Instrumentation and control

Module: Sensors and transducers

Notes: Resistive , Inductive and capacitive sensors

Faculty: Akhil Mohammed KK

DCE,Darbhanga

Objectives

At the end of this lesson, the student should be able to

- Name three methods of displacement measurement using passive electrical sensors.
- Sketch the construction and characteristics of LVDT.
- Explain the principles of operation of inductive and capacitive types of proximity sensors.
- Distinguish between variable distance and variable area type of capacitance displacement sensors.
- Sketch and explain the principle of operation of an optical type displacement sensor.
- Name two methods of noncontact type speed sensing and explain their principles of operation.

Introduction

Displacement and speed are two important parameters whose measurements are important in many position and speed control schemes. Error free measurements of these two parameters are necessary in order to achieve good control performance.
Displacement measurement can be of different types. The displacement may be in the range of few μm to few cm. Moreover the measurement may be of contact type or noncontact type. Again displacement to be measured can be linear or angular (rotary). Similar is the case for speed measurement. Accordingly different measuring schemes are used for measurement of these two parameters. In this lesson, we shall discuss about few such schemes.

Displacement Measurement

Broadly speaking, displacement measurement can be of two types: contact and noncontact types. Besides the measurement principles can be classified into two categories: electrical sensing and optical sensing. In electrical sensing, passive electrical sensors are used variation of either inductance or capacitance with displacement is measured. On the other hand the optical method mainly works on the principle of intensity variation of light with distance. Interferometric technique is also used for measurement of very small displacement in order of nanometers. But this technique is more suitable for laboratory purpose, not very useful for industrial applications.

Potentiometer

Potentiometers are simplest type of displacement sensors. They can be used for linear as well as angular displacement measurement, as shown in Fig. 1. They are the resistive type of transducers and the output voltage is proportional to the displacement and is given by:

$$e_o = \frac{x_i}{x_t} E ,$$

where x_i is the input displacement, x_t is the total displacement and E is the supply voltage.

The major problem with potentiometers is the contact problem resulting out of wear and tear between the moving and the fixed parts. As a result, though simple, application of potentiometers is limited.

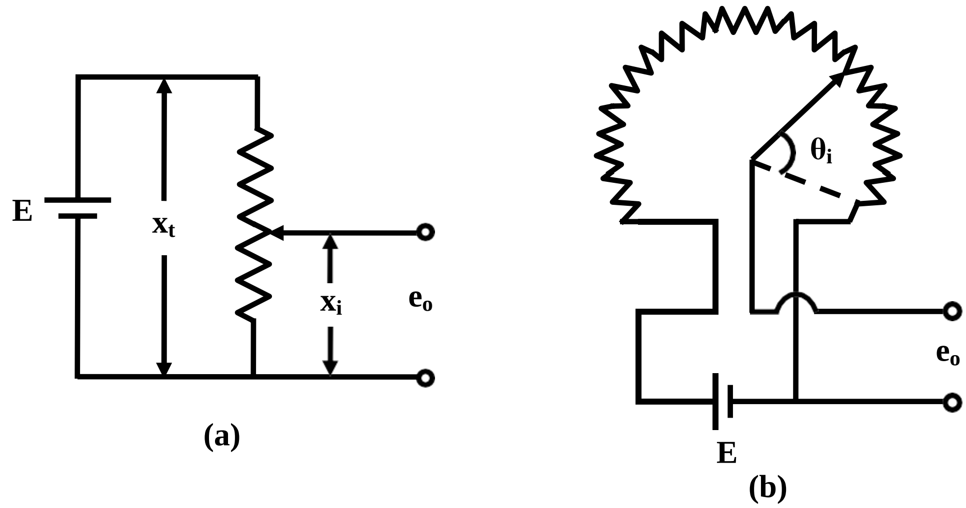

Fig. 1 Potentiometer
(a) Linear
(b) Rotary

Linear Variable Differential transformer (LVDT)

LVDT works on the principle of variation of mutual inductance. It is one of the most popular types of displacement sensor. It has good linearity over a wide range of displacement. Moreover the mass of the moving body is small, and the moving body does not make any contact with the static part, thus minimizing the frictional resistance. Commercial LVDTs are available with full scale displacement range of $\pm$0.25mm to $\pm$25mm. Due to the low inertia of the core, the LVDT has a good dynamic characteristics and can be used for time varying displacement measurement range.
The construction and principle of operation of LVDT can be explained with Fig. 2(a) and Fig. 2(b). It works on the principle of variation of the mutual inductance between two coils with displacement. It consists of a primary winding and two identical secondary windings of a transformer, wound over a tubular former, and a ferromagnetic core of annealed nickel-iron alloy moves through the former. The two secondary windings are connected in series opposition, so that the net output voltage is the difference between the two. The primary winding is excited by 1-10V r.m.s. A.C. voltage source, the frequency of excitation may be anywhere in the range of 50 Hz to 50 KHz. The output voltage is zero when the core is at central position (voltage induced in both the secondary windings are same, so the difference is zero), but increasing as the core moves away from the central position, in either direction. Thus, from the measurement of the output voltage only, one cannot predict, the direction of the core movement. A phase sensitive detector (PSD) is a useful circuit to make the measurement direction sensitive. It is connected at the output of the LVDT and compares the phase of the secondary output with the primary signal to judge the direction of movement. The output of the phase sensitive detector after low pass filtering becomes a d.c voltage for a steady deflection. The output voltage after PSD vs. displacement characteristics is shown in Fig. 2(c).

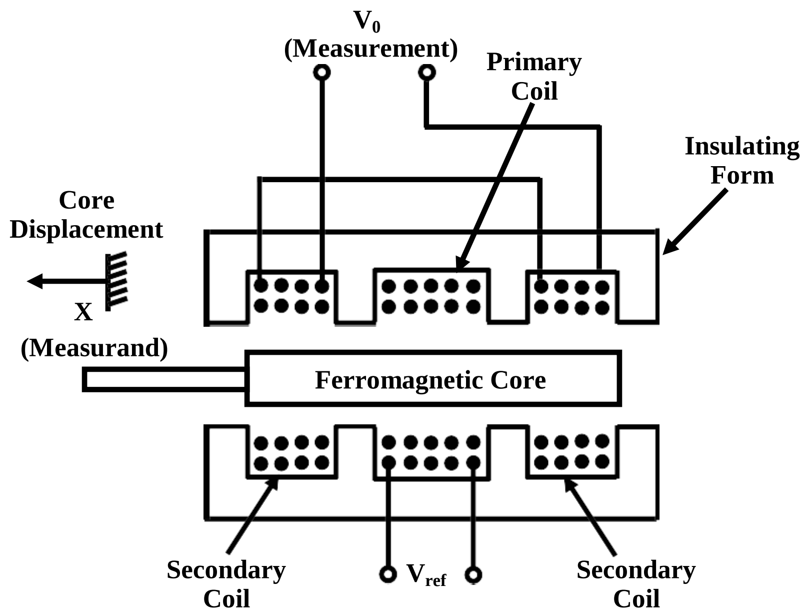

Fig. 2(a) Construction of LVDT.

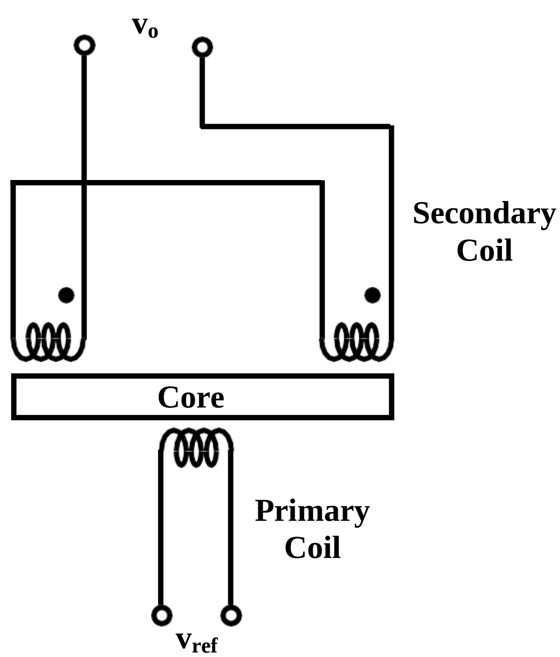

Fig. 2(b) Series opposition connection of secondary windings.

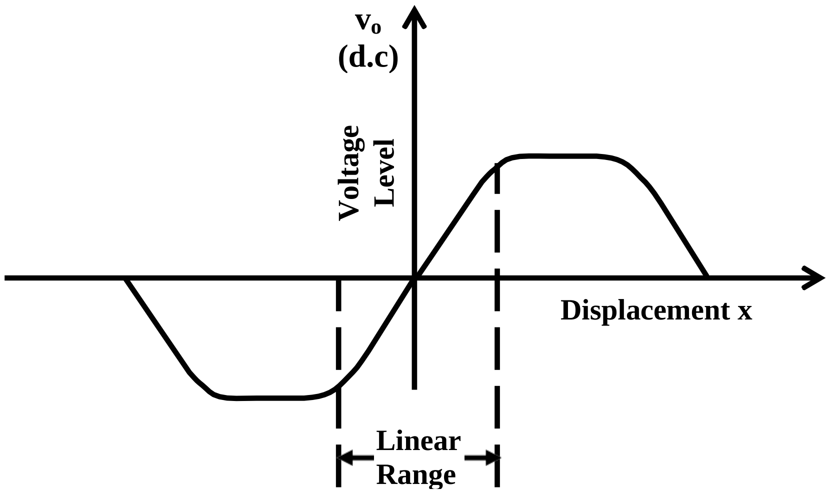

Fig. 2(c) Output voltage vs. displacement characteristics of LVDT after Phase sensitive detection.

Inductive type Sensors

LVDT works on the principle of variation of mutual inductance. There are inductive sensors for measurement of displacement those are based on the principle of variation of self inductance. These sensors can be used for proximity detection also. Such a typical scheme is shown in Fig. 3. In this case the inductance of a coil changes as a ferromagnetic object moves close to the magnetic former, thus change the reluctance of the magnetic path. The measuring circuit is usually an a.c. bridge.

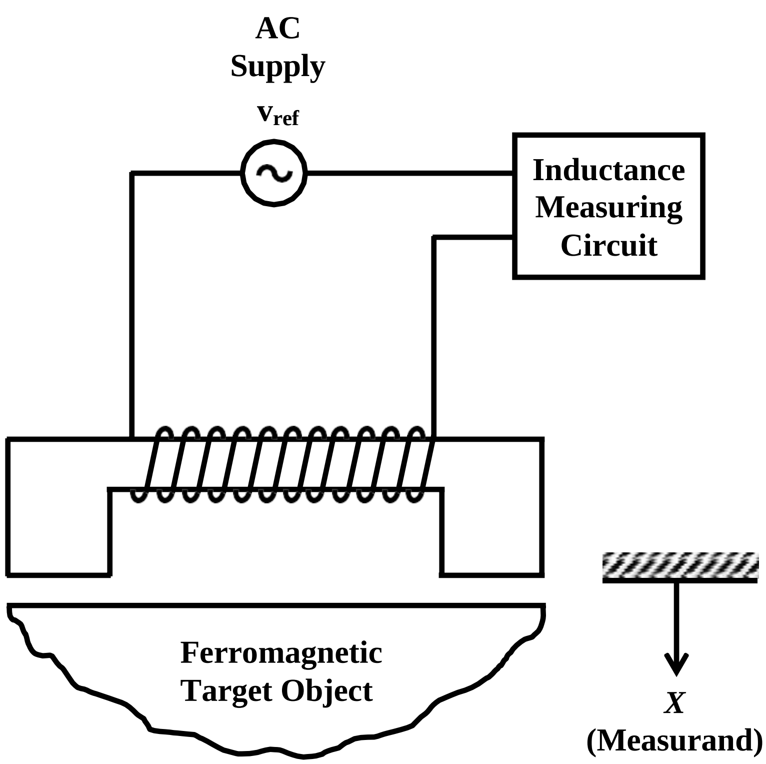

Fig. 3 Schematic diagram of a self inductance type proximity sensor.

Rotary Variable Differential Transformer (RVDT)

Its construction is similar to that of LVDT, except the core is designed in such a way that when it rotates the mutual inductance between the primary and each of the secondary coils changes linearly with the angular displacement. Schematic diagram of a typical RVDT is shown in Fig. 4.

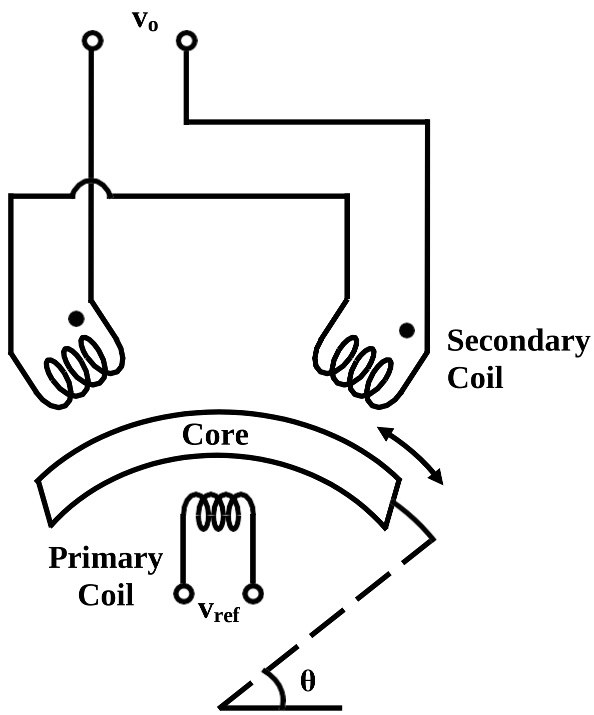

Fig. 4 Rotary Variable Differential Transformer (RVDT)

Resolver

Resolvers also work on the principle of mutual inductance variation and are widely used for measurement of rotary motion. The basic construction is shown in Fig. 5. A resolver consists of a rotor containing a primary coil and two stator windings (with equal number of turns) placed perpendicular to each other. The rotor is directly attached to the object whose rotation is being measured. If a.c. excitation of r.m.s voltage V_r is applied, then the induced voltages at two stator coils are given by:

$$v_{01} = KV_r \cos\theta$$

and $v_{02} = KV_r \sin\theta$; where K is a constant.

By measuring these two voltages the angular position can be uniquely determined, provided $(0 \le \theta \le 90^0)$. Phase sensitive detection is needed if we want to measure for angles in all the four quadrants.

Synchros work widely as error detectors in position control systems. The principle of operation of synchros is similar to that of resolvers. However it will not be discussed in the present lesson.

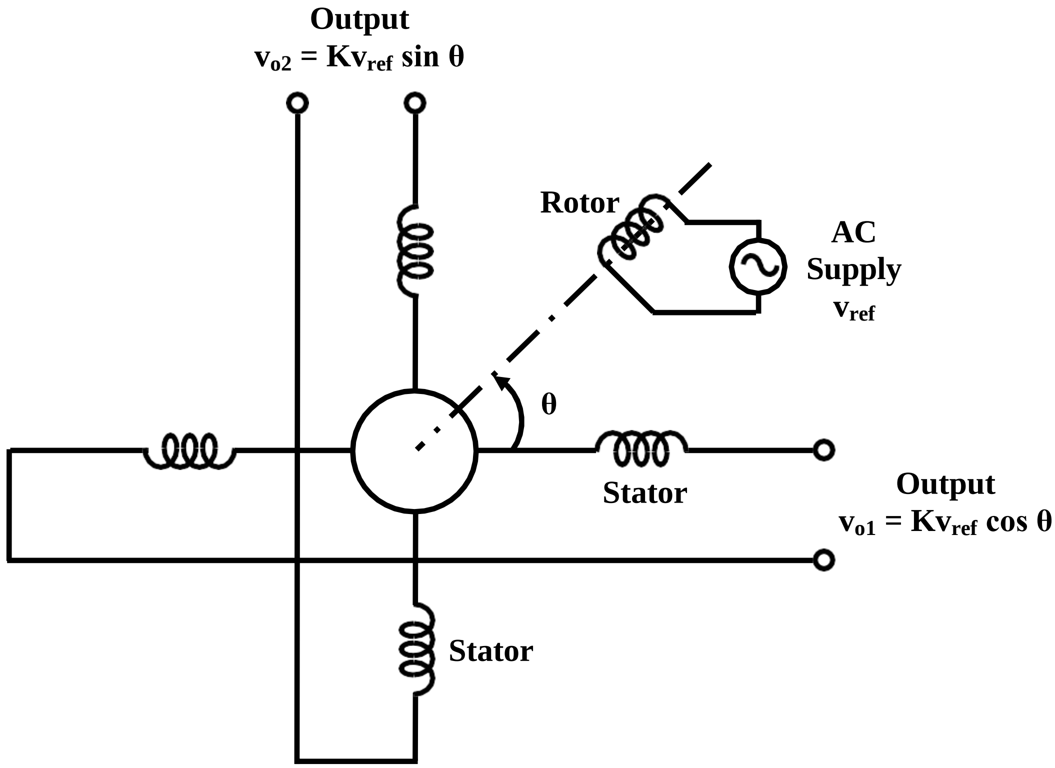

Fig. 5 Schematic diagram of the resolver.

Capacitance Sensors

The capacitance type sensor is a versatile one; it is available in different size and shape. It can also measure very small displacement in micrometer range. Often the whole sensor is fabricated in a silicon base and is integrated with the processing circuit to form a small chip. The basic principle of a capacitance sensor is well known. But to understand the various modes of operation, consider the capacitance formed by two parallel plates separated by a dielectric. The capacitance between the plates is given by:

$$C = \frac{\varepsilon_r \varepsilon_0 A}{d} \qquad (1)$$

where A=Area of the plates

d= separation between the plates

ε_r= relative permittivity of the dielectric

ε_0= absolute permittivity in free space = $8.854\times10^{-12} F/m$.

A capacitance sensor can be formed by either varying (i) the separation (d), or, (ii) the area (A), or (iii) the permittivity (ε_r). A displacement type sensor is normally based on the first two (variable distance and variable area) principles, while the variable permittivity principle is used for measurement of humidity, level, etc. Fig.6 Shows the basic constructions of variable gap and variable area types of capacitance sensors mentioned above. Fig. 6(a) shows a variable distance type sensor, where the gap between the fixed and moving plates changes. On the other hand, the area of overlap between the fixed plate and moving plate changes in Fig. 6(b), maintaining the gap constant. The variable area type sensor gives rise to linear variations of capacitance with the input variable, while a variable separation type sensor follows inverse relationship.

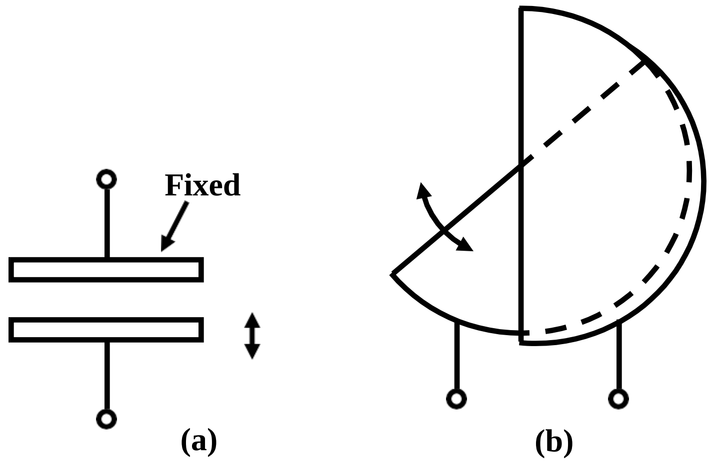

Fig.6 Capacitive type displacement Sensors:
a) variable separation type,
b) variable area type.

Capacitance sensors are also used for proximity detection. Such a typical scheme is shown in Fig. 4. Capacitive proximity detectors are small in size, noncontact type and can detect presence of metallic or insulating objects in the range of approximately 0-5cm. For detection of insulating objects, the dielectric constant of the insulating object should be much larger than unity. Fig. 7 shows the construction of a proximity detector. Its measuring head consists of two electrodes, one circular (B) and the other an annular shaped one (A); separated by a small dielectrical spacing. When the target comes in the closed vicinity of the sensor head, the capacitance between the plates A and B would change, which can be measured by comparing with a fixed reference capacitor.

The measuring circuits for capacitance sensors are normally capacitive bridge type. But it should be noted that, the variation of capacitance in a capacitance type sensor is generally very small (few *pF* only, it can be even less than a *pF* in certain cases). These small changes in capacitor, in presence of large stray capacitance existing in different parts of

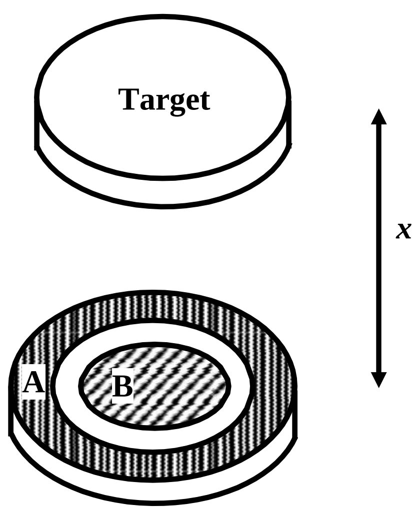

Fig. 7 Capacitance Proximity Detector.

the circuit are difficult. So the output voltage would generally be noisy, unless the sensor is designed and shielded carefully, the measuring circuit should also be capable of reducing the effects of stray fields.

Optical Sensors

Optical displacement sensors work on the basic principle that the intensity of light decreases with distance. So if the source and detector are fixed, the amount of light reflected from a moving surface will depend on the distance of the moving surface from the fixed ones. Measurement using this principle requires proper calibration since the amount of light received depends upon the reflectivity of the surface, intensity of the source etc. Yet it can provide a simple method for displacement measurement. Optical fibers are often used to transmit light to and from the measuring zone. Such a scheme with bundle fibers is shown in Fig. 8. It uses two bundle fibers, one for transmitting light from the source and the other to the detector. Light reflected on the receiving fiber bundle by the surface of the target object is carried to a photo detector. The light source could be Laser or LED; photodiodes or phototransistors are used for detection.

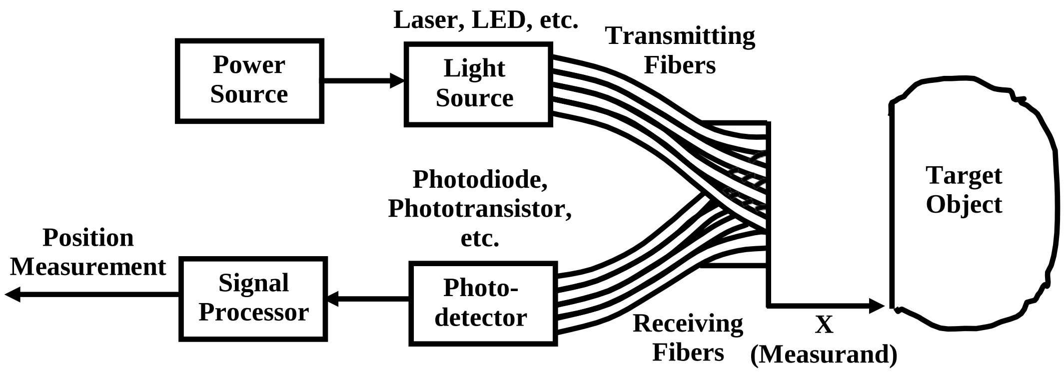

Fig. 8 A Fiber optic position sensor.

Speed Measurement

The simplest way for speed measurement of a rotating body is to mount a tachogenerator on the shaft and measure the voltage generated by it that is proportional to the speed. However this is a contact type measurement. There are other methods also for noncontact type measurements.
The first method is an optical method shown in Fig. 9. An opaque disc with perforations or transparent windows at regular interval is mounted on the shaft whose speed is to be measured. A LED source is aligned on one side of the disc in such a way that its light can pass through the transparent windows of the disc. As the disc rotates the light will alternately passed through the transparent windows and blocked by the opaque sections. A photodetector fixed on the other side of the disc detects the variation of light and the output of the detector after signal conditioning would be a square wave (as shown) whose frequency is decided by the speed and the number of holes (transparent windows) on the disc.

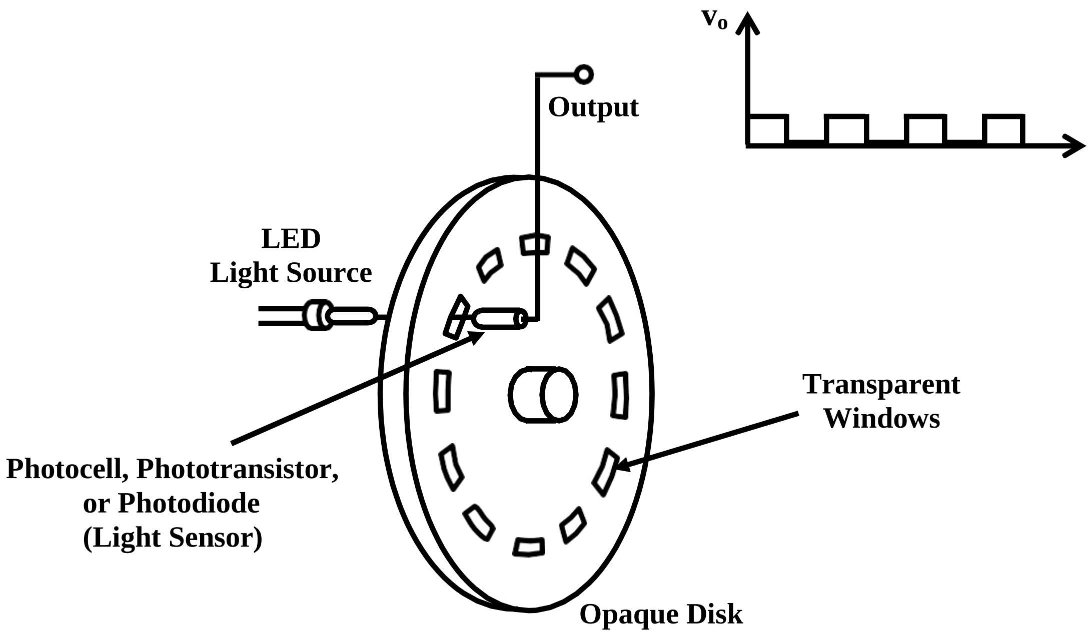

Fig. 9 Schematic arrangement of optical speed sensing arrangement.

Fig.10 shows another scheme for speed measurement. It is a variable reluctance type speed sensor. A wheel with projected teethes made of a ferromagnetic material is mounted on the shaft whose speed is to be measured. The static sensor consists of a permanent magnet and a search coil mounted on the same assembly and fixed at a closed distance from the wheel. The flux through the permanent magnet completes the path through the teeth of the wheel and cut the search coil. As the wheel rotates there would be change in flux cut and a voltage will be induced in the search coil. The variation of the flux can be expressed as:

$$\phi(t) = \phi_o + \phi_m \sin \omega t \qquad (2)$$

where ω is the angular speed of the wheel. Then the voltage induced in the coil is:

$$e = -N\frac{d\phi}{dt} = -N\omega\phi_m \cos\omega t \qquad (3)$$

where N is the number of turns in the search coil. So both the amplitude and frequency of the induced voltage is dependent on the speed of rotation. This voltage is fed to a comparator circuit that gives a square wave type voltage whose amplitude is constant, but frequency is proportional to the speed. A frequency counter is used to count the number of square pulses during a fixed interval and displays the speed.

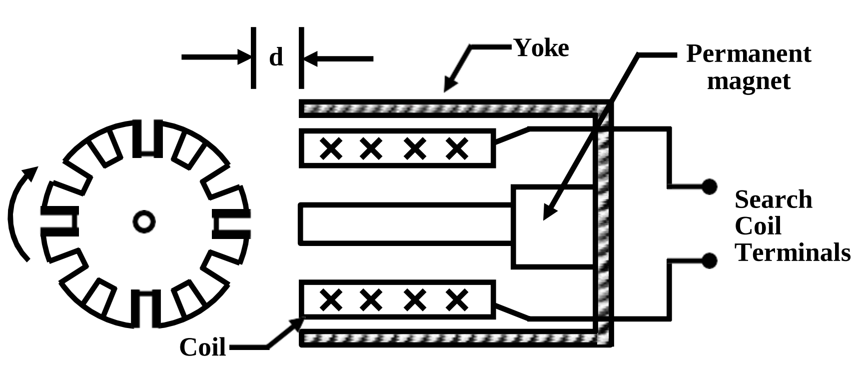

Fig. 10 Variable reluctance type speed sensor.

Conclusion

Few techniques commonly used for displacement and speed measurements have been discussed in this lesson. The selection of the sensing scheme depends on the requirement, environment and accessibility. Displacement/position sensing can be done in two ways. One method is to convert the displacement signal into variation of inductance or capacitance and then use suitable measuring circuit to measure their variation. On the other hand, in optical method the intensity of the light reflected from a moving surface is measured and calibrated in terms of the distance. An important application of displacement measurement is proximity sensing. Few such schemes have been discussed in this lesson. However eddy current type proximity sensing has not been discussed in this lesson.

The most popular type of speed sensor is the tachogenerator. The tachogenerator is mounted on the shaft and the voltage induced that is proportional to the speed is measured. But there are other noncontact methods also in which the speed signal is converted into frequency signal and the frequency is measured. Two such techniques have been discussed in this lesson.

References

1. J.P. Bentley: *Principles of Measurement Systems* (3/e), Longman, U.K., 1995.
2. E.O. Doeblin: *Measurement System Application and Design* (4/e), Mcgraw-Hill, Singapore, 1990.
3. L.K.Baxter: *Capacitance Sensors Design and Applications*, IEEE Press, New Jersey, 1997.
4. D. Patranabis: *Sensors and Transducers (2/e),* PHI, New Delhi, 2003.
5. C.W. de Silva: *Control Sensors and Actuators*, Prentice Hall, New Jersey, 1989.

Review Questions

1. What is the function of a Phase Sensitive Detector (PSD) in a LVDT circuit?
2. Discuss the construction and operating principle of a LVDT.
3. Distinguish between variable gap and variable area type capacitance displacement sensors.
4. What are the advantages and limitations of optical displacement (position) sensors?
5. Name two method of noncontact type speed measurement. Explain with a schematic diagram the principle of operation of any one of them.
6. An optical type speed sensor has a disc with 36 rectangular holes placed at regular intervals on the periphery of the disc. The frequency of the photodetector output is 360 Hz. Find the speed of the shaft in rpm on which the disc is mounted.