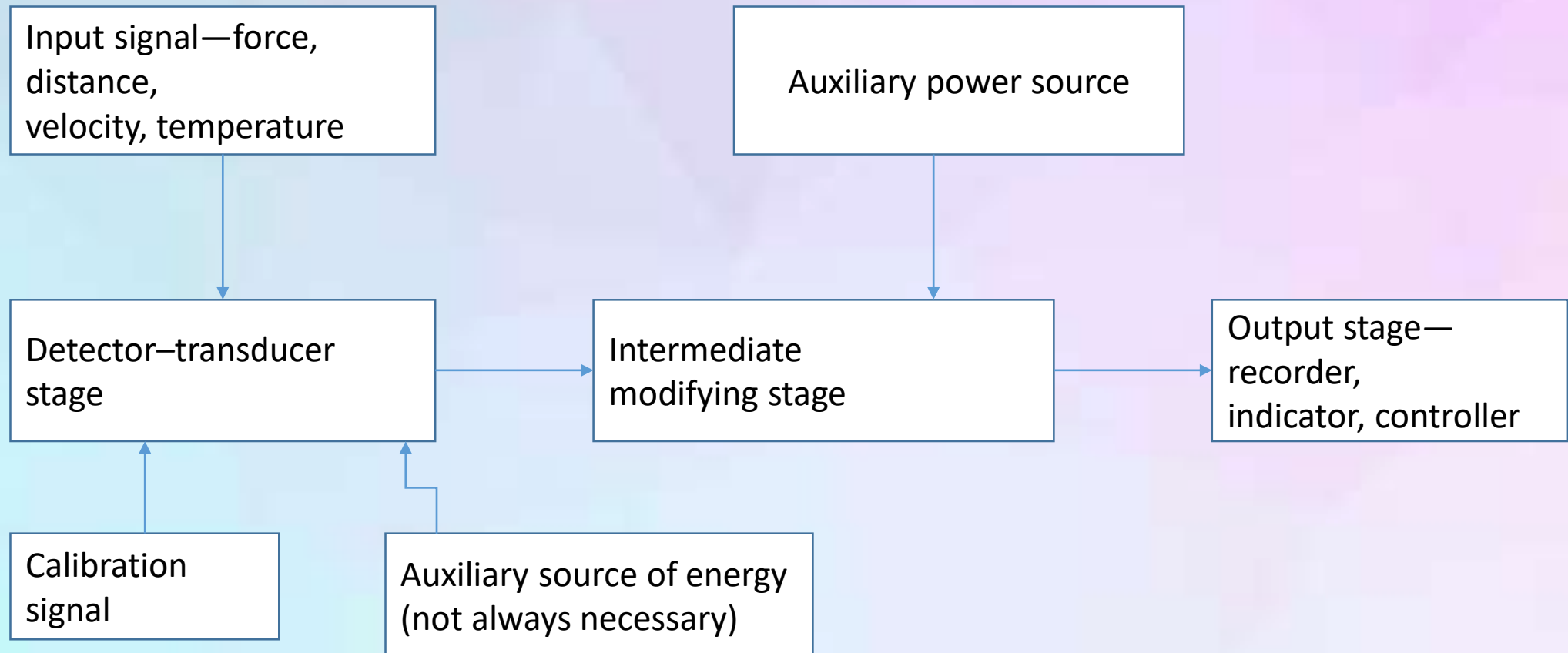
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Introduction

- We know that measurement is defined as the quantification of a physical variable using a measuring instrument. During the process of measurement, a specific value is assigned to the unknown quantity after due comparison with a predefined standard. The measuring process is schematically represented in Fig.1



➤ FUNCTIONAL ELEMENTS OF MEASUREMENT SYSTEMS



➤ MEASUREMENT OF FORCE

The methods for measuring force can be classified into two basic categories: ***direct and indirect***.

- In case of direct methods, a direct comparison is made between an unknown force and the known gravitational force on a standard mass. For this purpose, a beam balance may be employed where in masses are compared. In this case, the beam neither attenuates nor amplifies.
- Indirect comparison is made by a calibrated transducer that senses gravitational attraction or weight. Sometimes, the deformation due to a force applied on an elastic member is measured.

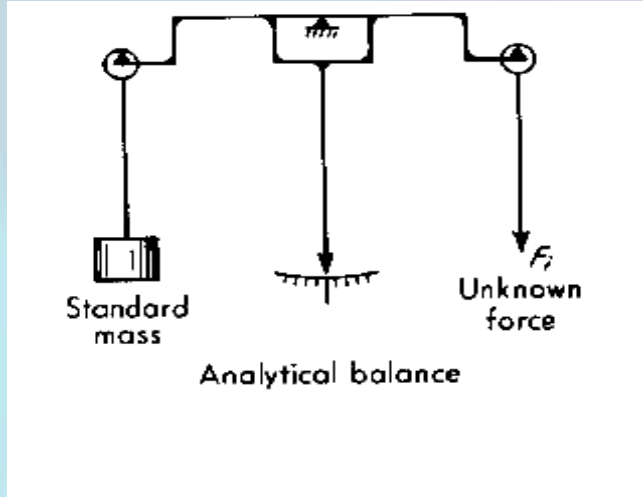
1. Direct Methods

Direct methods involve the comparison of an unknown force with a known gravitational force on the standard mass. A force is exerted on a body of mass m due to the earth's gravitational field, which can be represented by the following equation:

$$W = mg$$

Here m is the standard mass, g is the acceleration due to gravity, and W is the weight of the body . It is imperative to know the values of mass and acceleration due to gravity accurately in order to determine the force acting on the body. With the help of an **analytical balance**, a direct comparison can be drawn between an unknown force and the gravitational force.

➤ Analytical Balance

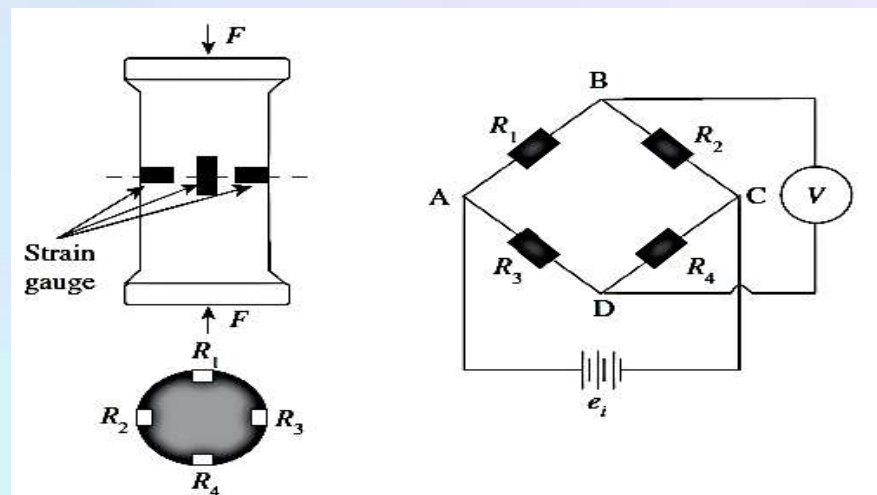


An analytical balance, also known as an equal arm balance, is probably the simplest force measuring system. An unknown force is directly compared with a known gravitational force. Comparison of masses is carried out by attaining some kind of beam balance by employing a null balance method. It is sufficient to only find out the magnitude since the unknown force and the gravitational force act in directions parallel to each other.

➤ Indirect Methods

1. Load Cells

Elastic members are generally used for the measurement of force through displacement measurement. When an elastic member is combined with a strain gauge and used for the measurement of force, it is termed as a load cell. In load cells, *elastic members act as primary transducers and strain gauges as secondary transducers*. A load cell is used in an indirect method of force measurement where force or weight is converted into an electrical signal. Load cells are used extensively for the measurement of force . A load cell comprises four strain gauges; two of these are used for measuring the longitudinal strain while the other two for measuring the transverse strain. The four strain gauges are mounted at 90° to each other, as shown in Fig below



Two gauges experience tensile stresses while the other two are subjected to compressive stresses. At the no-load condition, resistance in all the four gauges will be same. The potential across the two terminals B and D are same. The Wheatstone bridge is now balanced and hence output voltage is zero. When the specimen is stressed due to the applied force, the strain induced is measured by the gauges. Gauges $R1$ and $R4$ measure the longitudinal (compressive) strain, while gauges $R2$ and $R3$ measure the transverse (tensile) strain. In this case, voltages across the terminals B and D will be different, causing the output voltage to vary, which becomes a measure of the applied force upon calibration.

The longitudinal strain developed in the load cell is compressive in nature and given by the following relation:

$$\epsilon_1 = -\frac{F}{AE}$$

Here, F is the force applied, A is the cross-sectional area, and E is the Young's modulus of elasticity.

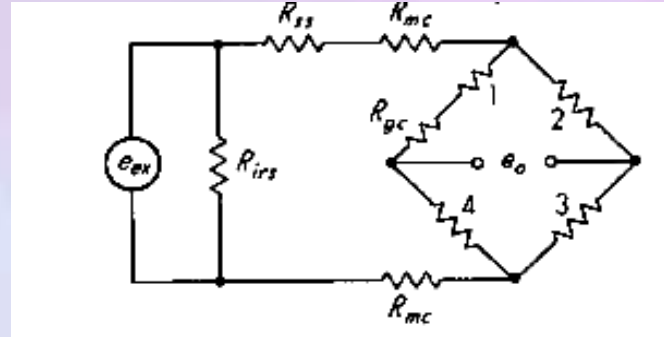
Gauges 1 and 4 experience this strain. Strain gauges 2 and 3 would experience a strain given by the following relation:

$$\epsilon_2 = -\frac{\gamma F}{AE}$$

Here, γ is the Poisson's ratio.

❖ Temperature Compensation of load cells

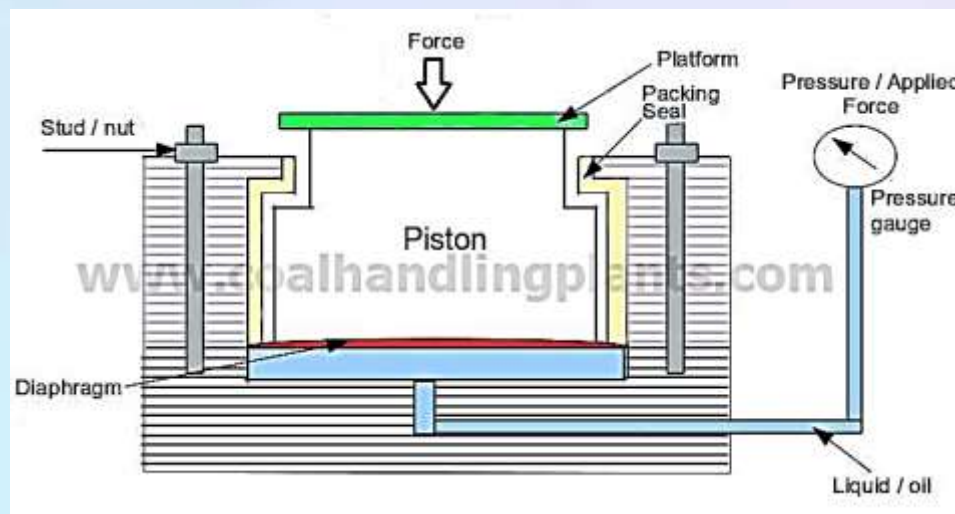
To achieve the high accuracy (0.3 to 0.1 percent of full scale) required in many applications, additional temperature compensation is needed. This is accomplished by means of the temperature-sensitive resistors R_{gc} and R_{mc} shown in Fig below:



These resistors are permanently attached internal to the load cell so as to assume the same temperature as the gages. The purpose of R_{gc} is to compensate for the slightly different temperature coefficients of resistance of the four gages. The purpose of R_{mc} is to compensate for the temperature dependence of the modulus of elasticity of the load-sensing member. That is, although we wish to measure force, the gages sense strain; thus any change in the modulus of elasticity will give a different strain (and thus a different e_o) even though the force is the same. Since all metals change modulus somewhat with temperature, this effect causes a sensitivity drift. The resistance R_{mc} compensates for this by changing the excitation voltage actually applied to the bridge by just the right amount to counteract the modulus effect. Two additional (non-temperature-sensitive) resistors are often found in commercial load cells. They are R_{ss} , which is adjusted to standardize the sensitivity for a nominal e_{ex} to a desired value, and R_{irs} , which is used to adjust the input resistance to a desired value.

2. Hydraulic Load Cells

Hydraulic load cells are force-balance devices, measuring weight as a change in pressure of the internal filling fluid. The liquid (usually oil) has a preload pressure. In a diaphragm-type hydraulic load cell (Fig shown below), the load or force acting on a platform is transferred to a piston that, in turn, compresses filling liquid confined within an elastomeric diaphragm chamber. The more the force, the higher the pressure of the hydraulic fluid, which is measured by a pressure transducer or displayed on a pressure gauge dial via a Bourdon tube. The pressure can be locally indicated or transmitted for remote indication or control. Output is linear and relatively unaffected by the amount of the filling fluid or by its temperature.



Advantages and disadvantages of hydraulic load cells.

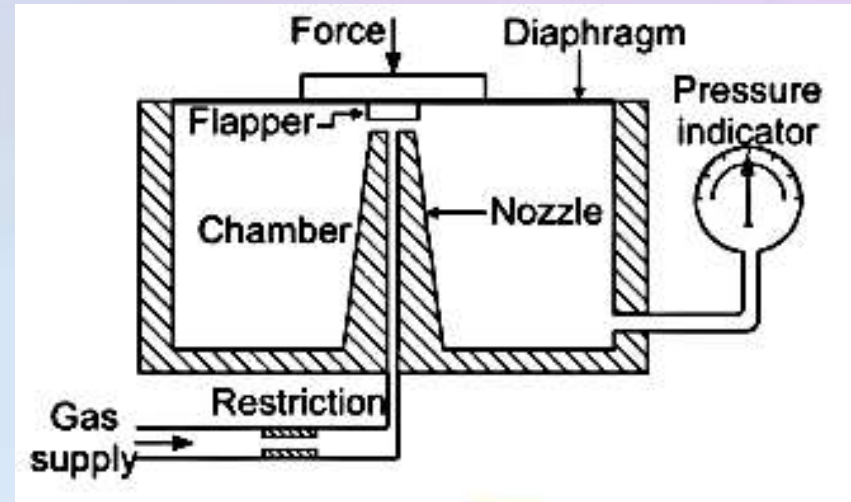
- I. Basically self-contained devices needing no external power, hydraulic load cells are inherently suitable for use in potentially hazardous areas. The operating cost is also low.
- II. One drawback is that the elastomeric diaphragm limits the maximum pressure that can be exerted on the piston . All-metal load cells also are available and can accommodate much higher pressures.
- III. The cells are sensitive to temperature changes and, therefore, usually have facilities to adjust the zero output reading. The hydraulic fluid may contaminate the process if the diaphragm ruptures.

Applications of hydraulic load cells.

- Typical hydraulic load cell applications include tank, bin and hopper weighing.

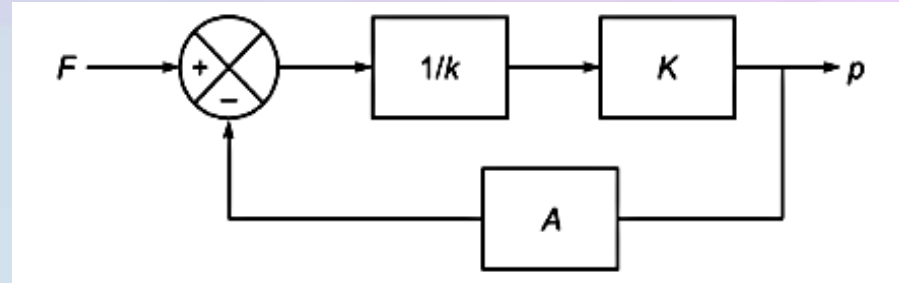
3. Pneumatic load cells

Pneumatic load cells also operate on the force-balance principle. Here, a nozzle-flapper assembly may be incorporated in the arrangement as shown in Fig below



The load platform, mounted on a diaphragm, act as the flapper while compressed dry air is introduced through the nozzle below. When a load is placed on the platform, the gap between the flapper and the nozzle decrease, thus stepping up the back pressure in the chamber. This higher pressure pushes the diaphragm up and a balance reached when a specific gap between the nozzle and the flapper is maintained The attached pressure gauge indicates the corresponding pressure which may be calibrated in load units .

The system can be represented by a feedback loop as shown in Fig below



Advantages and disadvantages.

The advantages of this type of load cell are that they are inherently explosion proof and insensitive to temperature variations. Also, they contain no fluids that might contaminate the process if the diaphragm ruptures.

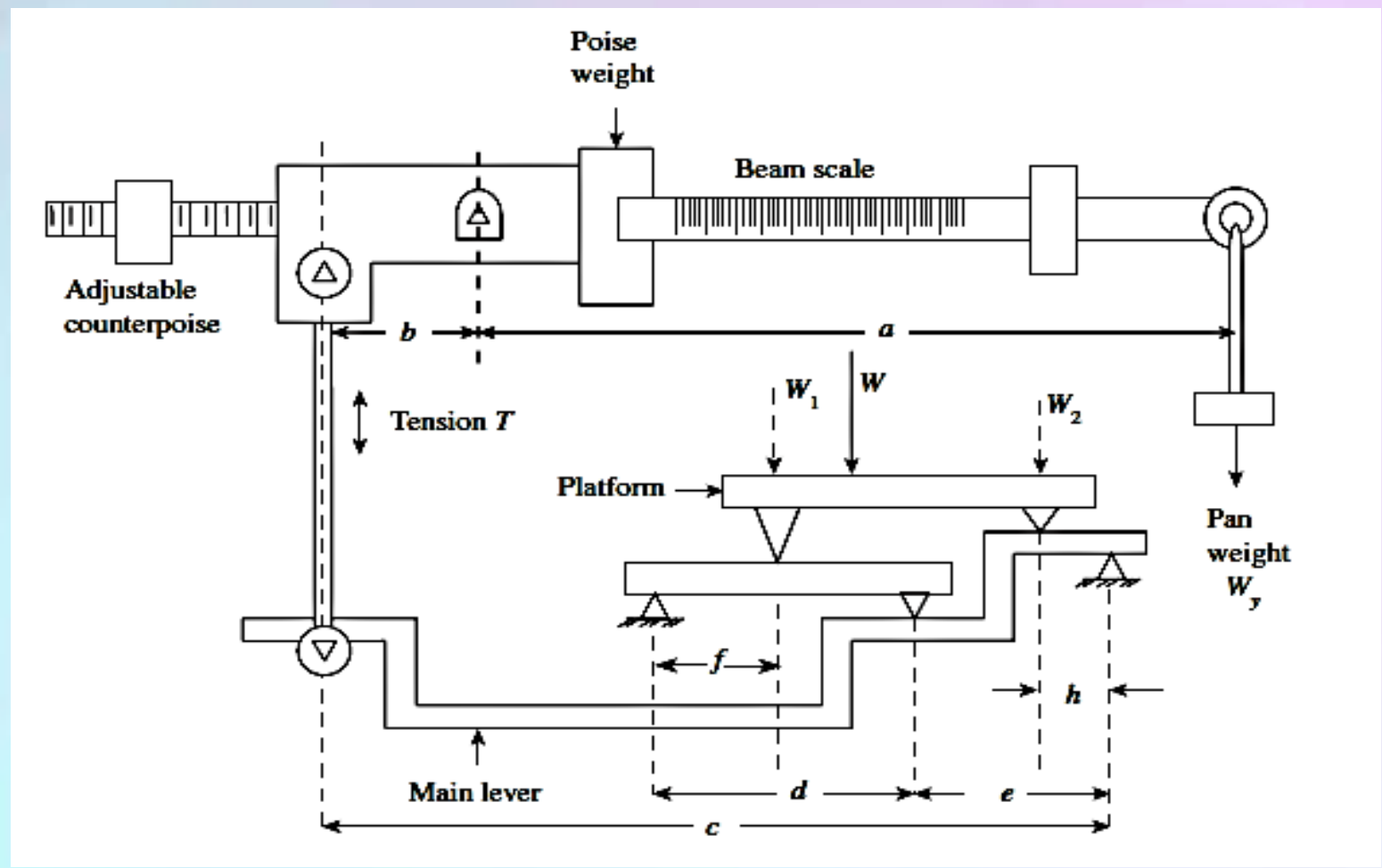
Disadvantages include their relatively slow speed of response and the need for clean, dry and regulated air or nitrogen.

Application.

Pneumatic load cells are used to measure relatively small weights in industries where safety is of the prime concern.

4. Multiple-lever system

For applications involving measurement of large weights, a platform balance or multiple-lever system is preferred. A platform balance is schematically represented in Fig below:



In a platform balance, two smaller weights, poise weight W_x and pan weight W_y , are used for the measurement of a large weight W . The initial zero balance can be set by an adjustable counterpoise. The poise weight W_x is set to zero of the beam scale, and then the counterpoise is adjusted for obtaining the initial balance before applying the unknown weight W on the platform. For ease of analysis, it can be assumed here that the two weights W_1 and W_2 are substituted by W . Since W_x has already been adjusted to zero, the entire unknown weight W is balanced by the pan weight W_y .

It can be seen that $T \times b = W_y \times a$ *eqn (1)*

and $T \times c = W_1(f/d)e + W_2 \times h$ *eqn (2)*

The linkage proportion can be arranged such that $h/e = f/d$.

Hence, we have $T \times c = (W_1 + W_2)h = Wh$ *eqn (3)*

It is clear from the above equation(3) that weight W can be placed anywhere on the platform and its position with respect to the knife edges of the platform is not significant.

From Eqs (1) and (2), we obtain the following equation:

$$W_y a/b = Wh/c$$

This gives a new equation, $W = ac / bh$

$W = S W_y$ where S is known as the *scale multiplication ratio*,

where $S=ac/bh$.

The multiplication ratio gives an indication of the weight that should be applied to the pan in order to balance the weight on the platform. This means that if the multiplication factor is 100, then a weight of 1 kg applied on the pan can balance a weight of 100 kg placed on the platform. Let us assume that the beam is divided with a scale of m kg per scale division, then a poise movement on the y scale division has to produce the same result as a weight W_x placed on the pan at the end of the beam; hence, $W_x y = m y a$. Therefore, we obtain the following equation:

$$m = W_x / a$$

The required scale divisions on the beam for any poise weight W_x is determined by this relationship. The length of the beam scale a is expressed in terms of scale divisions. The beam is balanced by appropriate combinations of pan weights and an adjustment of the poise weight along the calibrated beam scale.

➤ Measurement of Torque

Measurement of torque is important for the following reasons:

1. It is necessary to obtain load information for the analysis of stress or deflection. In this case, torque T is determined by the measurement force F at a known radius r using the following relationship:

$$T = Fr \text{ (in N m)}$$

2. Measurement of torque is essential in the determination of mechanical power. Mechanical power is nothing but the power required to operate a machine or the power developed by the machine, and is computed using the following relation:

$$P = 2\pi NT$$

:Here, N is the angular speed in revolution per second.

Torque-measuring devices employed for this purpose are popularly known as dynamometers.

Dynamometers are used to measure torque in internal combustion machines, small steam turbines, pumps, compressors, etc.

3. Measurement of torque is important for evaluating the performance characteristics of machines. The nature of the machine to be tested determines the kind of dynamometer to be used for torque measurement. If the machine generates power, the dynamometer employed must have the capability of absorbing that power. These dynamometers are called **absorption dynamometers**, which are particularly useful for measuring the power or torque developed by power sources such as engines or electric motors.

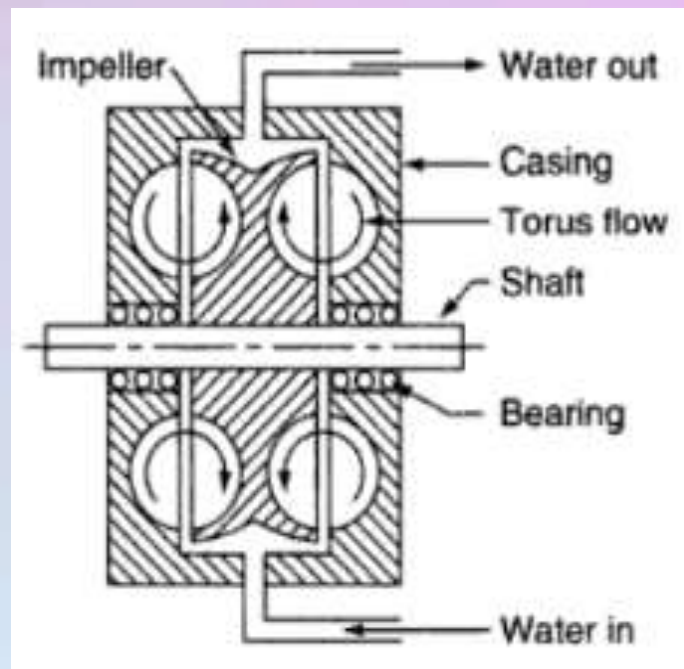
In case the machine is a power absorber, the dynamometer must have the capacity to drive it; such a dynamometer is known as a ***driving dynamometer***. Driving dynamometers are therefore useful in determining performance characteristics of devices such as pumps and compressors. The third type is the ***transmission dynamometer***. These are passive devices placed at an appropriate location within the machine or between machines. They are used to sense torque at that particular location. These are sometimes known as ***torque meters***.

1. Absorption Dynamometers

Absorption Dynamometer Absorption dynamometers produce the torque that they measure by creating a constant restraint to the turning of a shaft by either mechanical friction, fluid friction or electromagnetic induction. They are of following types:

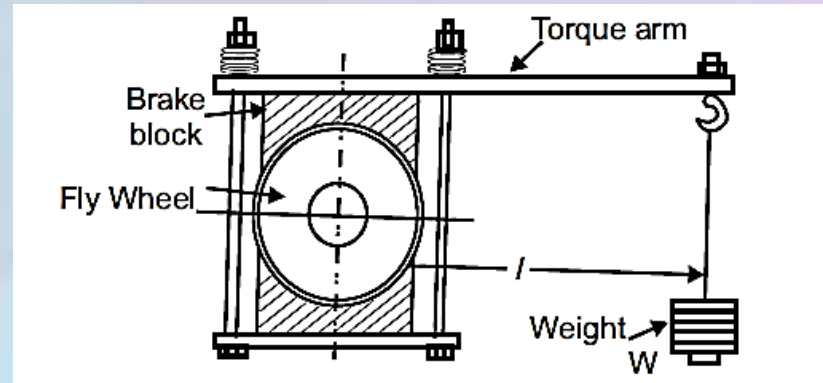
A. Heenan Froude Hydraulic Dynamometer

In principle, hydraulic dynamometer construction is similar to that of a fluid flywheel. Hydraulic dynamometer consists of an impeller or inner rotating member coupled to the output shaft of the engine. The impeller in this dynamometer rotates in a casing filled with a fluid. Due to the centrifugal force developed in the outer casing, tends to revolve with the impeller, but is resisted by a torque arm supporting the balance weight. The frictional forces generated between the impeller and the fluid are measured by the spring balance fitted on the casing. The figure of the apparatus is given below:



The heat developed due to the dissipation of power in Hydraulic dynamometer is carried away by a continuous supply of the working fluid. The output power can be controlled by regulating the sluice gates which can be moved in and out to partially or wholly obstruct the flow of water between the casing and the impeller.

b) Prony Brake Dynamometer



It consists of two wooden blocks clamped together on a pulley whose torque is to be measured. The upper block has a long lever attached to its free end containing a mass carriage . When the pulley rotates friction is developed between the blocks and the pulley which tends to rotate the blocks in the direction of rotation of the shaft. However, the weight due to suspended mass prevents this tendency. The grip of the blocks over the pulley is adjusted using the bolt clamp to run the engine at the required speed. Now the mass is added on the mass carriage so that the lever becomes horizontal. The torque is calculated by multiplying the force applied due to suspended mass and the horizontal distance of the mass from the center of the pulley:

$$T = F \times R = m \times g \times R$$

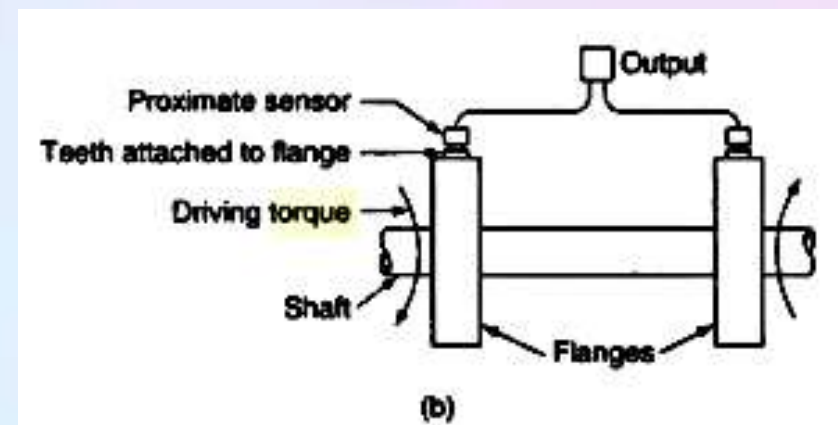
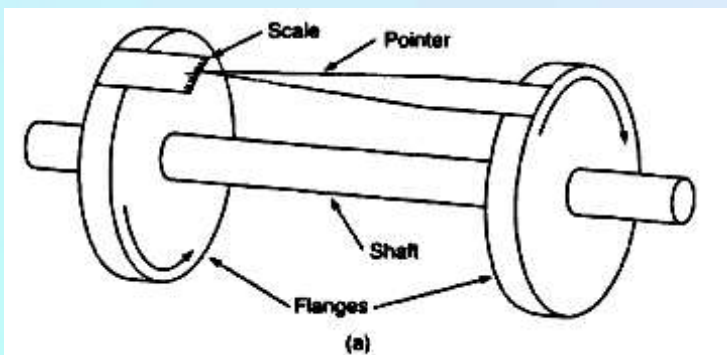
Since a lot of heat is produced due to friction, the rim of the pulley is cooled by water. It may be noted that the torque is independent of the size of the pulley and the coefficient of friction.

2. Transmission Dynamometer

The transmission dynamometers utilize devices that measure torque, in terms of the elastic twist of the shaft or of a special torque meter inserted between some sections of the shaft. They are of following types:

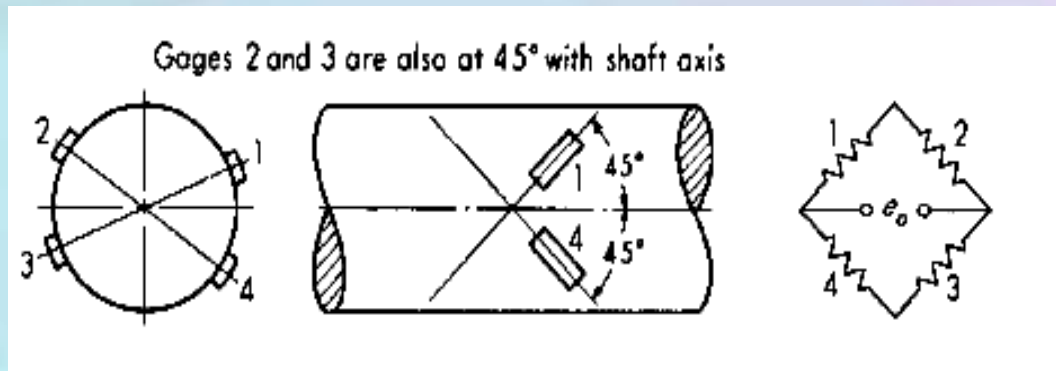
a) **Angular Displacement Method:**

Torque may be determined by measuring the angular displacement of two flanges attached on the shaft at some convenient distance apart. Figure(a) below shows that a torque applied to the shaft causes displacement of the pointer relative to the scale due to the twist of the length of shaft between the two flanges. For a stationary shaft, this displacement could be read off directly. If the shaft is rotation, the angular displacement can sensed by using some transducer similar to those used for small linear displacement such as eddy current transducer, linear variable differential transformer (LVDT), capacitive-type transducer, etc. Figure(b) below shows an arrangement using toothed wheels and proximity sensors of electromechanical types for measuring the angular displacement.



b) Direct Strain Method:

A shaft subjected to pure torsion has highest compressive and tensile strains at 45° to the shaft axis. The strains developed are measured by attaching the strain gauges to the surface of the shaft. This arrangement shown below (given accurate gage placement and matched gage characteristics) is temperature-compensated and insensitive to bending or axial stresses.



The gages must be precisely at 45° with the shaft axis, and gages 1 and 3 must be diametrically opposite, as must gages 2 and 4. Accurate gage placement is facilitated by the availability of special rosettes in which two gages are precisely oriented on one sheet of backing material. In some cases the shaft already present in the machine to be tested may be fitted with strain gages. In other cases a different shaft or a commercial torque-meter must be used to get the desired sensitivity or other properties.

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THANK YOU