Components of Digital Control Systems

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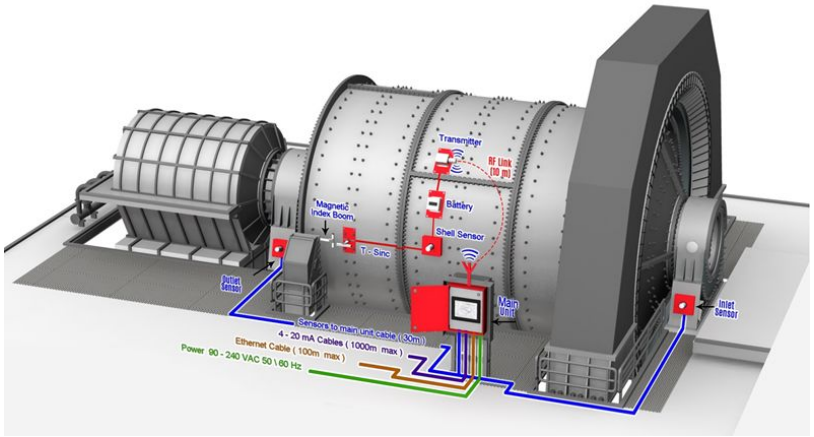
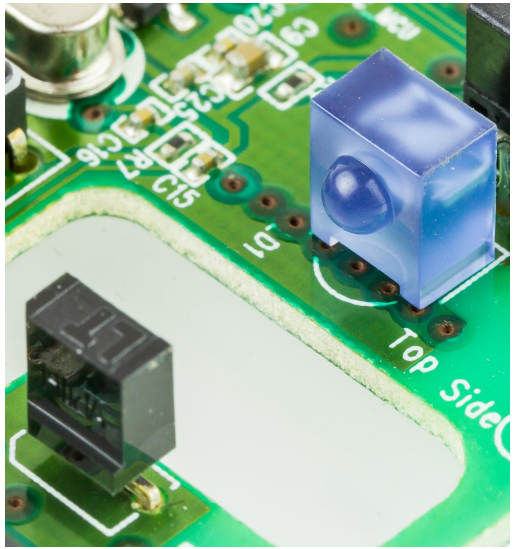
The following content is based on Introduction to Transducers, Sensors, and Actuators – Southwest Center for Microsystems Education (SCME), University of New Mexico

- Electronic
- Electrical
- Electro-mechanical
- Mechanical

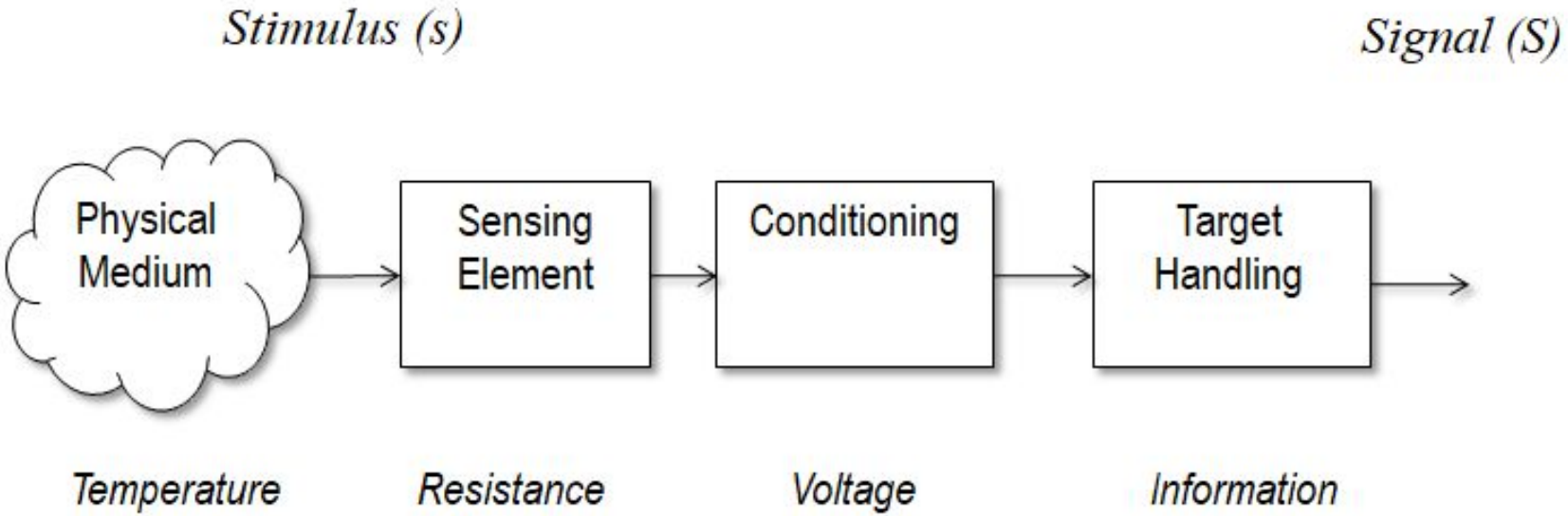


Sensors

- A sensor is a device that receives and responds to a signal.
- This signal must be produced by some type of energy, such as heat, light, motion, or chemical reaction.
- Once a sensor detects one or more of these signals (an input), it converts it into an analog or digital representation of the input signal.
- Sensors detect by receiving a signal from a device such as a transducer, then responding to that signal by converting it into an output that can easily be read and understood.



Sensors


Stimulus (s)
Signal (S)
Physical Medium
Sensing Element
Conditioning
Target Handling
Temperature
Resistance
Voltage
Information

Sensor Transfer Function

- $S=f(s)$
  - S = output signal;
  - s = stimulus;
  - $f(s)$ = functional relationship
- For binary sensors:
  - $S = 1$ if $s > 0$ and $S = 0$ if $s < 0$.
- The ideal functional form for an analogue measuring device is a simple proportional relationship, such as:
- Linear transfer function: $\boldsymbol{S=C+ms}$
  - C = output value at a stimulus value of zero
  - m = constant of proportionality (sensitivity)

Example

The output voltage of a particular thermocouple sensor is registered to be 42.3 mV at temperature 105°C.

It had previously been set to emit a zero voltage at 0°C.

Since an output/input relationship exists between the two temperatures, determine,

1. the transfer function of the thermocouple, and
2. the temperature corresponding to a voltage output of 15.8 mV.

Solution

$S=C+ms$

42.3 mV = 0 + m(105C) = m(105C)

m = 0.4028571429

S = 0.4 (s)

15.8 mV = 0.4 (s)

15.8 / 0.4 = s

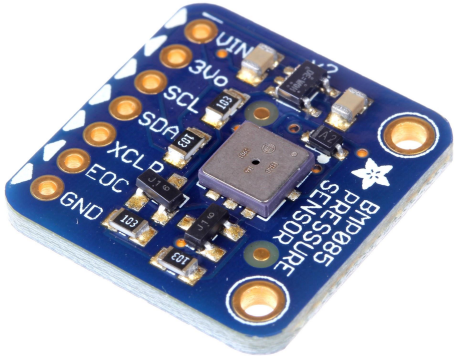
s = 39.22C

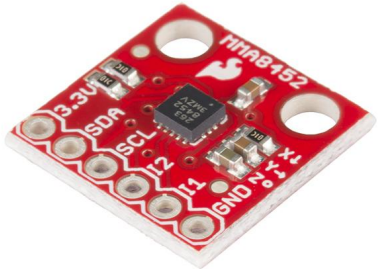
Thermal Sensors

- Thermometer
  - measures absolute temperature
- Thermocouple gauge
  - measures temperature by its effect on two dissimilar metals
- Calorimeter
  - measures the heat of chemical reactions or physical changes and heat capacity

Mechanical Sensors

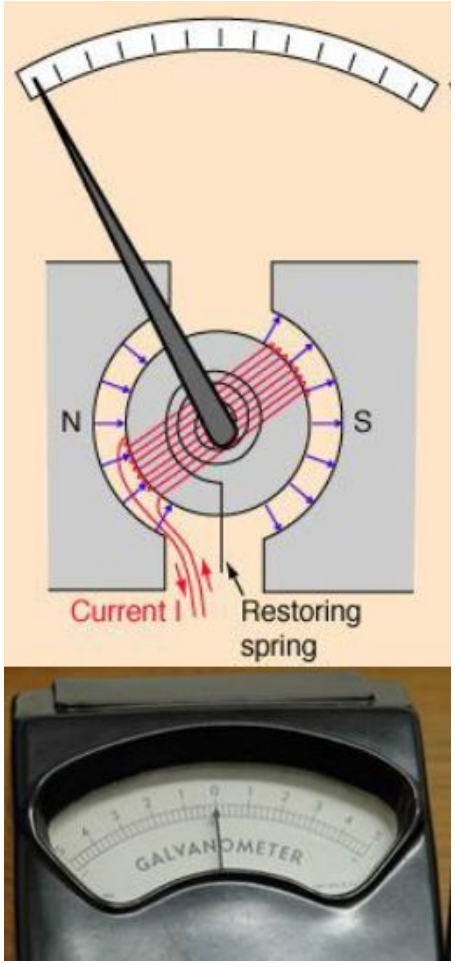
- Pressure sensor
  - measures pressure
- Barometer
  - measures atmospheric pressure
- Altimeter
  - measures the altitude of an object above a fixed level
- Liquid flow sensor
  - measures liquid flow rate
- Gas flow sensor
  - measures velocity, direction, and/or flow rate of a gas
- Accelerometer
  - measures acceleration





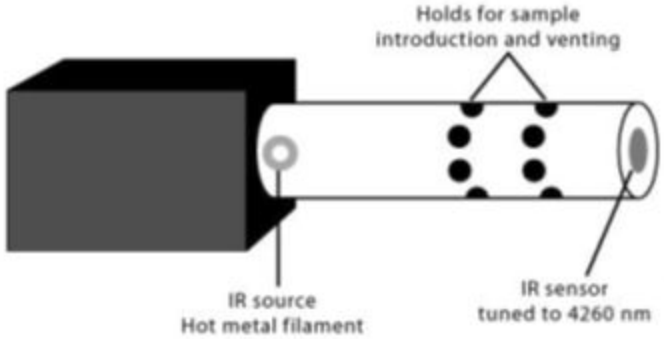
Electrical Sensors

- Ohmmeter
  - measures resistance
- Voltmeter
  - measures voltage
- Galvanometer
  - measures current
- Watt-hour meter
  - measures the amount of electrical energy supplied to and used by a residence or business



Chemical Sensors

- Chemical sensors detect the presence of certain chemicals or classes of chemicals and quantify the amount and/or type of chemical detected.
- Oxygen sensor
  - measures the percentage of oxygen in a gas or liquid being analysed
- Carbon dioxide detector
  - detects the presence of CO2

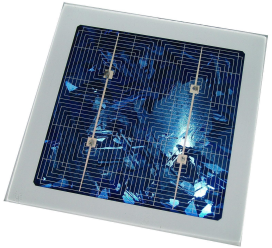


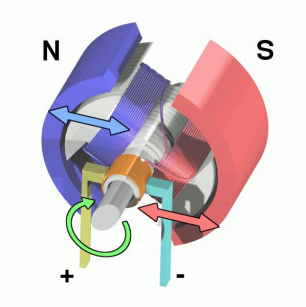
Other Types of Sensors

- Optical
  - Light sensors (photodetectors) – detects light and electromagnetic energy
  - Photocells (photoresistor) – a variable resistor affected by ambient light intensity
  - Infrared sensor – detects infrared radiation
- Acoustic
  - Seismometers – measures seismic waves
  - Acoustic wave sensors – measures the wave velocity in the air or an environment to detect the chemical species present
- Other
  - Motion – detects motion
  - Geiger counter – detects atomic radiation

Transducer

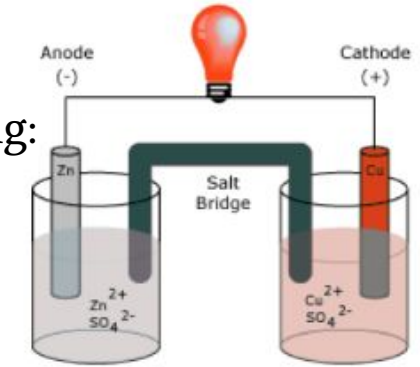
- A transducer is any device which converts one form of energy into another.
- Examples:
  - A microphone converts sound into electrical impulses and a loudspeaker converts electrical impulses into sound (i.e., sound energy to electrical energy and vice versa).
  - A solar cell converts light into electricity and a thermocouple converts thermal energy into electrical energy.
  - An electric motor is a transducer for conversion of electricity into mechanical energy or motion.

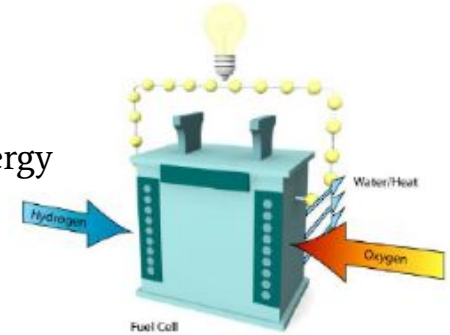




Electrochemical Transducers

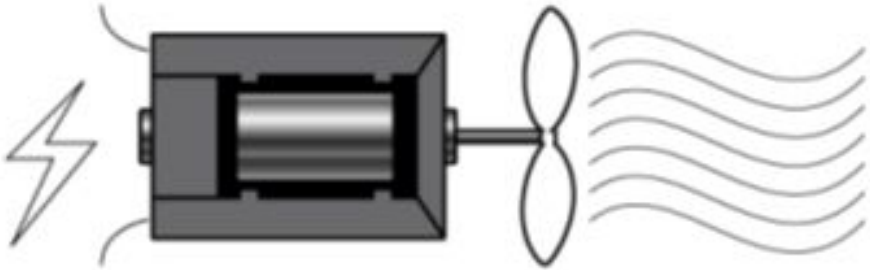
- Some common electrochemical transducers include the following:
  - pH probe
    - Converts chemical energy into an electrical energy
  - Molecular electric transducer
    - Converts motion in an electrolytic solution into electrical energy
  - Battery
    - Converts chemical energy directly into electrical energy
  - Fuel cell
    - Converts the energy from a reaction within a fuel cell to electrical energy





Electromechanical Transducers

- Electromechanical Transducers – (Some are also called actuators)
  - Strain gauge – Converts the deformation (strain) of an object into electrical resistance
  - Galvanometer – Converts the electric current of a coil in a magnetic field into movement
  - Generators – Converts mechanical energy (motion) into electrical energy
  - Motor – Converts electrical energy into mechanical energy



A motor converts electrical energy into mechanical energy

Electroacoustic, Electromagnetic and Electrostatic Transducers

- Common electroacoustic transducers:
  - Loudspeaker – Converts an electrical signal into sound
  - Microphone – Converts sound waves in air into an electrical signal
  - Hydrophone – Converts sound waves in water into an electrical signal.
- Common electromagnetic transducers:
  - Magnetic cartridge – Converts motion in a magnetic field into an electrical energy
  - Generator – Converts motion in a magnetic field into electrical energy
- Common electrostatic transducers:
  - Electrometer – Converts static or energy from a vibrating reed into electricity
  - Van de Graaf generator – Converts static into high voltage (see figure below)

Other Types of Transducers

- Photoelectric Transducers:
  - Cathode ray tube (CRT) – Converts electrical signals into light energy
  - Light bulb – Converts electrical energy into visible light and heat
  - Laser diode – Converts electrical energy into light energy
  - Photodiode – Converts light energy into electrical energy
- Thermoelectric Transducers:
  - Thermocouple – Converts heat energy into electrical energy
  - Temperature sensitive resistor (Thermister) – a variable resistor affected by temperature changes (heat energy to electrical energy)

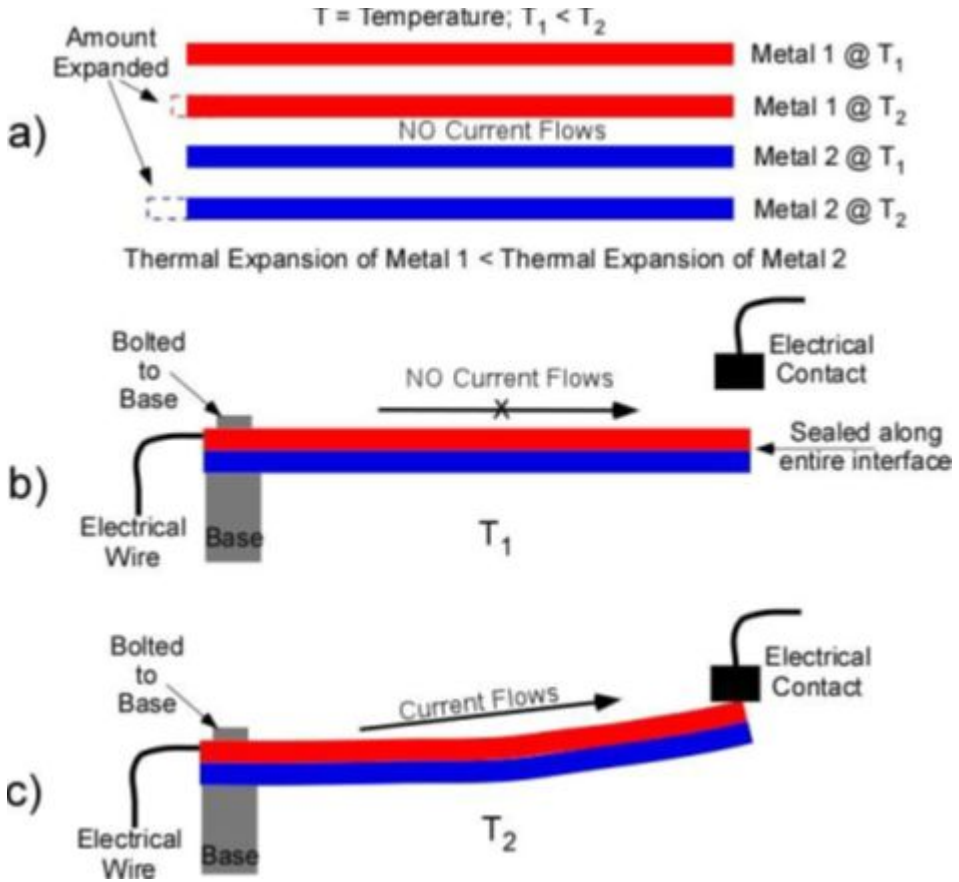
Actuator

- An actuator is a device that actuates or moves something.
- An actuator uses energy to provide motion.
- Therefore, an actuator is a specific type of a transducer.

Which of the previously mentioned examples is an actuator?

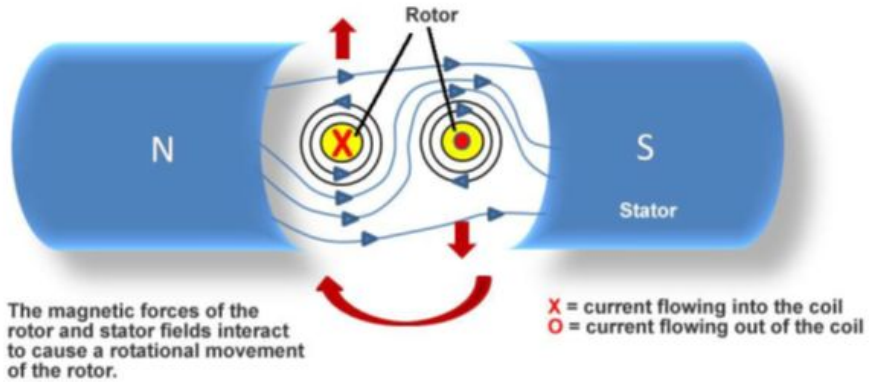
Thermal Actuators

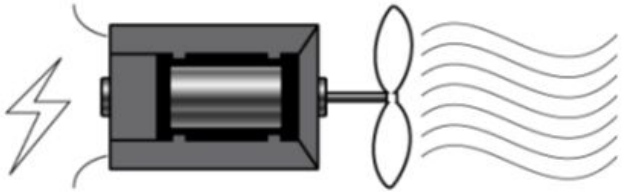
- One type of thermal actuator is a bimetallic strip.
- This device directly converts thermal energy into motion.
- This is accomplished by utilizing an effect called thermal expansion.



Electric Actuators

- Electric motors – An electric motor is an actuator that transforms electrical energy into mechanical energy or motion.
  - DC servomotors
  - AC motors
  - Stepper motors
- Solenoids





Mechanical Actuators

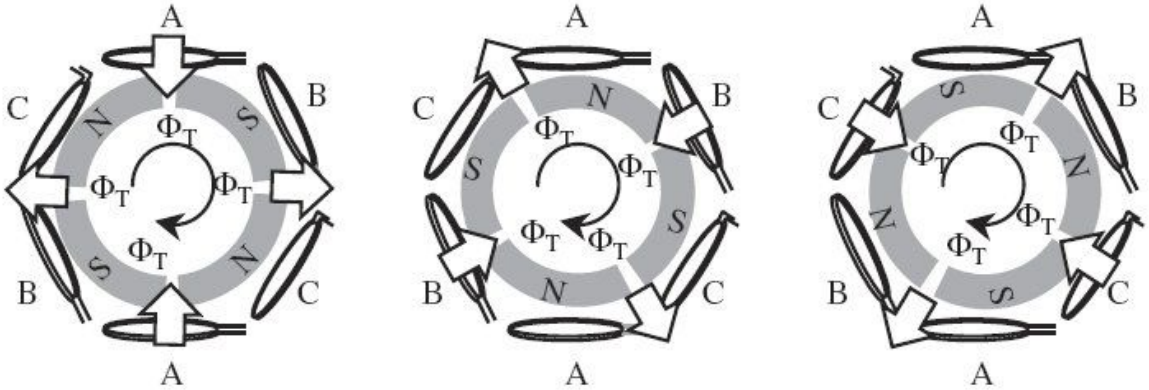
- Mechanical actuators convert a mechanical input (usually rotary) into linear motion.
- A common example of a mechanical actuator is a screw jack.
- Mechanical actuators can produce a rotational output with the proper gearing mechanism.

Other Actuators

- Hydraulic actuators
  - Use hydraulic fluid to amplify the controller command signal
- Pneumatic actuators
  - Use compressed air as the driving force

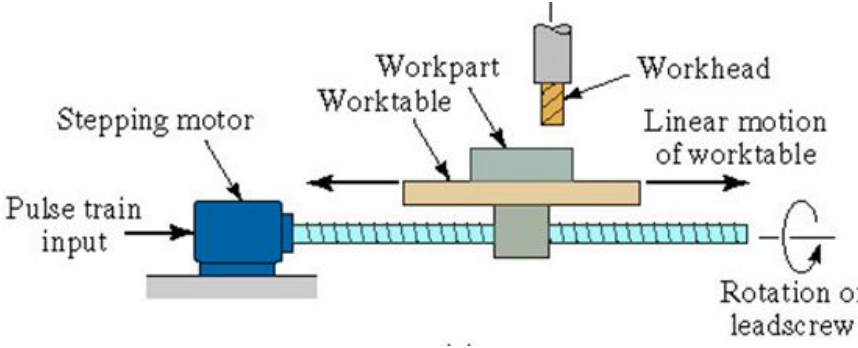
Servo Motors and Stepper Motors

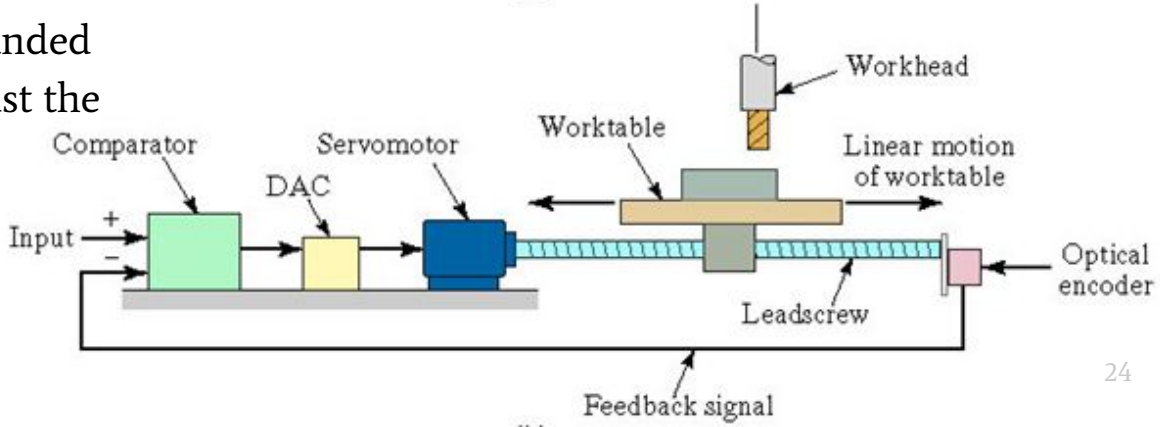
- Stepper motors typically use 50 to 100 pole brushless motors, while typical servo motors have only 4 to 12 poles.
  - A pole is an area of a motor where a North or South magnetic pole is generated either by a permanent magnet or by passing current through the coils of a winding.



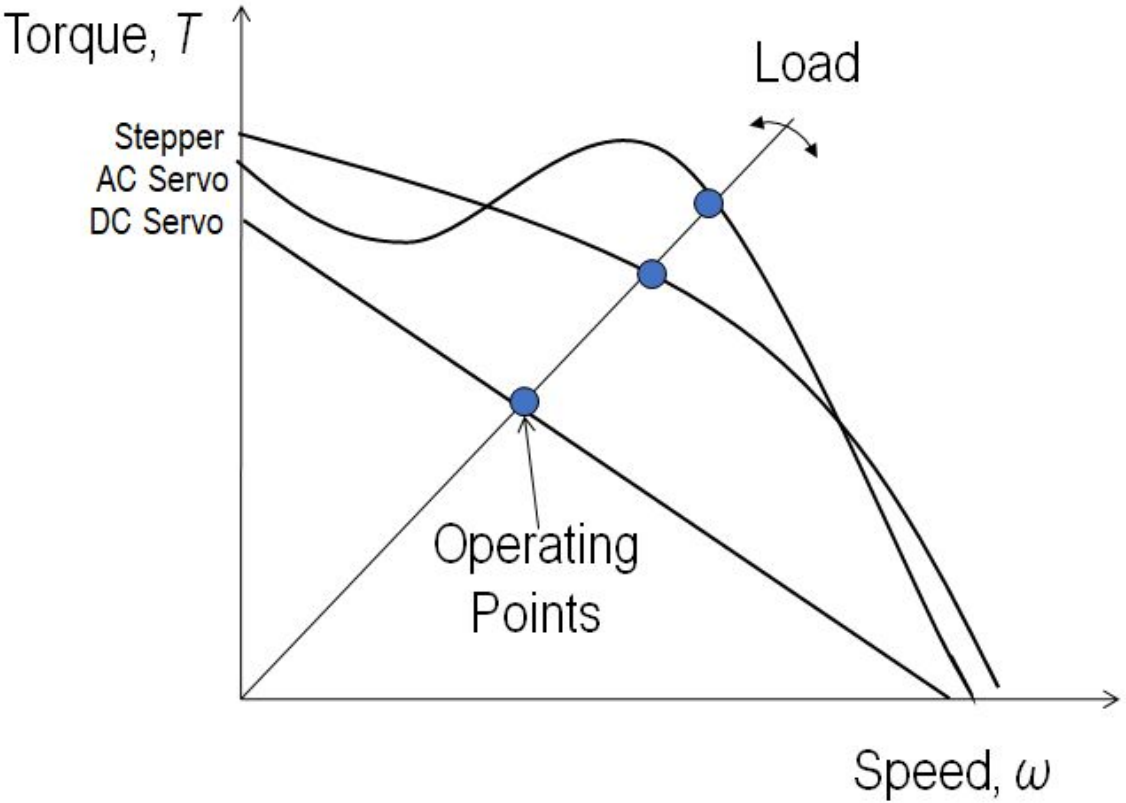
Servo Motors and Stepper Motors

- Steppers can accurately move between their many poles.
- Servos, with few poles, require an encoder to keep track of their position.
- Steppers simply move incrementally using pulses [open loop].
- Servo's read the difference between the motors encoder and the commanded position [closed loop], and adjust the current required to move.





Torque-Speed Curve



Stepper Motors

- Step angle is given by: $\alpha=360/n_s$
  - where n_s is the number of steps for the stepper motor (integer)
- Total angle through which the motor rotates is given by: $A_m=n_p\,\alpha$
  - where n_p = number of pulses received by the motor.
- Angular velocity is given by: $\omega=(2\pi f_p)/n_s$
  - where f_p = pulse frequency
- Speed of rotation is given by: $N=(60f_p)/n_s$

Example

A stepper motor has a step angle of 3.6°.

1. How many pulses are required for the motor to rotate through ten complete revolutions?
2. What pulse frequency is required for the motor to rotate at a speed of 100 rev/min?

Solution

(1) 3.6 = 360 / ns; 3.6 (ns) = 360; ns = 360 / 3.6 = 100 step angles

(2) Ten complete revolutions: 10(360) = 3600 = Am

Therefore np = 3600 / 3.6 = 1000 pulses

Where N = 100 rev/min:

100 = 60 fp / 100

10,000 = 60 fp

fp = 10,000 / 60 = 166.667 = 167 Hz

Summary

- A sensor is a device that receives and responds to a signal.
  - This signal must be produced by some type of energy, such as heat, light, motion, or chemical. Once a sensor detects one or more of these signals, it converts it into an analog or digital representation of the input signal.
- A transducer is a device which converts one form of energy into another.
  - Transducers are used in all aspects of life to measure changes in the environment, to enhance everyday applications, and to learn more about the world around us.
- An actuator is a device that converts energy into motion.
  - Therefore, it is a specific type of a transducer. When the output of the transducer is converted to a readable format, the transducer is called a sensor.

Project Building...