Actuators and Sensors: Encoders

ME 423: Machine Design
Instructor: Ramesh Singh

Sensors

- Optical encoders
- Interferometric sensors
- Laser triangulation sensors
- Focus Variation

Encoders

- Encoders are digital transducers that are used for measuring angular displacements and velocities
- Encoders can be generally categorized into:
  - optical (photoelectric)
  - magnetic encoders
  - mechanical contact

Optical Encoders

- Shaft Encoders are digital transducers that are used for measuring angular displacements and velocities
- Relative advantages of digital transducers over their analog counterparts:
  - High resolution (depending on the word size of the encoder output and the number of pulses per revolution of the encoder)
  - High accuracy (particularly due to noise immunity of digital signals and superior construction)
  - Relative ease of adaptation in digital control systems (because transducer output is digital)

Shaft Encoders

- Shaft Encoders can be classified into two categories depending on the nature and method of interpretation of the output:
  - Incremental Encoders
  - Absolute Encoders

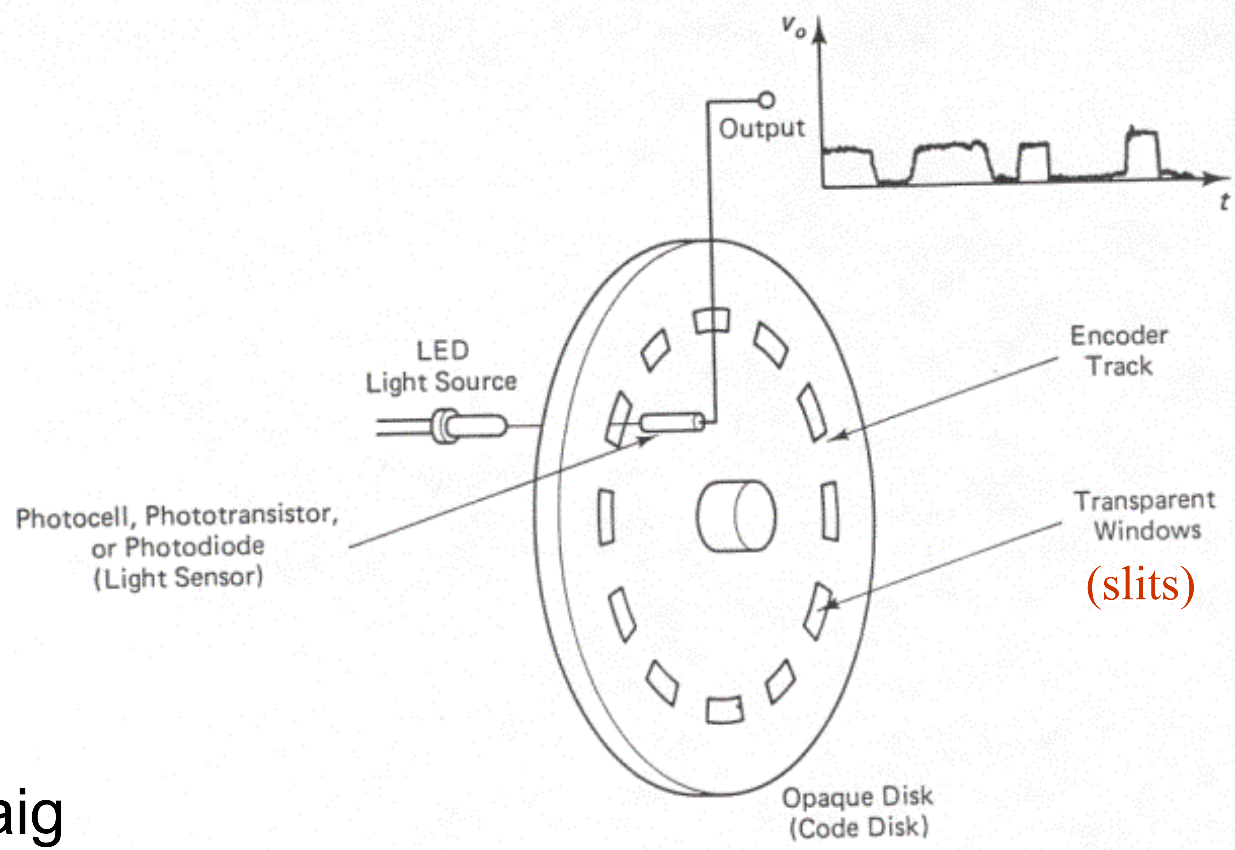
Incremental Encoders

- Output is a pulse signal that is generated when the transducer disk rotates as a result of the motion that is being measured.
- By counting pulses or by timing the pulse width using a clock signal, both angular displacement and angular velocity can be determined.
- Displacement, however, is obtained with respect to some reference point on the disk, as indicated by a reference pulse (index pulse) generated at that location on the disk. The index pulse count determines the number of full revolutions.

Incremental Encoder

- Direction of rotation for incremental encoders can also be a problem since the pulsed don't indicate direction.
- Bidirectional incremental encoders generally have two tracks placed so that the pulses will be 90 degrees out of phase with each other.

Schematic of an Incremental Encoder



Courtesy: K. Craig

Schematic Representation of an Optical Encoder
One Track and One Pick-Off Sensor Shown

Absolute Encoders

- An absolute 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 magnitude of each pulse signal will have one of two signal levels (i.e., a binary state) as determined by a level detector. This signal level corresponds to a binary digit (0 or 1). Hence, the set of pulse trains gives an encoded binary number at any instant.

Absolute Encoders

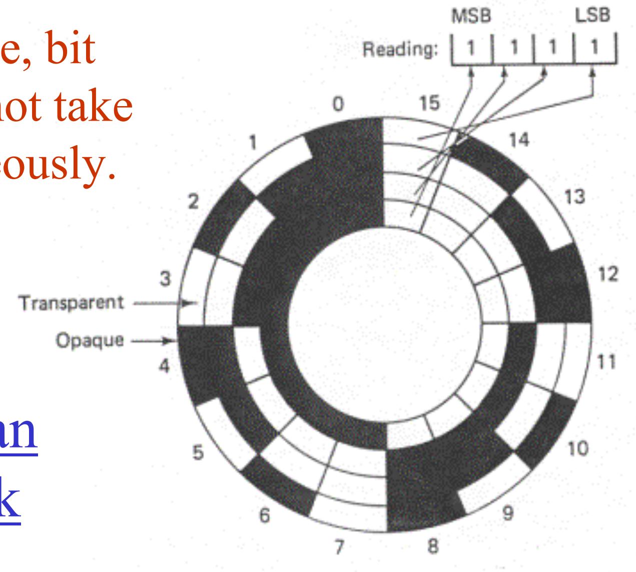
- The pulse windows on the tracks can be organized into some pattern (code) so that each of these binary numbers corresponds to the angular position of the encoder disk at the time when the particular binary number is detected.
- Pulse voltage can be made compatible with some form of digital logic (e.g., TTL)
- Direct digital readout of an angular position is possible

Absolute Encoder

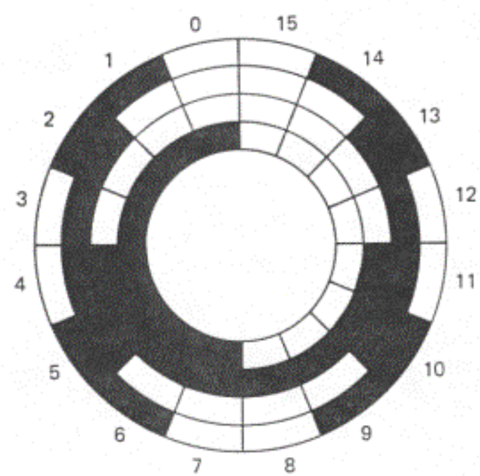
- Absolute encoders are commonly used to measure fractions of a revolution. However, complete revolutions can be measured using an additional track that generates an index pulse, as in the case of an incremental encoder.

Encoder

In Binary Code, bit switching may not take place simultaneously.



(a)



<u>Schematic Diagram of an Absolute Encoder Disk Pattern</u>

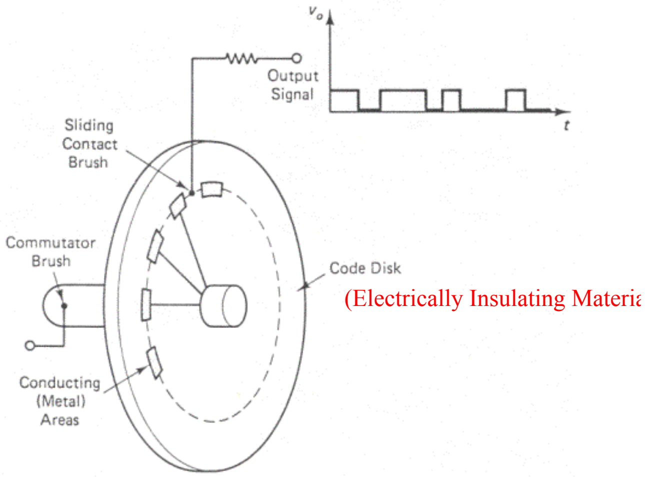
(a) Binary code

(b) Gray code

Ambiguities in bit switching can be avoided by using gray code. However, additional logic is needed to covert the gray-coded number to a corresponding binary number.

Absolute Encoders must be powered and monitored <u>only</u> when a reading is taken. Also, if a reading is missed, it will not affect the next reading.

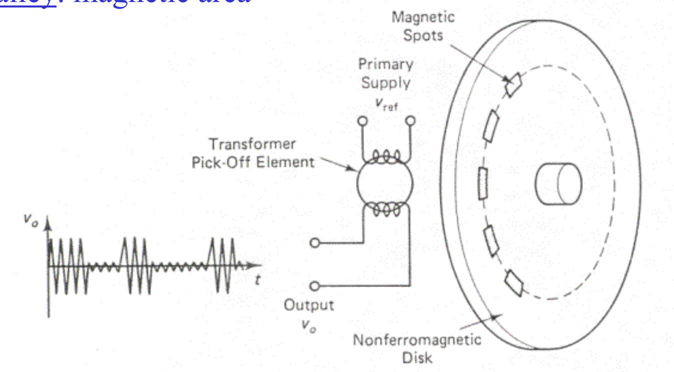
Other Encoders



Schematic Representation of a Sliding Contact Encoder

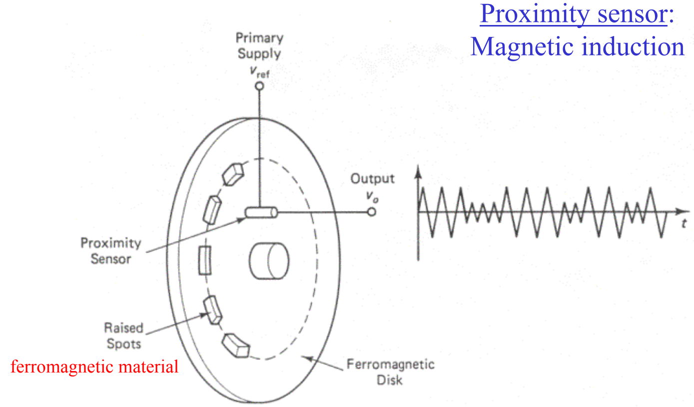
Pulse peak: nonmagnetic are

Pulse valley: magnetic area



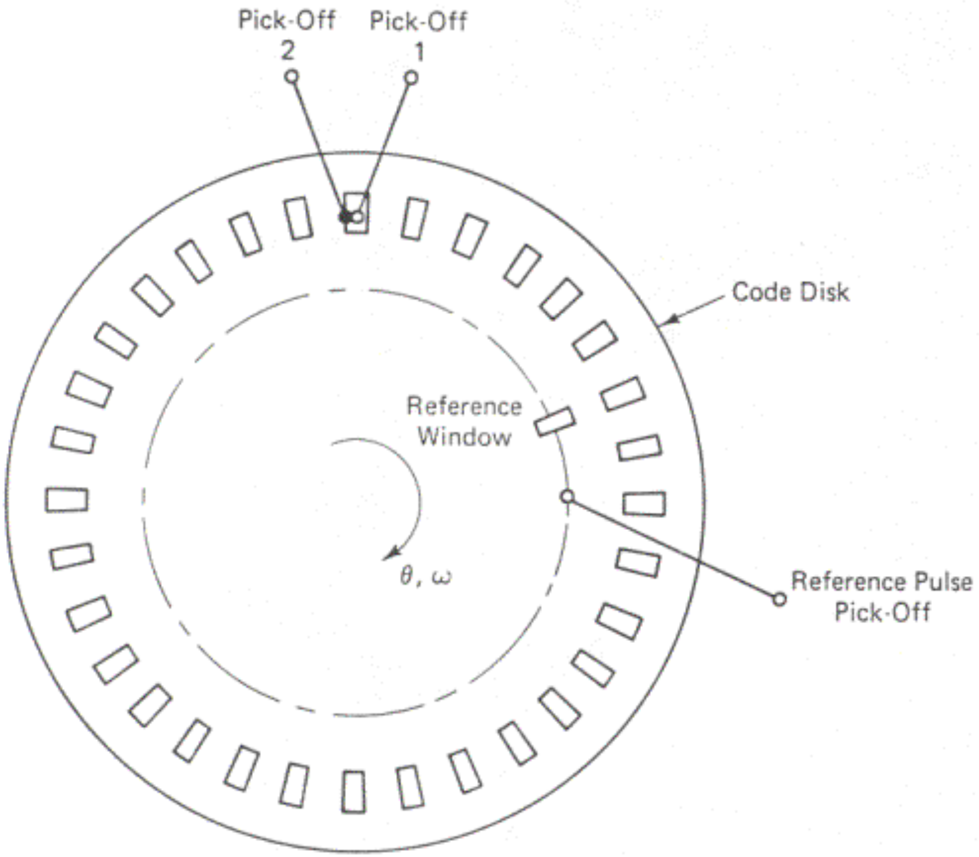
Schematic Representation of a Magnetic Encoder

Proximity sensor:
Magnetic induction



Schematic Representation of a Proximity Probe Encoder

Reference Signal



Incremental Optical Encoder Disk
Offset-Sensor Configuration

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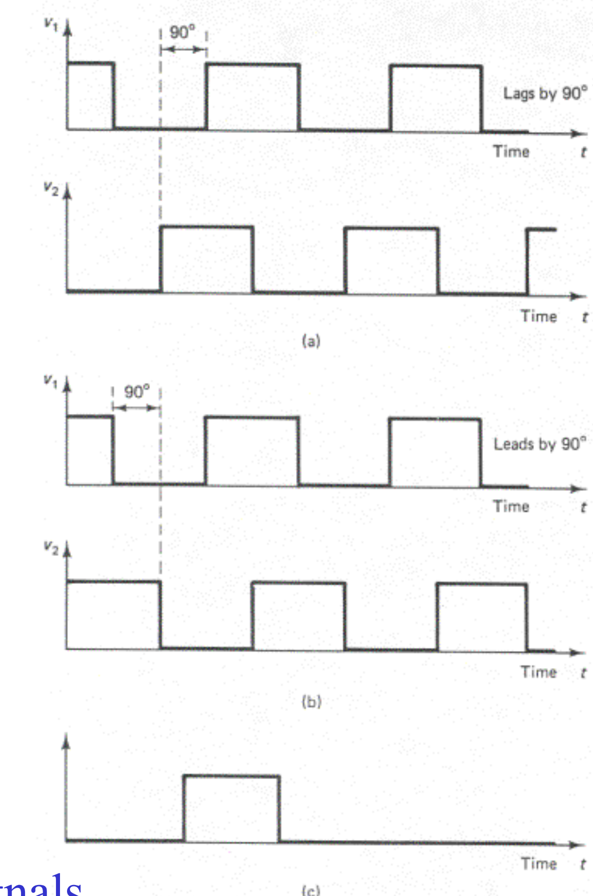
Schematic of Quadrature

Clockwise (CW) rotation:
V_1 lags V_2 by a quarter of a cycle
(i.e., a phase lag of 90°)
Counterclockwise (CCW) rotation:
V_1 leads V_2 by a quarter of a cycle



Incremental Encoder Pulse Signals
(a) CW rotation (b) CCW rotation (c) reference

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Resolution

- Maximum count possible: M pulses

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

- Range of the encoder: $\pm\ \theta_{max}$
- If the data size is r bits, allowing for a sign bit, $M = 2^{r-1}$, where zero count is also included.
- If zero count is not included, $M = 2^{r-1} – 1$
- If θ_{max} is 2π and θ_{min} is zero, then θ_{max} and θ_{min} will correspond to the same position of the code disk. To avoid this ambiguity,
- The conventional definition for digital resolution is: $(\theta max -\theta min)$

$$\frac{(\theta_{max} - \theta_{min})}{(2^{r-1} - 1)}$$

Glossary of Encoders

- ACCURACY is a measure of how close the output is to where it should be. It is usually expressed in units of distance, such as ±30 arc seconds or ±0.0001 inch. If it's expressed as a percent, make sure to state whether it's a percent of full scale (not usually meaningful with a rotary encoder) or a percent of nominal resolution.
- BIT is an abbreviation for Binary digit; it refers to the smallest element of resolution.
- ERROR is the algebraic difference between the indicated value and the true value of the input.
- FREQUENCY RESPONSE is the encoder's electronic speed limit, expressed in kilohertz (1 kHz = 1000 Hz = 1000 cycles/sec). For calculations, rotational speed must be in rev/sec (rps = rpm/60); linear speed must be either in/sec or mm/sec, depending on the scale line count.

Glossary of Encoder

- INDEX SIGNAL is a once-per-rev output used to establish a reference or return to a known starting position; also called reference, marker, home, or Z.
- INTERPOLATION involves an electronic technique for increasing the resolution from the number of optical cycles on the disc or scale to a higher number of quadrature square waves per revolution or per unit length. These square waves can then be quadrature decoded.
- MEASURING STEP is the smallest resolution element; it assumes quadrature decode. (see also QUANTUM)

Glossary of Encoder

- PPR (pulses per revolution) Commonly (but mistakenly) used instead of cycles/rev when referring to quadrature square wave output.
- QUADRATURE refers to the 90-electrical-degree phase relationship between the A and B channels of incremental encoder output.
- QUADRATURE DECODE (or 4X Decode) refers to the common practice of counting all 4 quadrature states (or square wave transitions) per cycle of quadrature square waves. Thus, an encoder with 1000 cycles/rev, for example, has a resolution of 4000 counts/rev.

Glossary of Encoder

- QUANTIZATION ERROR is inherent in all digital systems; it reflects the fact that you have no knowledge of how close you are to a transition. It is commonly accepted as being equal to ±1/2 bit.
- REPEATABILITY is a measure of how close the output is this time to where it was last time, for input motion in the same direction. It's not usually specified explicitly, but it is included in the accuracy figure. (As a rule of thumb, the repeatability is generally around 1/10 the accuracy.) RESOLUTION is the smallest movement detectable by the encoder. It can be expressed in either electrical terms per distance (e.g., 3600 counts/rev or 100 pulses/mm) or in units of distance (e.g., 0.1° or 0.01 mm).
- SLEW SPEED is the maximum allowable speed from mechanical considerations. It is independent of the maximum speed dictated by frequency response.

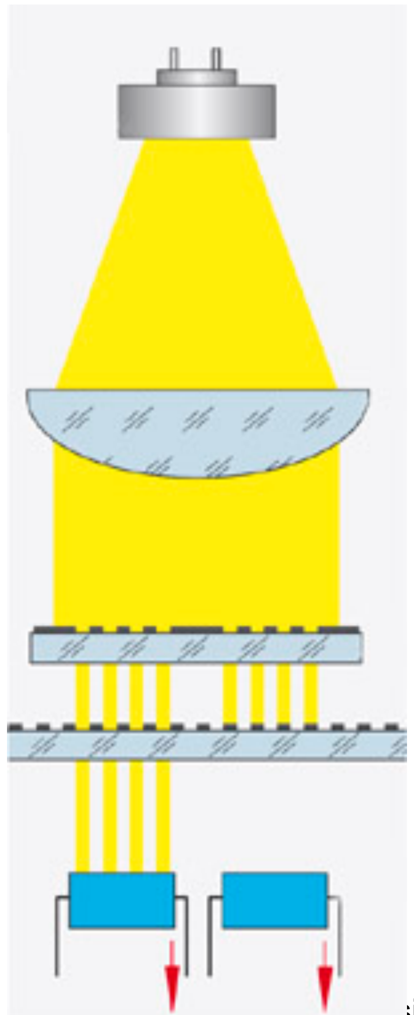
Linear Encoders

- Provide actual location feedback of a position and increase system accuracy.
- Allow a tight servo loop (when used with a linear servo motor).
  - *Although it is physically impossible to mount a linear encoder's read head in the same exact place as the user's load, it can be mounted nearby, telling you actual position (regardless of the drive mechanism accuracy).*
- Optical encoders use imaging and interferometric techniques
- Magnetic encoders use magentorestrictive sensors with a magnetic tape
- For applications with particularly demanding accuracy requirements, laser interferometers be considered.

Imaging Scanning

- The imaging scanning principle functions by means of projected-light signal generation: two graduations with equal grating periods are moved relative to each other—the scale and the scanning reticle.
- The carrier material of the scanning reticle is transparent, whereas the graduation on the measuring standard may be applied to a transparent or reflective surface.
- When parallel light passes through a grating, light and dark surfaces are projected at a certain distance. An index grating with the same grating period is located here. When the two gratings move relative to each other, the incident light is modulated.
- If the gaps in the gratings are aligned, light passes through. If the lines of one grating coincide with the gaps of the other, no light passes through. Photovoltaic cells convert these variations in light intensity into electrical signals.

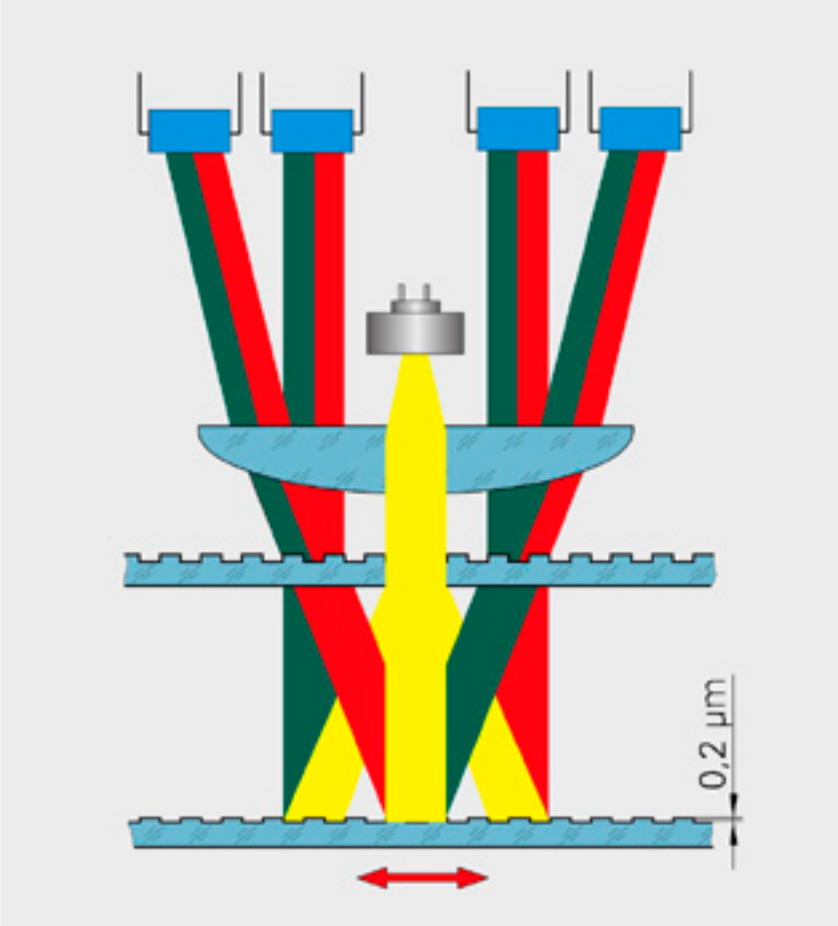
Imaging Scanning



Interferential Scanning Principle

- Interference of light on a fine graduation to produce signals used to measure displacement.
- A step grating is used as the measuring standard: reflective lines 0.2 µm high are applied to a flat, reflective surface. In front of that is the scanning reticle—a transparent phase grating with the same grating period as the scale.
- Interferential encoders function with grating periods of, for example, 8 µm,4 µm and finer. Their scanning signals are largely free of harmonics and can be highly interpolated.
- These encoders are therefore especially suited for high resolution and high accuracy.

Interferometric Encoder

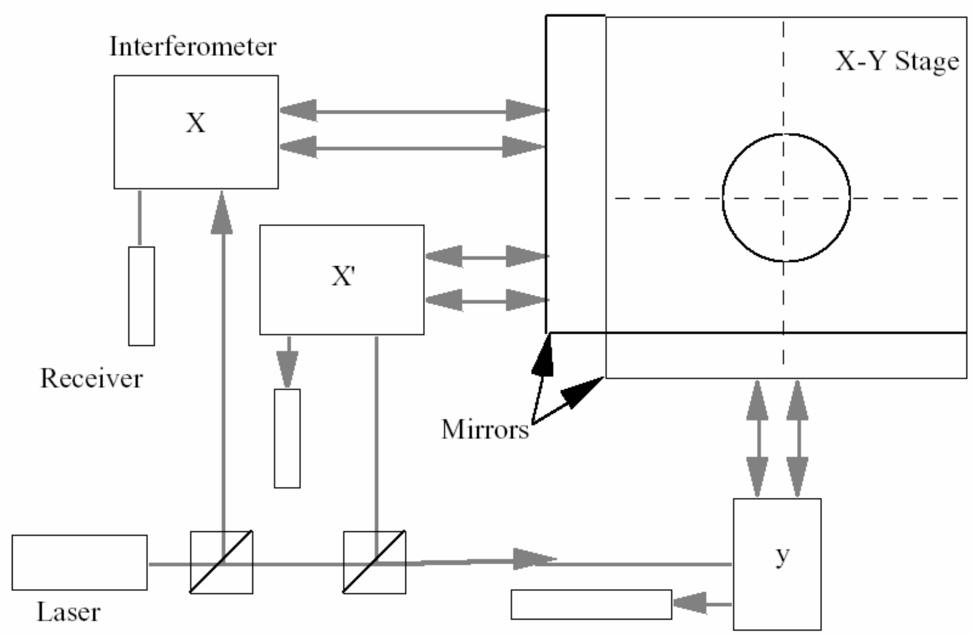


Magnetic Encoder

- Magnetic linear encoders use a read head with a sensing element in conjunction with a scale that is magnetically coded with alternating polarity.
- The alternating north and south magnetic poles are spaced at a precise distance, referred to as the pole pitch.
- The read head contains either Hall or magnetoresistive sensors, and as the read head moves over the tape, it detects the magnetic poles on the scale through either a change in voltage or a change in magnetic resistance.
- Usually less precise than the optical encoder

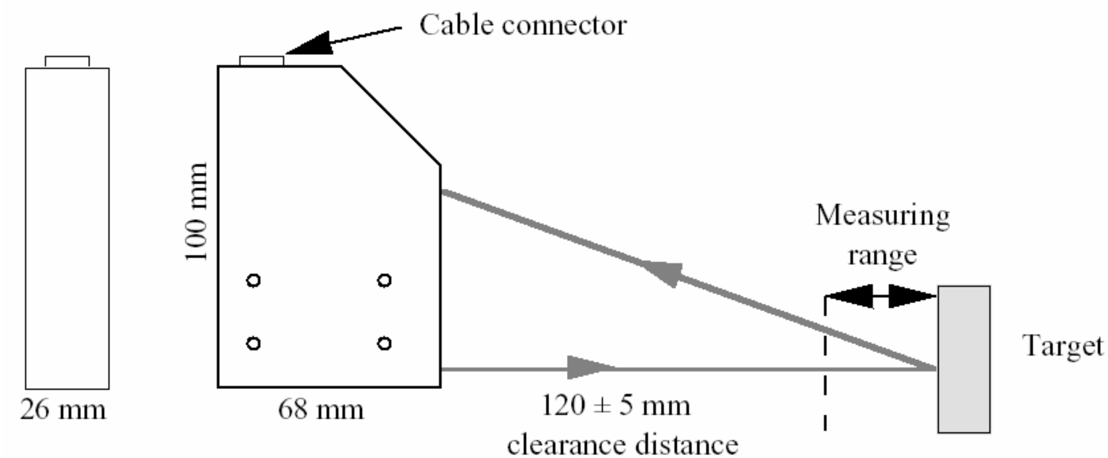
Laser Interferometer

- Work on the interference due to path difference
- Can be used for very precise measurements in semiconductor industry



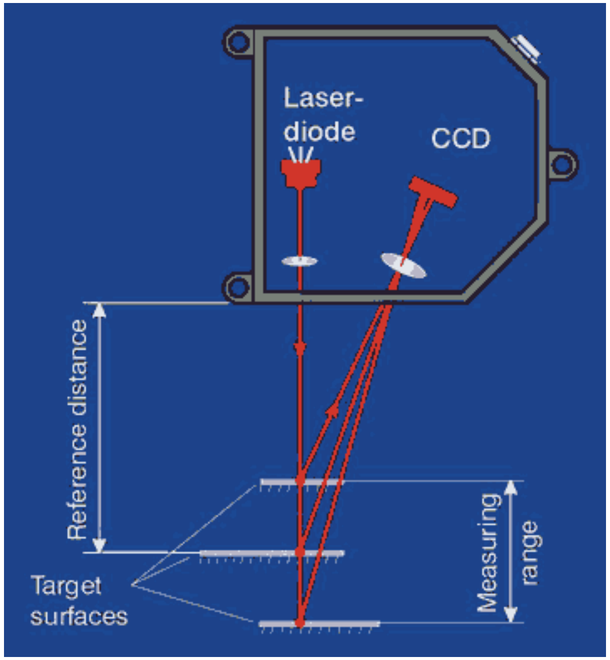
Laser Triangulation Sensor

- Typically used as non-contact displacement sensors.
- Very useful for gaging applications.



Laser Triangulation Sensor

- This type of sensor determines the position of a target by measuring the light reflected from its surface.
- A transmitter (laser diode) projects a light spot onto the target.
- The optical lens system then focuses the reflected light onto a light-sensitive device called a *receiving element*, which is built into the sensor head.
- If the target changes its position from the reference point, the position of the projected spot on the detector changes as well.



Focus Variation Sensors

- Focus-Variation integrates the small depth of focus of an optical system with vertical scanning to give color and topographical data from the variation of focus.
- The key component of the system is a precision optic that contains a variety of lens systems that can be fitted with different objectives, enabling measurements with different resolution.