Displacement and Position Sensing

LINEAR DISPLACEMENT

Motion control systems typically require a sensor in a feedback loop to ensure that the moving member or component reaches its commanded position. Position sensors are typically used on machine-tool controls, elevators, liquid-level assemblies, forklift trucks, automobile throttle controls, and numerous other applications. Position sensors measure either absolute or incremental displacement, and are made with a variety of different materials. Also, when the sensor's power fails, some retain the measured position data, and other types lose the information.

One common device is a resistive position sensor or potentiometer. It may be a single-turn or a multi-turn rotary sensor with an element made of carbon or any one of a number of more durable, high-temperature, conductive-plastic film materials. Some types of potentiometers connect to the moving member through a rigid or flexible coupling while others are actuated with a string wrapped around its output shaft. Yet other position sensors include LVDT's (linear variable differential transformers), sonically operated devices, and digital encoders.

String-Potentiometer Transducers

String-type potentiometers are basically rotational devices that typically measure linear motion as shown in Figure 9.01. Because a cable connects between the moving member and the potentiometer, the cable must be preloaded with a spring, have a low coefficient of expansion under wide ranges of temperature (-65 to +125˚C), and have little tendency to stretch. Because of these constraints, its accuracy is somewhat less than that of a more rigid, shaft-coupled sensor.

Most modern potentiometers are extremely linear and are made with special alloys or precious metal wipers and conductive plastic resistive elements to withstand as many as 100 million revolutions. They are usually part of a voltage divider and provide an output voltage proportional to displacement, but they may also drive analog-to-digital converters to feed microprocessor-based instruments directly. However, when digital outputs are needed, a more common practice uses digital encoders that inherently supply higher accuracy.

String-Potentiometer Position Sensor

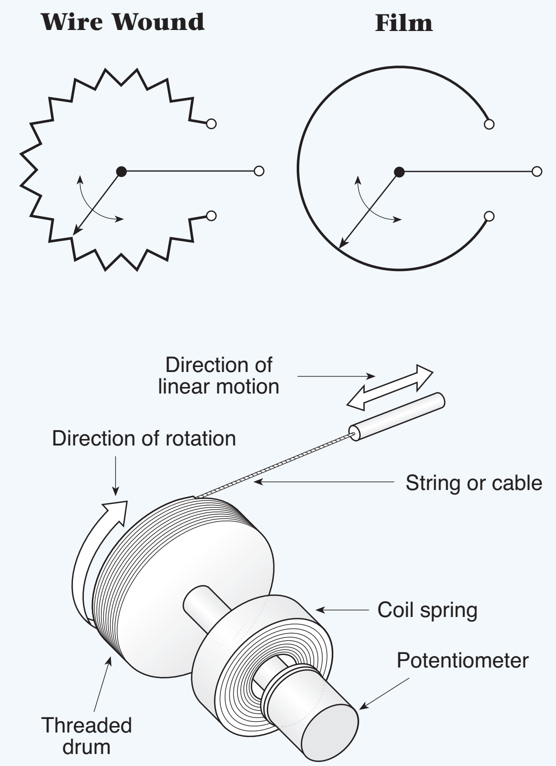


Fig. 9.01. *String potentiometers occupy relatively little overall space in a machine installation or device under test. In some applications where a sensor cannot be mounted on the device being measured, the potentiometer may be conveniently located some distance from the test bed without sacrificing accuracy or repeatability.*

LVDT: Linear Variable Differential Transformers

LVDTs are electronic devices comprised of a special transformer with a movable metal actuator in its hollow-core. The transformer contains two differentially wound secondary windings on either side of a primary winding. As the actuator in the core moves in and out, it couples

Measurement Computing • 10 Commerce Way • Norton, MA 02766 • (508) 946-5100 • info@mccdaq.com • mccdaq.com

LVDT Position Sensor

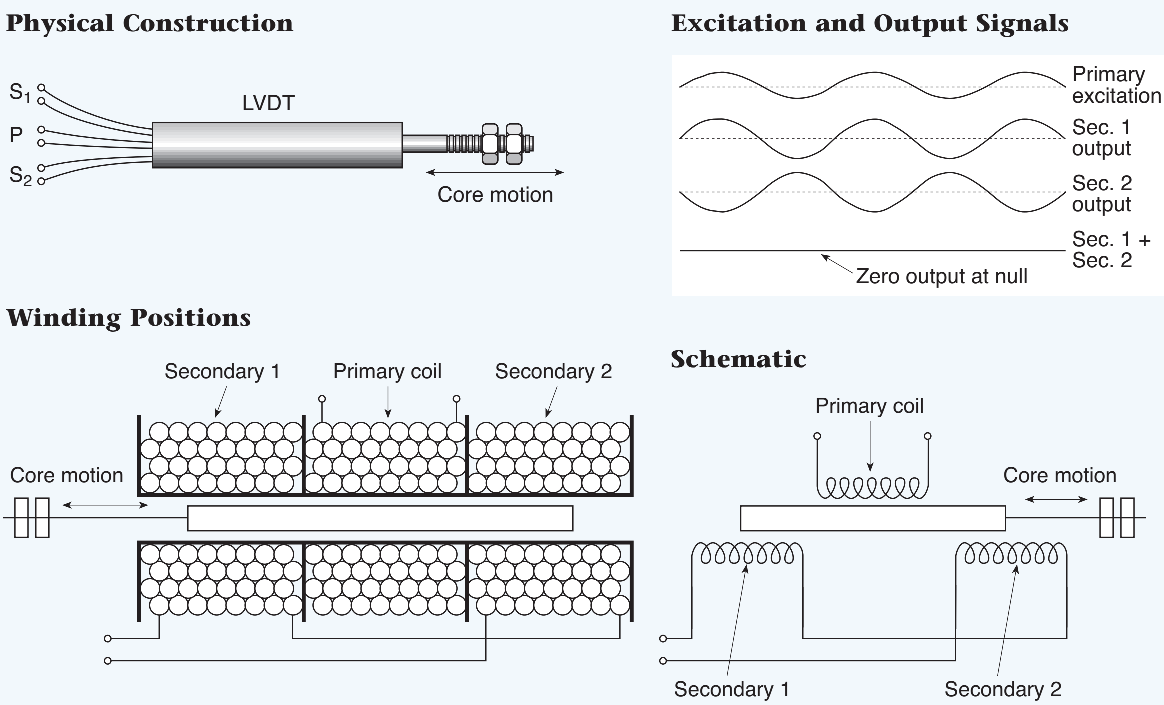


Fig. 9.02. *LVDT sensors provide distance and direction information with extremely high accuracy. But a drawback for some installations is their relatively long length. The minimum length of the sensor is its body, and the core can extend only as far as the length of the body.*

Magnetostrictive Position Sensor

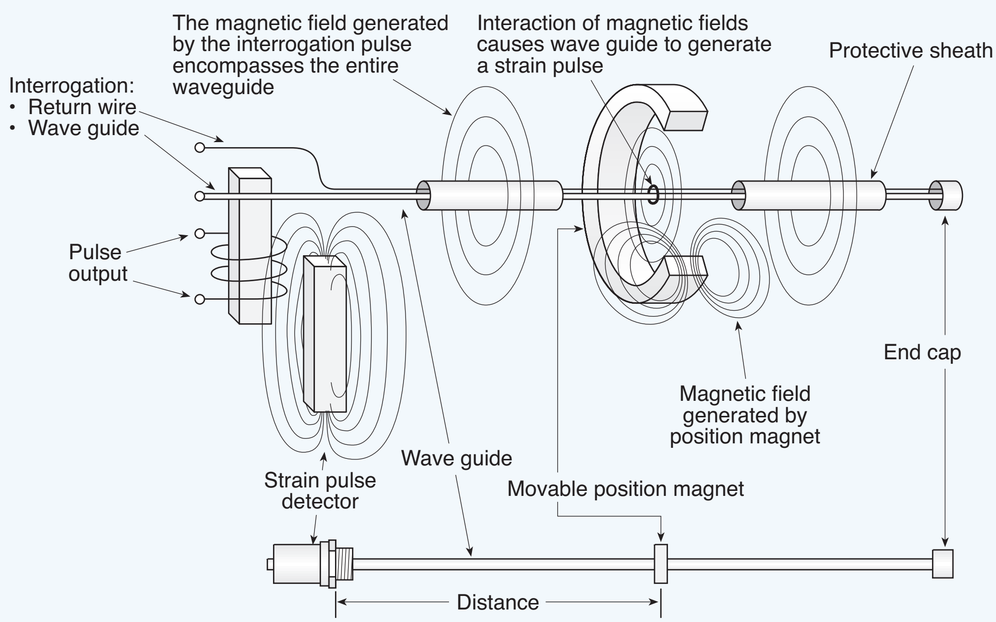


Fig. 9.03. *Magnetostrictive position sensors have a high signal-to-noise ratio, shock and vibration resistance, and accuracy. They are rugged devices that deliver from 30 to 400 mV signals at their output terminals and require little or no additional signal conditioning. A possible disadvantage for some applications, however, is its wave-guide, which must be at least as long as the measured stroke.*

Two-Channel Linear Position Encoder

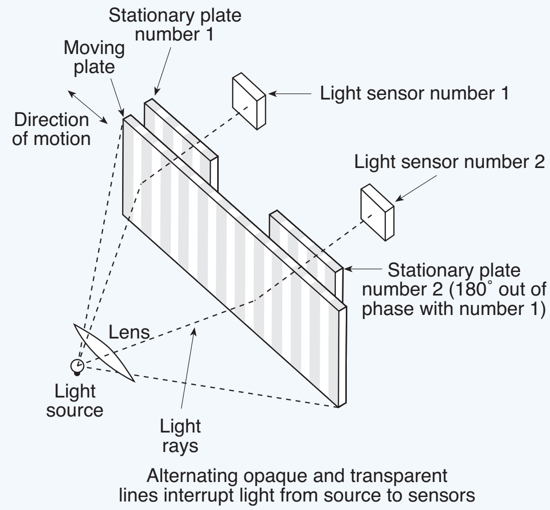


Fig. 9.04. *Two-channel encoders provide step and direction vectors with an output signal that can be a sinewave, squarewave, or a series of equally spaced pulses generated at regular intervals on the waveform.*

Rack and Pinion Encoder Assembly

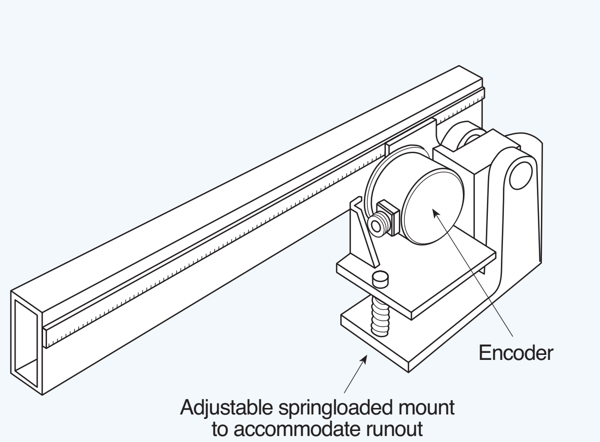


Fig. 9.05. *A rack and pinion sensor assembly should have a flexible mount to compensate the combined runout error. In a machine application, the sensor should be protected from metal chips and other foreign objects to ensure measurement accuracy.*

a signal from primary to secondary in proportion to the displacement. Being differentially wound, LVDTs also can provide directional signals with the appropriate signal conditioning circuits. With the actuator at the center position, the output signal is null or zero. As the actuator moves out in one direction, the signal is positive, and when it moves in the opposite direction from null, the signal is negative. (See Figure 9.02.)

LVDTs require electronic circuits to provide an ac signal to excite the primary and a demodulator to convert the output to a dc signal with directional polarity. Some LVDTs contain the electronics onboard and only require power to obtain an output, while others require separate signal conditioners or modules. The LVDTs themselves are rugged devices and have a MTBF of as much as 3 million hours. The main limitation is the displacement range of the core to ensure high linearity.

Ultrasonic Sensors

Another relatively new type of position sensor is based on the theory of operation of the interaction of two magnetic fields on magnetostrictive materials. The major components of the sensor include an external permanent magnet, integral sensing and output signal conditioning circuits, a sensor tube, and a wave-guide element. The permanent magnet fastens to the movable object, and the housing remains attached to a stationary reference point. (See Figure 9.03.)

The output signal conditioning circuit generates a current pulse and magnetic field which travel down the waveguide. When the transmitted field reaches the permanent magnet field, the combination induces a strain pulse in the magnetostrictive tube. The strain pulse, in turn, travels down the waveguide to the head of the sensor where it is detected. The time measured between the application of the interrogation pulse and the arrival of the strain pulse determines the precise, absolute distance between the movable magnet and the pulse generator. Resolution is about 0.002 mm, durability is high, and the stroke ranges from 5 to 20,000 mm. Higher resolutions require additional interpolating circuits. The output signal, which is proportional to displacement, can be either analog or digital, and it can represent both position and velocity.

Absolute Contact Encoder Disc

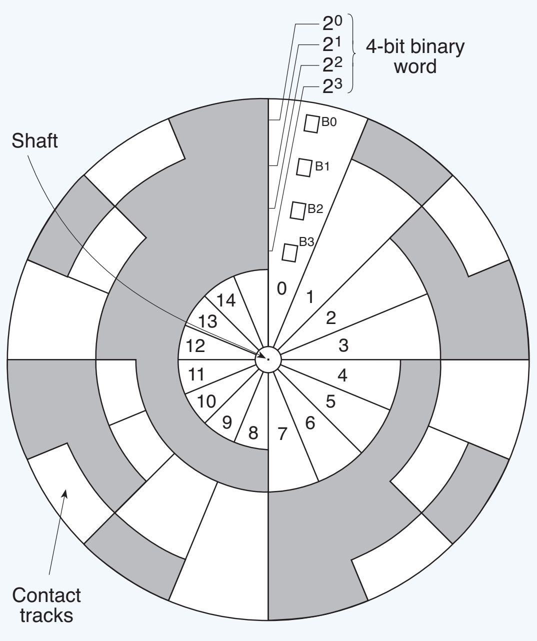


Fig. 9.06. *The disc pattern on the contacting encoder is a digital word, which represents the absolute position of the encoder shaft.*

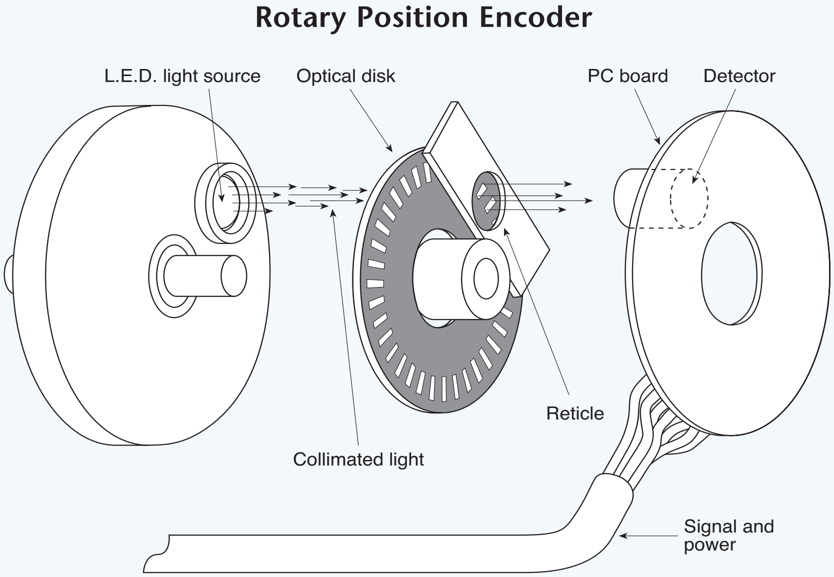


Fig. 9.07. *The shutter is one of the most critical components of the encoder assembly. The sensor's resolution and accuracy hinge on the quality of the vendor's manufacturing and assembly processes.*

Linear Encoders

Linear encoders have evolved over the years to provide extremely accurate position information. Their principle of operation depends upon sensing position from precision graduations (position codes) etched on a linear scale. They come in both contacting and non-contacting types, and their length is primarily limited to their temperature-sensitive coefficient of expansion to preserve accuracy. Most modern scales are glass, and optical sensors detect the graduations. (See Figure 9.04.) The benefit of a non-contacting type is typically longer life because it uses optical components instead of brushes or a contacting wiper. All optical encoders contain a light source, light detector, code wheel or scale, and signal processor.

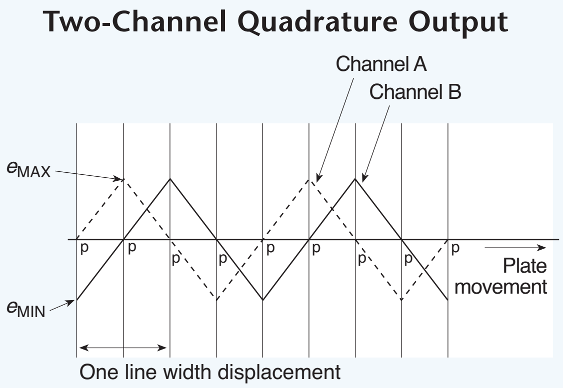


Fig. 9.08. *The two light sensors in a dual channel linear position encoder are connected in a push-pull configuration and track one another, so equal changes in the input produce equal changes in the output.*

ROTATIONAL POSITION

Rotational position may be measured with potentiometers, coupled to a rack and pinion assembly or gear trains to obtain a suitable ratio of potentiometer revolutions to measured component rotation or movement. (See Figure 9.05) Potentiometers commonly come in single turn to as many as 25 turns and fit numerous applications. But, most rotational measurements, whether they are velocity, rpm, or position, are best handled with digital encoders. Like linear encoders, several types have been used over the years including both contacting (see Figure 9.06) and non-contacting. They contain a disc (code wheel) or a plate made with alternating opaque and transparent segments that move between a light source such as an LED, and a photo-detector. (See Figure 9.07.)

Absolute Encoders

Absolute encoders typically contain several detectors and slots on a revolving wheel to provide a unique output binary code for each shaft position within its range of resolution. Therefore, the shaft position can be determined absolutely. Moreover, the correct position is always retained before and after a power failure. The tracks on the encoder wheel may be arranged to provide a 0.5 bit maximum error. Absolute encoders come in single and multi-turn versions.

Incremental Encoders

Incremental encoders usually provide two channels of square wave output signals. Each pulse represents an increment of rotation of relative position. These encoders often contain a third slot called the reference slot used to calibrate the encoder. Dual channel encoders are more accurate than single channel types. They register direction, and when a code wheel stops on the edge of a slot, incident vibrations cannot generate an error count, as it does for single-channel sensors.

Misalignment Error in Glass Scales

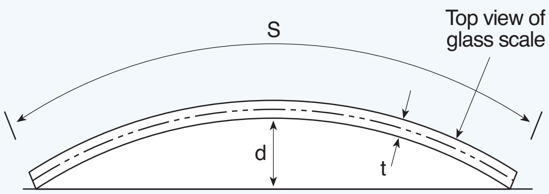


Fig. 9.09. *The top view of an exaggerated bow in linear scale illustrates the errors that could undermine measurement accuracy. The error in this case is proportional to the displacement "d."*

Quadrature Encoders

The two channels, A and B, of a dual output incremental encoder are usually displaced by 90 degrees from each other. Therefore, the spacing between pulses is one-half the line width. When the disc contains 1024 lines and 1024 spaces, the sensor generates 4 x 1024 = 4096 pulses per revolution; hence the output signals are delivered in quadrature. (See Figure 9.08.) The angular movement in this arrangement resolves to 5.27 minutes of arc.

Signal conditioning circuits generate the output signal waveform and complementary signals, sense their direction, and filter the output. The amplitude of the input voltage controls two stable output states of a shaper circuit. The shaper output feeds several gates, which in turn generate the pulses that mark the encoder's zero-signal crossings. The circuits also sense whether channel A leads or lags channel B to provide direction information.

Errors

Encoder manufacturers endeavor to minimize device errors, but users must be concerned with total system errors. Encoder errors consist of instrument and quantization errors, as well as manufacturing and assembly errors. For example, the light sources must be closely matched and the code wheel must have low disc eccentricity.

Encoder error is relatively easy to quantify, whereas total error depends upon each application and is a little more difficult to pin down. Several sources contribute to total error, including manufacturing and assembly tolerances, LED characteristics, scale and disc alignment, and power supply stability. Others include electrical interference, temperature variations, mechanical coupling, and mechanical vibration.

In some cases, encoder misalignment errors can be calculated. For example, a linear sensor often incorporates a glass scale to sense linear displacement. When the scale is bent or bowed, the curvature introduces an error that is proportional to the displacement d, as shown in Figure 9.09. When d is small relative to S, the concave surface of the scale is shortened by Δ, and the convex surface is elongated by Δ, where $\Delta = 4td/S$.

For example, when:

S = 8 in.
t = 0.20 in.
d = 0.0010 in,
then:
$\Delta = (4 \times 0.20 \times 0.0010)/8 = 0.0001$ in.

Lines etched on the convex side produce an error of +0.0001 in., and lines on the opposite side produce an error of -0.0001 in./foot.

Power supply stability and freedom from electrical interference are critical requirements for encoders. Both anomalies can produce intermittent and random operation, which are frequently difficult to diagnose.

Temperature has minimal influence on today's encoder electronics, although the maximum operating temperature at rated power for LEDs is 150˚F compared to 200˚F for incandescent lamps. But LEDs have more than double the expected life of lamps, and they work with superior signal conditioning circuits, so they are used almost exclusively. Temperature fluctuations affect linear glass scales more significantly. For example, a ±150˚F temperature change can produce an error of ±0.0008 in./ft.

The mechanical coupling to the moving member should suit the application, considering axial and radial loads, acceleration, velocity, vibration, accuracy, and resolution. The proper coupling reduces errors and increases the encoder's life.

Measurement Computing • 10 Commerce Way • Norton, MA 02766 • (508) 946-5100 • info@mccdaq.com • mccdaq.com

Data Acquisition Solutions

QUADRATURE ENCODER MODULE

USB-QUAD08

- 8 channels
- 10-MHz counters, ±12V input range
- Programmable debounce times
- 8 digital I/O lines, 42.4 Vpk/50 VDC max
- Two timer outputs
- 16-, 32-, 48-bit resolution
- Included software and drivers

HIGH-SPEED MULTIFUNCTION MODULES

USB-1616HS Series

- 1 MS/s sampling
- Measure voltage of thermocouples
- 16-bit resolution
- Up to 64 analog inputs
- 24 digital I/O, 4 counters/timers
- Up to 4 analog outputs
- Included software and drivers

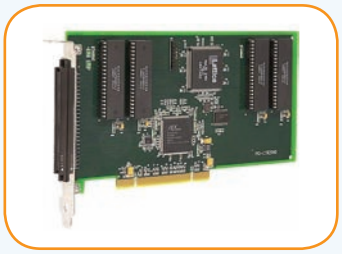
COUNTER/TIMER BOARDS AND MODULES

USB-4300 Series

- 5 or 10 channels
- Input frequencies up to 20 MS/s
- Event counting, PWM, duty cycle generation, frequency measurement/division, and more
- 16 digital I/O
- Included software and drivers

COUNTER/TIMER BOARDS

PCI-CTR Series



- 5, 10, or 20 channel
- Digital I/O
- 9513 based
- Included software and drivers

Measurement Computing • 10 Commerce Way • Norton, MA 02766 • (508) 946-5100 • info@mccdaq.com • mccdaq.com