Measuring devices frequently used in mechanical engineering

1. Measuring pressure

1.1. Liquid column gauge (U tube)

Liquid column gauges consist of a vertical column of liquid in a tube whose ends are exposed to different pressures. The column will rise or fall until its weight is in equilibrium with the pressure differential between the two ends of the tube. A very simple version is a U-shaped tube half-full of liquid, one side of which is connected to the region of interest while the reference pressure (which might be the atmospheric pressure or a vacuum) is applied to the other. The difference in liquid level represents the applied pressure.

Although any fluid can be used, mercury is preferred for its high density (13.534 g/cm^3) and low vapour pressure. For low pressure differences well above the vapour pressure of water, water is commonly used (and "meters of water" is a common pressure unit).

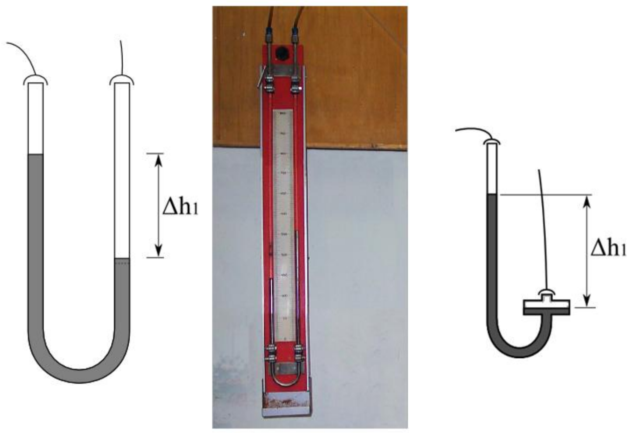


Figure 1 (left) Schematic draw of a liquid column gauge (middle) Liquid column gauges and schematic draw of s single column gauge

1.2. Inclined manometer

Similar to the single column gauge the inclined manometer has a reservoir with relatively large area and a scaled column. Its column can be inclined thus a more precisely reading is achievable

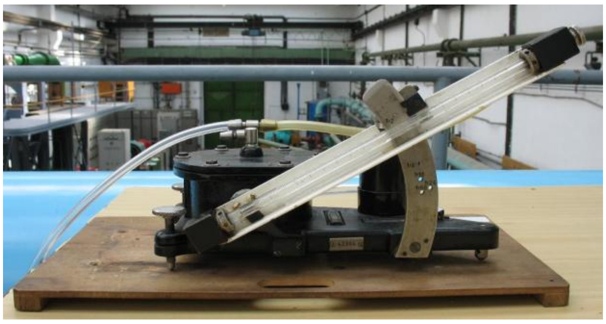


Figure 2 (left) Inclined manometer

1.3. Bourdon gauge

The Bourdon pressure gauge uses the principle that a flattened tube tends to change to a more circular cross-section when pressurized. Although this change in cross-section may be hardly noticeable, the displacement of the material of the tube is magnified by forming the tube into a C shape or even a helix, such that the entire tube tends to straighten out or uncoil, elastically, as it is pressurized.

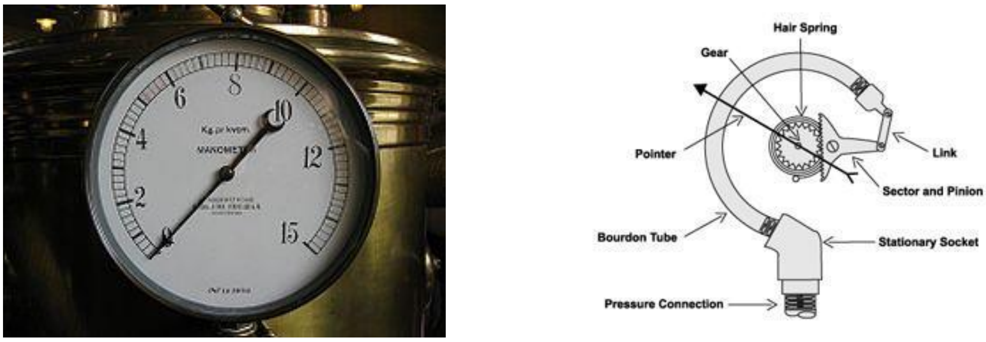


Figure 3 (left) Bourdon gauge (right) Mechanism of the Bourdon gauge

In practice, a flattened thin-wall, closed-end tube is connected at the hollow end to a fixed pipe containing the fluid pressure to be measured. As the pressure increases, the closed end moves in an arc, and this motion is converted into the rotation of a (segment of a) gear by a connecting link which is usually adjustable. A small diameter pinion gear is on the pointer shaft, so the motion is magnified further by the gear ratio. The positioning of the indicator card behind the pointer, the initial pointer shaft position, the linkage length and initial position, all provide means to calibrate the pointer to indicate the desired range of pressure for variations in the behaviour of the Bourdon tube itself.

Bourdon tubes measure gage pressure, relative to ambient atmospheric pressure, as opposed to absolute pressure; vacuum is sensed as a reverse motion. When the measured pressure is rapidly pulsing, such as when the gauge is near a reciprocating pump, an orifice restriction in the connecting pipe is frequently used to avoid unnecessary wear on the gears and provide an average reading; when the whole gauge is subject to mechanical vibration, the entire case including the pointer and indicator card can be filled with an oil or glycerin. Typical high-quality modern gauges provide an accuracy of ±2% of span, and a special high-precision gauge can be as accurate as 0.1% of full scale.

1.4. Electronic pressure sensors

A **pressure sensor** measures pressure, typically of gases or liquids. A pressure sensor usually acts as a transducer; it generates an electronic signal as a function of the pressure imposed. Although there are various types of pressure transducers, one of the most common is the strain-gage base transducer. The conversion of pressure into an electrical signal is achieved by the physical deformation of strain gages which are bonded into the diaphragm of the pressure transducer. Pressure applied to the pressure transducer produces a deflection of the diaphragm which introduces strain to the gages. The strain will produce an electrical resistance change proportional to the pressure.

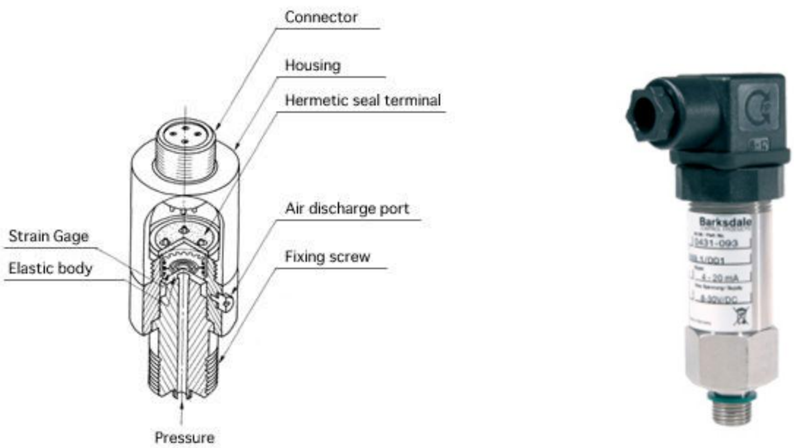


Figure 4 (left) Cut-away of an electronic pressure sensor (right) pressure sensor

2. Measuring flow rate

2.1. Metering tank (bucket-and-stopwatch)

Perhaps the simplest way to measure volumetric flow is to measure how long it takes to fill a known volume container. A simple example is using a bucket of known volume, filled by a fluid. The stopwatch is started when the flow starts, and stopped when the bucket overflows. The volume divided by the time gives the flow:

$$Q = \alpha \frac{\Delta m}{\Delta t} \left[\frac{dm^3}{s} \right]$$

where

α [dm3/mm] is the constant of the tank being the volume of a 1 mm high quantity of liquid in the tank,

Δm [mm] is the rising of the level

Δt [s] is the time taken for rising.

2.2. Orifice plate

An orifice plate (metering orifice) is a plate with a hole through it, placed in the flow; it constricts the flow, and measuring the pressure differential across the constriction gives the flow rate.

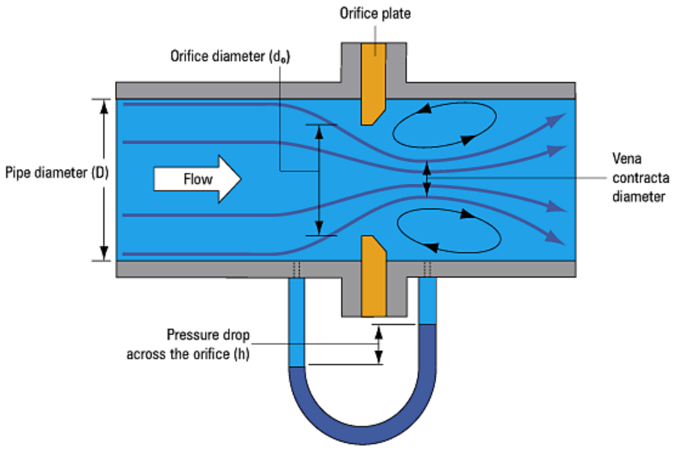


Figure 5 Cut-away of a metering orifice

The square root of measured pressure difference is proportional to the flow rate:

$$Q = K\sqrt{\Delta p}$$

where K is constant (its computation is described by standards).

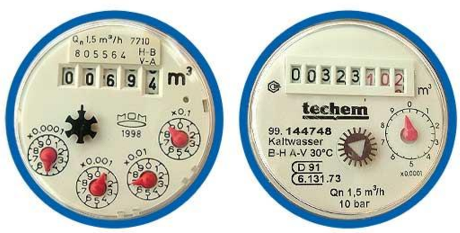
2.3. Measurement of the revolution number

From the point of view of the *measuring concept* the instruments measuring the revolution number can be divided into three groups:

- speed indicators measuring the average revolution number,
- tachometers measuring the momentary revolution number and
- stroboscopes working on the principle of comparison.

a) Measurement of small revolution number can be performed simply with **stopwatch** and by counting revolutions with naked eye. When the mark on the rotating machine part gets to the marked position, we start the stopwatch and begin counting (with 0). Having measured the time (T) and the number of revolutions (N) the revolution number is simply n=N/T.

b) For higher speed of rotation a special counting device must be used. One of the simplest of these is the so-called **jumping-figure speed counter**. The



rotating shaft of this device turns gears. One of them completes one revolution while the other rotates only 1/10, and so on. Reading the numbers uniformly painted from 0-9 on the cylinder jacket we get the number of revolutions. Such a device is used in kilowatt-hour meters, water consumption, tape recorders, speedometers of cars etc.

c) **Mechanical tachometers** count the revolutions only for a fixed time, generally for 6 seconds. The time measuring device of the instrument connects its pointer for 6 seconds with that shaft of the instrument which joints the rotating machine part. After these six seconds there is no more connection which means at the same time the end of the measurement. A widely used example of this device is the Jacquet indicator. With pressing the starting button the instrument is zeroed and after releasing it the counting and the clockwork starts.

d) **Electric tachometers** operate with the same principle (counting the number of revolutions during some period of time), but the number of revolutions is measured in an optical way.

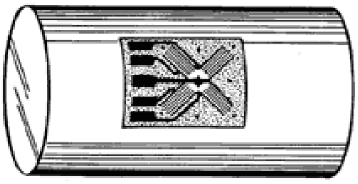
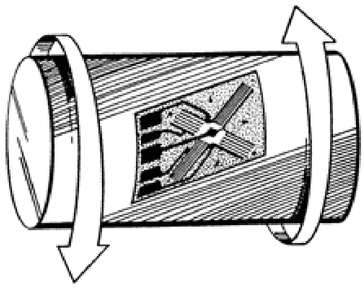
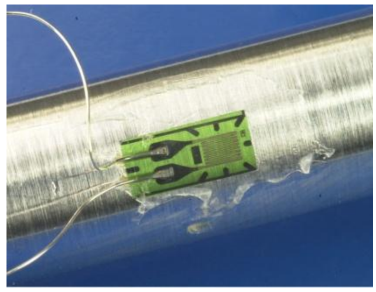
e) A **stroboscope**, also known as a strobe, is an instrument used to make a cyclically moving object appear to be slow-moving, or stationary. In its simplest form, a marker is placed to the rotating shaft and a lamp capable of emitting brief and rapid flashes of light is used. The frequency of the flash is adjusted so that it equals to the shaft's cyclic speed, at which point the object is seen to be either stationary or moving backward or forward, depending on the flash frequency.

2.4. Measurement of torque

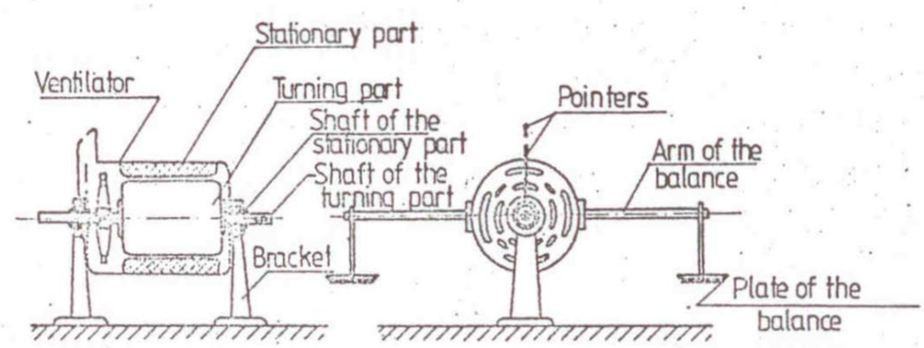
There are many ways of measuring torque, out of which the two most important ones are

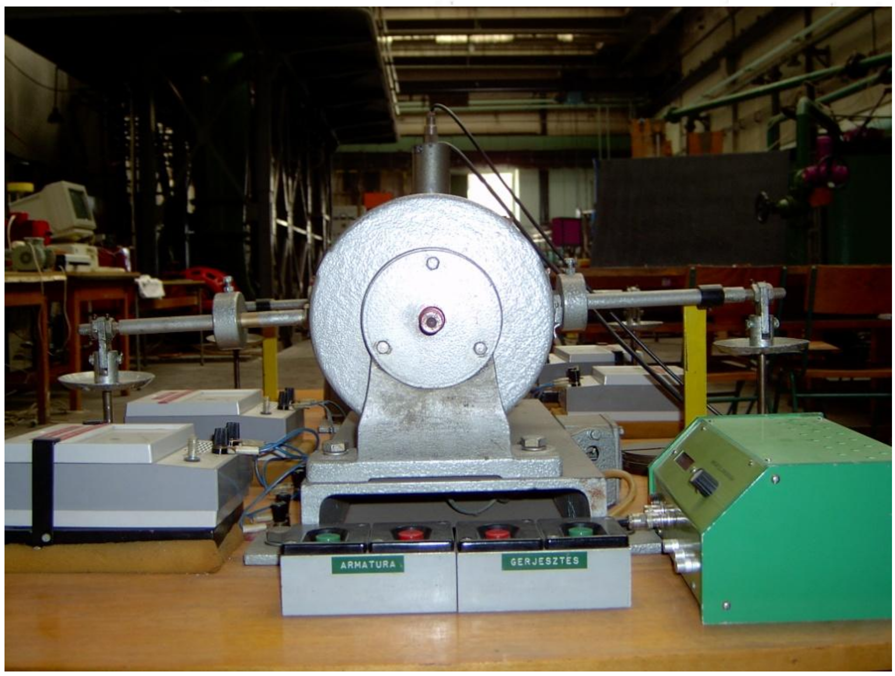
- strain gauges and
- balancing motors

a) A **strain gauge** is a small electrical 'element' printed on a non-conductive substrate. The pattern of the element is arranged so that if the gauge is stretched (or compressed) in one direction (along operating axis of the gauge), the resistance of the element increases (or decreases) in relation to that stretch. A stretch perpendicular to the axis of the strain gauge has little effect on the resistance of the element. If a gauge is bonded to the shaft, with its axis aligned with the direction in which the shaft material stretches when a torque is applied, the strain gauge will also stretch and therefore the element will increase in resistance. By measuring the change of resistance, after appropriate calibration, one can measure the torque applied to the shaft.

b) **Balancing machines** (motor or generator) are special machines, whose housing is free to rotate and arms are mounted onto it.





The torque is to be measured in ***generator*** *running is*

$$M = (G + G_0) \cdot k .$$

The torque is to be measured in ***motor*** *running is*

$$M = (G - G_0) \cdot k .$$

where

M   is the shaft torque to be measured. This torque is produced by the power machine and is transmitted by the coupling to the rotating part of the generator,

G   is the weight needed for balancing the stationary part,

G_0 is the weight needed for unloaded operation,

k   is the length of arm.

3. Measuring electric quantities

3.1. Universal multimeter

A multimeter or a multitester, also known as a volt/ohm meter or VOM, is an electronic measuring instrument that combines several measurement functions in one unit. A typical multimeter may include features such as the ability to measure voltage, current and resistance. Multimeters may use analogue or digital circuits - analogue multimeters and digital multimeters (often abbreviated DMM or DVOM.)