Displacement, Proximity and Position sensors

Position means the determination of the object's coordinates (linear or angular) with respect to a selected reference. Displacement means moving from one position to another for a specific distance or angle. In other words, a displacement is measured when an object is referenced to its own prior position rather than to another reference.

A critical distance is measured by proximity sensors. In effect, a proximity sensor is a threshold version of a position detector.

4.Digital displacement Sensors

A digital transducer is a measuring device that produces a digital output. A transducer whose output is a pulse signal may be considered in this category since the pulses can be counted and presented in the digital form using a counter. Similarly, a transducer whose output is a frequency falls into the same category as it can use a frequency counter to generate a digital output.

3.1 Shaft Encoders

Shaft encoders are digital transducers that are used for measuring angular displacements and angular velocities. They generate a coded (digital) reading of a measurement can be termed as an encoder.

Shaft encoders can be classified into two categories depending on the nature and the method of interpretation of the transducer output:

(1) incremental encoders
(2) absolute encoders

The output of an incremental encoder is a pulse signal, which is generated when the transducer disk rotates as a result of the motion that is measured. By counting the pulses or by timing the pulse width using a clock signal, both angular displacement and angular velocity can be determined.

With an incremental encoder, displacement is obtained with respect to some reference point. The reference point can be

- the home position of themoving component (say, determined by a limit switch)
- a reference point on the encoder disk, as indicated by a reference pulse (index pulse)

An absolute encoder (or, whole-word encoder) has many pulse tracks on its transducer disk. When the disk of an absolute encoder rotates, several pulse trains,equal in number to the tracks on the disk, are generated simultaneously. At a given instant, the set of pulse trains gives an encoded binary number. The pulse windows on the tracks can be organized into some pattern (code) so that the generated binary number at a particular instant corresponds to the specific angular position of the encoder disk at that time.

Note that an incremental encoder disk requires only one primary track that has equally spaced and identical window (pick-off) regions. The window area is equal to the area of the inter-window gap (i.e., 50% duty cycle). Usually, a reference track that has just one window is also present to generate a pulse (known as the index pulse) to initiate pulse counting for angular position measurement and to detect complete revolutions.

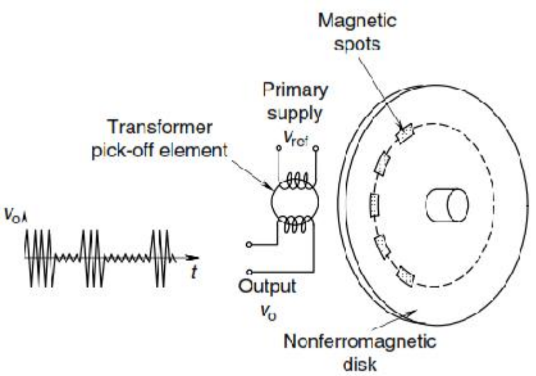
In contrast, absolute encoder disks have several rows of tracks, equal in number to the bit size of the output data word. Furthermore, the windows in a track are not equally spaced but are arranged in a specific pattern to obtain a binary code (or a gray code) for the output data from the transducer. It follows that absolute encoders need at least as many signal pick-off sensors as there are tracks, whereas incremental encoders need just one pick-off sensor to detect the magnitude of rotation.

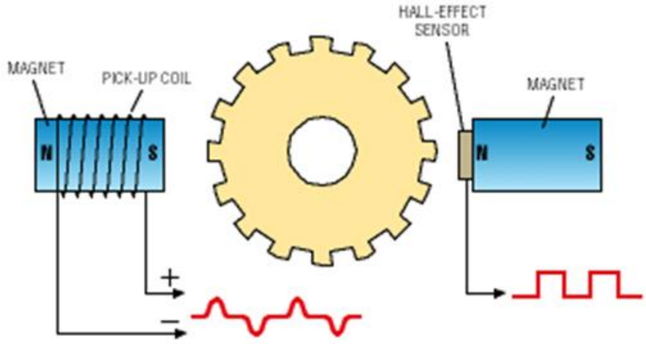
The same signal generation (and pick-off) mechanism may be used in both types (incremental and absolute) of transducers. Two techniques of transducer signal generation are Optical Sensing and Magnetic sensing

Magnetic encoders

Magnetic encoders have high-strength magnetic regions imprinted on the encoder disk using techniques such as etching, stamping, or recording. The signal pick-off device is a microtransformer, which has primary and secondary windings on a circular ferromagnetic core.

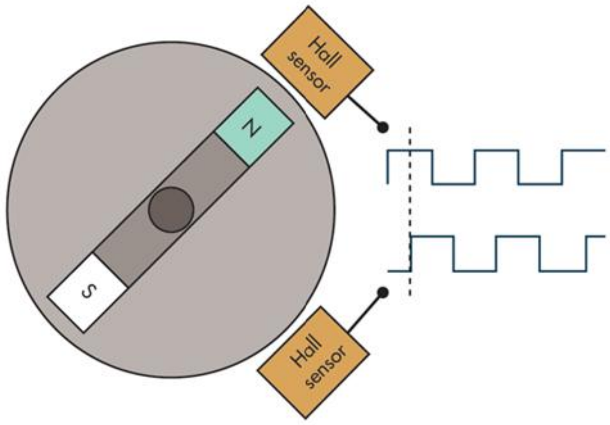
A high-frequency (typically 100 kHz) primary voltage induces a voltage in the secondary winding of the sensing element at the same frequency, operating as a transformer. A magnetic field of sufficient strength can saturate the core, however, thereby significantly increasing the reluctance and dropping the induced voltage. By demodulating the induced voltage, a pulse signal is obtained.





a pulse peak corresponds to a nonmagnetic area and a pulse valley corresponds to a magnetic area for each track. If a permanent magnet and hall effect used in given manner a better pulse can be obtained

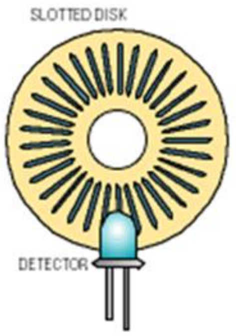
<u>Absolute Magnetic Encoder</u>

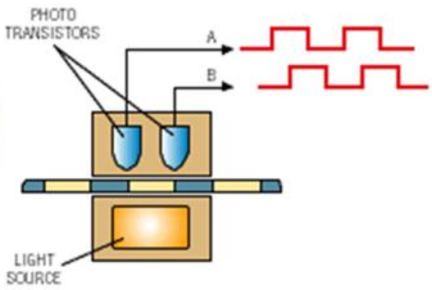


Typical construction uses magnets placed around the edge of a rotor disc attached to a shaft and positioned so the sensor detects changes in the magnetic field as the alternating poles of the magnet pass over it.
The simplest configuration would have a single magnet, with its north and south poles on opposite edges of the rotor, and a single sensor. Such a device would produce a sine wave output with a frequency equal to the rotational speed of the shaft.
With a second sensor, set 90° apart from the first and therefore generating a cosine output, it becomes possible to not only detect the direction of rotation but also to interpolate the absolute position of the shaft from the sine and cosine signals

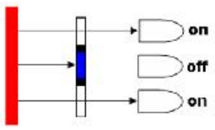
Optical encoders
Optical encoders encompass a variety of devices, all of which use light as the means to transform movement into electrical signals All devices have two basic building blocks: a main grating and a detection system. It is the position of one with respect to the other that is detected.
The main grating represents the measurement standard. For linear measurements, the main grating, commonly called the scale, is one or more sets of parallel lines of constant or specially coded pitch supported by a substrate. Similarly, a rotary encoder has a grating with radial lines on a disk.

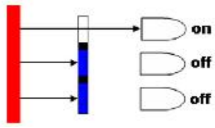
Both linear and rotary encoders can, in principle, be absolute or incremental, although in practice, linear absolute encoders employing optical principles are quite uncommon



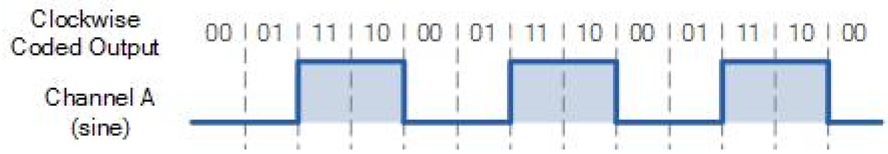


Optical encoders consist of a light source (LEDs or IR LEDs), an optical using a lens to make the beams parallel, Photodetector(s) (Either Photodiodes or Phototransistors) and a code disk (One or more “tracks” with slits to allow light to pass through).
A parallel beam of light (e.g., from a set of light-emitting diodes or LEDs) is projected to all tracks from one side of the disk. The transmitted light is picked off using a bank of photosensors on the other side of the disk, which typically has one sensor for each track.



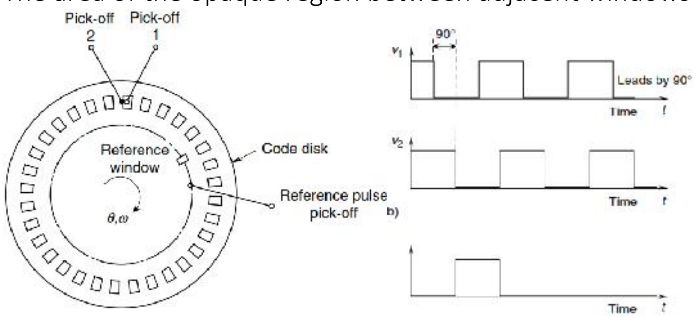


Since the light from the source is interrupted by the opaque regions of the track, the output signal from the photosensor is a series of voltage pulses. This signal can be interpreted (e.g., through edge detection or level detection) to obtain the increments in the angular position.

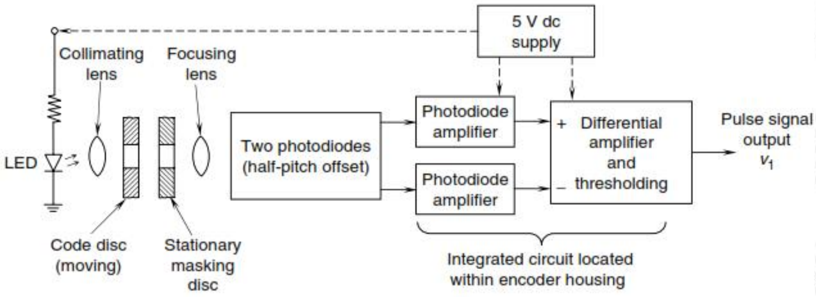


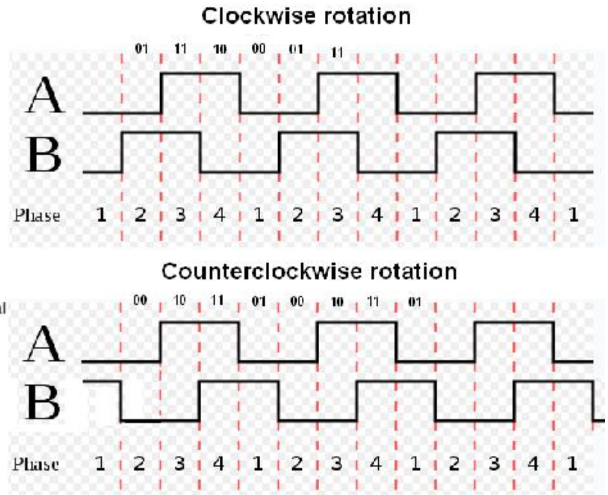
The sensor element of such a measuring device is the encoder disk, which is coupled to the rotating object (directly or through a gear mechanism). The transducer stage is the conversion of disk motion (analog) into the pulse signals, which can be coded into a digital word.

Incremental Optical Encoders: The disk has a single circular track with identical and equally spaced transparent windows. The area of the opaque region between adjacent windows is equal to the window area.



Two photodiode sensors (pick-offs 1 and 2) are positioned facing the track at a quarter-pitch (half the window length) apart. The forms of their output signals (v1 and v2), after passing them through pulse-shaping circuitry (idealized),
An additional track with a lone window and associated sensor is also usually available. This track generates a reference pulse (index pulse) per revolution of the disk. Output pulse signal is on for half the time and off for half the time, giving a 50% duty cycle.
The quarter-pitch offset in sensor location (or in track placement) is used to determine the direction of rotation of the disk. e direction of rotation is obtained by determining the phase difference of the two output signals, using phase-detecting circuitry. In this case, we first detect a high level (logic high or binary 1) in signal v2 and then check whether the edge in signal v1 rises or falls during this period.





If rising edge in V1 occurs when v2 is high cw rotation
If falling edge in V1 occurs when v2 is high ccw rotation

Displacement Measurement: As it is obvious, An incremental encoder measures displacement as a pulse count and it measures velocity as a pulse frequency. A digital processor is able to express these readings in engineering units (radians, degrees, rad/s, etc.) using pertinent parameter values of the physical system.
Suppose that the maximum count possible is m pulses and the range of the encoder is +/- θ_{max} .

$$\theta = \frac{n}{M}\theta_{max}$$

Where n is pulse counted.
The *resolution of an encoder* represents the smallest change in measurement that can be measured. Dissplacement Resolution is governed by the number of windows N in the code disk and the digital size (number of bits) of the buffer (counter output).
Suppose that the encoder count is stored as digital data of r bits. Allowing for a sign bit, we have:

$$M = 2^{r-1}$$

The displacement resolution of an incremental encoder is given by the change in displacement corresponding to a unit change in the count (n)

Typically, $\theta_{max} = \pm 180°$ or $360°$. Then,

$$\Delta\theta = \frac{\theta_{max}}{M} = \frac{\theta_{max}}{2^{r-1}} \qquad \Delta\theta_d = \frac{180°}{2^{r-1}} = \frac{360°}{2^r}$$

$$\theta_{max} = \theta_{min}(2^{r-1} - 1)\Delta\theta$$

Digital resolution: $\Delta\theta = \dfrac{\theta_{max} - \theta_{min}}{(2^{r-1} - 1)}$

The physical resolution of an encoder is governed by the number of windows N in the code disk. Encoder resolution formulas are:

- Incremental Optical Encoder

$$Resolution = \frac{360°}{n}$$

n = Number of Windows on Code Disk per Channel

If we read the rising edge of Channel A **and** Channel B,

$$Resolution = \frac{360°}{2n}$$

If we read the falling edge of Channel A **and** Channel B,

$$Resolution = \frac{360°}{2n}$$

If we read the rising edge **and** the falling edge of Channel A **and** Channel B,

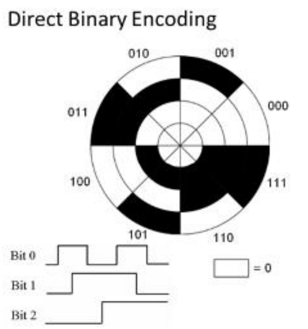
$$Resolution = \frac{360°}{4n}$$

Absolute Optical Encoders

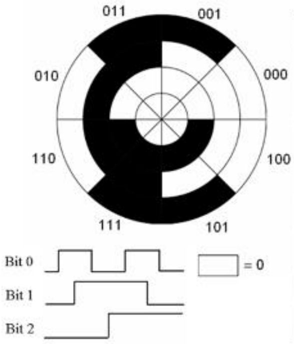
An absolute encoder directly generates a coded digital word to represent each discrete angular position (sector) of its code disk. This is accomplished by producing a set of pulse signals (data channels) equal in number to the word size (number of bits) of the reading.

A code disk with transparent and opaque regions and pairs of light sources and photosensors, is the most common technique. The code disk may have direct binary coding or a graycode coding on it.

Direct Binary Code: The disk is divided into n sectors. Each partitioned area of the matrix thus formed corresponds to a bit of data. For example, a transparent area will correspond to binary 1 and an opaque area to binary 0.Each track has a pick-off sensor similar to that used in incremental encoders. The set of n pick-off sensors is arranged along a radial line and facing the tracks on one side of the disk. As the disk rotates, the bank of pick-off sensors generates pulse signals, which are sent to n parallel data channels (or pins).



Angle	Binary	Dec
0-45	000	0
45-90	001	1
90-135	010	2
135-180	011	3
180-225	100	4
225-270	101	5
270-315	110	6
315-360	111	7



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180-225	110	4
225-270	111	5
270-315	101	6
315-360	100	7

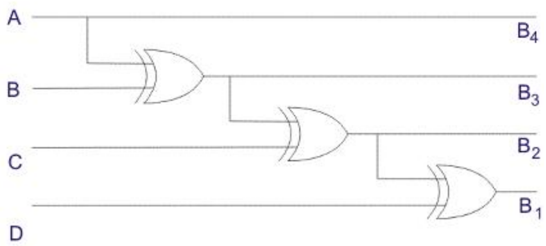
For direct binary encoding, an angle shift results in multiple bit changes.

Example: 1 => 2	001	(start at 1)
	000	(turn off bit 0)
	010	(turn on bit 1)

There is a data interpretation problem associated with the direct binary code in absolute encoders: from one sector to an adjacent sector may require more than one switching of bits in the binary data.

Gray Coding: In the case of gray code, each adjacent transition involves only one bit switching.Therefore, it requires additional logic to convert the gray coded number to the corresponding binary number. This logic may be provided in hardware or software. In particular, an Exclusive-Or gate can implement the necessary logic, as given by:

$$B_{n-1} = G_{n-1}$$
$$B_{k-1} = B_k \oplus G_{k-1} \quad k = n-1, \ldots, 1.$$



Logic Circuit for Gray to Binary Code Converter

The resolution of an absolute encoder is limited by the word size of the output data. Specifically, the displacement (position) resolution is given by the sector angle, which is also the angular separation between adjacent transparent and opaque regions on the outermost track of the code disk.

$$\Delta\theta = \frac{360^\circ}{2^n}$$