# EET-250 Handouts for Chapters 1 - 5.



## CHAPTER 1

## Introduction to Industrial Control Systems






## Introduction

- The Industrial Revolution represented the change from manufacturing processes based upon one-at-a-time production to mass production because of the advent of the steam engine. Eventually, the electric motor and hydraulic systems replaced steam, and Industrial Controls were developed to automate the manufacturing process.






## Industrial Control Classifications

- Motion and Process Control
  - Motion control - position or velocity
  - Process control - temperature, pressure, flow, level, pH, humidity, or chemical composition
    - Batch processing
    - Continuous processing






## Animation Lessons

To view an animation lesson on Industrial Control Classifications, link to

http://www.wisc-online.com/Objects/ViewObject.aspx?ID=IAU306





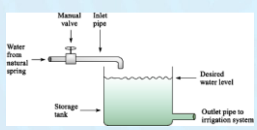

## Open- and Closed-Loop Systems

- How systems are controlled can also define the control process.
- Open-loop systems depend upon a command signal to inform the output device what to do.
- Closed-loop systems are self-correcting and allow for continuous operation without interruption.

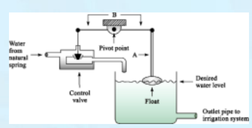





## Open- and Closed-Loop Level Control



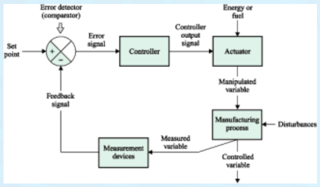

Open-loop level control requires manual operation to maintain proper level.




Closed-loop level control allows for unattended level control.

# Elements of Open- and Closed-Loop Systems

- Controlled Variable
- Measurement Device
- Feedback Signal
- Set Point
- Error Detector
- Error Signal
- Controller
- Actuator
- Manufacturing Process
- Disturbance







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# Animation Lessons

To view an animation lesson on the Elements of a Control Loop, link to

https://www.wisc-online.com/learn/career-clusters/stem/iau3306/elements-of-a-closed-loop-system

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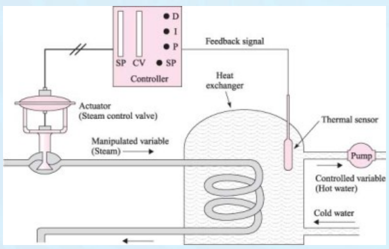


Closed-loop temperature control system

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# Closed-Loop Temperature Control System

- Closed-Loop Elements
  - Controller
  - Thermal Sensor
  - Feedback Signal
  - Actuator (Steam Control Valve)
  - Manipulated Variable (Steam)
  - Controlled Variable (Hot Water)

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# Temperature Set Point Decreased

- **Reaction**
  - Controller detects the measured temperature is higher than the set point.
  - Controller output causes the control valve to partially close.
  - Less steam through the heat exchanger lowers the temperature of the outgoing hot water.

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# Disturbance Lowers Water Temperature

- **Reaction**
  - Controller detects the measured temperature is less than the set point.
  - Controller output causes the control valve to open more.
  - More steam through the heat exchanger increases the temperature of the outgoing hot water.

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# Animation Lessons

To view an animation lesson on a Feedback System Application, link to

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# Dynamic Response

- Describes the time it takes for a corrective action when there is a disturbance or set point.
- Factors influencing the dynamic response are
  - Response Time
  - Time Duration
  - Static Inertia
  - Dead Time

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# Feed-Forward Control

- Two factors can make feedback control ineffective
  - Large magnitude disturbances
  - Large process lag times
- Feed-forward control prevents errors from occurring. However, feed-forward control is seldom used alone, typically in conjunction with feedback systems.

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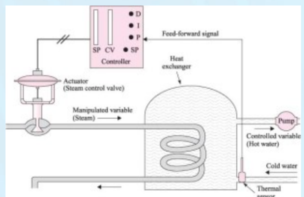


Feed-forward control of a temperature control system

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# Feed-Forward with Feedback Control

- The feed-forward control system does not operate perfectly.
- There are always immeasurable disturbances not detected, such as
  - Worn valve
  - Sensor out of tolerance
  - Inexact mathematical calculations used by the controller
- Adding a feedback system compensates for immeasurable disturbances.

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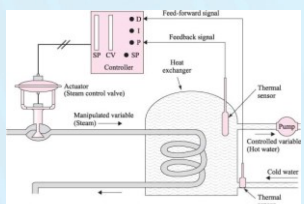


Feed-forward control loop with a feedback control loop

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# Animation Lessons

To view an animation lesson on a
Feed-Forward System Application, link to

http://www.wisc-online.com/Objects/ViewObject.aspx?ID=IAU3406

# CHAPTER 2

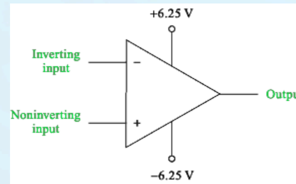
# Interfacing Devices






## Operational Amplifier Comparator

- Produces an output error signal determined by the difference between the two inputs.
- The outputs produced are either positive or negative saturation voltages 80% of the power supply values or 0 volts.









The following equations provide a summary of the Op Amp Comparator

Inverting input voltage < noninverting input voltage = positive output voltage

Inverting input voltage > noninverting input voltage = negative output voltage

Inverting input voltage = noninverting input voltage = zero output voltage






## Examples of How the Comparator Responds to Several Input Voltages

| Inverting Input Terminal (Volts) | Noninverting Input Terminal (Volts) | Output Saturation Voltage (Volts) |
|---|---|---|
| +1 | -1 | -5 |
| +1 | +2 | +5 |
| +2 | +1 | -5 |
| 0 | 0 | 0 |
| -1 | +1 | +5 |
| 0 | -1 | -5 |
| 0 | +1 | +5 |
| 3 | +3 | 0 |






## Animation Lessons

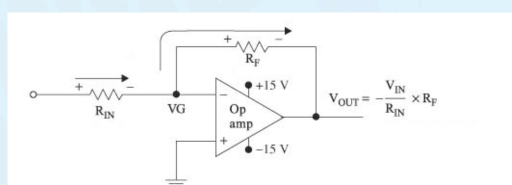
To view an animation lesson on Operational Amplifier Comparators, link to

https://www.wisc-online.com/Objects/ViewObject.aspx?ID=SSE4603






Inverting Op Amp



# Inverting Operational Amplifier

- The inverting op amp is capable of amplifying a voltage applied to its input.
- The amount that is amplified is determined by the resistance ratio of $R_F$ (feedback resistor) and $R_{IN}$ (input resistor).
- The amplified output cannot exceed 80 percent of the power supply voltage and its polarity is opposite to the polarity applied to the input.






The voltage produced at the output can be calculated by using this formula

$$V_{OUT} = \frac{R_F \text{ x } V_{IN}}{R_{IN}}$$

Where: $V_{OUT}$ = Output Voltage
$V_{IN}$ = Applied Input Voltage
$R_F$ = Feedback Resistor
$R_{IN}$ = Input Resistor






# Animation Lessons

To view an animation lesson on the Inverting Operational Amplifier, link to

https://www.wisc-online.com/Objects/ViewObject.aspx?ID=SSE5403






# Summing Operational Amplifier

- A summing op amp consists of two or more inputs tied together that are connected to the inverting input.
- It is capable of adding the algebraic sum of the inputs and then amplifying them to produce a negative or positive output.
- The amplified sum cannot exceed 80% of the power supply voltage.






# Animation Lessons

To view an animation lesson on the Summing Operational Amplifier, link to

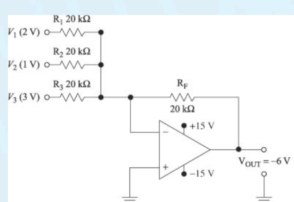
https://www.wisc-online.com/Objects/ViewObject.aspx?ID=SSE7306






The voltage produced at the output can be determined by the following calculations

Inverting Summing Amplifier




$$I_{R1} = \frac{V_{R1}}{R_1} = \frac{2\text{ V}}{20\text{ k}\Omega} = 0.1\text{ mA}$$

$$I_{R2} = \frac{V_{R2}}{R_2} = \frac{1\text{ V}}{20\text{ k}\Omega} = 0.05\text{ mA}$$

$$I_{R3} = \frac{V_{R3}}{R_3} = \frac{3\text{ V}}{20\text{ k}\Omega} = 0.15\text{ mA}$$

$$I_{R_F} = 0.1\text{ mA} + 0.05\text{ mA} + 0.15\text{ mA} = 0.3\text{ mA} \quad \text{or} \quad -0.3\text{ mA (inverted)}$$

$$V_{OUT} = I_{RF} \times R_F = -0.3\text{ mA} \times 20\text{ k}\Omega = -6\text{ V}$$

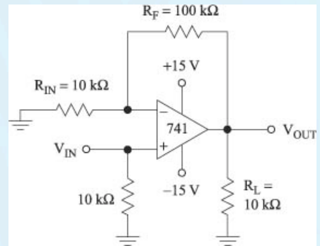
## Noninverting Operational Amplifier

- The noninverting op amp produces a voltage of the same polarity that is applied to the input.
- The amount that it amplifies is determined by the ratio of the input resistor and the feedback resistor.






Noninverting Operational Amplifier









## Animation Lessons

To view an animation lesson on the Noninverting Operational Amplifier, link to

https://www.wisc-online.com/Objects/ViewObject.aspx?ID=SSE7906






The voltage produced at the output can be calculated by using the following formula

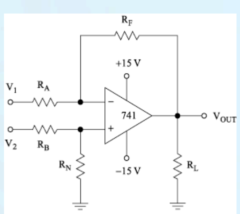
$$V_{OUT} = \left[1 + \frac{R_F}{R_{IN}}\right](V_{IN})$$






## Difference Operational Amplifier

- Finds the algebraic difference between two input voltages.
  - Signals are applied to both terminals and the difference between them is amplified




All resistors are 10 kΩ.






## Animation Lessons

To view an animation lesson on the Difference Operational Amplifier, link to

https://www.wisc-online.com/Objects/ViewObject.aspx?ID=SSE8006

# Integrator Operational Amplifier

- An integrator op amp replaces the feedback resistor with a capacitor.
- The magnitude of its output is proportional to the time period that a DC input signal is present.

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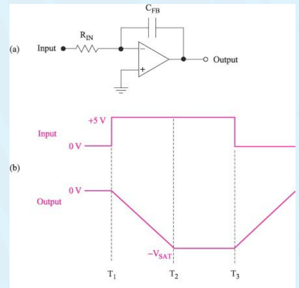
Integrator Operational Amplifier

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# Animation Lessons

To view an animation lesson on the Integrator Operational Amplifier, link to

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# Differentiator Operational Amplifier

- The input resistor is replaced by a capacitor in a differentiator operational amplifier.
- The magnitude of its output is proportional to the rate at which the input signal changes.

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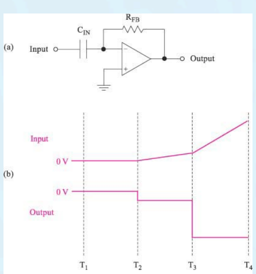
Differentiator Operational Amplifier

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# Animation Lessons

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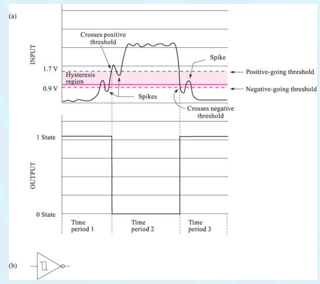
# Schmitt Trigger

- The Schmitt trigger is a device that converts sine waves or arbitrary waveforms into a square wave signal.
- It performs a hysteresis function in which it switches when the voltage of a positive going input is different than a negative going input.






Schmitt Trigger



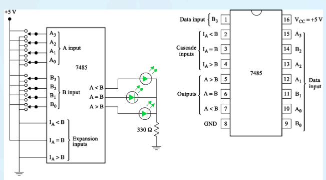






# Digital Magnitude Comparator

- Compares two binary numbers and indicates whether one number is greater than, smaller than, or equal to the other.









# Animation Lessons

To view animation lessons on the Digital Magnitude Comparator, link to

https://www.wisc-online.com/Objects/ViewObject.aspx?ID=DIG3403

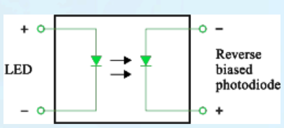
https://www.wisc-online.com/Objects/ViewObject.aspx?ID=DIG3703






# Optoelectronic Interface Devices

- Photodiodes
  - PN device used in reverse bias mode.
  - Current flow increases with the intensity of light falling upon the PN junction.



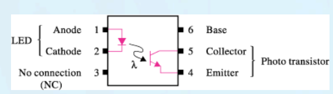






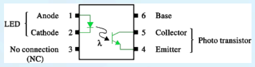
# Phototransistors

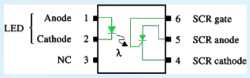
- Depend upon a light source instead of an external base lead.
- Higher current capacity than photodiodes, but slower response times.

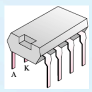


# Other Optoelectronic Devices

- Photo SCR
- Photo TRIAC
- Optoelectronic (optoisolator) Packaging



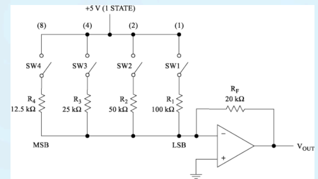








# Digital-to-Analog Converters

- Integrated-Circuit Digital-to-Analog Converter
- Converts digital signals to proportional analog signals







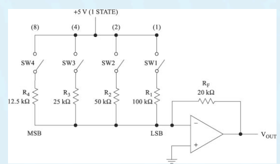


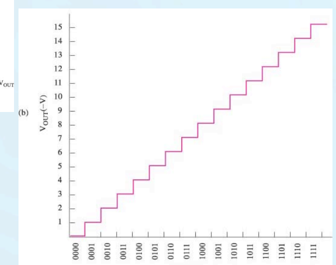
# Digital-to-Analog Converters (con't)

- The voltage produced at the output is equivalent to the binary number applied to the input of the position of the switches.
- The graph shows the analog output produced for digital inputs 0000-1111.






Analog output vs. digital input for the circuit shown above






# Digital-to-Analog Converters (con't)

- When a binary 1001 is applied to the input, the output is determined by the following calculations

$$I_{R1} = \frac{V_{R1}}{R_1} = \frac{5\ V}{100\ kohms} = .05\ mA$$

$$I_{R4} = \frac{V_{R4}}{R_4} = \frac{5\ V}{12.5\ kohms} = .4 mA$$

$$I_{RF} = .05 mA + .4\ mA = .45\ mA$$

$$V_{OUT} = I_{RF} \times R_F$$
$$= .45\ mA \times 20\ kohms = 9\ V$$

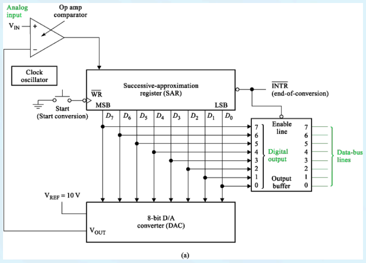





# Analog-to-Digital Converters

- Convert analog signals into proportional digital numbers.
- High speed A/D converters use Successive Approximation Registers.
- The more output bits that are available, the more accurate the conversion process.

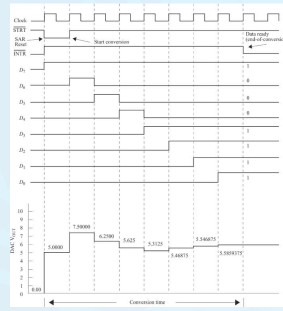
## Simplified SAR A/D Converter





Timing diagram for a successive-approximation-register ADC





## Timing Devices

- Produce rectangular pulses referred to as square wave signals or a continuous string of pulses
- Typically used as “clocks” for digital circuits
- 555 Astable Multivibrator
- 555 Monostable Multivibrator (one-shot)



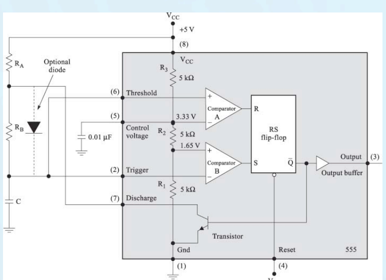
## Astable Multivibrator

- The astable multivibrator produces a continuous square wave when power is applied to the circuit.



Schematic diagram of the 555 IC astable timer





## Formula to Calculate Frequency

$$f = \frac{1.44}{(R_A + 2R_B)C}$$

# Animation Lessons

To view animation lessons on the Astable Multivibrator, link to

https://www.wisc-online.com/Objects/ViewObject.aspx?ID=SSE7806

https://www.wisc-online.com/Objects/ViewObject.aspx?ID=SSE8106

https://www.wisc-online.com/Objects/ViewObject.aspx?ID=SSE8206



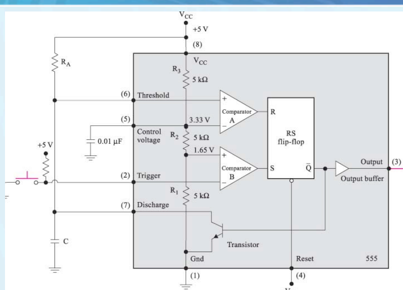


# Monostable Multivibrator

- The monostable multivibrator produces a logic 1 for a specified time when actuated by an input before it returns to a logic 0.








Schematic diagram of a 555 timer with the external timing components to form a monostable multivibrator





# Formula to Calculate Frequency

$$T = 1.1RC$$





# Animation Lessons

To view an animation lesson on the Monostable Multivibrator, link to

https://www.wisc-online.com/Objects/ViewObject.aspx?ID=SSE8306

# CHAPTER 3

# The Controller Operation






## Control Modes

- On-off
- Proportional
- Proportional-Integral
- Proportional-Integral-Derivative

All four control modes respond to error signals. They differ in speed and accuracy when correcting an error.






## On-Off Control

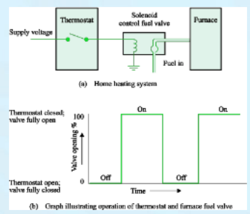
- The most basic of the control modes.
- On-off control is an all-or-nothing control method.
- One state is used when the controlled variable is above the set point; the other state is used when the controlled variable is below the set point.






## On-Off Controller

- Also referred to as two-position or bang-bang control.
- Home heating systems are typical examples of on-off control.



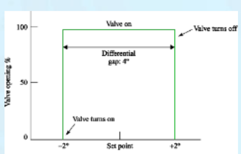






## Characteristics of On-Off Control

- Process disturbances cause the output to shift from the set point.
- Corrective action cannot adjust to match the process demand, typically cycling to correct for errors.
- To prevent rapid cycling, differential gap is added to the controller function.



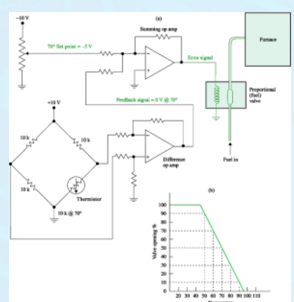






## Proportional Control

- Used where tighter control is required.
- Is called proportional as its output changes proportionally with the error signal.
- Can operate anywhere between full on and fully off.



## Controller Amplification

- Controllers have the capability of amplifying the amount of output based upon the proportion of its input signal.
- Amplification by a proportional controller is referred to as
  - Proportional Gain
  - Proportional Band

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## Proportional Gain and Proportional Band

- Proportional Gain is the ratio of change in output to change in input

$$\text{Gain} = \frac{\text{Percentage of Output Change}}{\text{Percentage of Input Change}}$$

- Proportional Band is the percentage change in the controlled variable that causes the final correcting element to go through 100% of its range

$$\text{PB} = \frac{\text{Controlled Variable \% Change}}{\text{Final Control Element \% Change}} \text{x}100$$

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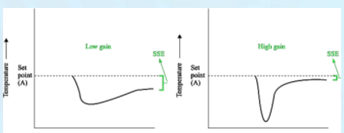
## Steady-State Error

- The result of long-term deviations in the controlled variable.
- Is often referred to as 'offset'.

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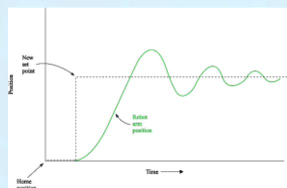
## Reducing Offset

- Decreasing the proportional band (adding gain to the system) can reduce offset.
- If too much gain is introduced, the system may become unstable and oscillate.

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## Proportional-Integral Control

- Integral (or reset) mode of control is designed to eliminate offset in a system.
- Integral control is always used in conjunction with proportional control.
- As an error occurs within a system, the proportional component makes an initial correction; if an error remains, the integral component adds to the corrective action.

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## Proportional-Integral Control (con't)

- The amount of control added to the proportional signal is dependent upon the length of time the error has been present, in other words, the integral of the time constant.
- Proportional-integral control is used where load changes occur frequently and set point changes are infrequent.
- Proportional-integral control is also used when load changes are slow.

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## Integral Operational Amplifier

- The amplitude of the integral signal is proportional to the time at which the offset exists.
- The integral function is used with the proportional mode when load changes are slow and more frequent than set point changes.






## Proportional-Integral-Derivative Control

- The derivative mode is used in a control system to reduce overshoot and oscillations within a control system.
- Derivative refers to a rate of change. A derivative controller produces a signal that is proportional to the rate of change of the error signal.
- Derivative control is never used alone.
- Derivative control is sometimes referred to as anticipatory or predictive control.






## Proportional-Integral-Derivative Control (con't)

- When the error signal is increasing, the derivative function provides a boost that aids the proportional function.
- When the error signal is decreasing, the derivative function provides a braking action.
- When the error signal is not changing, the derivative function does not exist.






## Time-Proportional Control

- A common way of controlling a DC voltage actuator, such as a DC motor, is by using time proportioning.
- Also known as the PWM (Pulse Width Modulation) Technique, time proportioning is a method in which a DC amplifier output is abruptly switched fully-on and fully-off.



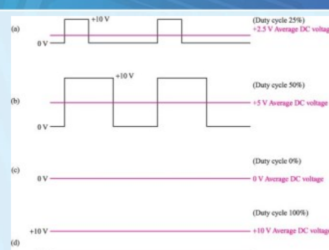



## Time-Proportional Control (con't)

- Changing the ratio of signal-on to signal-off varies the average voltage produced by the amplifier.
- The average voltage produced varies by how much power is applied to the actuator.
- The ratio of time the square wave is on to total time is called the duty cycle.






Waveforms of average DC voltages at different duty cycles: (a) 25 percent duty cycle; (b) 50 percent duty cycle; (c) 0 percent duty cycle; (d) 100 percent duty cycle

## Animation Lessons

To view an animation lesson on the Time Proportioning Operational Amplifier, link to

http://www.wisc-online.com/Objects/ViewObject.aspx?ID=SSE4503

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## Animation Lessons

To view an animation lesson on the Time Proportioning Application, link to

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# CHAPTER 4

# Pressure Systems




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## Pressure Laws

- Pressure is measured as force per unit area (pounds per square inch)
- **Pressure (P) = Force (F) / Area (A)**

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## Properties of a Liquid

- Molecules of a liquid are closely attracted to one another, giving the property of incompressibility.
- The ability of a liquid's molecules to flow and take the shape of its container is called viscosity.
- Head is used to describe the height of a liquid above the measurement point. It is expressed in inches, feet, or other units of distance.

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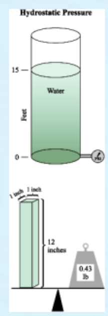
## Properties of a Liquid (con't)

- Density is the weight of a certain volume of liquid, expressed in pounds per unit volume.
- By multiplying the height of a liquid by its density, hydrostatic pressure can be calculated.
- Specific Gravity indicates how much lighter or heavier a substance is compared to water. Water has a specific gravity of 1.0.

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## Animation Lessons

To view an animation lesson on Hydrostatic Pressure, link to

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## Temperature and Atmospheric Pressure

- The temperature of a liquid affects the pressure it exerts.
- Increasing the temperature expands the liquid and increases the pressure if it is in an enclosed container. In an open vessel the hydrostatic pressure remains the same.

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## Atmospheric Pressure

- Normal atmospheric pressure is 14.7 psi at sea level.
- Atmospheric pressure will exert a force on a liquid in an open vessel.






## Properties of a Gas

- Gases are another type of fluid.
- A gas can be vapor, air, or steam.
- Gas molecules remain separate, unlike molecules in solids or liquids.
- Gases will distribute their molecules evenly within an enclosed container.
- Gases exert equal pressure in all directions.






## Temperature of a Gas

- Gas molecules are constantly moving.
- Gas molecules collide with one another in an enclosed container; a pressure gauge will interpret these collisions as one pressure.






## Temperature of a Gas (con't)

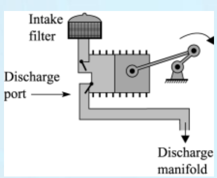
- When heat is applied to an enclosed container of gas, the molecules have more collisions and the pressure of the gas increases.
- If the gas is heated in an unenclosed container, the volume of the gas will increase and the pressure remains constant.






## Volume of a Gas Container

- When an area of an enclosed container is decreased, the space between the gas molecules is decreased.
- This action is called compression.
- Compression can also be achieved by increasing the amount of gas in a container using a compressor.









## Gas Removal from a Container

- As gas is removed from a container, the pressure decreases.
- Any reduction of pressure below atmospheric pressure is referred to as a partial vacuum.
- If all of the gas is removed, a full vacuum exists.
- A vacuum pump is used to remove gas from a container.

# Pressure Measurement Scales

- There are four basic scales used to measure pressure
  - Gauge pressure
  - Absolute pressure
  - Differential pressure
  - Vacuum pressure






# Gauge Pressure Scale

- Gauge pressure scales use atmospheric pressure as a reference.
- If the sensing element is exposed to the atmosphere, it registers zero pressure.
- The units of measurement are recorded as psig (pounds per square inch, gauge).






# Absolute Pressure Scale

- Absolute pressure is referenced to absolute zero, or the complete lack of pressure.
- Absolute pressures are always indicated by positive numbers.
- If the sensing element is exposed to the atmosphere, it will register 14.7 psia (pounds per square inch, absolute).






# Differential Pressure Scale

- Differential pressure is used to express the difference between two measured pressures.
- It is determined by subtracting the lower reading from the higher reading.





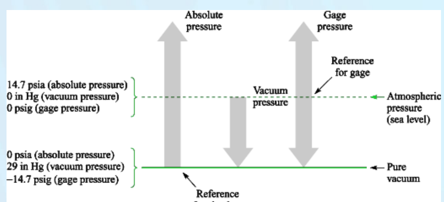

# Vacuum Pressure Scale

- Vacuum scales use atmospheric pressure as a reference point.
- Most common vacuum scales use inches of mercury (in Hg) to express the value.
- A vacuum gauge will read zero when measuring atmospheric pressure and 29.92 in Hg when measuring a complete vacuum.






# Comparison of Pressure Scales



## Animation Lessons

To view an animation lesson on Pressure Scales, link to

http://www.wisc-online.com/Objects/ViewObject.aspx?ID=IAU3806






## Pressure Measurement Instruments

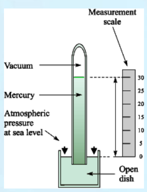
- Pressure control is an important process in many industrial applications requiring accurate measurement and control.
- Instruments are often classed by whether they make direct or inferred measurements.
- Both electronic and non-electronic instruments are used in pressure measurement.






## Liquid Column Gauges

- Measuring pressure is possible by monitoring the height of a liquid in a column.
- These gauges are very accurate and may be used as calibration tools for other instruments.
- A barometer is an example of a liquid column gauge.









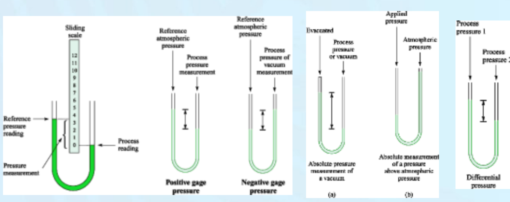
## Manometer

- The most common liquid column device to measure pressure is the manometer.
- Each column is exposed to a different pressure source.
- Read the rise of liquid in one column and the drop in the other, and add them together.






## Types of Manometers







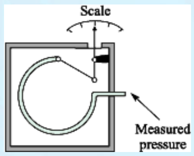


## Mechanical Gauges

- Mechanical gauges are more rugged than liquid-filled gauges and are often preferred.
- They are relatively inexpensive and reliably accurate.
- Major types of mechanical gauges include
  - Bourdon tube
  - Diaphragm gauge
  - Bellows gauge

## Bourdon Tube Gauge

- The Bourdon tube is a C-shaped metal tube.
- As pressure increases, the tube coil unwinds.
- As it unwinds, a needle attached to the end will move to indicate a higher pressure reading.
- Bourdon tubes are available to measure pressures from 0-15 psi and 0-6000 psi.



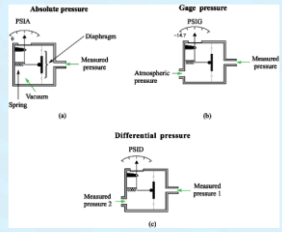






## Diaphragm Gauge

- Diaphragm gauges are quite common in industrial pressure systems.
- Diaphragm gauges are typically spring-loaded as a means of setting the range and sensitivity.
- Diaphragm gauges can be used to measure absolute, gauge, and differential pressures.



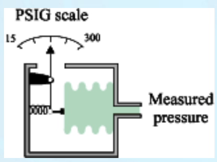






## Bellows Gauge

- Bellows gauges have wider ranges of operation than do diaphragm gauges because of the pleated sides of the bellows.
- Bellows material may be brass, phosphor bronze, or stainless steel.
- An opposing spring is used to control range and sensitivity.









## Electronic Pressure Sensors

- Electronic pressure sensors are more reliable, more accurate, and less expensive than many mechanical measuring instruments.
- Two types of pressure sensors are
  - Strain Gauges
  - Variable Capacitor Pressure Detectors





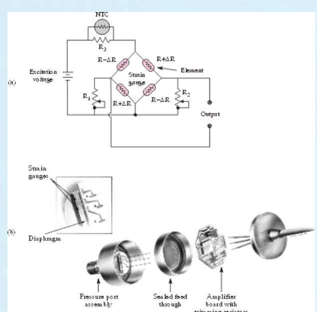

## Strain Gauge

- Strain gauges measure pressure by detecting the strain on an object caused by pressure.
- Strain gauges are typically constructed of piezoelectric semiconductor material.
- Pressure on the elements of a strain gauge causes the elements to expand or contract.
- Strain gauges are used as part of a Wheatstone Bridge to measure pressure.



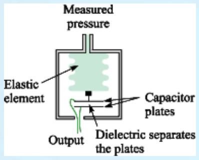



## Strain Gauge Configuration



# Variable Capacitor Pressure Detector

- Uses two conductive plates oriented adjacent to one another and separated by air
- One plate is fixed, and the other is attached to a bellows.
- The charge of the capacitor is influenced by the distance between the plates, and therefore, the pressure being exerted on the bellows.







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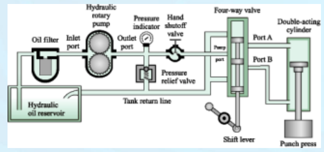
# Hydraulic Systems

- Hydraulic systems use oil-based fluids to develop high levels of pressure for many industrial applications.
- Hydraulic system components include
  - Pump
  - Filter
  - Valves
  - Control elements
  - Load
  - Reservoir

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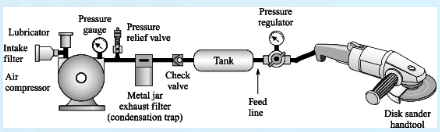
# Pneumatic Systems

- Pneumatic pressure systems are found in nearly every industrial facility.
- Operation is very similar to hydraulic systems except air is compressible and hydraulic fluid is not.

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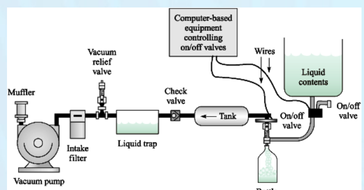
# Vacuum Systems

- Vacuum systems can be used to provide a number of functions in industrial applications.

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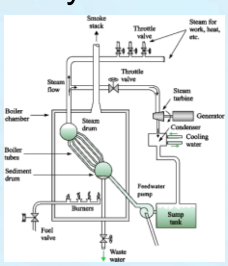
# Steam Pressure Systems

- Steam pressure is used for a variety of purposes in industry
  - Heat source for food processing
  - Refining
  - Chemical processing
  - Warming the facility

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# CHAPTER 5

# Temperature Control




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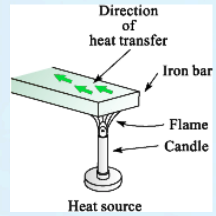
## Thermodynamic Transfer

- Transfer of heat through a solid is called conductance.
- Transfer of heat through fluids (liquids and gases) is called convection.
- Heat transfer may also occur by radiation, as is the case in a vacuum.

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## Fundamentals of Temperature

- Molecular motion creates heat known as thermal energy.
- Thermal movement from hot to cold is called thermodynamics.
- Absolute zero (no molecular motion) means no heat is produced.

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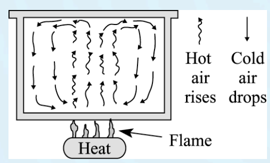
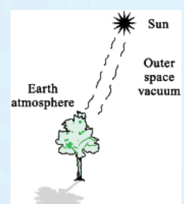
## Thermodynamic Transfer Examples

**Convection**




**Radiation**

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## Thermal Control Systems

- Thermal systems supply heat energy from a source, provide a path for distribution, and convert the energy into some form of work.
- Temperature in a Thermal Control System is controlled either manually or automatically.
- Two types of control systems used are
  - ON/OFF
  - Proportional

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## Animation Lessons

To view an animation lesson on Thermodynamic Transfer, link to

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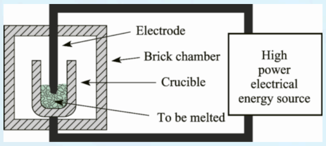
## Thermal Energy Sources

- Industrial Furnaces
  - Combustion Furnace
- Electric Furnaces
  - Arc Furnace
  - Resistance Furnace
  - Induction Furnace
- Cooling Systems







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## Temperature Measurements

- Reasons to monitor temperature
  - Control chemical reactions
  - Prevent over-temperature conditions
  - Maximize fuel efficiency

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## Temperature Scales

- Fahrenheit Scale
  - At sea level, the freezing point is 32° and the boiling point is 212°.
- Celsius Scale
  - At sea level, the freezing point is 0° and the boiling point is 100°.

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## Temperature Scales (con't)

- Each of these temperature scales can be converted to the other by the following equations

$$C° = 5/9\ (F - 32)$$
$$F° = (9/5 \times C) + 32$$

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## Thermal Energy

- Heat is thermal energy that has the ability to perform work.
- Thermal energy is rated in work units called
  - Calories
  - BTUs (British Thermal Units)

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## Thermal Energy (con't)

- A BTU is the heat required to raise the temperature of 1 pound of water 1 degree Fahrenheit.
- A calorie is the heat required to raise the temperature of 1 gram of water 1 degree Celsius.

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## Temperature Indicating Devices

- Crayons - melt at specific temperatures
- Paints - turn glossy at predetermined temperature
- Pellets - same principle as crayons; used when temperature is observed from a distance
- Labels - change color based upon temperature




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## Electronic Sensors

- Two main types
  - Thermoresistive - change resistance as the temperature varies
  - Thermocouples - produce a voltage proportional to the change in temperature

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## Temperature Indicating Devices (con't)

- Liquid Crystal Indicator
- Liquid Filled Thermometers
  - Glass thermometer
  - Filled-bulb thermometer
- Bimetallic Thermometers

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## Thermistors

- Thermistor - thermal resistor
- Exhibits large change in electrical resistance when subjected to small amount of temperature change.
- Exhibits negative temperature coefficient
  - Resistance is inversely proportional to temperature.

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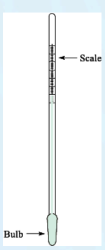
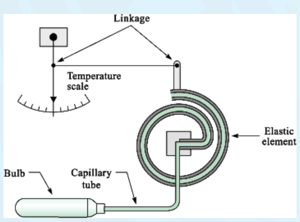
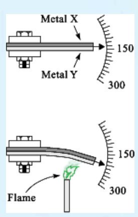
## Temperature Indicating Devices (con't)

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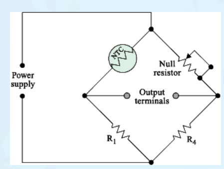
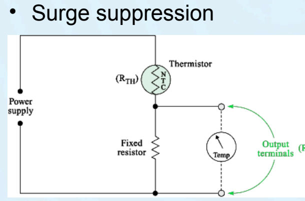
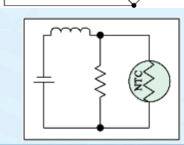
## How Thermistors Are Used

- Temperature measurement
- Temperature compensation
- Surge suppression

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# Resistance Temperature Detectors

- Metals have a positive temperature coefficient.
- RTD's use
  - Nickel - more sensitive to temperature changes
  - Platinum - wider range of temperatures




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# Temperature Sensor Comparison

| Type/Range | Advantages | Disadvantages |
|---|---|---|
| **Thermistor**<br>Resistive negative<br>Temperature coefficient<br>-40F to 300F | High sensitivity<br>Fast response<br>Low cost<br>Vibration resistant | Narrow temperature span<br>Nonlinear output |
| **RTD**<br>Resistive positive<br>Temperature coefficient<br>-150F to 1400F | Linear output<br>Large temperature span<br>Large resistance range<br>Interchangeability | Low sensitivity<br>High cost<br>Vibration |
| **Thermocouple**<br>Produces voltage or<br>Current proportional<br>to temperature<br>-300F to 4200F | Linear output within a<br>Given temperature range | Least sensitive<br>Requires reference |

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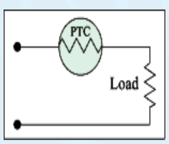
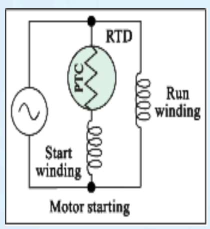
# RTD Applications

- Overcurrent protection
- Motor starting

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# Radiation Pyrometry

- Noninvasive temperature detection.
- Uses a pyrometer to detect temperature.
- Useful where conventional sensors may not be employed.
  - Moving objects
  - Extremely hot temperatures
  - Non-contact measurement required
  - Corrosive or hazardous environments
  - Where temperatures must be taken from a distance

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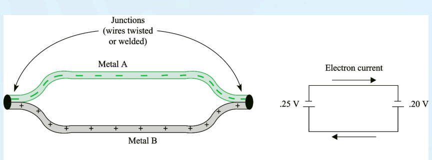
# Thermocouples

- Dissimilar wires joined at both ends.
- EMF is developed based upon the Seebeck effect.
- Converts heat into voltage.

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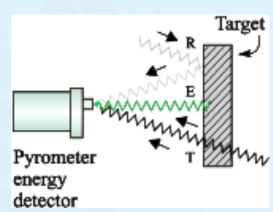
# Categories of Pyrometers

- Broadband
- Optical Detector
- Ratio Pyrometer

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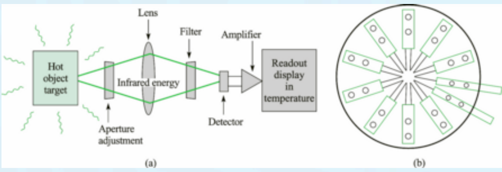
# Pyrometer Illustrations







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# Pyrometer Illustrations (con't)