Mechatronics
Sensors, transducers, and transmitters

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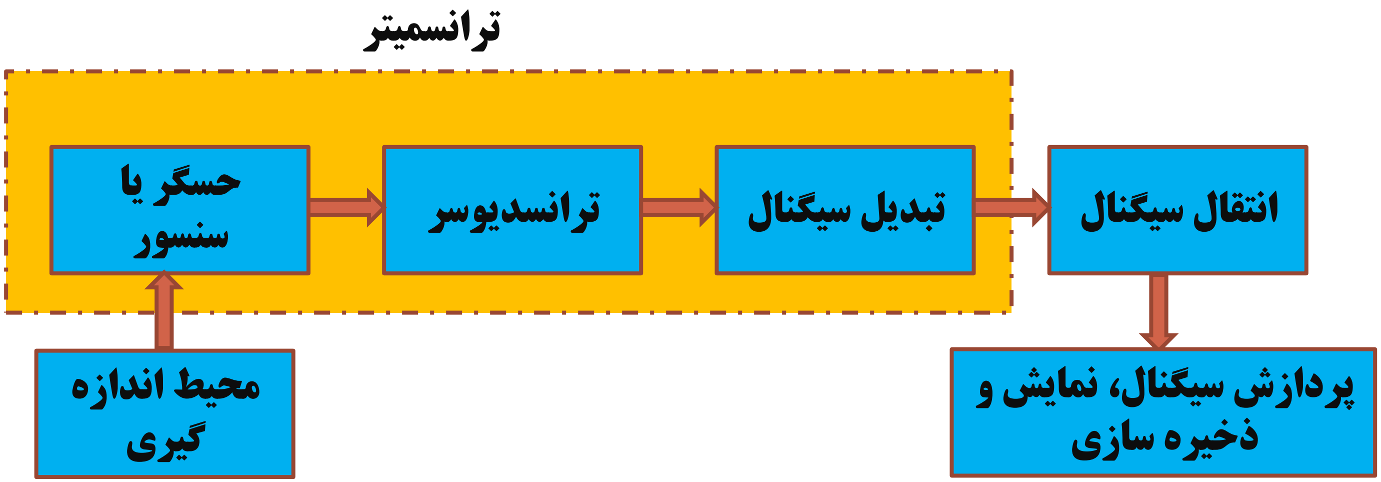
Sensors, transducers, and transmitters

ساختار کلی یک سیستم اندازه گیری



محیط اندازه گیری: محیطی است که پارامتر فیزیکی قابل اندازه گیری مانند دما، فشار و غیره در آن قرار دارد.

Sensors, transducers, and transmitters

حسگر اولیه (سنسور): قطعه ای است که در اثر شدت پارامتر فیزیکی از خود عکس العمل نشان می دهد و ما می توانیم در اثر آن به شدت پارامتر فیزیکی پی ببریم. خروجی آن می تواند انرژی الکتریکی یا دیگر صورت های انرژی باشد.

ترانسدیوسر (transducer): ترانسدیوسر یا مبدل، خروجی سنسور را دریافت کرده و آن را تبدیل به معمولاً سیگنال الکتریکی می کند. به عبارت دیگر، ترانسدیوسر انرژی را از صورتی به صورت دیگر تبدیل می کند.

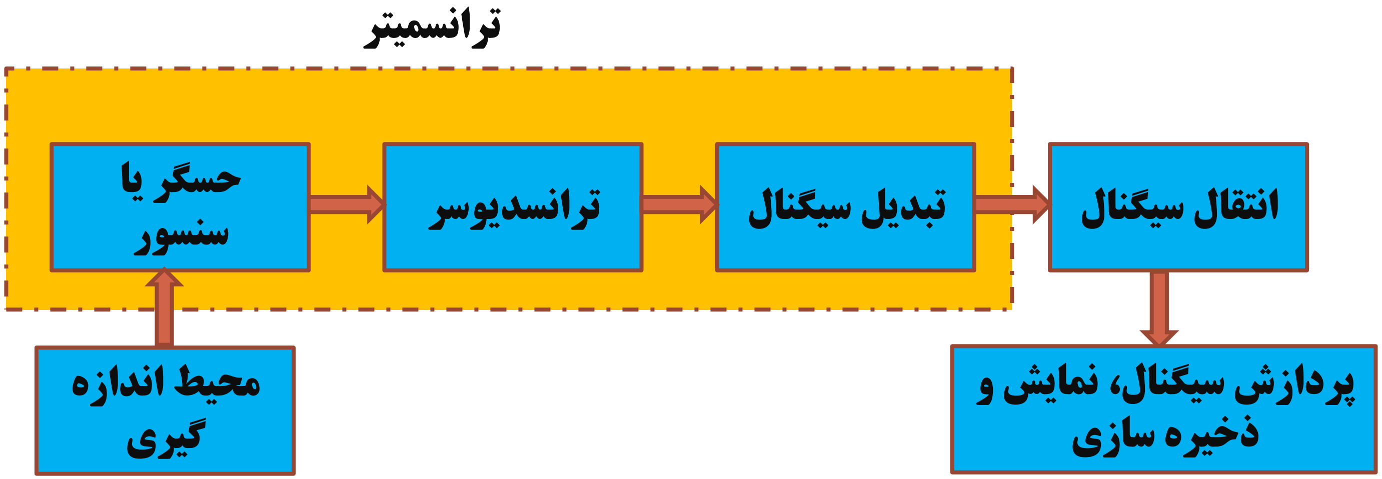
Sensors, transducers, and transmitters

تبدیل سیگنال: در تبدیل سیگنال، خروجی ترانسدیوسرها به صورت استاندارد تبدیل می شود. این قسمت شامل
تقویت کننده ها، انواع فیلترها، مبدل های آنالوگ به دیجیتال و غیره می باشد. معمولاً خروجی این قسمت به صورتهای
۰ الی ۵ ولت، ۰ الی ۱۰ ولت، ۴ الی ۲۰ میلی آمپر و ۳ الی ۱۵ PSI است.

انتقال سیگنال: در مواردیکه محل پردازش سیگنال از محیط اندازه گیری دور باشد، خروجی قسمت تبدیل سیگنال را توسط
قسمت انتقال سیگنال به آن محل انتقال می دهیم. انتقال سیگنال شامل کابل ها و سیم های عایق بندی شده، فیبرهای
نوری و لوله های هوا می تواند باشد.

Sensors, transducers, and transmitters

پردازش سیگنال، نمایش و ذخیره سازی: با استفاده از این قسمت، سیگنال های اندازه گیری شده مورد پردازش
قرار می گیرند و برای استفاده های بعدی ذخیره سازی می شوند. همچنین این قسمت شامل نمایش پارامتر اندازه گیری نیز می باشد.



Static & Dynamic characteristics

The performance characteristics of an instrument are mainly divided into two categories:

i) Static characteristics
ii) Dynamic characteristics

Static characteristics:

The set of criteria defined for the instruments, which are used to measure the quantities which are slowly varying with time or mostly constant, i.e., do not vary with time, is called 'static characteristics'.

i) Accuracy ii) Precision iii) Resolution iv) Linearity

Dynamic characteristics

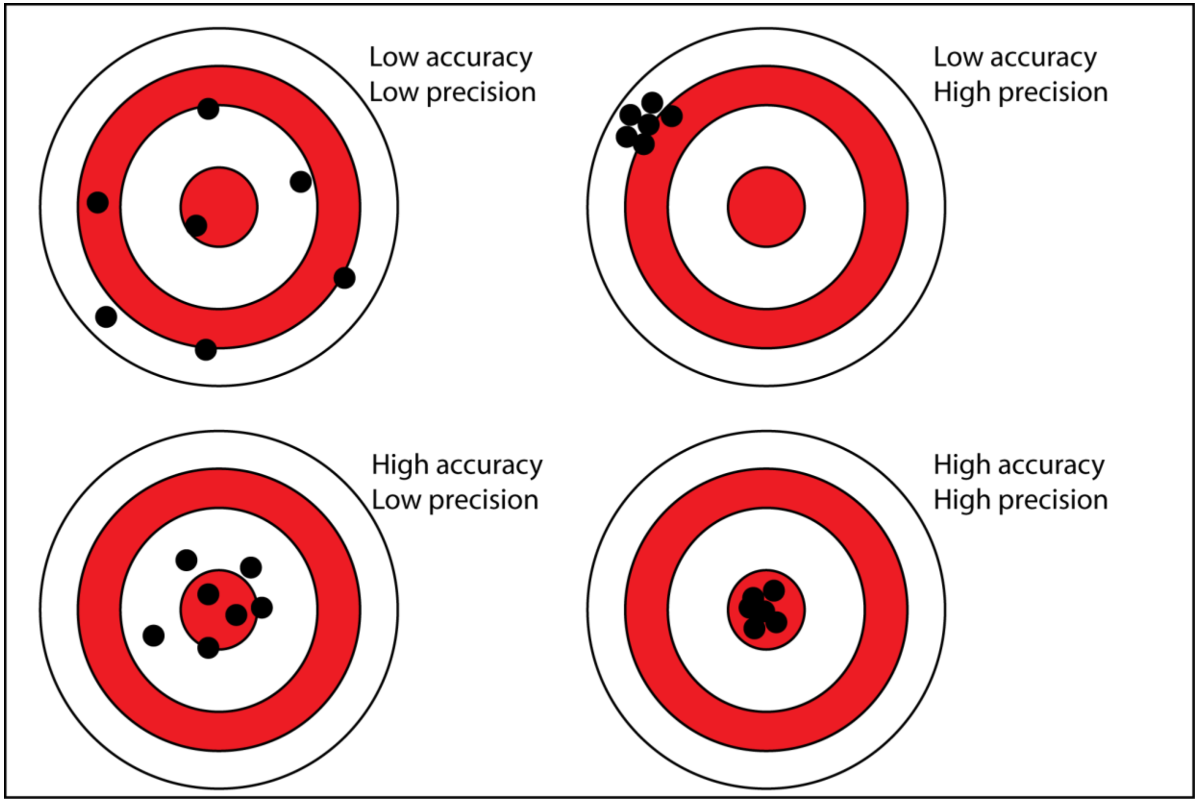
The set of criteria defined for the instruments, which are changes rapidly with time, is called ‘dynamic characteristics’.

i) Speed of response
ii) Measuring lag
iii) Dynamic error

Static Ch. Accuracy vs. Precision

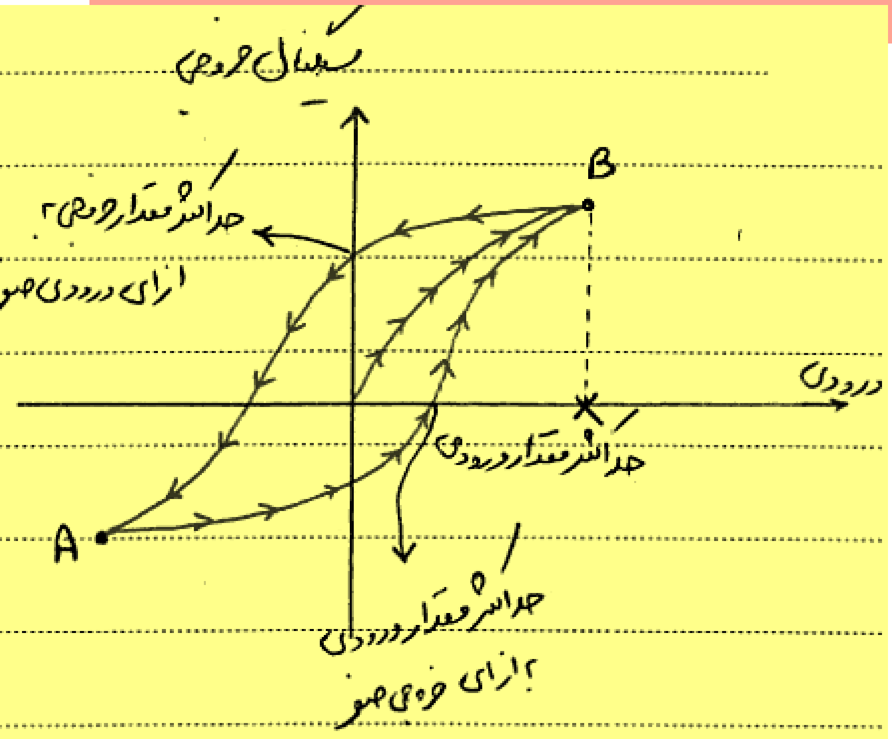
Accuracy **(صحت یا درستی)**

Precision **(دقت)**



Hysteresis

پس ماند یا هیسترزیس: در صورتی که مقدار خروجی یک ترانسدیوسر به ازای یک ورودی معین، تابعی از جهت رو به افزایش یا رو به کاهش ورودی باشد، مبدل دارای پسماند یا هیسترزیس است.



در نمودار هیسترزیس مقابل ملاحظه می‌شود که به ازای هر ورودی، دو خروجی داریم که این دو خروجی را با هم جمع می‌کنیم و بر ۲ تقسیم می‌کنیم تا مبدل را خطی کنیم و هیسترزیس را حذف کنیم

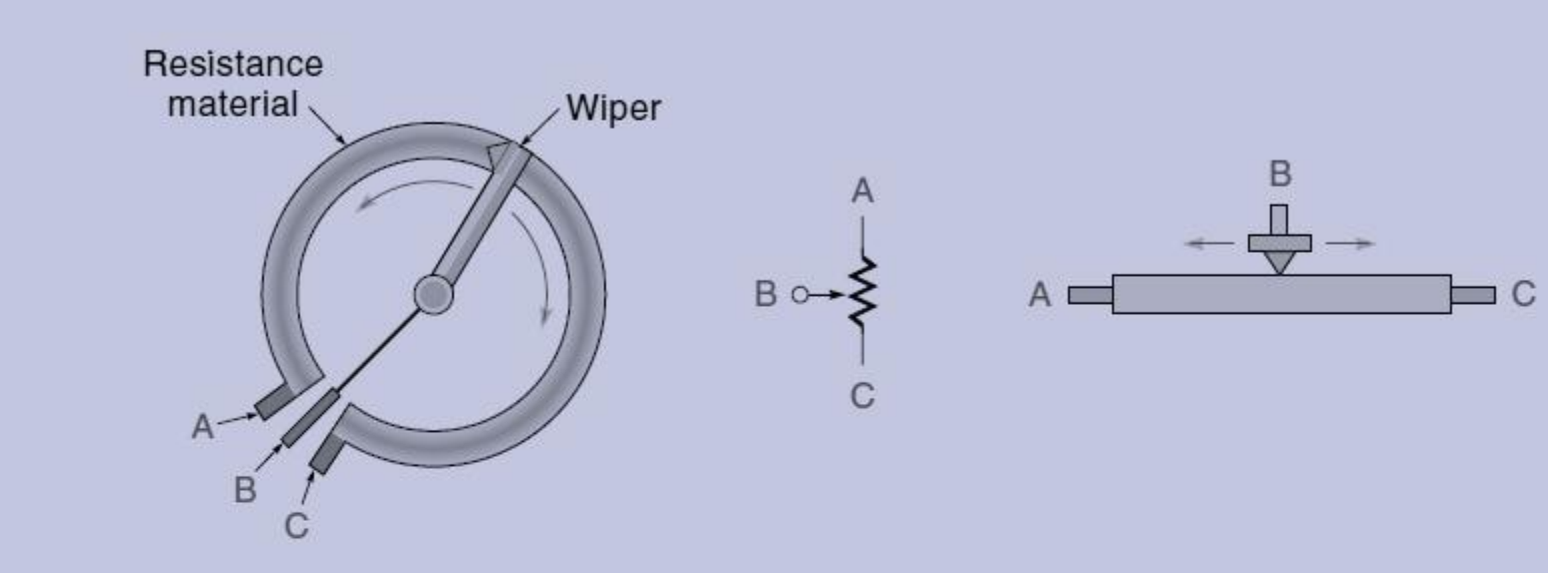
Position Sensors

Position sensors report the physical position of an object with respect to a reference point. The information can be an angle, as in how many degrees a radar dish has turned, or linear, as in how many inches a robot arm has extended.

1- Potentiometers
2- Optical rotary encoders
3- Linear variable differential transformers

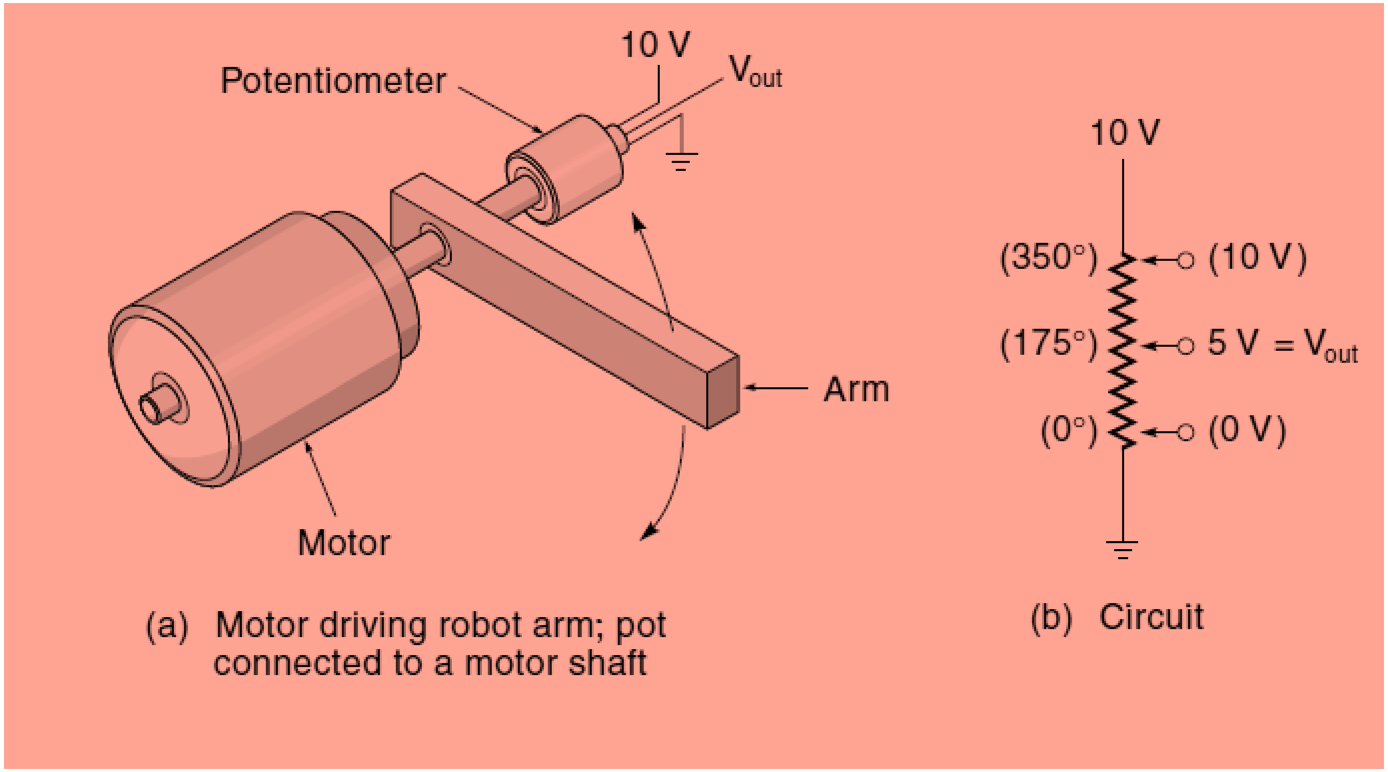
Potentiometers

A **potentiometer** (pot) can be used to convert rotary or linear displacement to a voltage.



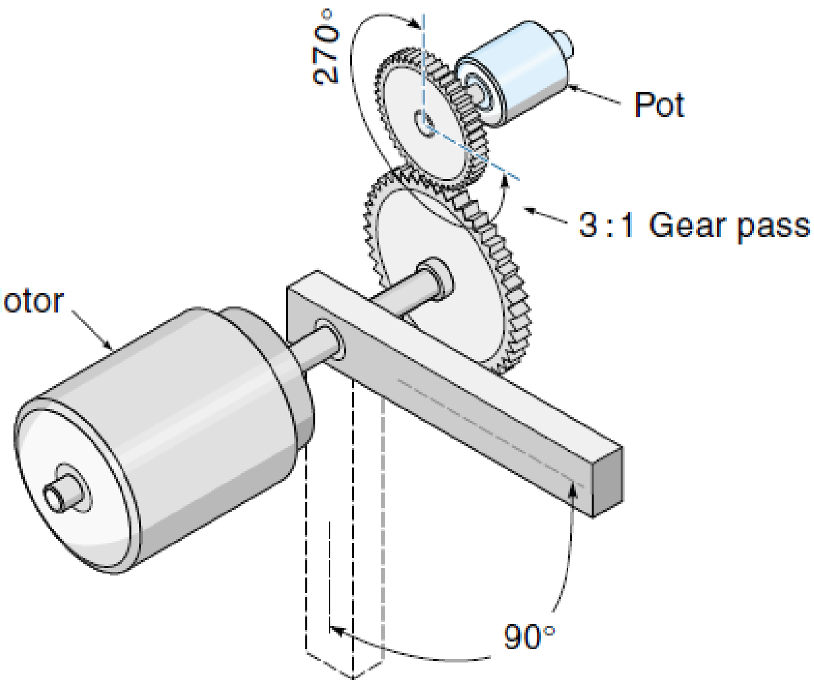
(a) Rotary pot (b) Symbol (c) Linear-motion pot

Potentiometers



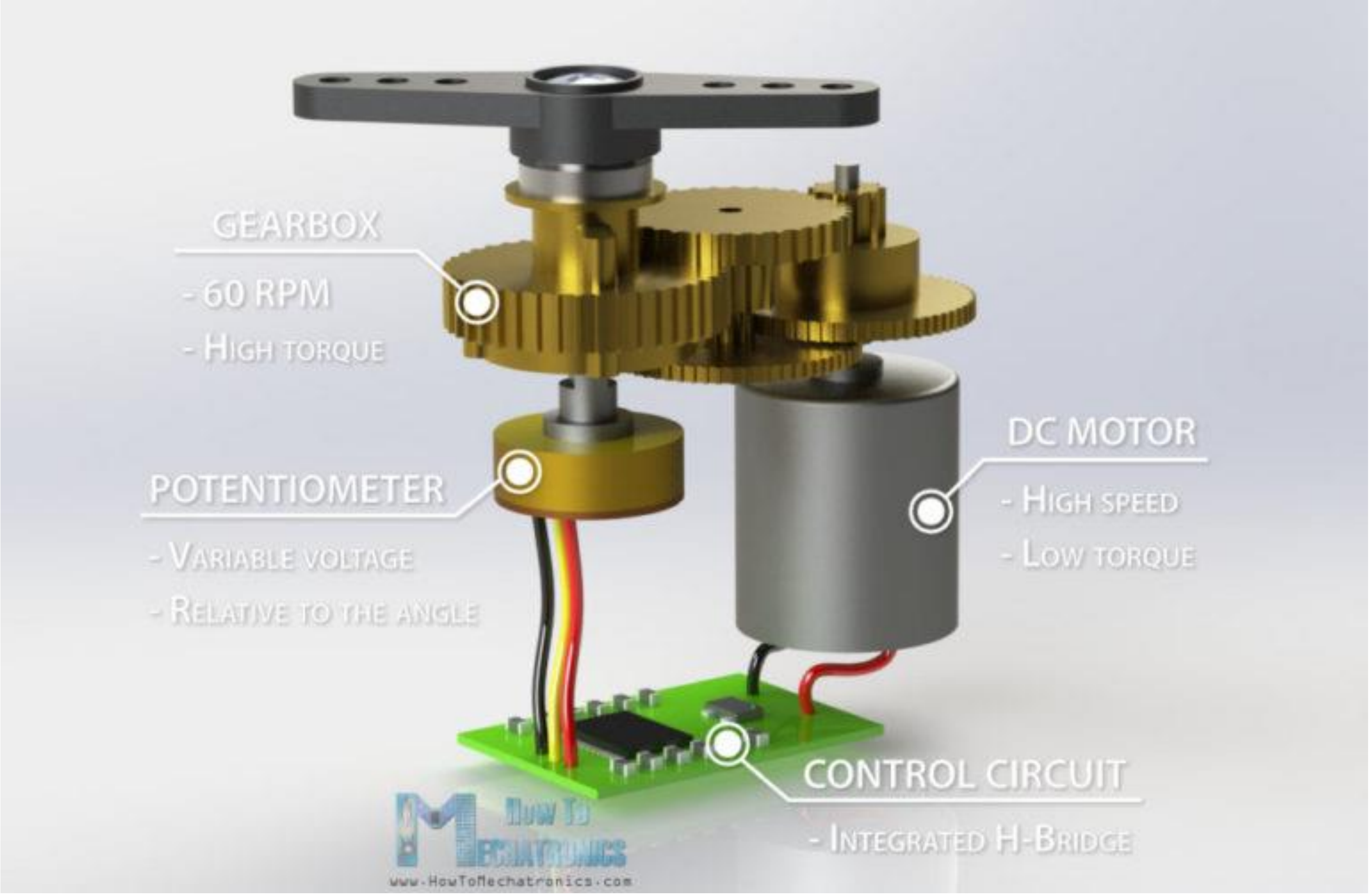
When the wiper is at the top, the output is 10 V corresponding to 350°; in the exact middle, a 5-V output indicates 175° (350°/2 = 175°).

Average error decrease using Gearbox



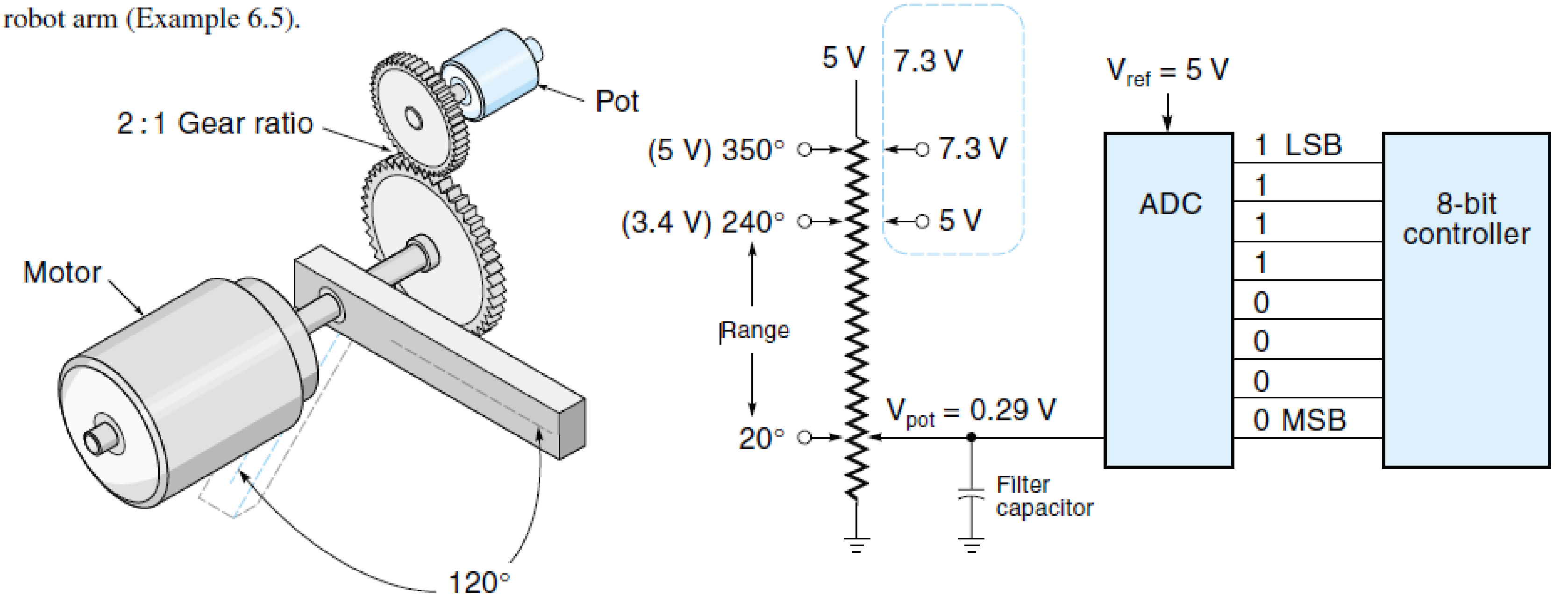
Using as much of the pot's range as possible in order to get a lower average error rate.

Experimental POT for control



POT for a digital feedback control

Figure 6.7
Pot sensor position system for robot arm (Example 6.5).



(a) Hardware setup

(b) Sensor circuit

$$\underbrace{\frac{1^\circ_{arm}}{2^\circ_{pot}}}_{\text{Gears}} \times \underbrace{\frac{350^\circ_{pot}}{5\text{ V}}}_{\text{Pot}} \times \underbrace{\frac{5\text{ V}}{255\text{ states}}}_{\text{ADC}} = \frac{0.686^\circ_{arm}}{\text{state}}$$

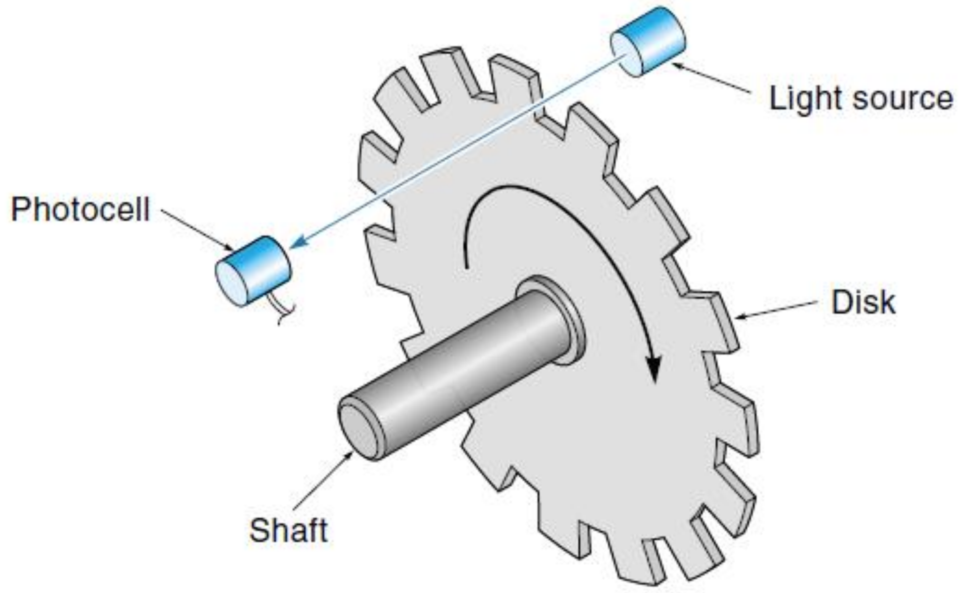
$$\frac{1^\circ_{arm}}{2^\circ_{pot}} \times \frac{350^\circ}{7.3\text{ V}} \times \frac{5\text{ V}}{255\text{ states}} = 0.470^\circ/\text{state}$$

Potentiometer sensors

Linear Potentiometer Sensors

Optical Rotary Encoders

An **optical rotary encoder** produces angular position data directly in digital form, eliminating any need for the ADC converter.



The angle of the shaft is deduced from the output of the photocell

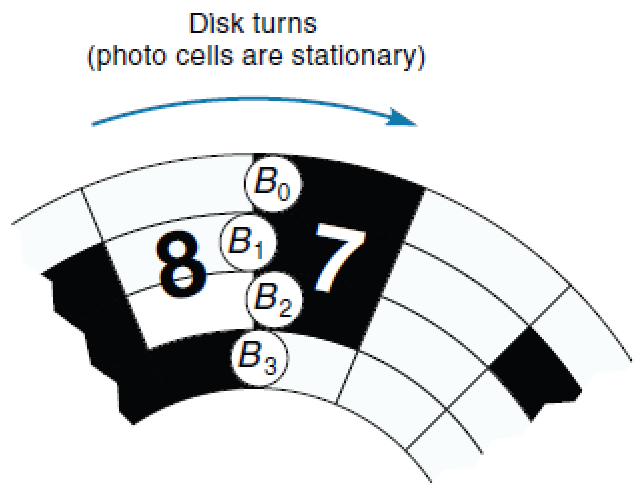
Optical Rotary Encoders

There are two types of optical rotary encoders: the absolute encoder and the incremental encoder:

absolute encoder's problem(binary)

Figure 6.9
An absolute optical
enc
stra

Figure 6.10
An absolute optical encoder showing how an out-of-alignment photocell can cause an erroneous state. (*Note:* Dark areas produce a 1, and light areas produce a 0.)

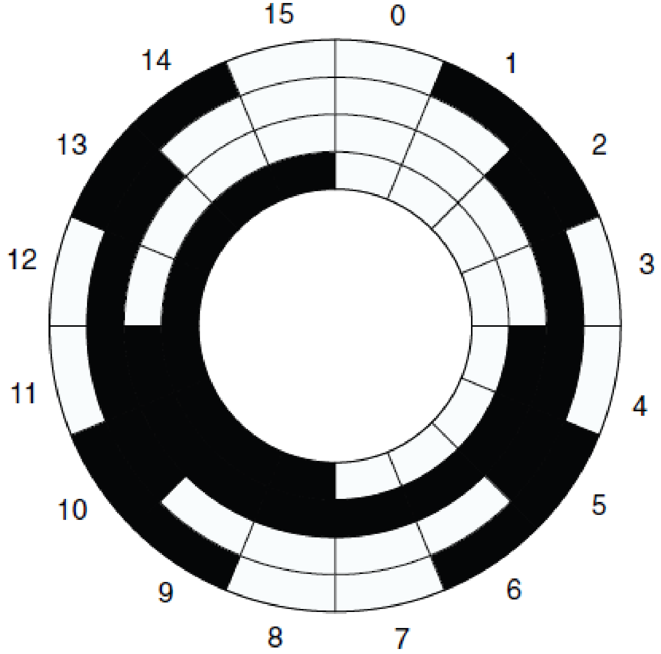


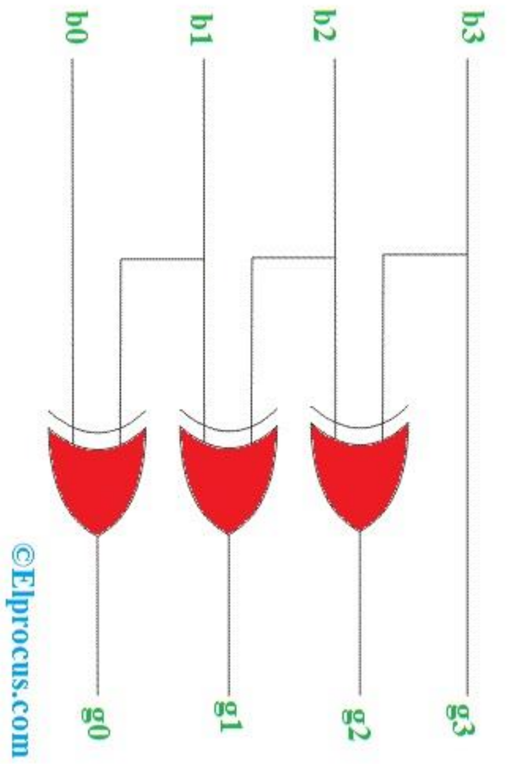
8	5	7	
0	1	1	B_0
0	0	1	B_1
0	1	1	B_2
1	0	0	B_3

Erroneous state

Optical Rotary Encoders:
absolute encoder: Grey coding

Figure 6.11
An absolute optical encoder using a grey code.

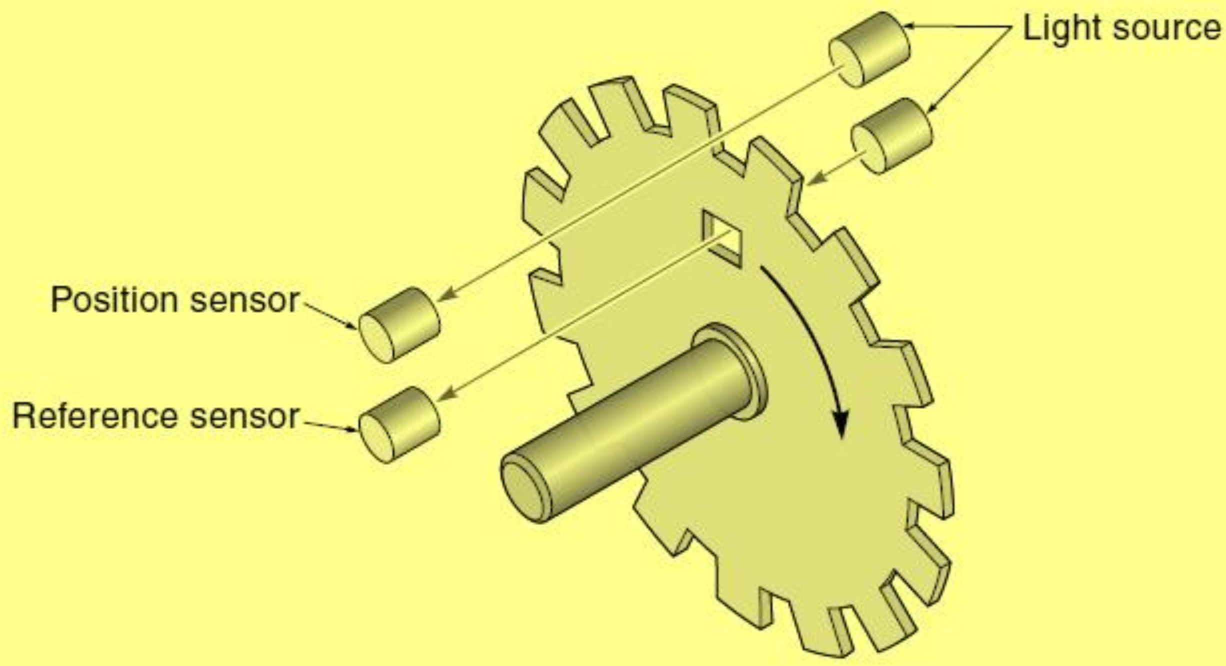




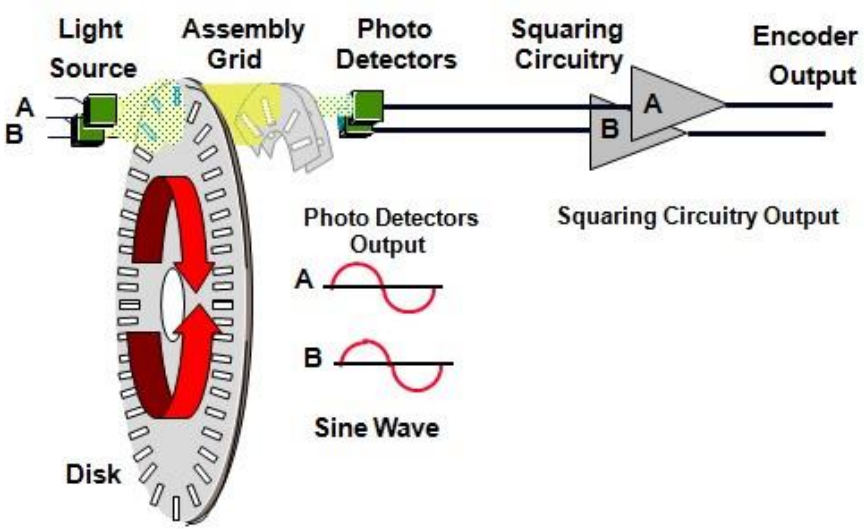
Incremental Optical Encoders

The **incremental optical encoder** has only one track of equally spaced slots. Position is determined by counting the number of slots that pass by a photo sensor, where each slot represents a known angle

Figure 6.12
An incremental optical encoder.



Optical Rotary Encoders

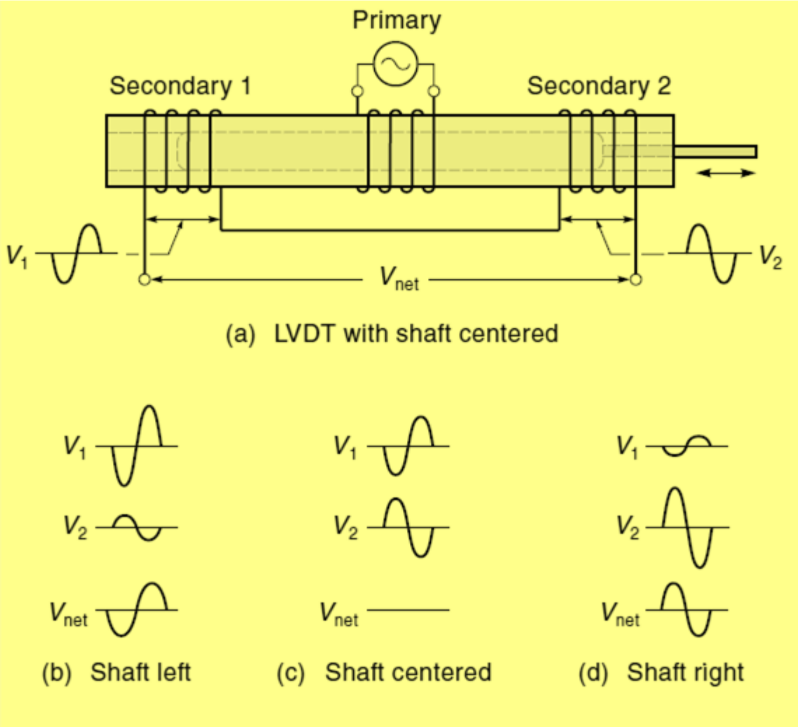


Linear Variable Differential Transformers

The **linear variable differential transformer** (LVDT) is a high-resolution position sensor that outputs an AC voltage with a magnitude proportional to linear position. It has a relatively short range of about 2 in., but it has the advantage of no sliding contacts

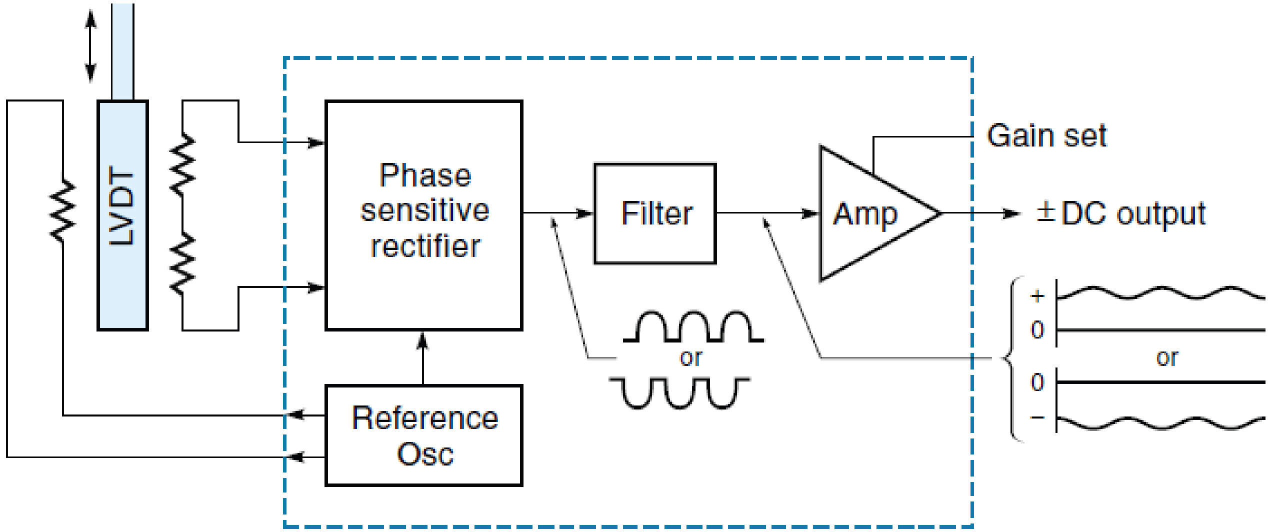
the output of the LVDT is an AC voltage with a magnitude and phase angle.

The magnitude represents the distance that the core is off center, and the phase angle represents the direction of the core (left or right.)



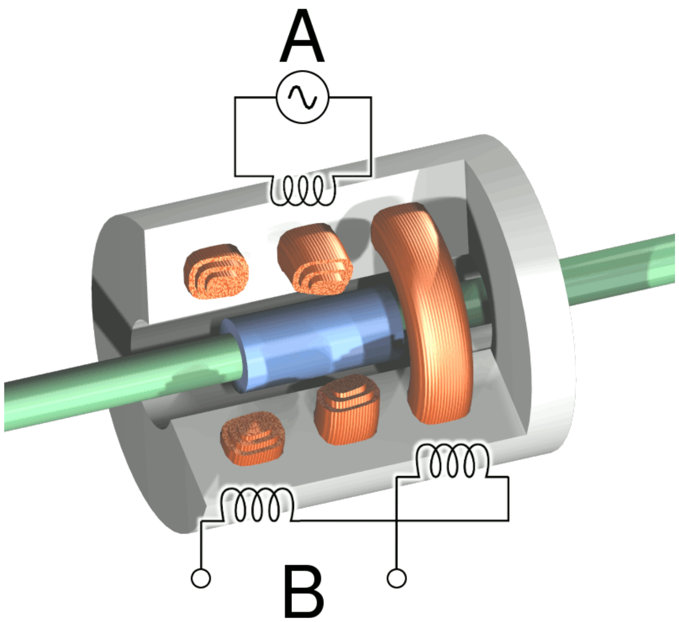
Interface Circuit for LVDT

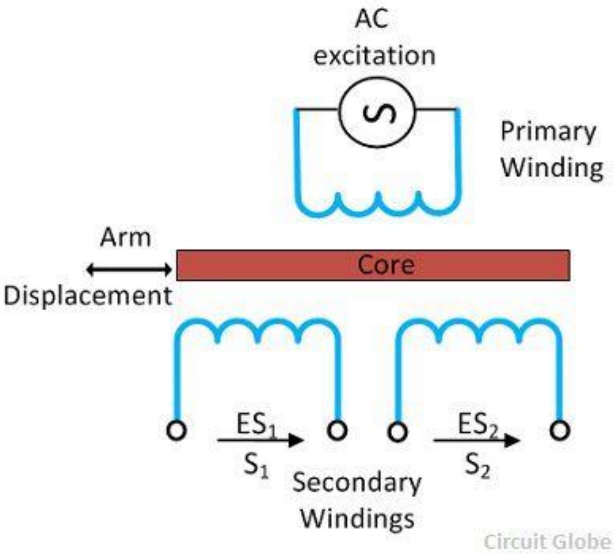
Figure 6.21
An interface circuit for an LVDT.



An **oscillator provides** the AC reference voltage to the primary—typically, 50-10 KHz at 10 V or less. The output of the LVDT goes first to a phase-sensitive rectifier. This circuit compares the phase of LVDT output with the reference voltage. If they are in phase, the rectifier outputs only the positive part of the signal. If they are out of phase, the rectifier outputs only the negative parts. Next, a low-pass filter smoothes out the rectified signal to produce DC. Finally, an amplifier adjusts the gain to the desired level. The output of the LVDT interface circuit is a DC voltage whose magnitude and polarity are proportional to the linear distance that the core is offset from the center.

Schematic for LVDT





ANGULAR VELOCITY SENSORS

Angular velocity sensors are devices that give an output proportional to angular velocity

If the system already has a position sensor, such as a potentiometer, using this approach eliminates the need for an additional (velocity) sensor

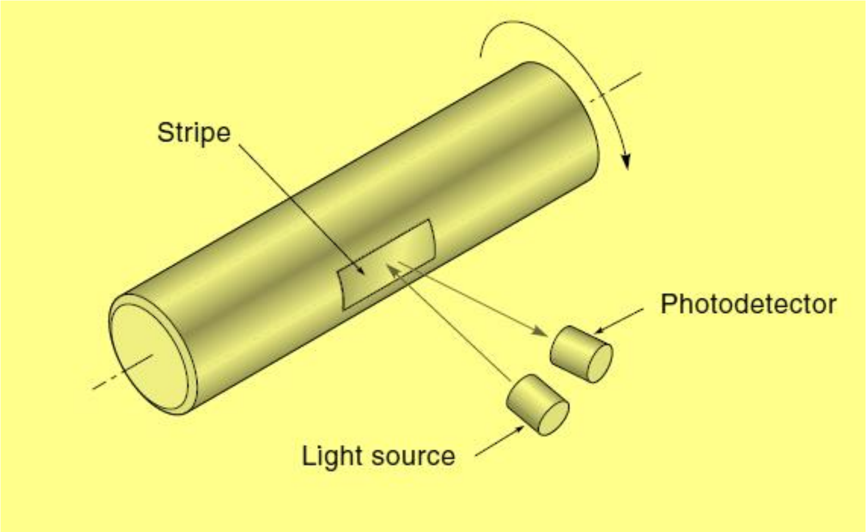
$$velocity = \frac{\Delta\theta}{\Delta t} = \frac{\theta_2 - \theta_1}{t_2 - t_1}$$

Velocity data can be derived from an optical rotary encoder, too.

Tachometers

The **optical tachometer,** a simple device, can determine a shaft speed in terms of revolutions per minute (rpm).

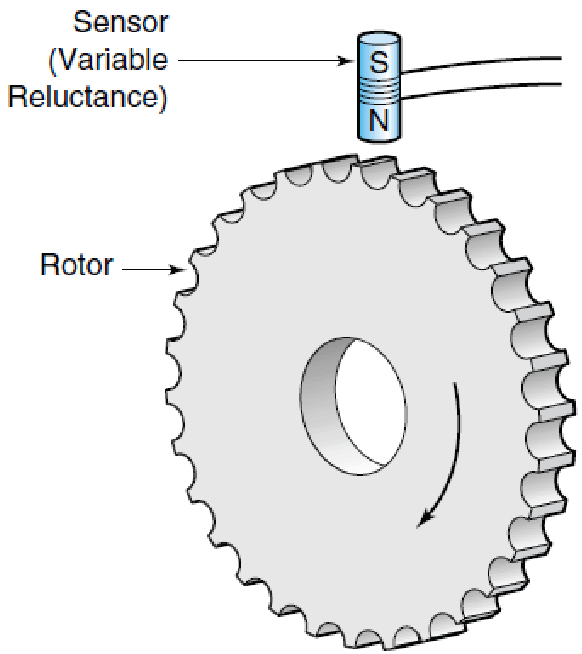
a contrasting stripe is placed on the shaft. A photo sensor is mounted in such a way as to output a pulse each time the stripe goes by. The period of this waveform is inversely proportional to the rpm of the shaft and can be measured using a counter circuit



optical tachometer

Toothed-Rotor Tachometers

A **toothed-rotor tachometer** consists of a stationary sensor and a rotating, toothed, iron-based wheel



The sensor generates a pulse each time a tooth passes by. The angular velocity of the wheel is proportional to the frequency of the pulses. For example, if the wheel had 20 teeth, then there would be 20 pulses per revolution.

Direct Current Tachometers

A **direct current tachometer** is essentially a DC generator that produces a DC output voltage proportional to shaft velocity. The output polarity is determined by the direction of rotation.

CK20 DC TACHOMETER

The model CK20 is a moving coil tachometer designed for use in applications requiring velocity feedback with minimum system inertia load.

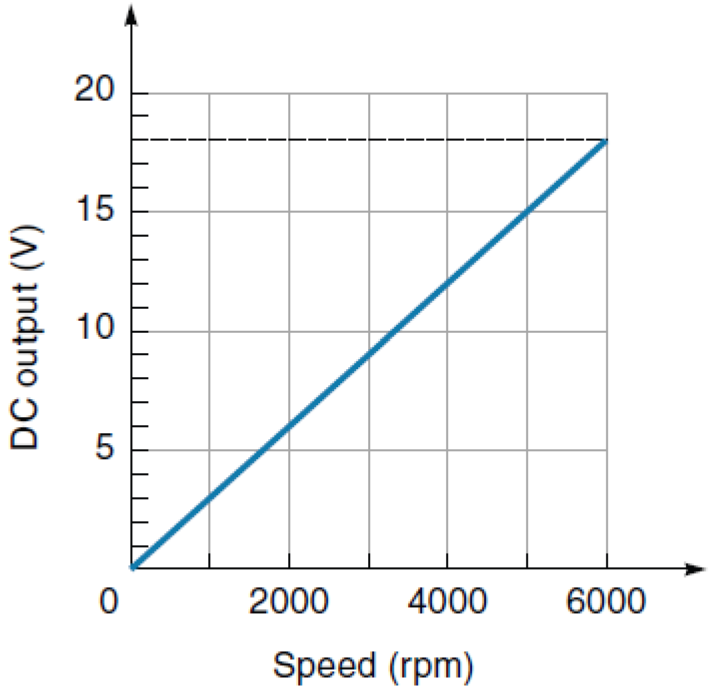
Parameter	Value	Units
Linerity	.2	% max. deviation
Ripple	1.5	max, % peak to peak AC
Ripple Frequency	19	Cycles per revolution
Speed Range	1-6000	RPM
Armature Inertia	9×10^{-4}	in-oz-sec^2
Friction Torque	.25	in-oz, max.
Rated Life	10,000	Hours at 3000 RPM

WINDING VARIATIONS

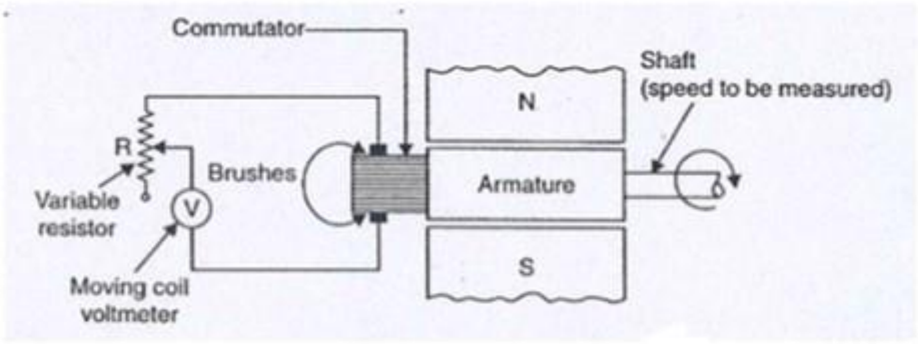
	CK20-A	CK20-B	CK20-C
Output Voltage Gradient (V/KRPM)	3.0	2.5	1

One can see that the CK20 comes in three models. For example, the CK20-A outputs 3 V for 1000 rpm
(3 V/Krpm). It has a speed range of 0-6000 rpm, so the maximum voltage would be
18 V at 6000 rpm.

Direct Current Tachometers

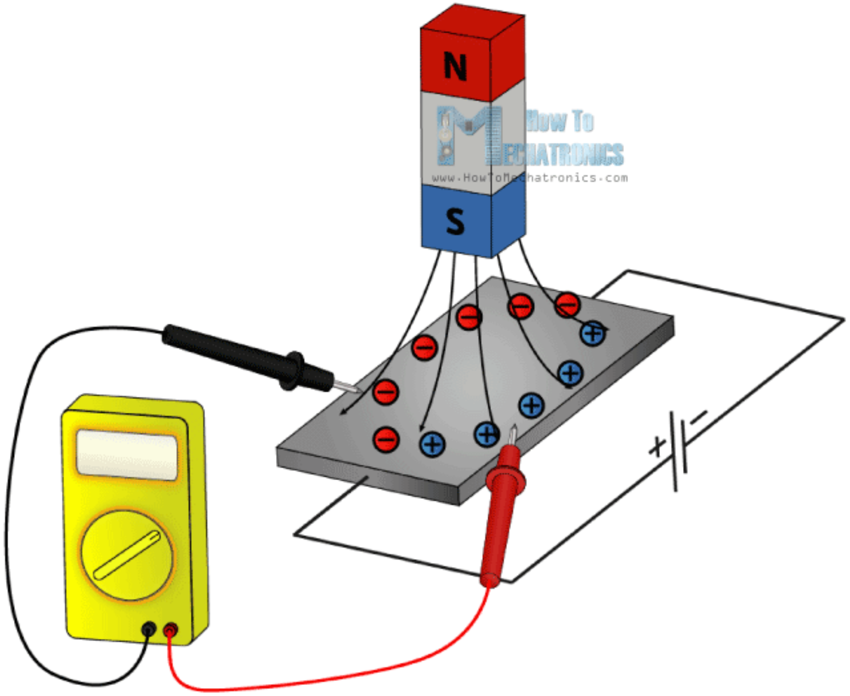


The polarity of the output voltage indicates the direction of rotation, which is a major advantage of using a DC tachometer generator.

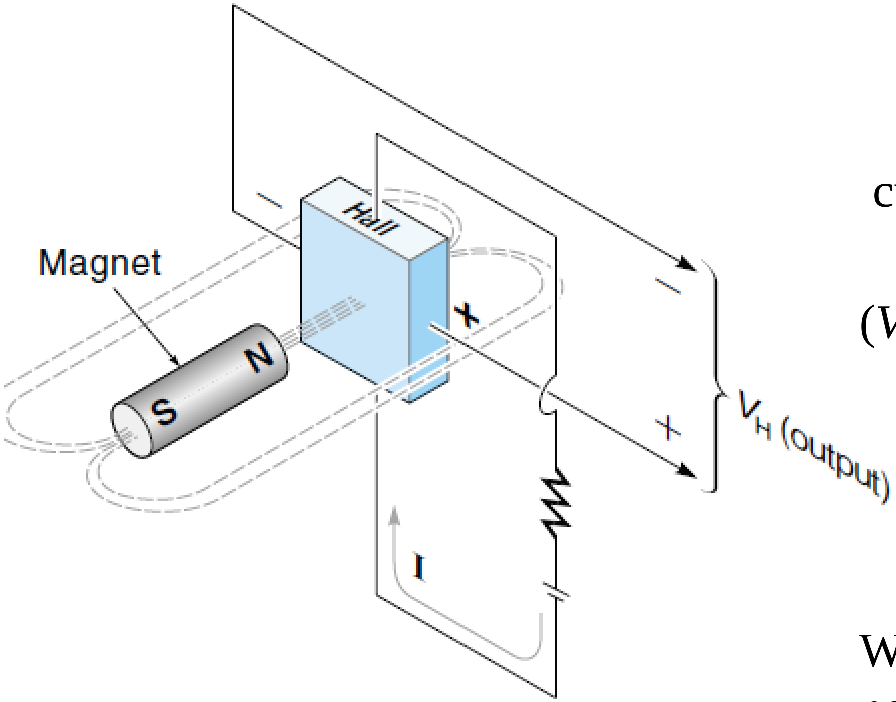


Hall Effect Speed Sensor

The Hall Effect is the most common method of measuring magnetic field and the Hall Effect sensors are very popular and have many contemporary applications. For example, they can be found in vehicles as wheel speed sensors as well as crankshaft or camshaft position sensors. Also they are often used as switches, MEMS compasses, proximity sensors and so on.



Hall Effect Speed Sensor



$$V_H = \frac{KIB}{D}$$

current (I) in the semiconductor crystal

(VH) is sensed across the sides of the crystal

When a magnetic field is brought near, the negative charges are deflected to one side producing a voltage.

Hall Effect

Video#1

TEMPERATURE SENSORS

Temperature sensors give an output proportional to temperature. Most temperature sensors have a *positive temperature coefficient* (desirable),

bimetallic temperature sensor

Thermocouples

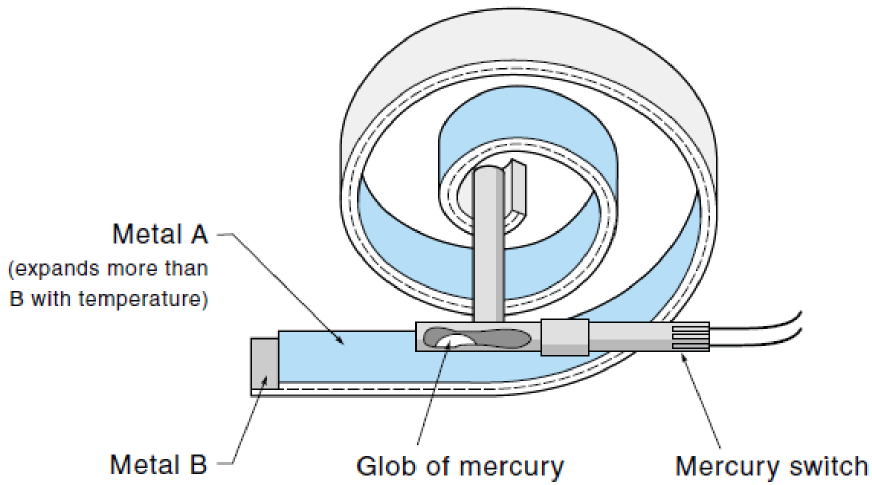
Resistance temperature detector (RTD)

Thermistors

Integrated-Circuit Temperature Sensors

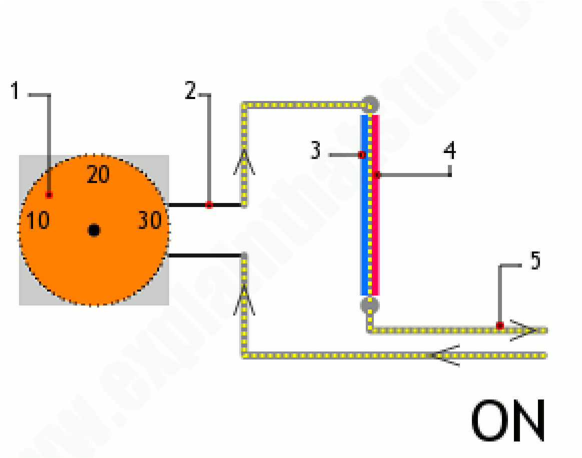
bimetallic temperature sensor

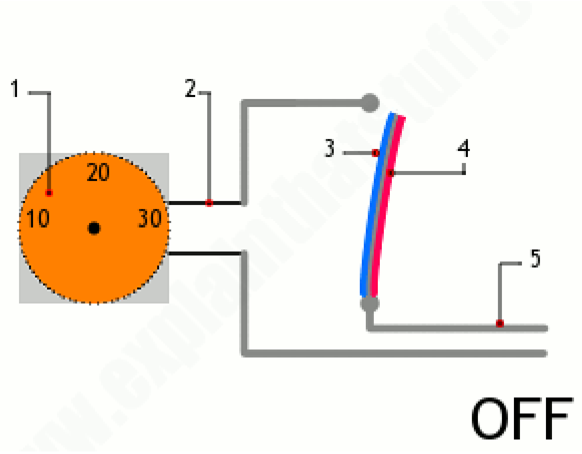
The **bimetallic temperature sensor** consists of a bimetallic strip wound into a spiral (Figure 6.44). The bimetallic strip is a laminate of two metals with different coefficients of thermal expansion. As the temperature rises, the metal on the inside expands more than the metal on the outside, and the spiral tends to straighten out.



bimetallic thermostat switches on and off

The bimetal ("two metal") strip is made of two separate metal strips fastened together: a piece of brass (blue) bolted to a piece of iron (red).





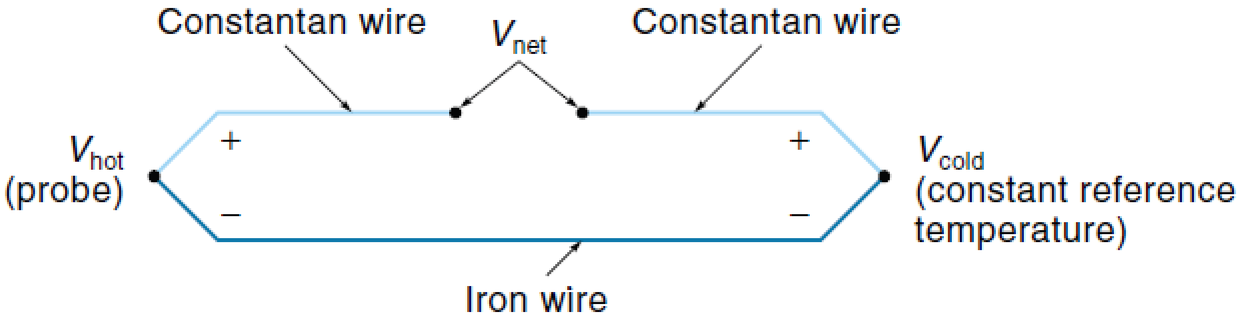
Iron expands less than brass as it gets hotter, so the bimetal strip curves inward as the temperature rises. (on-off control)

Thermocouples

The **thermocouple** was developed over 100 years ago and still enjoys wide use, particularly in high-temperature situations

voltage that is proportional to temperature can be produced from a circuit consisting of two dissimilar metal wires

$$V_{net} = V_{hot} - V_{cold}$$



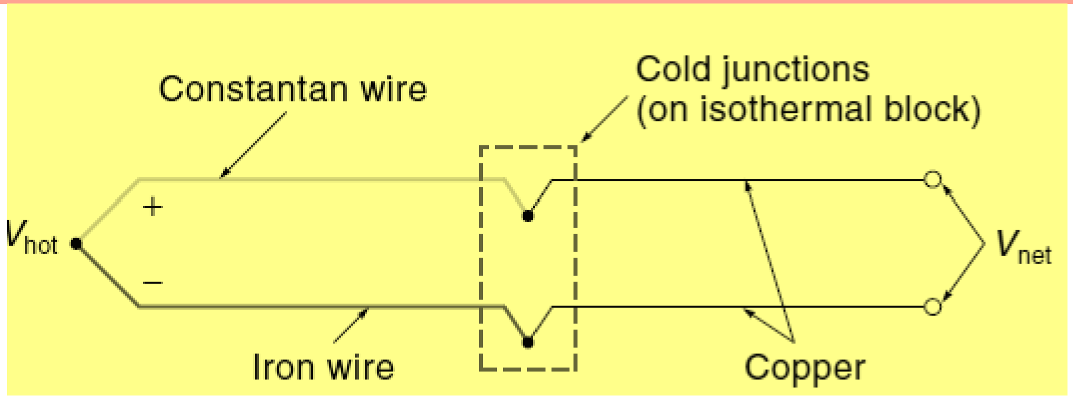
(a) Basic principle

generates a voltage of approximately 35 μV/°F

Thermocouples

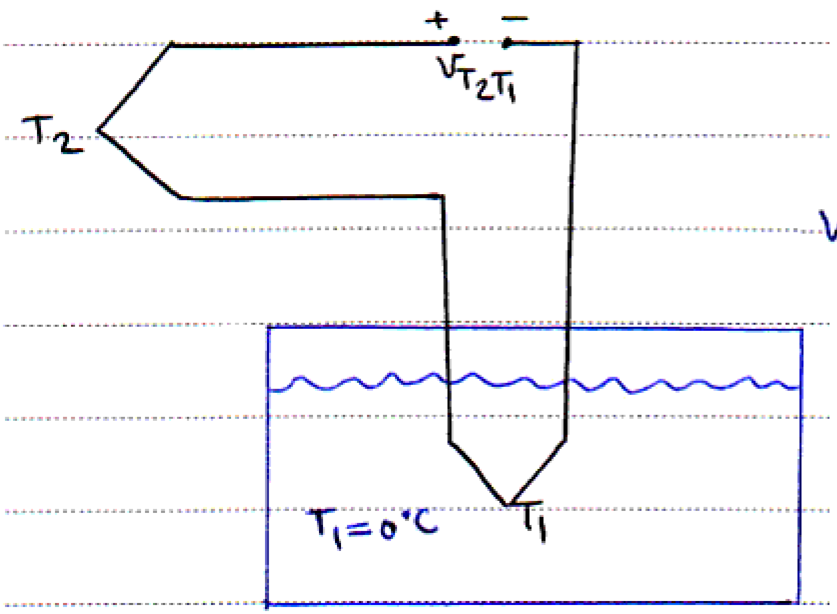
ولتاژ نیروی الکتریک مستقل از دمای سیم کشی رابط بوده و فقط به دمای محل اتصالات بستگی دارد.

در صورتیکه فلز سوم C به مدار A یا B اضافه شود به شرطی که اتصالات جدید دارای دمای یکسان باشند ولتاژ نیروی الکتریک تغییر نخواهد کرد.



Thermocouples

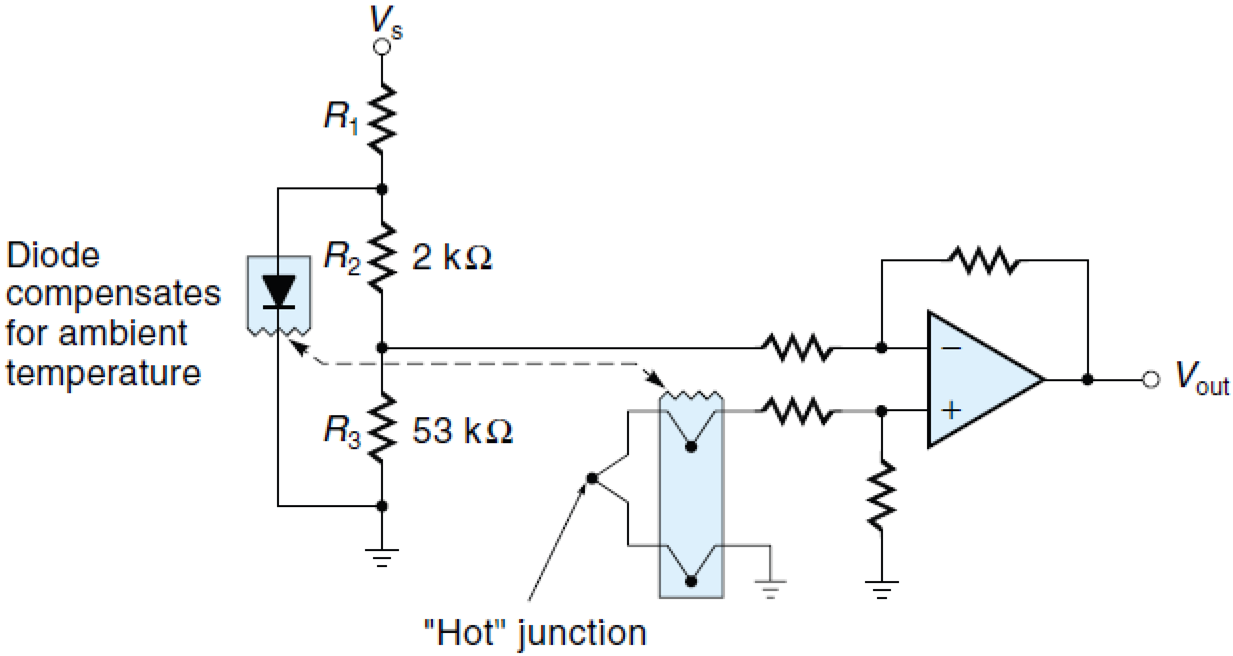
Traditionally, the cold junction was kept at 32°F in an **ice-water bath,** which is water with ice in it.



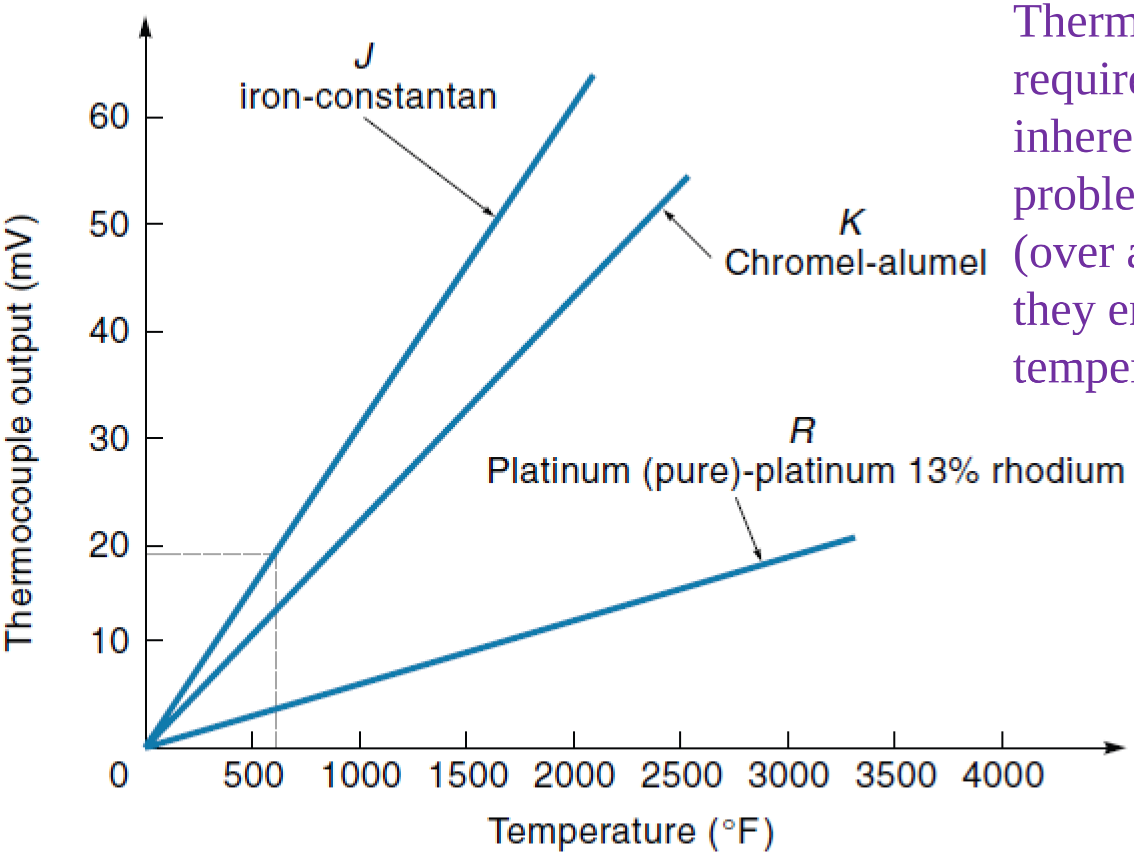
$$V_{T_2T_1} = \alpha_1 T_2 + \alpha_2 T_2^2 + \alpha_3 T_2^3 + \cdots + \alpha_n T_2^n$$

Thermocouples

The cold junctions are maintained at the same temperature as the diode by mounting them all on an *isothermal* block. As the ambient temperature increases, the diode forward-voltage drop (about 0.6 V) decreases at a rate of about 1.1 mV/°F. This voltage is scaled down (with *R*2 and *R*3) to 28 µV/°F, *which is the same rate that the real cold-junction voltage increases with ambient temperature.*



Thermocouples



Thermocouples are simple and rugged but require extra electronics to deal with the inherent low-sensitivity and cold-junction problems. However, because they are linear (over a limited range), reliable, and stable, they enjoy wide use in measuring high temperatures in furnaces and ovens.

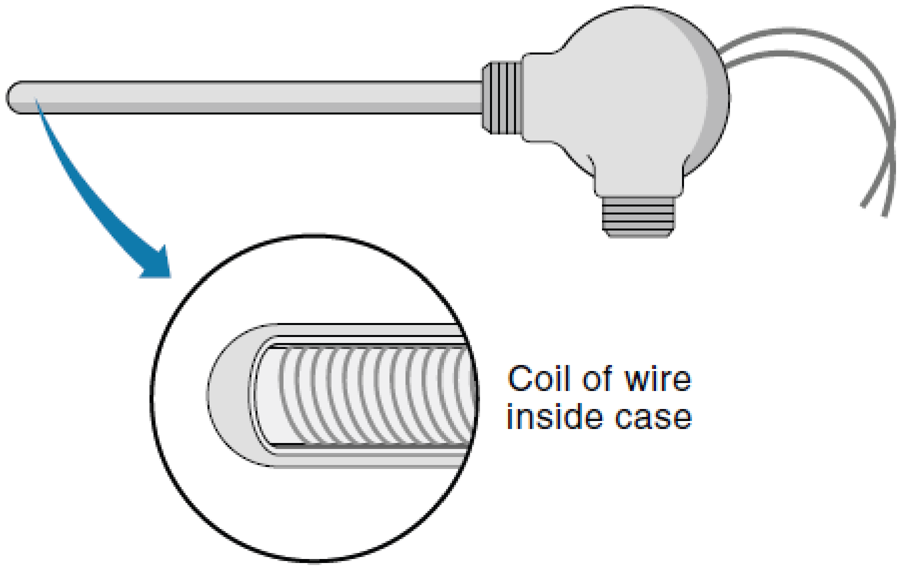
Thermocouples

resistance temperature detector (RTD)

The **resistance temperature detector** (RTD) is a temperature sensor based on the fact that metals increase in resistance as temperature rises. a typical RTD, A wire, such as platinum, is wrapped around a ceramic or glass rod (sometimes the wire coil is supported between two ceramic rods). Platinum wire has a temperature coefficient of 0.0039 Ώ/ Ώ /°C, which means that the resistance goes up 0.0039 W for each ohm of wire for each Celsius degree of temperature rise

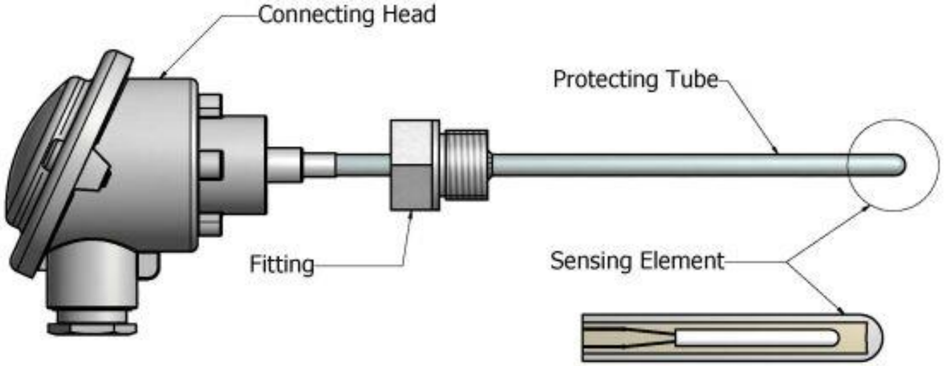
Each ohm of wire for each Celsius degree of temperature rise

RTDs have the advantage of being very accurate and stable (characteristics do not change over time). The disadvantages are low sensitivity



RTD

Pt100	Pt1000	PTC	NTC	NTC	NTC
Typ: 404	Typ: 501	Typ: 201	Typ: 101	Typ: 102	Typ: 103

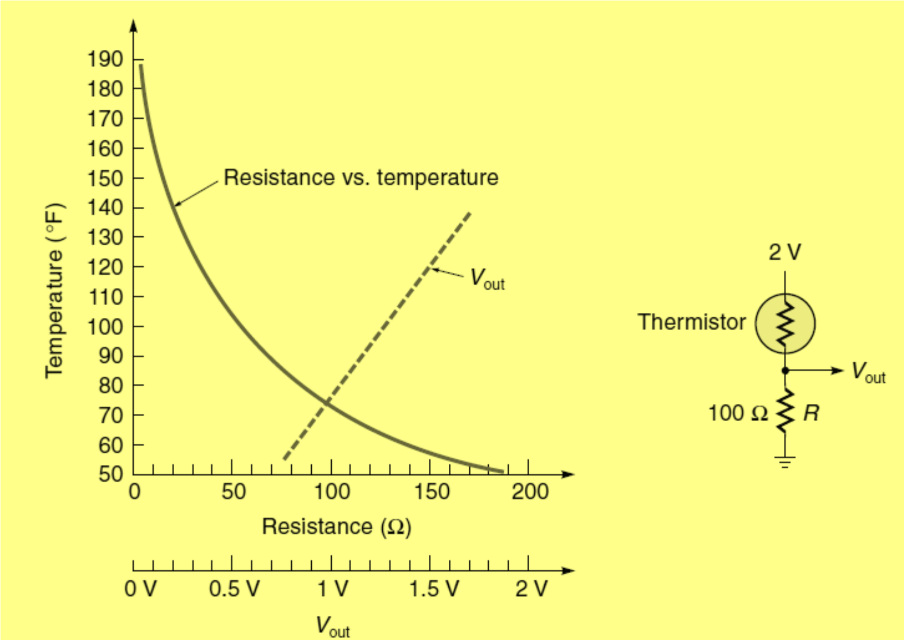


Thermistors

A **thermistor** is a two-terminal device that changes resistance with temperature. Thermistors are made of oxide-based semiconductor materials and come in a variety of sizes and shapes.

most thermistors have a negative temperature coefficient, which means the resistance decreases as temperature increases

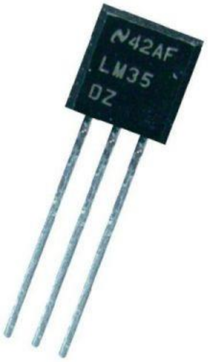
Negative temperature coefficient (NTC)



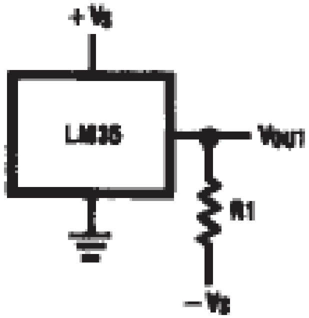
Integrated-Circuit Temperature Sensors

Integrated-circuit temperature sensors come in various configurations. A common example is the LM34 and LM35 series. The LM34 produces an output voltage that is proportional to Fahrenheit temperature, and the LM35 produces an output that is proportional to Celsius temperature.

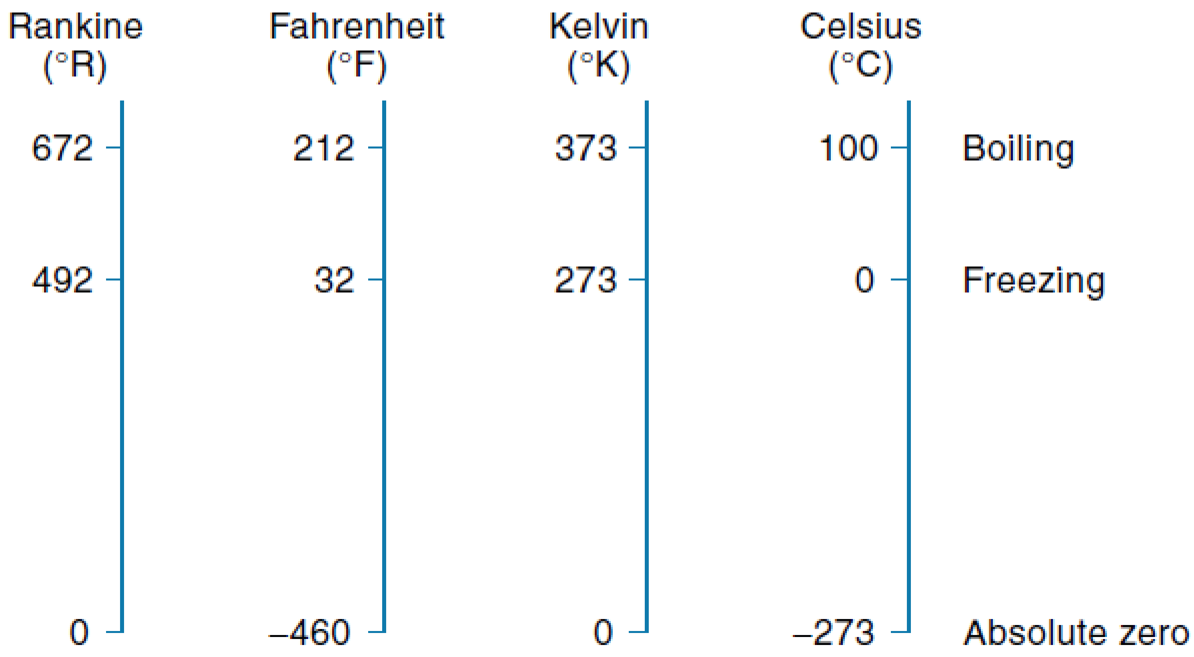
supply voltage (Vs), ground,
and Vout.



Vout = 10 mV/°C



Comparison of Rankine, Fahrenheit,Kelvin, and Celsius temperature scales



comparison

RTD:
- رنج: -۲۰۰°C ← ۴۰۰°C
- خطی
- نیاز به تحریک توسط منبع خارجی
- بسیار ارزان قیمت
- تکرارپذیری و درستی بالا

ترموکوپل:
- رنج وسیع: -۲۰۰°C ← ۲۳۰۰°C
- تکرارپذیری و درستی بالا
- نیاز به اتصال سرد
- ولتاژ خروجی کوچک
- غیرخطی

مدارهای مجتمع IC:
- رنج: -۵۰°C ← ۲۰۰°C
- خطی
- درستی بالا
- نیاز به منبع تحریک خارجی

ترمیستور:
- رنج: ۰ ← ۱۰۰°C
- غیرخطی
- نیاز به تحریک خارجی
- حساسیت بالا
- دقت زیاد

Proximity Sensors

A **proximity sensor** simply tells the controller whether a moving part is at a certain place

Limit Switches

Optical Proximity Sensors

Hall-Effect Proximity Sensors

limit switch

A **limit switch** is an example of a proximity sensor. A limit switch is a mechanical push-button switch that is mounted in such a way that it is actuated when a mechanical part or lever arm gets to the end of its intended travel

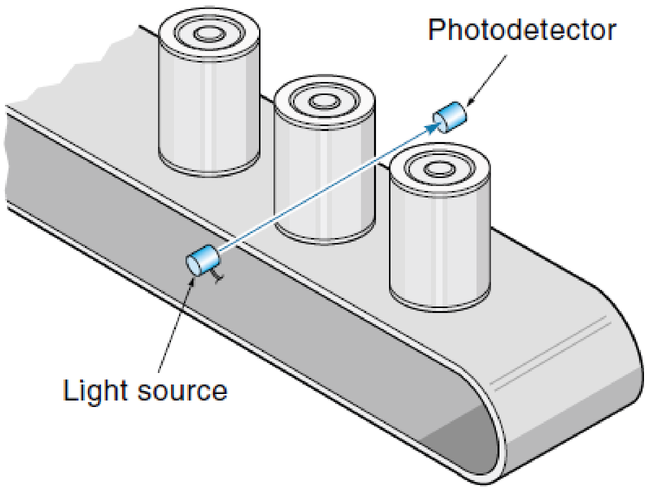
in an automatic garage-door opener

Video#2

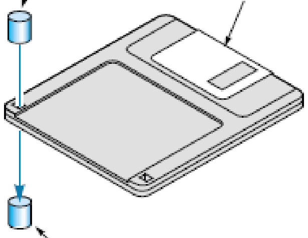
limit switch

Optical Proximity Sensors

Optical proximity sensors, sometimes called *interrupters*, use a light source and a photo sensor that are mounted in such a way that the object to be detected cuts the light path.



(a) Counting cans on a conveyor belt



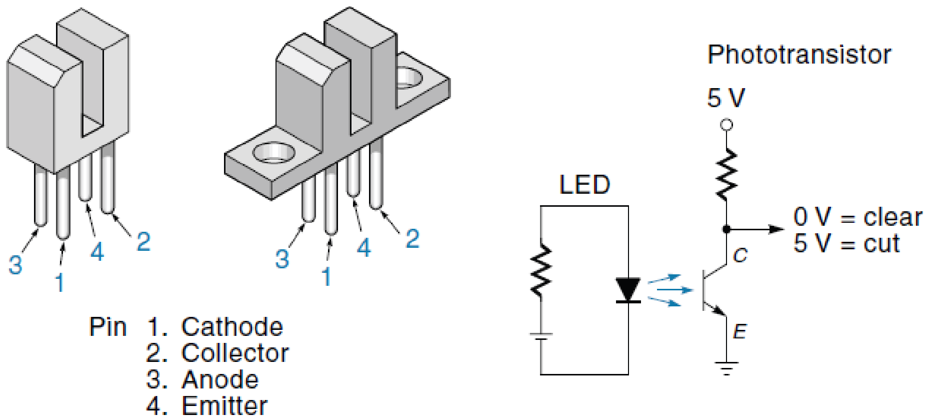
(b) Detecting "read only" hole in a floppy disk

Video#3

Optical Proximity Sensors

Some applications make use of an optical proximity sensor called a **slotted coupler,** also called an *optointerrupter*

This device includes the light source and detector in a single package.

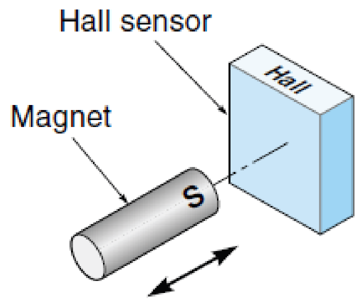


(a) Case types (b) Circuit

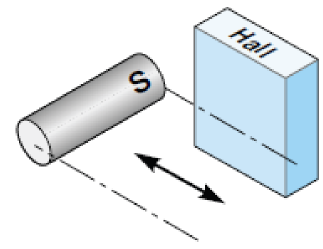
When the slot is open, the light beam strikes the transistor, turning it on, which grounds the collector.

When the beam is interrupted, the transistor turns off, and the collector is pulled up to 5 V by the resistor.

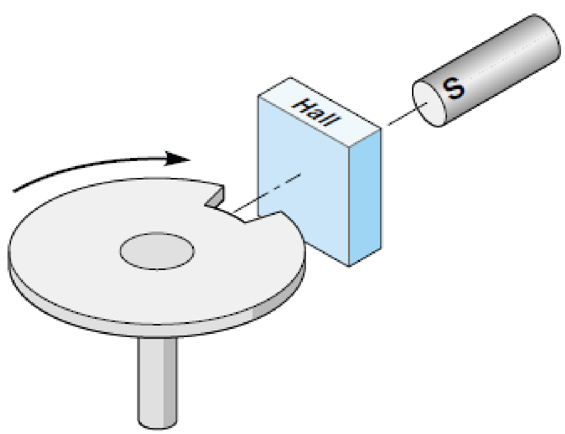
Hall-Effect Proximity Sensors



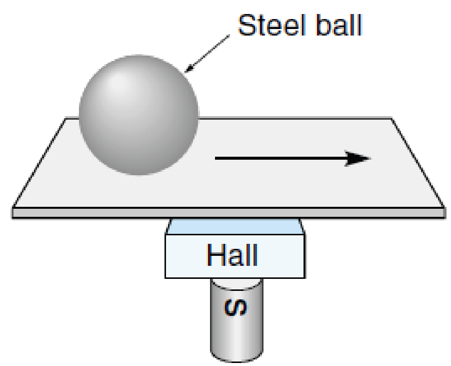
(a) Head-on



(b) Slide-by



(c) Notch sensor
(notch reduces flux)



(d) Metal detector
(ball increases flux)

Hall-Effect Proximity Sensors

Hall-Effect Proximity Sensors

55110-3H-02-A 	5052609 Data Sheet	**LITTELFUSE** **Hall Effect Proximity Sensor, Flange Mount, LED, 55110 Series, 3 Wire, 59 G, 3.8 to 24 Vdc** (0) Sensing Range Max **18mm** Supply Voltage DC Min **3.8V** Supply Voltage DC Max **24V** + See all product info	**47** In stock Check Stock & Lead Times	Each	1+ **£8.96** 5+ **£7.94** 10+ **£6.91** 50+ **£6.73** 100+ **£5.59**	1 **Add** Min: 1 Mult: 1
S1456 	2409231 Data Sheet RoHS	**COMUS** **Hall Effect Proximity Switch, M12, 10 mm, 4.5 to 24 Vdc, 25 mA, Pre-wired** (0) Supply Voltage DC Min **4.5V** Supply Voltage DC Max **24V** Sensor Terminals **Cable** + See all product info	**68** In stock Check Stock & Lead Times	Each	1+ **£30.43** 5+ **£29.49** 10+ **£28.22** 25+ **£27.66** 50+ **£27.09**	1 **Add** Min: 1 Mult: 1

LOAD SENSORS

Load sensors measure mechanical force. The forces can be large or small—for example, weighing heavy objects or detecting low-force tactile pressures. In most cases, it is the slight deformation caused by the force that the sensor measures, not the force directly

The ratio of the force to deformation is a constant for each material, as defined by Hooke's law:

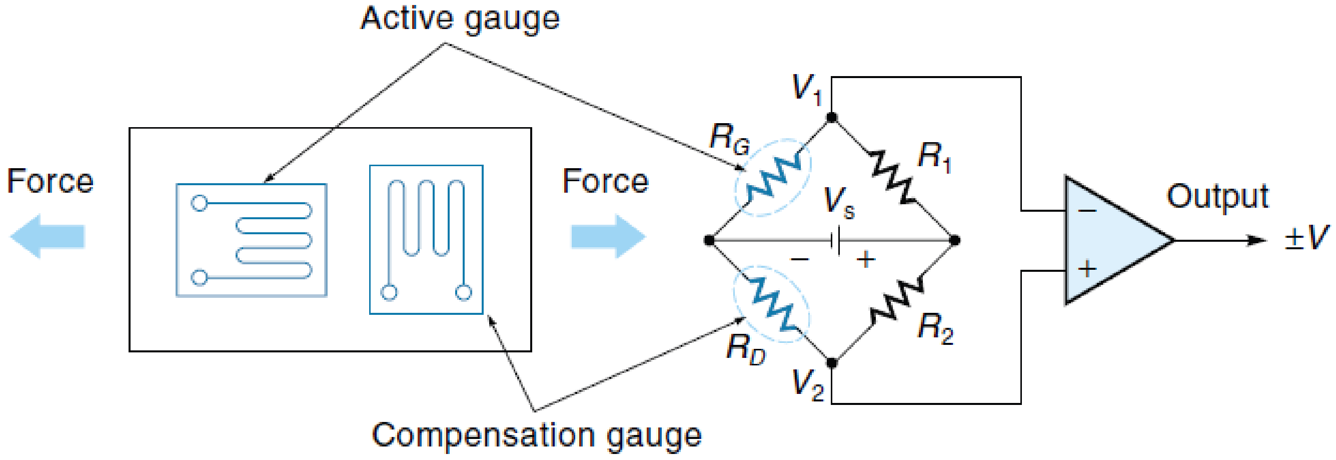
$F = KX$

For example, if a mechanical part has a spring constant of 1000 lb/in. and it compresses 0.5 in. under the load, then the load must be 500 lb.

Bonded-Wire Strain Gauges

The **bonded-wire strain gauge** can be used to measure a wide range of forces, from 10 lb to many tons.

If the object is put under tension, the gauge will stretch and elongate the wires. The wires not only get slightly longer but also thinner. Both actions cause the total wire resistance to rise



(a) Placement of gauges (b) Interface circuit using a bridge

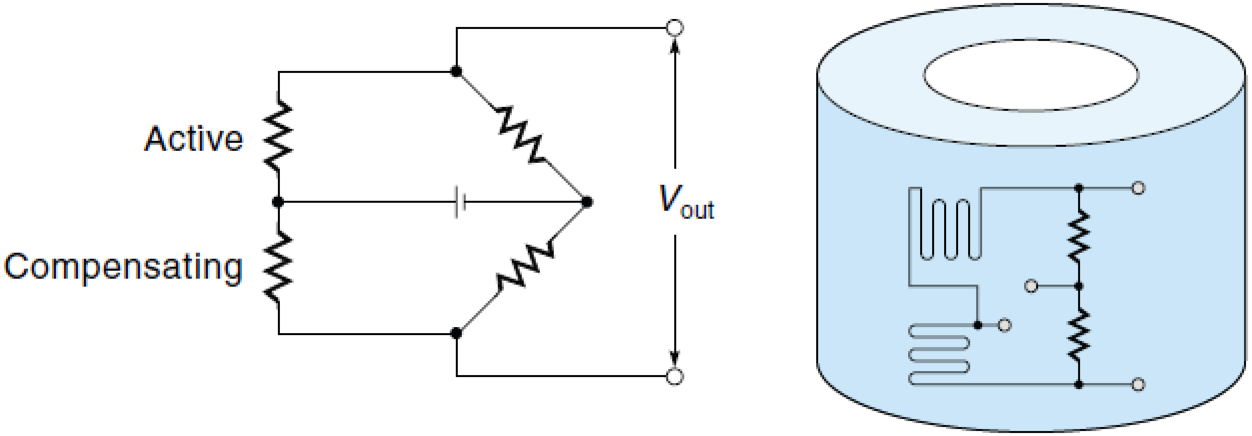
Bonded-Wire Strain Gauges

$$R = \frac{\rho L}{A}$$

where
R = resistance of a length of wire (at 20°C)
r = resistivity (a constant dependent on the material)
L = length of wire
A = cross-sectional area of wire

The change in resistance of the strain-gauge wires can be used to calculate the elongation of the strain gauge. If you know the elongation and the spring constant of the supporting member, then the principles of Hooke's law can be used to calculate the force being applied.

Bonded-Wire Strain Gauges

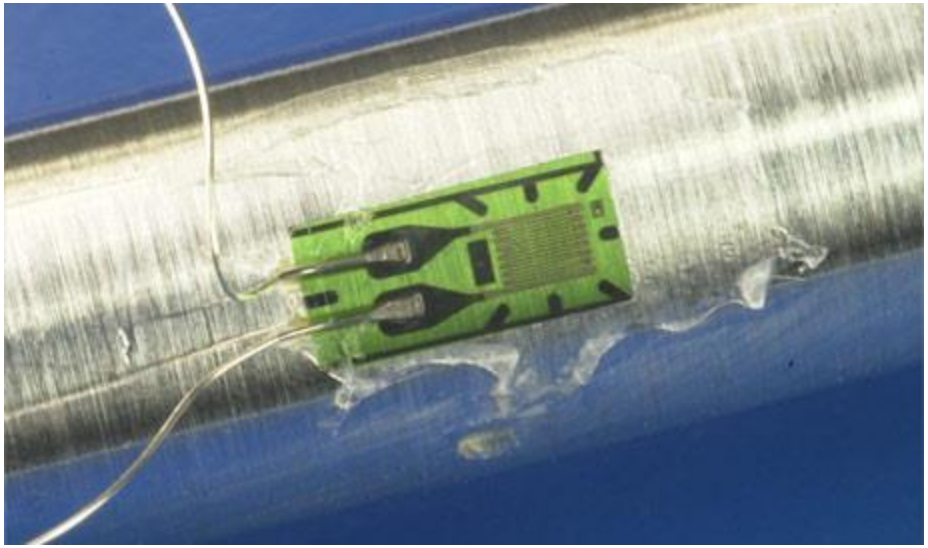


(a) Active and compensating gauges are placed together so that they will be at the same temperature

(b) Load cell with strain gauge and bridge

Bonded-Wire Strain Gauges

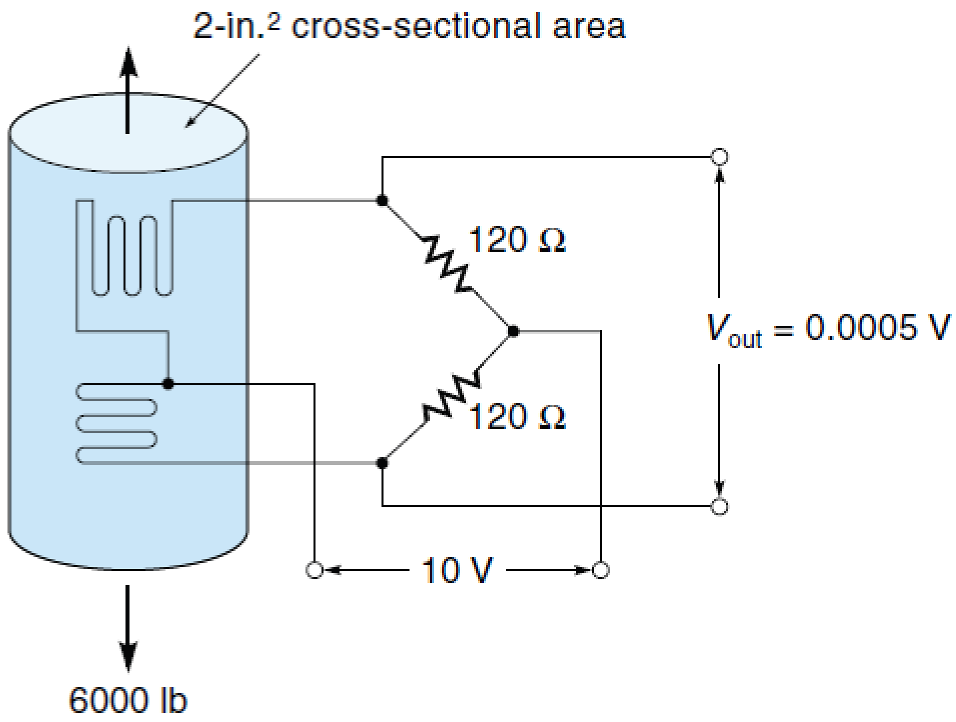
استرین گیج نصب شده بر روی پره های یک توربین آبی



رای اندازه گیری کرنش یک جسم ، کرنش سنج را با چسب های محکم و انعطاف پذیر مانند سیانوآکریلات یا جسب های سیلیکونی به سطح جسم مورد نظر می چسبانند

Bonded-Wire Strain Gauges

Strain-gauge measuring tension in steel bar



PRESSURE SENSORS

Pressure is defined as the force per unit area that one material exerts on another

Pressure sensors usually consist of two parts: The first converts pressure to a force or displacement, and the second converts the force or displacement to an electrical signal.

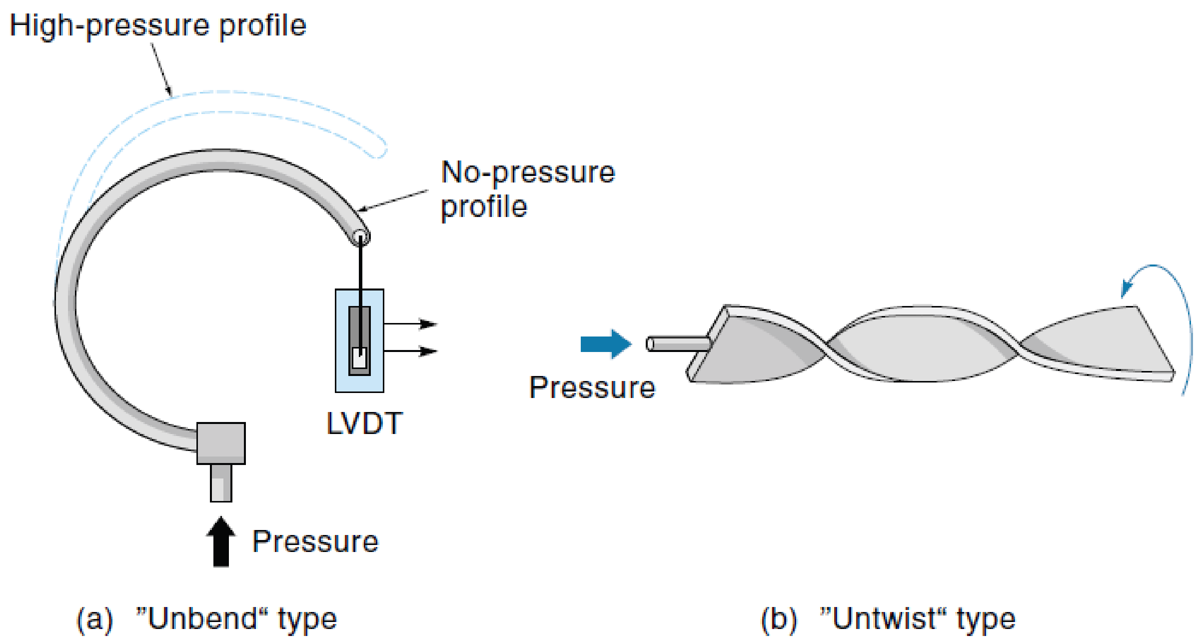
Bourdon Tubes

Bellows

Semiconductor Pressure Sensors

Bourdon Tubes

A **Bourdon tube** is a short bent tube, closed at one end. When the tube is pressurized, it tends to straighten out. This motion is proportional to the applied pressure. Notice that the displacement can be either linear or angular. A position sensor such as a pot or LVDT can convert the displacement into an electrical signal. Bourdon-tube sensors are available in pressure ranges from 30 to 100,000 psi. Typical uses include steam- and water-pressure gauges.

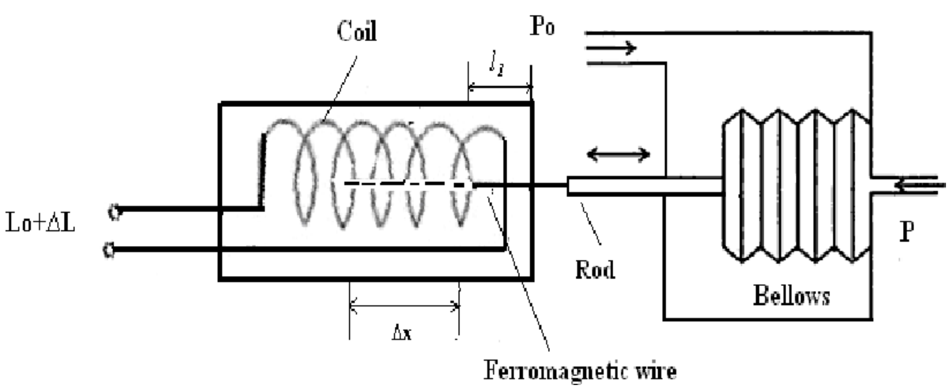


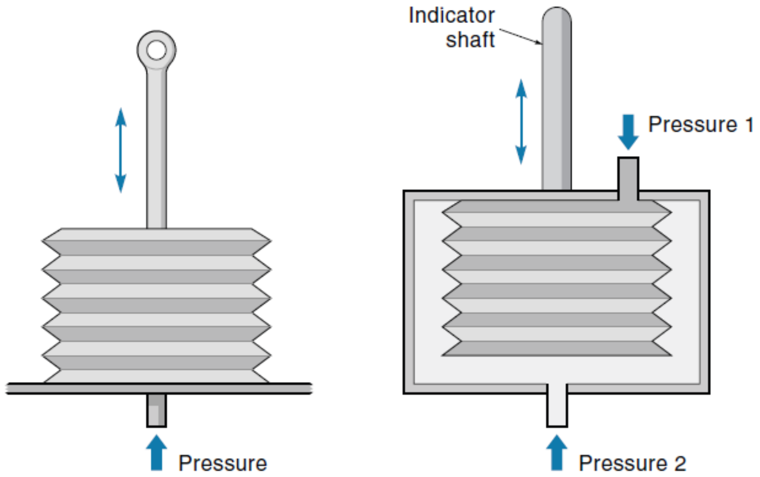
Bellows

This sensor uses a small metal bellows to convert pressure into linear motion

As the pressure inside increases, the bellows expand against the resistance of a spring (the spring is often the bellows itself). This motion is detected with a position sensor such as a pot

Bellows are capable of more sensitivity than the Bourdon tube in the lower-pressure range of 0-30 psi.



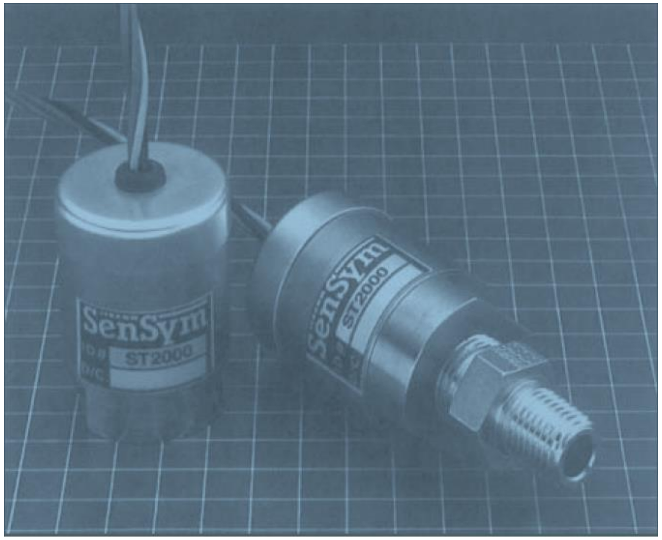


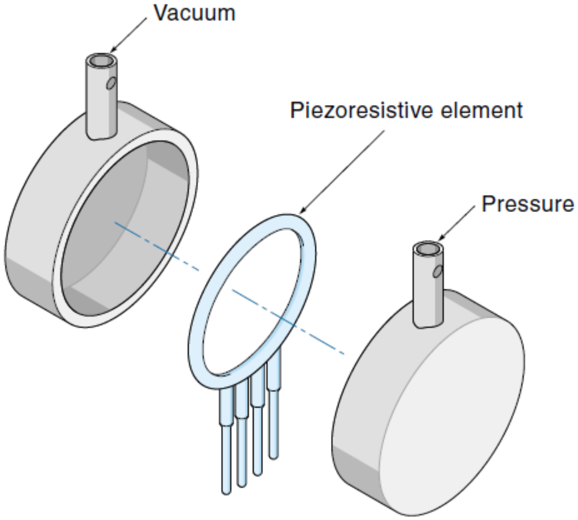
(a) Single-pressure type (b) Differential-pressure type

Semiconductor Pressure Sensors

Some commercially available pressure sensors use the piezoresistive property of silicon

The piezoresistive element converts pressure directly into resistance, and resistance can be converted into voltage. These sensors have the advantage of “no moving parts” and are available in pressure ranges from 0-1.5 psi to 0-5000 psi. An example of a commercial semiconductor pressure sensor is the ST2000 series from Sen Sym Inc.





FLOW SENSORS

Flow sensors measure the quantity of fluid material passing by a point in a certain time. Usually, the material is a gas or a liquid and is flowing in a pipe or open channel

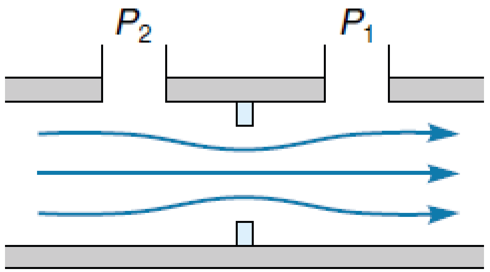
Pressure-Based Flow Sensors

Turbine Flow Sensors

Magnetic Flowmeters

Pressure-Based Flow Sensors

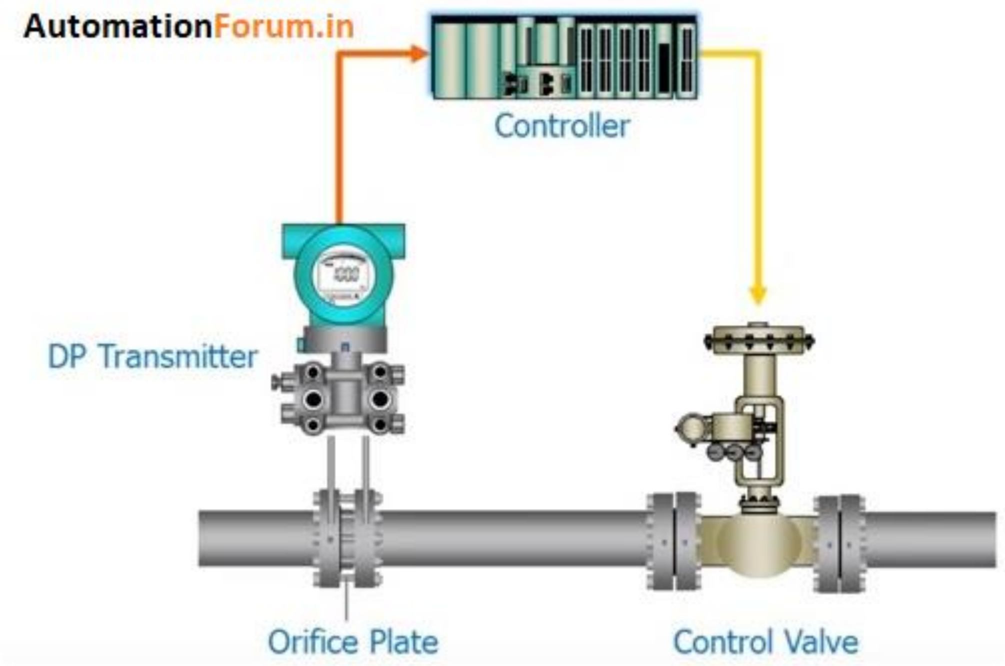
This group of flow sensors is based on the fact that pressure in a moving fluid is proportional to the flow. The pressure is detected with a pressure sensor; based on the physical dimensions of the system, the flow can be calculated. The simplest flow sensor is called the **orifice plate**



The flow is proportional to the pressure difference between these ports and is calculated as follows:

$$Q = CA\sqrt{\frac{2g}{d}(P_2 - P_1)}$$

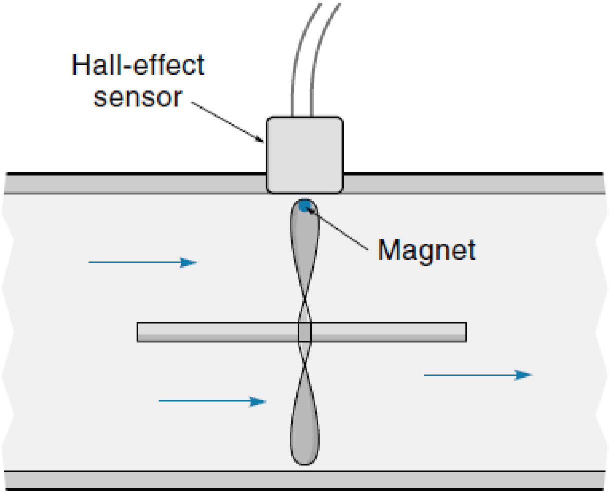
orifice plate



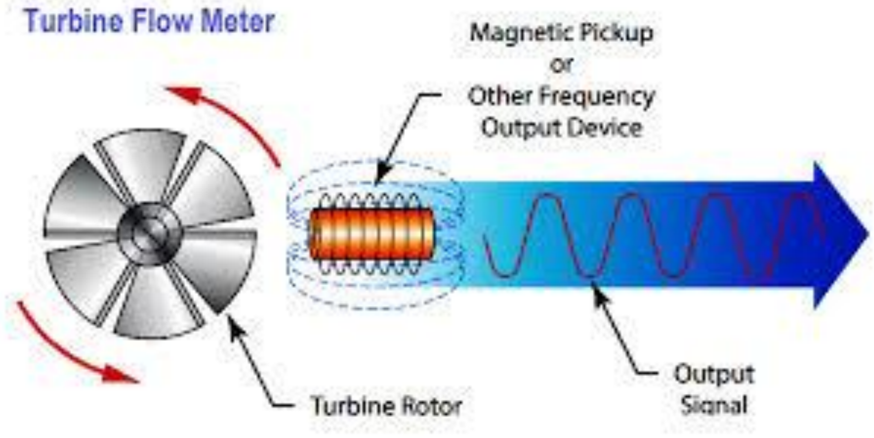
Turbine Flow Sensors

Turbine, or spin-type, flow sensors (also called flowmeters), employ a paddle wheel or propeller placed in the line of flow. The rotational velocity of the wheel is directly proportional to flow velocity

A small magnet is attached to one of the blades, and a Hall-effect sensor is mounted in the housing. The Hall sensor gives a pulse for each revolution of the blades.

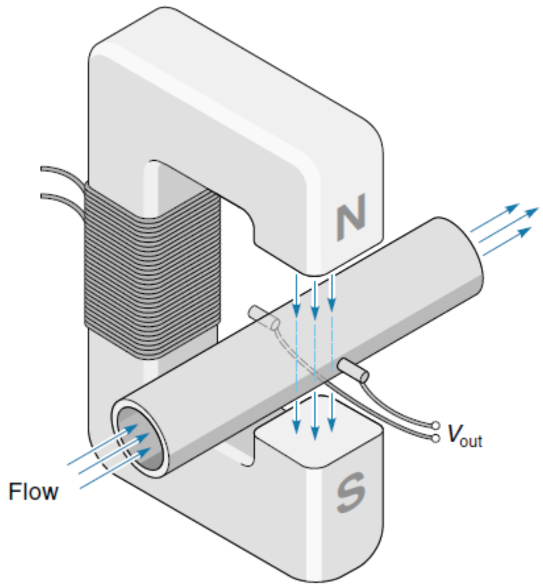


Turbine Flow Sensors



Magnetic Flowmeters

If a liquid is even slightly conductive (and many are), a magnetic flowmeter can be used. the magnetic flowmeter has no moving parts and presents no obstruction to the flow. A nonconducting section of pipe is placed in a magnetic field. The moving fluid in the pipe is like the moving conductor in a generator—it produces a voltage. The voltage, which is proportional to the fluid velocity, is detected from electrodes placed in the sides of the pipe.



End of This part