5.2 TORQUE MEASUREMENT

Measurement of applied torques is of fundamental importance in all rotating bodies to Ensure that the design of the rotating element is adequate to prevent failure under shear stresses.

- Torque measurement is also a necessary part of measuring the power transmitted by rotating shafts.
- The four methods of measuring torque consist of
    - Measuring the strain produced in a rotating body due to an applied torque
    - An optical method
    - Measuring the reaction force in cradled shaft bearings
    - Using equipment known as the Prony brake.

5.2.1 PRONY BRAKE SYSTEM

The Prony brake is another torque-measuring system that is now uncommon. It is used to measure the torque in a rotating shaft and consists of a rope wound round the shaft. One end of the rope is attached to a spring balance and the other end carries a load in the form of a standard mass, *m*. If the measured force in the spring balance is *Fs*, then the effective force, *Fe*, exerted by the rope on the shaft is given by $F_e = mg - F_s$.

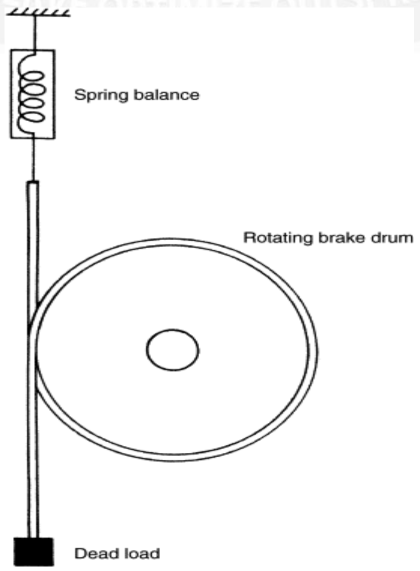

Fig. 5.20 Prony Brake

[source: https://www.sciencedirect.com/topics/engineering/prony-brake]

If the radius of the flywheel is R, the torque is given by

Torque, T = (mg-F_s) R_e

Where R_e = R+r

R = Radius of the Brake drum

R = Radius of the rope or thickness of the belt.

5.2.2 Torque Measurement Using strain gauges

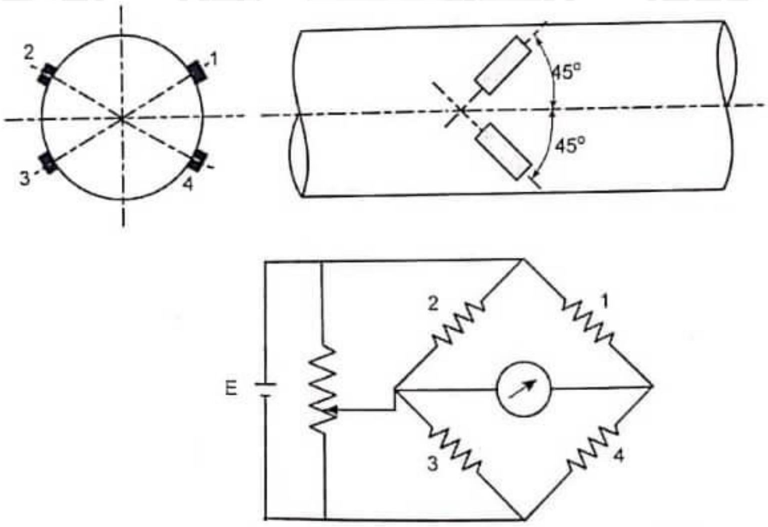

Fig. 5.21 Strain gauges for shaft torque measurement

[source: https://theteche.com/torque-measurement-using-strain-gauges/]

Measuring the strain induced in a shaft due to an applied torque has been the most common method used for torque measurement in recent years. Torque transducers based on strain measurement are normally made by applying strain gauges to a shaft to measure the shear strain caused by torsion. The shear stress causes strains to appear at 45° to the longitudinal axis of the shaft. So, the strain gauges must be placed precisely at 45° to the shaft axis as shown in fig.

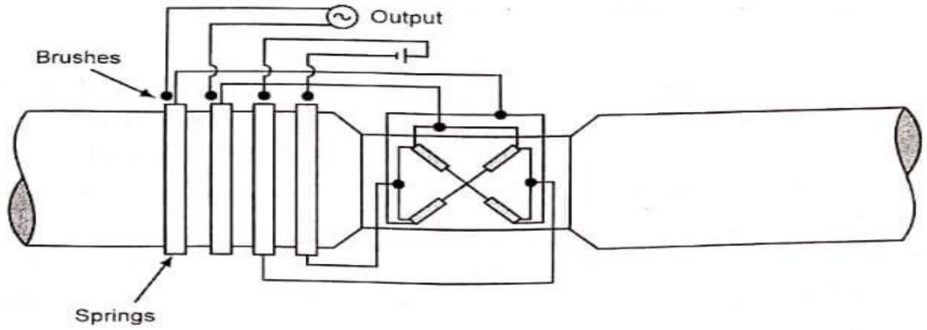

Fig. 5.22 Slip Ring arrangement in torque transducer

[source: https://theteche.com/torque-measurement-using-strain-gauges/]

Otherwise, the arrangement is sensitive to bending and axial stresses in addition to those caused by torsion. The output is increased by using four gauges so that the adjacent arms have strains of opposite nature. Also this arrangement provides complete thermal compensation. For taking signals in and out of the rotating shaft, slip rings and brushes are used. The arrangement of slip rings and brushes are shown on fig.

It is easier to measure bending strains rather than strains due to torque at 45° and so an arrangement using beams may be employed, in which the transmitted torque results in bending the beams. This arrangement is shown in fig.

A slip ring arrangement results in noise due to change in contact resistance also slip rings and brushes wear out and hence it needs to be renewed. A non-contacting type of arrangement as shown in fig is preferred.

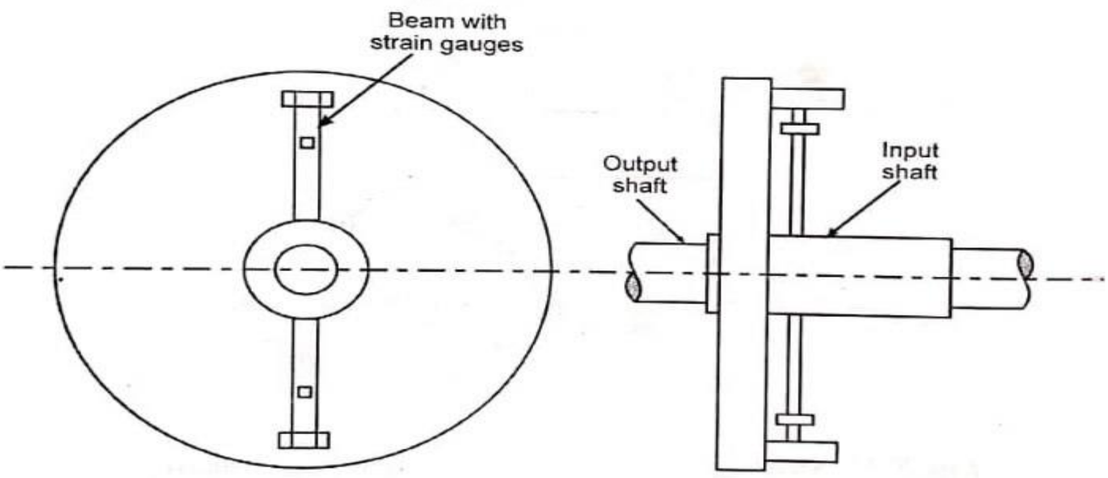

Fig. 5.23 Strain gauge transducer using beams in bending

[source: https://theteche.com/torque-measurement-using-strain-gauges/]

This bridge supply and output signals are transmitted between the rotating and stationary member through transformers. Through AC supply of the bridge, an amplitude modulated AC voltage proportional to the torque is obtained as the output of the bridge. The AC voltage necessary for supply, the strain gauge bridge and the measurement signal can be transmitted via rotating transformer.

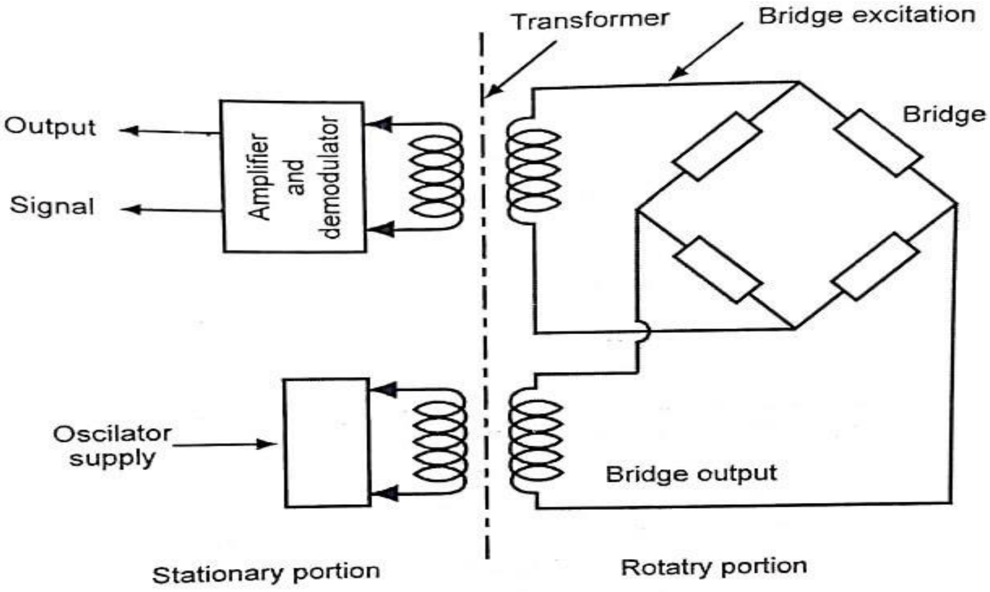

Fig. 5.24 Block circuit diagram for rotating sensors with AC supply

[source: https://theteche.com/torque-measurement-using-strain-gauges/]

5.2.3 Torque Measurement Using Torsion Bars

5.2.3.1 Optical Method

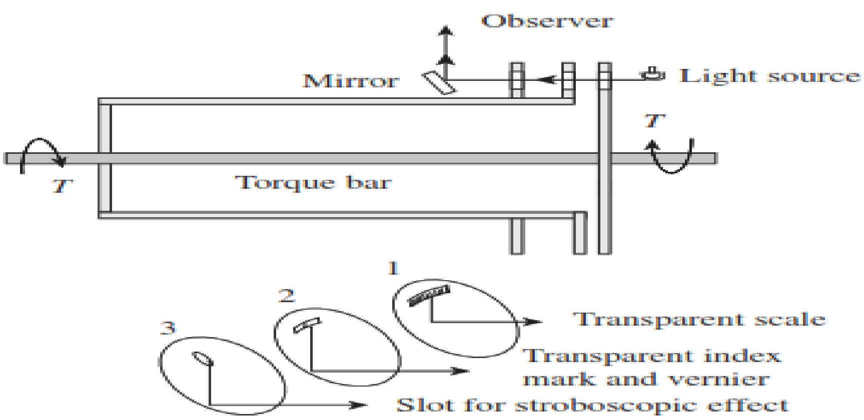

Fig. 5.25 Torsion Bar Torque Transducer

[source: Engineering Metrology and Measurements, N.V. Raghavendra, Pg. No 349]

Elastic deflection of the transmitting element may be used for the measurement of torque, which can be achieved by measuring either a gross motion or a unit strain. The main problem associated with either case is the difficulty in reading the deflection of the rotating shaft. A torsion-bar dynamometer is also known as a torsion-bar torque meter, which employs optical methods for deflection measurement, as shown in Fig.

Calibrated scales are used to read the relative angular displacement of the two sections of the torsion bar. This is possible because of the stroboscopic effect of intermittent viewing and persistence of vision. Transmission dynamometers, which employ this principle, are available in ranges up to 60,000 m kgf and 50,000 r/min, having an error of ±0.25%.

Replacing the scales on disks 1 and 2 with sectored disks, which are alternately transparent and opaque sectors, and the human eye with an electro-optical transducer, a version having an electrical output is obtained. When there is no torque, the sectored disks are positioned to give a 50% light transmission area. The area of proportionality increases with positive torque and decreases with negative torque, thus giving a linear and direction-sensitive electric output.

5.2.3.2 Capacitive Method

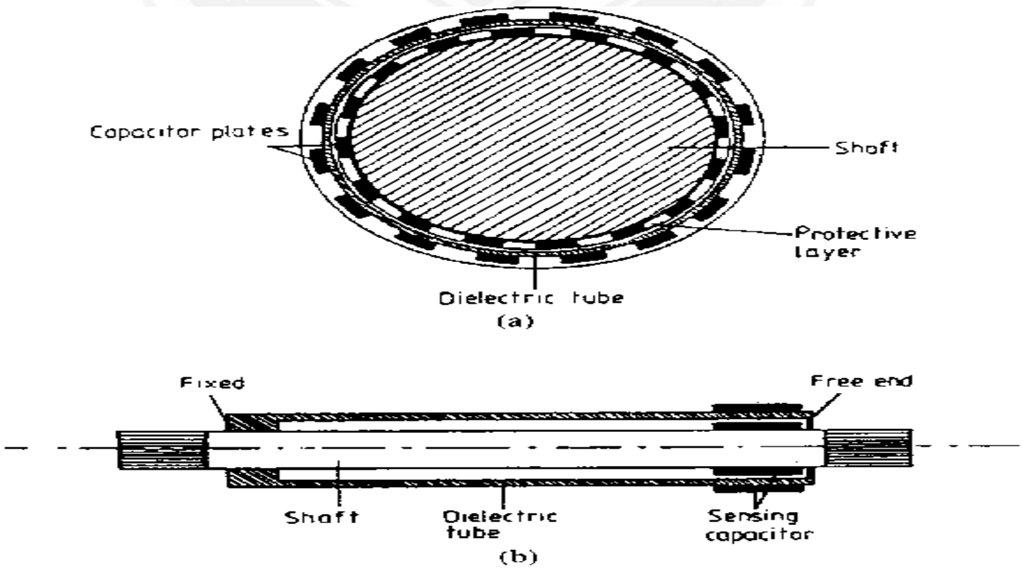

Fig. 5.25 Torsion Bar Torque Transducer

[source: https://www.semanticscholar.org/paper/Noncontact-capacitive-torque-sensor-for-use-on-a-Wolffenbuttel-Foerster/2cc240329d42e4a64b59bcff6bdd4532e38fe227]

A Torsion bar system using capacitive torque sensing method. A shaft is fitted with a concentric sleeve of die electric material. The sleeve is fixed to the shaft at one end and its rests on a rubbing bearing at other end. When the torque is applied to the shaft, it causes a relative motion between surface of a shaft and free end of a concentric tube. The motion is used to vary the capacitance applied to two opposing patterns of conducting strips. One of them is applied to vary the capacitance applied to two opposing patterns of conducting strips. One of them is applied to the shaft and the other one is applied to the tube.

The capacitive sensor is connected to an inductor coil wound around the shaft. The resulting passive circuit thus has a resonance frequency which depends on the applied torque. The passive resonance circuit rotates with the drive shaft. Torque measurement can be done by measuring the resonance frequency.

When the oscillator frequency is the same at which the resonance occurs in the passive circuit, an increased current is drawn. If the frequency at which it occurs is measured, it can be used to indicate torque. The advantage of this arrangement is that no physical connection between rotating shaft and frame.

5.2.4 Laser Optic Method

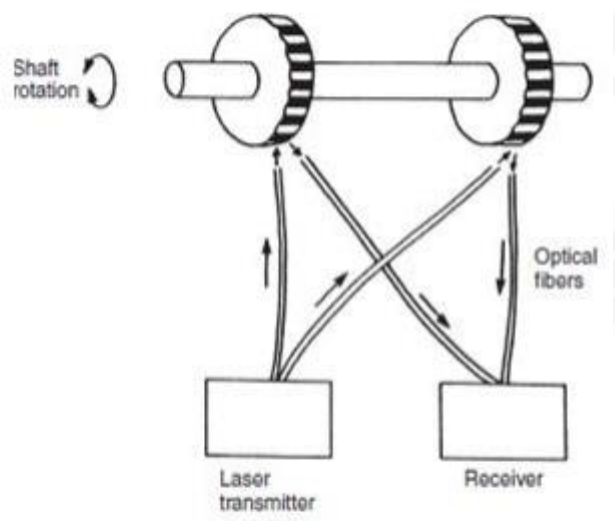

Fig. 5.26 Laser Optic Method

[source: https://www.brainkart.com/article/Torque-Measurement_5863/]

Laser Optical techniques for torque measurement have become available recently with the development of laser diodes and fiber-optic light transmission systems. One such system is shown in Figure. Two black-and-white striped wheels are mounted at either end of the rotating shaft and are in alignment when no torque is applied to the shaft. Light from a laser diode light source is directed by a pair of fiber-optic cables onto the wheels. The rotation of the wheels causes pulses of reflected light, which are transmitted back to a receiver by a second pair of fiber-optic cables. Under zero torque conditions, the two pulse trains of reflected light are in phase with each other. If torque is now applied to the shaft, the reflected light is modulated. Measurement by the receiver of the phase difference between the reflected pulse trains therefore allows the magnitude of torque in the shaft to be calculated. The cost of such instruments is relatively low, and an additional advantage in many applications is their small physical size.

5.2.5 Proximity Sensor Method

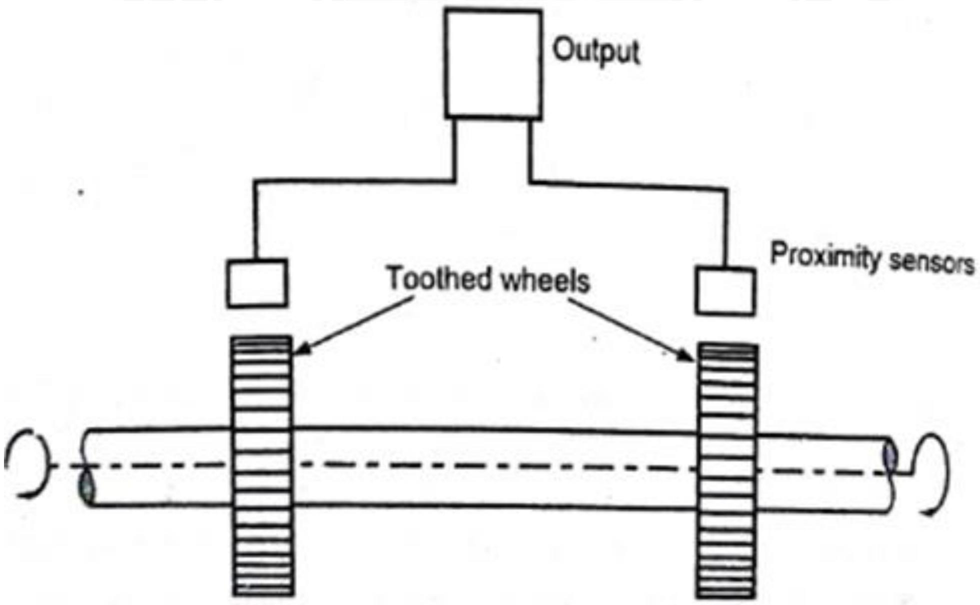

Fig. 5.27 Proximity Sensors for Torque Measurement

[source: Metrology and Measurements, Dr. Vijayaragavan, Pg. No 5.29]

An arrangement using toothed wheels and proximity sensors is shown in figures. Two identical toothed wheels are fixed on the shaft at a certain distance. The two proximity sensors produce the output voltage with phase difference proportional to torque. Alternatively, an arrangement using photocells and a light source maybe employed.

5.2.6 Stroboscope Method

Principle of Stroboscope Method

When a shaft is connected between a driving engine and driven load, a twist (angular displacement) occurs on the shaft between its ends. This angle of twist is measured and calibrated in terms of torque.

Construction of Stroboscope Method

The main parts of the mechanical torsion meter are as follows:

A shaft which has two drums and two flanges mounted on its ends as shown in the diagram. One drum carries a pointer and other drum has a torque calibrated scale. A stroboscope is used to take readings on a rotating shaft.

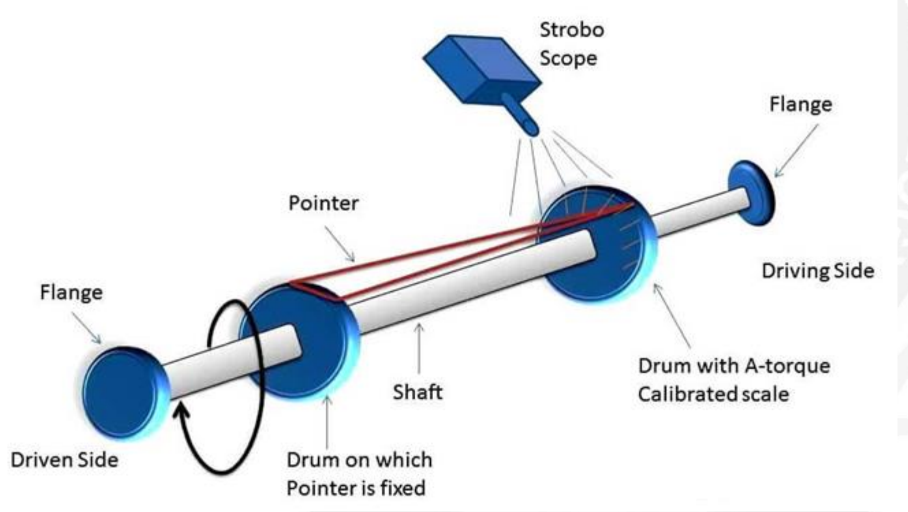

Fig. 5.28 Stroboscope Method

[source: https://instrumentationtools.com/mechanical-torsion-meter-principle/]

Operation of Stroboscope Method:

One end of the shaft of the torsion meter is connected to the driving engine and its other end to the driven load.

An angle of twist is experienced by the shaft along its length between the two flanges which is proportional to the torque applied to the shaft.

A measure of this angle of twist becomes a measure of torque when calibrated.

The angular twist caused is observed on the torque calibrated scale corresponding to the position of the pointer. As the scale on the drum is rotating, reading cannot be taken directly. Hence a stroboscope is used. The stroboscope's flashing light is made to fall on the scale and the flashing frequency is adjusted till a stationary image is obtained. Then the scale reading is noted.

Application of Stroboscope Method

- Simple and inexpensive method
- Power of shaft can be calculated (flashing frequency gives information about speed).

Limitation of Stroboscope Method

- Poor accuracy due to small displacement of the pointer.
- Sensitivity is reduced even due to small variation in speed.
- It can be used only on shafts rotating at a constant speed.

5.2.7 Magnetostrictive method

Magnetostriction is the process in which a ferromagnetic material can change its size or shape when it is placed in a magnetic field. This device can be used to do the position control. The Magnetostrictive position sensor uses a ferromagnetic element in order to determine the location of a position magnet which is displaced along its length. This sensor has good accuracy and it is also resistant to vibration and shock. These sensors can be considered as a rugged device that can deliver 30 to 400mv signals at their output terminals and it would only need less or no additional signal conditioning. The important requirement in this sensor is that the waveguide must be as long as the measured stroke.

This sensor is composed of a magnetic core, a small amount of the current is applied to the core by using a drive coil that is around it. The senor has a steel housing and the drive coil and the core is situated inside it. The housing, piston, and core would act as a closed magnetic flux path. The materials that are used in this position sensors are transition metals and they are iron, nickel, and cobalt.

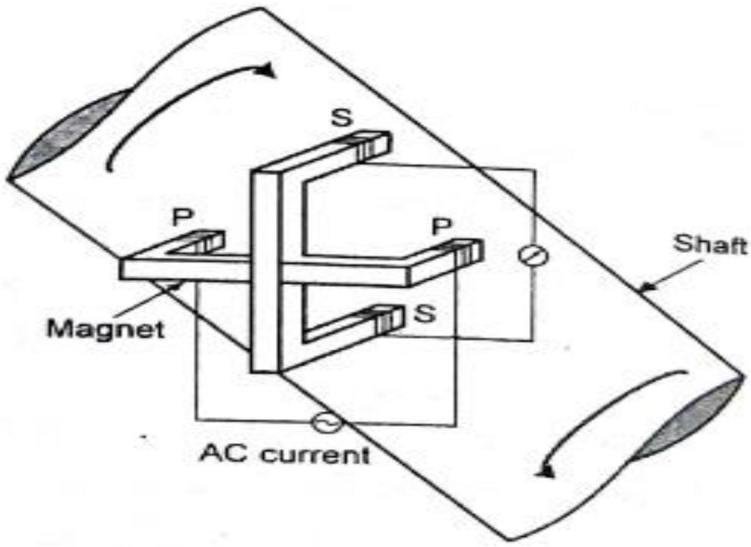

Fig. 5.29 Magnetostrictive Transducer

[source: Metrology and Measurements, Dr. Vijayaragavan, Pg. No 5.30]

The magneto-resistors can be used similar to a hall element, it is simpler because there is no need to create a control current. The Magnetostrictive material will be exposed to a magnetic field to be sensed. The sensitivity of this device is higher than the hall device, the bidirectional effect between the magnetic and the mechanical states of Magnetostrictive material is a transduction capability that is used for actuation and sensing.

APPLICATIONS

- It can be used for position sensing
- It is used in the torque measurement system
- It can be used for water level sensing
- Accelerometer sensor
- Load sensor
- It is used in sonars
- Acoustic devices use this sensor
- Medical and industrial field