Electronics Workforce Development System

Electromechanical/ Automated Control Systems Module

Brevard Community College

Cirent Semiconductor

Hillsborough Community College

Seminole Community College

University of Central Florida

University of South Florida

Valencia Community College

Introduction

Electromechanical/Automated Control Systems Module

This course is a study of devices and components that translate electrical energy into mechanical motion such as: stepper motors, DC motors, AC motors, solenoids, contactors, relays, etc. In addition, the course will offer an introduction to concepts in robotics and industrial process control.

Module Design

The Electromechanical/Automated Control Systems module was prepared at Valencia Community College based on recent needs identified by high-technology business and industry representatives. The module is designed for use in conjunction with the book by James H. Harter, Electromechanics: Principles, Concepts, and Devices. New York: Prentice Hall, 1995. As such, it contains an extensive outline of the topics to be covered in the course, as well as additional material from other references. This module is one of a series of modules that form part of the Electronics Workforce Development System.

About the Electronics Workforce Development System

The Electronics Workforce Development system is aiming to increase the number of skilled technicians available in the engineering/electronics field. The focus of this System is to improve the quality of courses in basic mathematics, science and engineering core courses, as well as more specialized engineering technology courses that yield technicians needed by the electronics industry.

After completing their education, community college graduates may elect to immediately seek employment in the engineering technology field or choose to pursue a four-year degree. Valencia Community College, Hillsborough Community College, Brevard Community College, and Seminole Community College have an articulation agreement with the University of Central Florida to offer a Bachelor of Science degree program in Electrical Engineering Technology (BSEET) or Engineering Technology (BSET).

About the NSF

The National Science Foundation (NSF), through the Advanced Technological Education (ATE) program has provided support for this project to strengthen science and mathematics preparation of technicians being educated for the high-performance workplace of advanced technologies.

Focusing on both national and regional levels, the ATE centers and projects result in major improvements in advanced technological education serve as models for other institutions, and yield nationally usable educational products.

For further information regarding this module, please contact:
William Morales, wmorales@valencia.cc.fl.us

VALENCIA
Community College

EST 2511C Electromechanical Systems

Course Outcome Summary

Course Information

Title	Electromechanical/Automated Control Systems
Course Number	EST 2511C
Credits	3
Organization	Valencia Community College
Developer	William Morales
Development Date	10/01/01
Instructional Level	Associate in Science (A.S.) or Associate in Arts (A.A.) Degree
Instructional Area	Electronics Engineering Technology

Types of Instruction

Instructional Type	Contact Hours	Outside Hours	Credits
Classroom	2		2
Laboratory	1		1
Totals	3	—	3

Target Population This course has been designed for students enrolled in the Electronics Engineering Technology (EET) program leading to an A.S. or A.A. degree.

Prerequisites PHY1007C (Physics) or PHY1053C (Introductory Physics I) and EET 1141C (Semiconductor Devices)

Course Description This course is a study of devices and components that translate electrical energy into mechanical motion such as: stepper motors, DC motors, AC motors, solenoids, contactors, relays, etc. In addition, the course will offer and introduction to concepts in robotics and industrial process control.

Textbooks Harter, James H. Electromechanics: Principles, Concepts and Devices. New York: Prentice Hall, 1995.

Supplies Motor Control Station, Manufacturer: Amatrol
Industrial Transducers Kit, Manufacturer: Amatrol
Pegasus Robot Station, Manufacturer: Amatrol
(supplies are required)

EST 2511C Electromechanical/Automated Control Systems
Syllabus

Course Information

Title	Electromechanical/Automated Control Systems
Course Number	EST 2511C
Credits	3
Organization	Valencia Community College
Instructor	William Morales
Office	9-220
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Office Hours	TBA
Prerequisites	PHY1007C (Physics) or PHY1053C (Introductory Physics I) and EET 1141C (Semiconductor Devices)
Course Description	This course is a study of devices and components that translate electrical energy into mechanical motion such as: stepper motors, DC motors, AC motors, solenoids, contactors, relays, etc. In addition, the course will offer an introduction to concepts in robotics and industrial process control.
Textbooks	Harter, James H. Electromechanics: Principles, Concepts and Devices. New York: Prentice Hall, 1995.
Supplies	Motor Control Station, Manufacturer: Amatrol Industrial Transducers Kit, Manufacturer: Amatrol Pegasus Robot Station, Manufacturer: Amatrol (supplies are required)

Grading Policy

Exam 1………….. 25%		**A**	90 – 100
Exam 2………….. 25%		**B**	80 – 89
Labs ……….……. 25%		**C**	70 – 79
Final Exam.....…. 25%		**D**	58 – 69
		F	0 – 57

Material to be Covered:

Session	Lesson	Topic
1	**1**	Terms, Abbreviations, Units and Symbols
2	**2**	Linear Motion: Force and Newton's Laws
3	**6**	Work, Power and Energy: Work, Power, Energy, Torque
4	**6**	Work, Power and Energy (cont.): Rotary Motion, Angular Measure, Angular Velocity
5	**7**	Power Transmission: Gears, Belts and Chain Drives
6	**TEST I**	TEST I – Material from Sessions 1-5
7	**10**	Electromagnetic Circuits and Devices: Magnetic Circuits, Magnetic Contactors, Relays, Solenoids
8	**15**	Introduction to Motors: DC Motors, Permanent Magnet, Series and Shunt DC motors
9	**14**	Introduction to Motors (cont.): AC Motors, Synchronous motor, Squirrel-Cage motor, Wound-Rotor motor
10	**14**	Introduction to Motors (cont.): NEMA induction motor classification, motor nameplate, Stepper Motors
11	**15**	Introduction to Motors (cont.): Single-phase AC motors
12	**TEST II**	TEST II – Sessions 7-11
13	**13**	Sequential Process Control: Input Devices, Output Devices, Analog Controllers
14	**13**	Sequential Process Control: Digital Controllers, PLCs and Ladder Logic
15	—	Introduction to Robotics
16	Final Exam – Comprehensive	

Core Abilities and Indicators Matrix

Core Ability	Indicator
1. Thinks Critically	1. Learner is able to link information from multiple fields into a coherent picture of the whole. 2. Learner is capable of abstract thought and theoretical insight. 3. Learner can identify a problem and come up with multiple solutions. 4. Learner can break down a problem into its constituent parts and analyze each. 5. Learner can evaluate the problem and determine an appropriate solution for a particular situation.
2. Learns Efficiently	1. Learner takes responsibility for his/her own learning. 2. Learner identifies and studies relevant facts. 3. Learner organizes information effectively. 4. Learner presents knowledge clearly and concisely. 5. Learner uses the appropriate resources to enhance the learning process.
3. **Applies Knowledge Successfully**	1. Learner understands the relationship between theoretical concepts and their practical application. 2. Learner can evaluate the limitations of applying abstract knowledge to real-world solutions. 3. Learner can evaluate the usefulness of theoretical insight to practical applications. 4. Learner is able to extrapolate the solution to future applications from situations encountered. 5. Learner can solve successfully real-world problems with knowledge acquired conceptually.
4. **Communicates Effectively**	1. Learner is able to express him/herself concisely. 2. Learner is able to convey complex technical information in an understandable manner. 3. Learner communicates effectively using the written word. 4. Learner knows how to present data using the best tools available. 5. Learner is able to summarize the most important fact or idea of a given topic.
5. **Works well With Others**	1. Learner can work cooperatively. 2. Learner can communicate with others effectively. 3. Learner is a team player. 4. Learner can assume responsibility in a group environment. 5. Learner is sensitive to the opinions of others.

Competencies and Performance Standards Matrix

Competency	1. Understand Force and Newton's Laws of Motion
Criteria	**Performance will be satisfactory when:** 1. Learner can name all three of Newton's Laws of Motion. 2. Learner understands how to use the equations applicable when there is uniform acceleration. 3. Learner can effectively communicate the difference between SI units and British units.
Conditions	**Competence will be demonstrated through:** 1. Homework problems. 2. Laboratory exercises. 3. Written examination.
Learning Objectives	1. Develop a clear understanding of the importance of units and their relevance to practical problem solving. 2. Articulate the importance of Newton's Laws in the understanding of electromechanical device behavior.

Competency	2. Know how the Concepts of Energy, Torque and Power are Applied to Electrical Machines
Criteria	**Performance will be satisfactory when:** 1. Learner is able to describe the difference between energy and power. 2. Learner can give the correct definitions for kinetic, potential and rotational energies. 3. Learner knows how to calculate torque and frictional forces of simple machines.
Conditions	**Competence will be demonstrated through:** 1. In-class exercises. 2. Laboratory exercises. 3. Written examination.
Learning Objectives	1. Understands how the concepts mentioned above can help us in analyzing the performance of real-world machines. 2. Can successfully explain the importance of machine efficiency in an industrial environment.

Competency	3. Understand Both Theoretical as Well as Practical Concepts Having to Do Power Transmission
Criteria	**Performance will be satisfactory when:** 1. Learner understands the different types of gears used and their applications. 2. Learner is able to calculate the gear ratio and torque ratio of simple gear systems. 3. Learner can name the model belts available and their use in rotational power transmission.
Conditions	**Competence will be demonstrated through:** 1. Practical lab experiments. 2. Written examination. 3. Homework assignments.
Learning Objectives	1. Develops knowledge of where the different types of gears and belts are appropriate. 2. Articulates the effects upon machinery maintenance of using different types of rotational power transmission elements.

Competency	4. Understand Electromagnetic Circuits
Criteria	**Performance will be satisfactory when:** 1. Learner understands how to use magnetic circuits and their importance in electrical machine analysis. 2. Learner is able to express the difference between magnetic flux, magnetic density, magnetomotive force and field strength. 3. Learner is able to distinguish between a contactor, a solenoid and a relay.
Conditions	**Competence will be demonstrated through:** 1. In-class demonstrations. 2. Homework assignments. 3. Laboratory exercises.
Learning Objectives	1. Knows how magnetic field saturation in ferromagnetic materials affects magnetic circuits. 2. Understands when and how contactors, solenoids and relays are used in an industrial environment.

Competency	5. Study and Understand Electrical Motors
Criteria	**Performance will be satisfactory when:** 1. Learner has understood how to distinguish between DC and AC Motors and the relative advantages and disadvantages of the two. 2. Learner possesses a clear understanding of the different types of DC and AC motors available. 3. Learner knows what the NEMA categories of induction motors are, and knows what information is contained in a motor nameplate.
Conditions	**Competence will be demonstrated through:** 1. Active class participation. 2. Laboratory exercises. 3. Written assignments.
Learning Objectives	1. Acquires technical understanding of how each of the different motors work. 2. Understands motor application, maintenance and suitability, especially in an industrial environment.

Competency	6. Develop a Working Knowledge of Sequential Process Control
Criteria	**Performance will be satisfactory when:** 1. Learner is capable of naming input and output devices used in sequential process control. 2. Learner can distinguish between analog and digital controllers, how they work and the relative advantages and disadvantages of each. 3. Learner is able to read a Ladder Logic diagram.
Conditions	**Competence will be demonstrated through:** 1. Homework problems. 2. Laboratory exercises. 3. Examinations.
Learning Objectives	1. Knows the suitability of each input sensor to measure a specific physical variable and the output device to control it. 2. Characterizes the accuracy of each sensor and output device and names their maintenance characteristics.

Competency	7. Become Familiar with the Principles Governing Industrial Robot Application
Criteria	**Performance will be satisfactory when:** 1. Learner understands the configurations of industrial robots and their applicability. 2. Learner is familiar with the types of teaching methods available for industrial robots. 3. Learner knows the different coordinate systems employed with robotic control.
Conditions	**Competence will be demonstrated through:** 1. In-class exercises. 2. Research assignments. 3. Laboratory exercises.
Learning Objectives	1. Knows which robot design to chose for different manufacturing tasks. 2. Establishes the pros and cons of robot utilization for a given manufacturing operation.

Table of Contents

Lesson 1

Linear Motion

Terms, Abbreviations, Units and Symbols

Term	Symbol	Definition
Force	**F**	= a push or pull that tends to cause motion or tends to stop motion
Inertia	**p**	= the property of objects to resist changes in their motion
Mass	**m**	= the quantity of matter that a given object possesses
Weight	**w**	= the force exerted by gravity upon an object
Displacement	**s**	= the change in the position of an object
Velocity	**v**	= the rate of change of an object’s position an direction with time
Speed		= the magnitude of the velocity
Acceleration	**a**	= the rate of change of velocity with time

Term	SI Unit Name	SI Unit Symbol	BES Unit Name	BES Unit Symbol
Force	newtons	N	pound	lb
Inertia	N/A	kg·m/s	N/A	slugs
Mass	kilograms	kg	slug	slug
Weight	newtons	N	pound	lb
Displacement	meters	m	feet	ft
Velocity	meters per second	m/s	feet per second	ft/s
Acceleration	N/A	m/s^2	N/A	ft/s^2

Force

Force can be defined as a push or pull upon an object that tends to cause motion or tends to stop motion.

Newton's Laws of Motion

- Newton's First Law**:** Law of Inertia

An object at rest will remain at rest, and an object in motion will remain in motion at the same speed and direction unless it is acted upon by an outside force.

- Newton's Second Law: Law of Acceleration

When a net outside force (F) acts on an object of mass (m) and causes it to accelerate, the acceleration may be computed by the formula:

$$\mathbf{F = m\,a}$$

where,
the acceleration is in the direction of the net outside force.

- Newton's Third Law: Law of Action and Reaction

Forces always occur in pairs; that is, for every action there is an equal and opposite reaction with equal force but opposite direction.

When the acceleration (force) of the body is constant, the following equations can be defined:

$$\mathbf{v = v_0 + a\ t}$$

where,
v = speed of object (m/s)
$\mathbf{v_0}$ = initial speed of object (m/s)
a = constant acceleration (m/s^2)
t = time (seconds)

$$\mathbf{x = x_0 + v_0\ t + \tfrac{1}{2}\ a\ t^2}$$

where,
x = distance object travels (meters)
$\mathbf{x_0}$ = original displacement (meters)
t = time (seconds)
a = constant acceleration (m/s^2)

Lesson 2

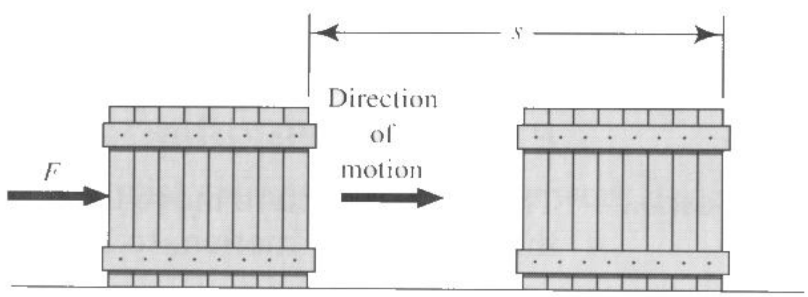
Work, Power and Energy

Work

Mechanical Work is done when a force is applied to an object and the object moves. The fundamental unit of work in the SI system is the joule (J), and in the BES system it is the foot-pound (ft-lb). Stated as an equation:

$$\mathbf{W = F\ s}$$

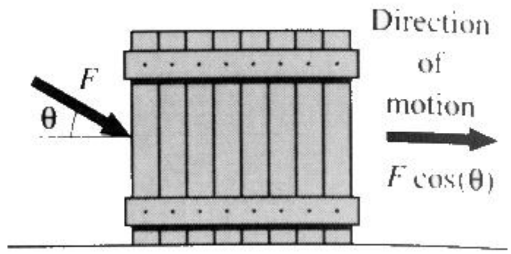
where,
W = work done by a force in moving a mass a distance a (J or ft-lb)
F = force applied to the object to get it to move (N or lb)
s = distance the object moved (m or ft)



If the applied force is not in the same direction as the movement, the equation for mechanical work becomes:

$$\mathbf{W = F\ s\ cos\ (\theta)}$$

where,
W = work (J or Ft-lb)
F = force (N or lb)
s = distance (m or ft)
θ = angle between the line of action of the force and the line of movement (direction of motion), in degrees. (See the figure shown below.)



Frictional Forces

Whenever the surface of a body rubs slides over the surface of another body, the bodies exert a frictional force on the other. When the bodies are at rest, they exert a frictional force called static friction. The magnitude of this static friction force is given by:

$$\mathbf{F_s = \mu_s N}$$

where,

$\mathbf{F_s}$ = static friction force
$\boldsymbol{\mu_s}$ = static friction coefficient (dependent on surface material)
N = magnitude of normal force between two surfaces

When the two bodies are in motion, they exert a kinetic frictional force given by:

$$\mathbf{F_k = \mu_k N}$$

where,
$\mathbf{F_k}$ = kinetic friction force
$\boldsymbol{\mu_k}$ = kinetic friction coefficient (dependent on surface material)
N = magnitude of normal force between two surfaces

Power

Power is the rate at which energy is converted, transformed or expended. The fundamental unit of power in the SI system is the watt (W), and in the BES systems it is the horsepower (hp). Stated mathematically,

$$\mathbf{P} = \frac{\mathbf{W}}{\mathbf{t}}$$

where,
P = average power (W or ft-lb/s)
W = energy transformed or the work done (J or ft-lb)
t = time during which the work is done or energy is transformed (seconds)

A useful form of the power equation expressed in terms of velocity and force is:

$$\mathbf{P} = \mathbf{F}\ \mathbf{v}$$

where,
P = power (W or ft-lb/s)
F = force (N or lb)
v = velocity (m/s or ft/s)

Energy

Mechanical energy can be classified into two categories: potential energy and kinetic energy. Mechanical energy follows the law of conservation of energy, which states that: “Energy can neither be created nor destroyed but can only be converted from one form to another.” Energy and work are measured in the same units: joules in the SI system and foot-pounds in the BES.

Potential Energy

Potential Energy is the energy possessed by an object due to its position. The potential energy (PE) of an object at rest above a surface is exactly equal to the work done in lifting the object and it is given by:

$$\mathbf{PE = m\ g\ h}$$

where,
PE = potential energy of the object (J or ft-lb)
m = mass (kg or slugs)
g = acceleration due to gravity, 9.8 m/s^2 or 32 ft/s^2
h = height of object above the reference surface (m or ft)

Kinetic Energy

Kinetic energy is the energy due to the motion of an object. Mathematically, we have that:

$$\mathbf{KE = \tfrac{1}{2}\ m\ v^2}$$

where,
KE = kinetic energy of object (J or ft-lb)
m = mass of object (kg or slugs)
v = speed of object (m/s or ft/s)

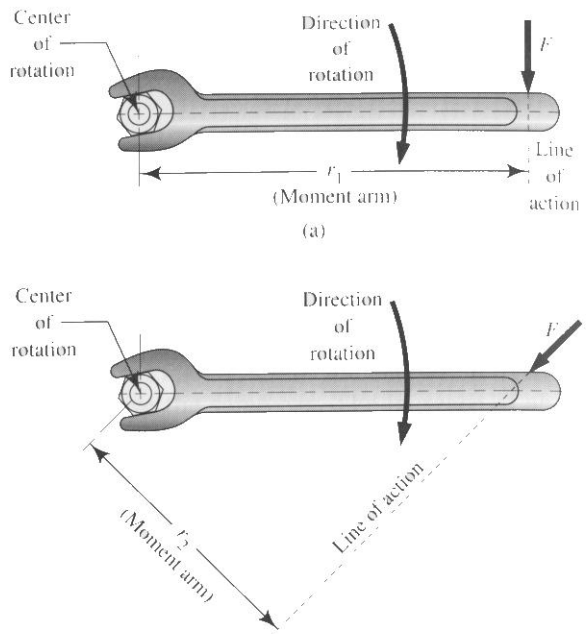
Torque

Torque is a force applied through a distance that results in a twisting or turning effect. The distance through which the force is applied to create a torque is referred to as the moment arm of the force. The length of the moment arm is determined by taking the perpendicular distance between the line of action of the force and the center of rotation (the pivot point). Torque in the SI system is measured in newton-meters (N·m), and in BES it is measured in pound-feet (lb-ft).

Stated as a formula, torque is the product of the force applied to the moment arm times the length of the moment arm:

$$\boldsymbol{\tau} = \mathbf{F}\ \mathbf{r}$$

where,
τ = torque (N·m or lb-ft)
F = force applied to the moment arm (N or lb)
r = length of the moment arm (m or ft)



Rotary Motion

Rotary motion implies that an object is turning around an axis. That is, the object spins around a central point. Some of the variables used in the study of rotary motion are described below.

Angular Displacement:

Angular displacement indicates the angle that an object has turned in a given interval of time. The symbol used typically to denote angular displacement is the Greek letter theta (θ).
Various systems are in use for measuring angular displacement:

- Degrees: The subdivision of a circle swept out by a rotating object, where the circle is 360º.
- Radians: The ratio of the length of an arc of a circle to the length of the radius of the circle.
- Revolutions: The number of times an object revolves about an axis.

Angular Velocity:

Angular velocity is the rate of change of angular displacement with respect to time. When the rotary motion is uniform, we have that:

$$\boldsymbol{\omega = \frac{\theta}{t}}$$

where,
ω = angular velocity (rad/s)
θ = angular displacement (rad)
t = time (s)

Angular velocity is also commonly measured and expressed in revolutions per minute (rev/min or rpm). A simple conversion factor from revolutions per minute to radians per second is
1 rev/min = 0.1047 rad/s.

Angular Acceleration:

Angular acceleration is the rate of change of angular velocity with time. It is measured in radians/second/second (rad/s^2). The Greek letter alpha (α) is typically used to denote angular acceleration.

Lesson 3

Power Transmission

Gears

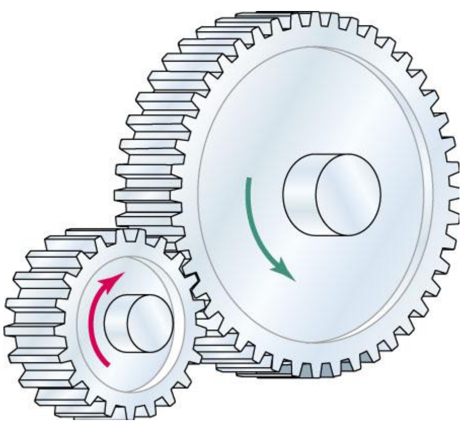
Gears provide positive transmission of rotational power (rotary motion and torque) from one shaft to another.

Types of Parallel-Shaft Gears

Shafts that are parallel are connected by spur gears, helical gears, or herringbone gears (double helical gears).

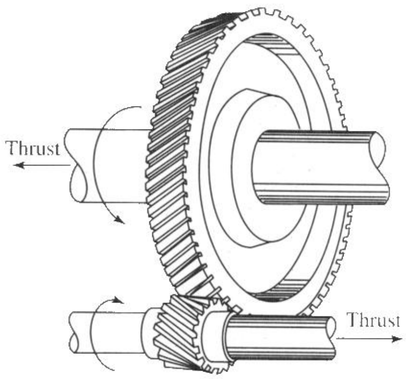
Spur Gears

Spur gears are inexpensive and widely used. However, with this type of design, only a single tooth carries the entire torque load. They are available in a wide variety of sizes and materials.



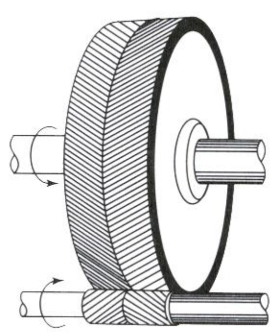
Helical Gears

Helical gears are quieter than spur gears. Because the teeth are inclined at an angle, however, they create an axial thrust that must be counterbalanced by using thrust bearings.



Herringbone Gears

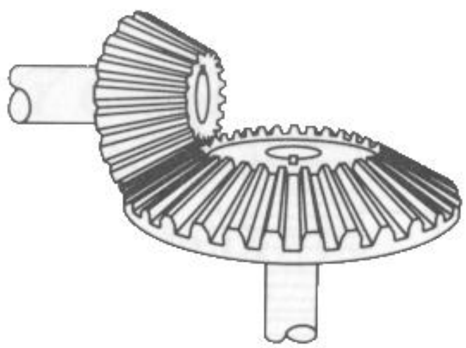
Herringbone (or double helical) gears are used to eliminate the axial load present with helical gears. They run smoothly and are used extensively for high-speed applications.



Types of Right Angle Shaft Gears

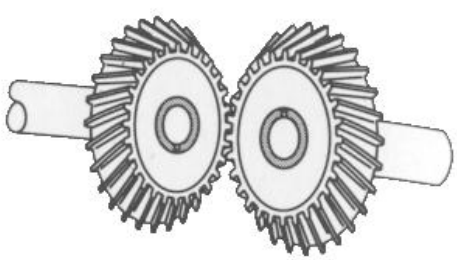
Shafts coming together at right angles use bevel gears to transmit torque. They are usually sold as matched sets with either straight or helical teeth.

Straight Bevel Gears



Spiral Bevel Gears

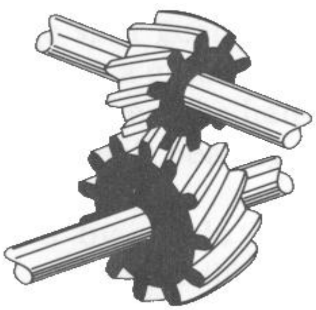
Like the helical gear, this type of gear suffers from the problems of axial thrust.



Types of Crossed-Axis Shaft Gears

Crossed-axis shafts (shafts that do not intersect) are connected by helical gears or worm gear sets.

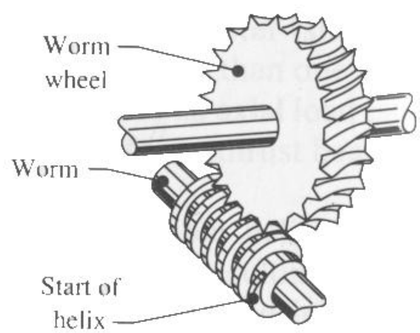
Crossed-Axis Helical Gears



Because of their helical nature, these types of gears also develop an unwanted axial thrust component.

Worm Gears

Worm gears are usually used in applications requiring high torques at low speeds. Worm gears are unusual in that only the worm can drive the wheel and not the other way around.



Gear Ratio

The angular velocity ratio of a set of meshed gears is referred to as the gear ratio. Gear ratio equals:

$$\frac{\omega_D}{\omega_d} = \frac{N_d}{N_D} = \frac{PD_d}{PD_D}$$

where,
ω_D = angular velocity of driver gear (rad/s or rev/min)
ω_d = angular velocity of driven gear (rad/s or rev/min)
N_D = number of teeth on the driver gear
N_d = number of teeth on the driven gear
PD_D = pitch diameter of the driver gear (in.)
PD_d = pitch diameter of the driven gear (in.)

Torque Ratio

The torque ratio between of two gears is given by the following relationship. Torque ratio

$$\frac{r_d}{r_D} \quad \frac{\tau_d}{\tau_D}$$

where,
r_D = radius of driver gear (m or ft)
r_d = radius of driven gear (m or ft)
τ_D = torque at the driver gear (N·m or lb-ft)
τ_d = torque at the driven gear (N·m or lb-ft)

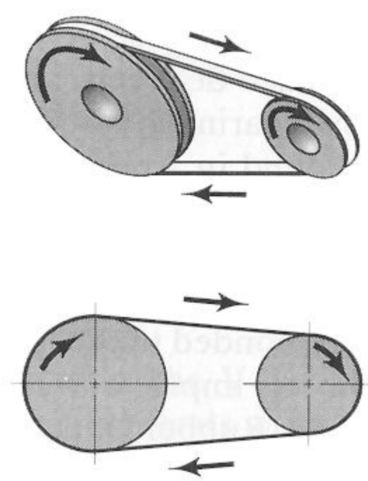
Belt Drives

Belt drives transmit power between parallel shafts through the use of belts and pulleys. The advantages of belt drive systems include: low noise, long working distances possible, no lubrication and they are relatively inexpensive.

Types of Belt Drive Systems:

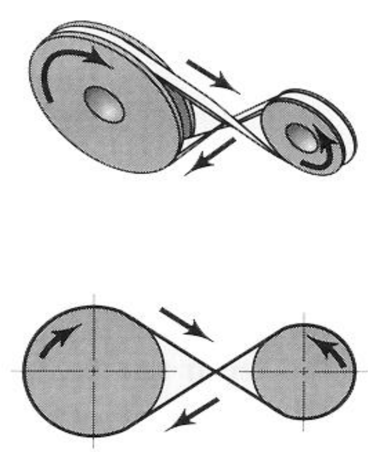
Open-Belt System

In this type of belt drive system, the driver pulley, the driven pulley and the belt are all rotating in the same direction.



Crossed-Belt System

In the crossed-belt type of system, the pulleys rotate in opposite directions.

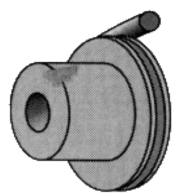


Belt Types:

Belts may be divided into four general categories:

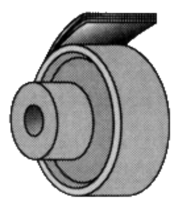
Round Belts

These types of belts are used when bends and twists of the belt are expected. They are used with light loads.



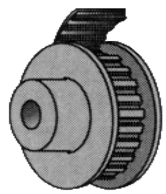
Flat Belts

Flat belts are used for both low-power and high-power applications. They require correct tensioning to maintain the proper frictional force to drive the load. Their operation is relatively quiet.



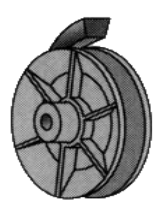
Synchronous Belts

Synchronous belts (often called timing belts) are used where power transmission and proper positioning (no slippage) are important. Because of their toothed nature, synchronous belts can also be used in very high-speed applications.



V-Belts

This is the most common type of belt. In this system, the sides of the belt rest against the inside of the pulley, and the friction between the two increases with increasing load. This results in the belt being able to transmit a higher torque. V-belts are typically very quiet in operation.



Center Distance and Belt Length

The length of the belt needed to connect two pulleys is given by:

$$L = 2CD + \pi/2\ (D + d)$$

where,
L = pitch length (pitch circumference) of the belts (inches)
CD = Center distance between the shaft supporting the driver and the one supporting the driven pulley (inches)
D = pitch diameter of larger pulley (inches)
d = pitch diameter of smaller pulley (inches)

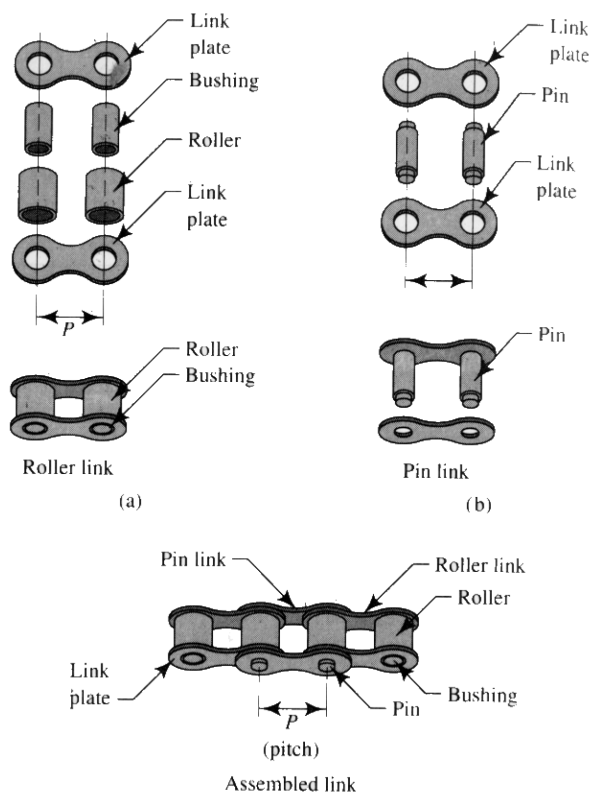
Chain Drives

Chain drives, like gearing and belt drives, transmit power from the driver element to the driven element. Chain drives are used in three principal applications:

- Transmission of power
- Conveyance of materials
- Synchronizing of movement

Unlike belt drives, which rely on friction, chain drives require little or no pretensioning, are more compact in size for the same design power rating and don’t creep or slip. There are several types of chain drives, however, the standard roller and inverted tooth (silent) types are most often used in power transmission in industrial, commercial and agricultural applications.

Standard Roller Chain

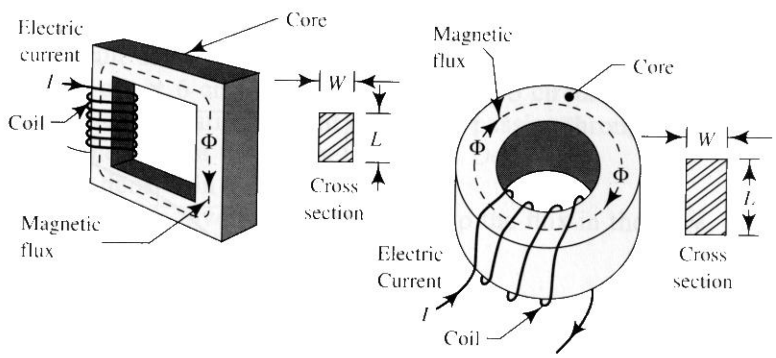


Lesson 4

Electromagnetic Circuits and Devices

Electromagnetic Circuits

A series electromagnetic circuit is formed when a closed ferromagnetic pathway, called a core, is wrapped with a coil of insulated wire thought which electric current is passed.



Terms, Formulas, Units, and Symbols

Magnetic Flux (Φ)

Circulates in the core of the magnetic circuit when current passes through the coil. Magnetic flux is measured in units of webers (Wb) in the SI system.

Flux Density (B)

The magnetic flux density is the amount of magnetic flux per unit cross sectional area. It is used as an indicator of the force of the magnetic flux. The flux density in the core of a magnetic circuit is measured in teslas (T). Stated mathematically:

$$\mathbf{B} = \frac{\boldsymbol{\Phi}}{\mathbf{A}}$$

where,
B = flux density (T)
Φ = flux in the core (Wb)
A = area (m^2)

Magnetomotive Force (mmf)

In order for magnetic flux to be present in the core, a magnetomotive force must be applied to the magnetic circuit. The magnetomotive force can be obtained by the following formula:

$$\mathbf{mmf = N\ I}$$

where,
mmf = magnetomotive force (A, amp-turns)
N = number of wire turns in the coil
I = electric current in the coil (A, amps)

Magnetic Field Strength (H)
The magnetic field strength takes into account the length of the path taken by the magnetic flux around the circuit. The mathematical equation is:

$$\mathbf{H} = \frac{\mathbf{mmf}}{\mathbf{l}}$$

where,
H = magnetic field strength (A/m, amp-turns per meter)
mmf = magnetomotive force (A, amp-turns)
l = average length of the magnetic path (m)

Permeability of the Core Material (μ)

The permeability of a substance is an indication of its ability to carry magnetic flux when acted on by a magnetomotive force. The relationship between the flux density, field strength and permeability is:

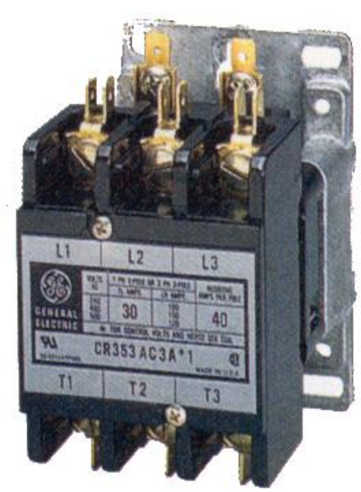
$$\mathbf{B} = \boldsymbol{\mu}\, \mathbf{H}$$

where,
B = magnetic flux density (T)
μ = permeability of the material in the magnetic core (Wb/A·m)
H = magnetic field strength (A/m)

Magnetic Contactors

- Electromagnetically operated switch
- Serves to open and close high-energy electric circuits
- Designed to connect the source voltage to the load (lights, heaters, transformers, etc.)
- Uses sets of high-current, low-resistance contacts

3-Pole Magnetic Contactor



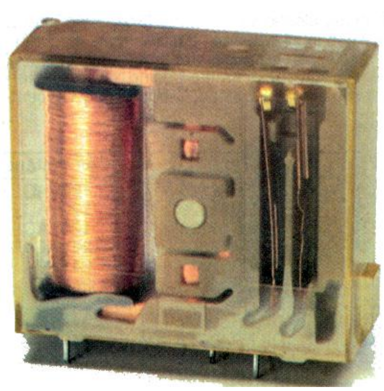
Relays

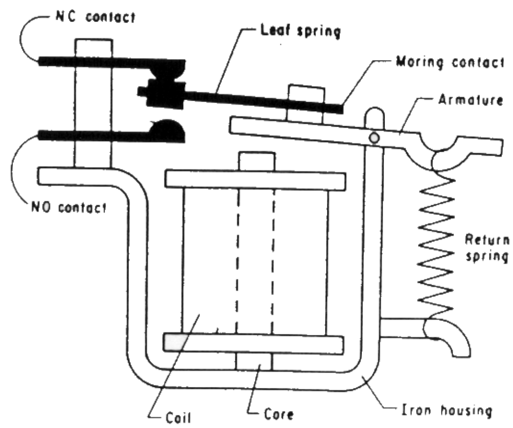
Applications of relays:

- Remote operation of loads
- Control of high power loads with small power signals
- Circuit electrical isolation
- Logical operations

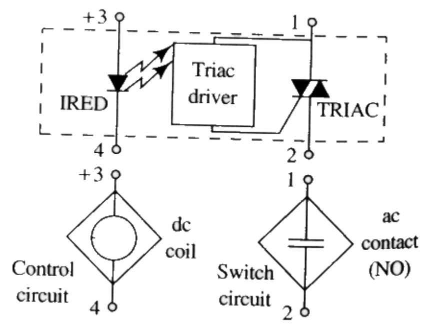
Types of Relays:

Electromechanical (Coil)





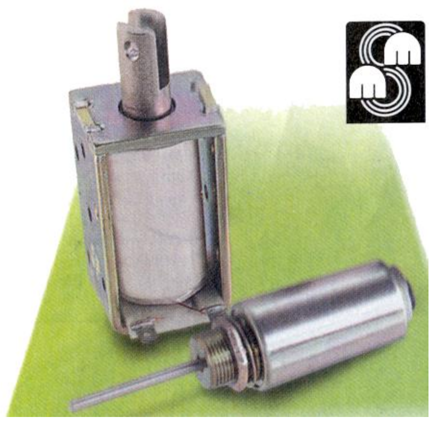
Solid State Relay (SSR)

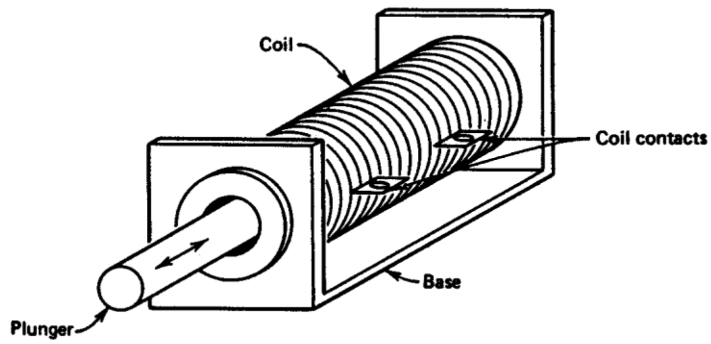


Solenoids

Properties:

- Electromechanical device
- Consists of a coil and a plunger
- Provides short linear movement
- Displacement limits are mechanical
- Coil can be AC or DC
- Force depends on the particular model





AC Solenoid:

- Does not need DC power supply
- Makes more noise than DC solenoid
- Burns out more easily than DC solenoid
- Initial force greater than DC

DC Solenoid:

- Does not burn out as easily as AC
- Can use “magnetic latching”
- Contributes to contact deterioration

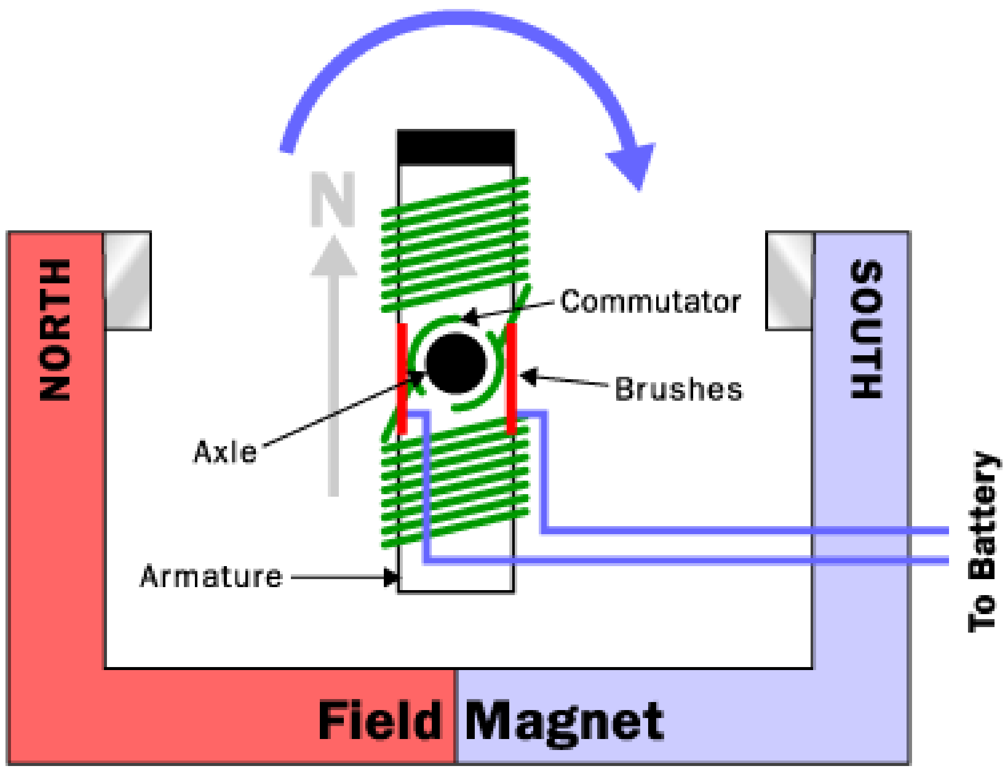
Lesson 5

Introduction to Motors

DC Motors

Direct Current (DC) motors are used in industrial applications because of the ease with which their speed can be controlled. Also, the direction of rotation of a DC motor can be changed without power switching.

The main parts of a DC motor are shown in the figure below.

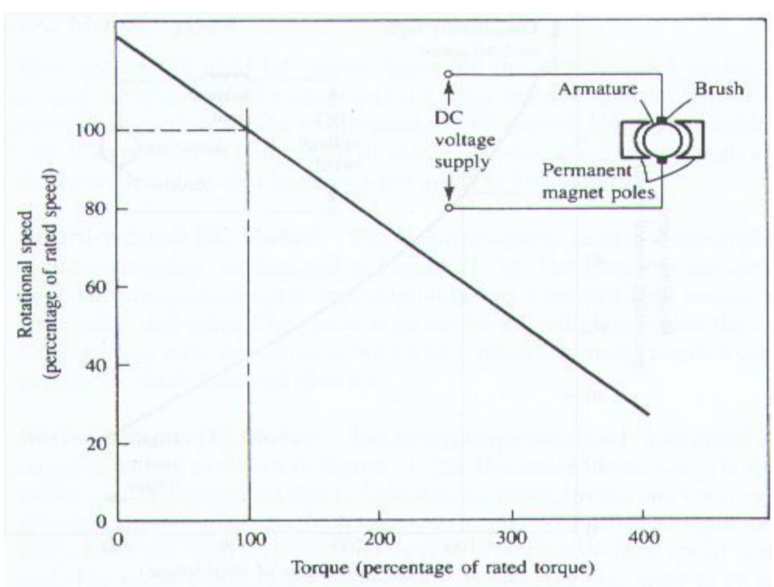


Types of DC Motors:

Permanent Magnet Motor

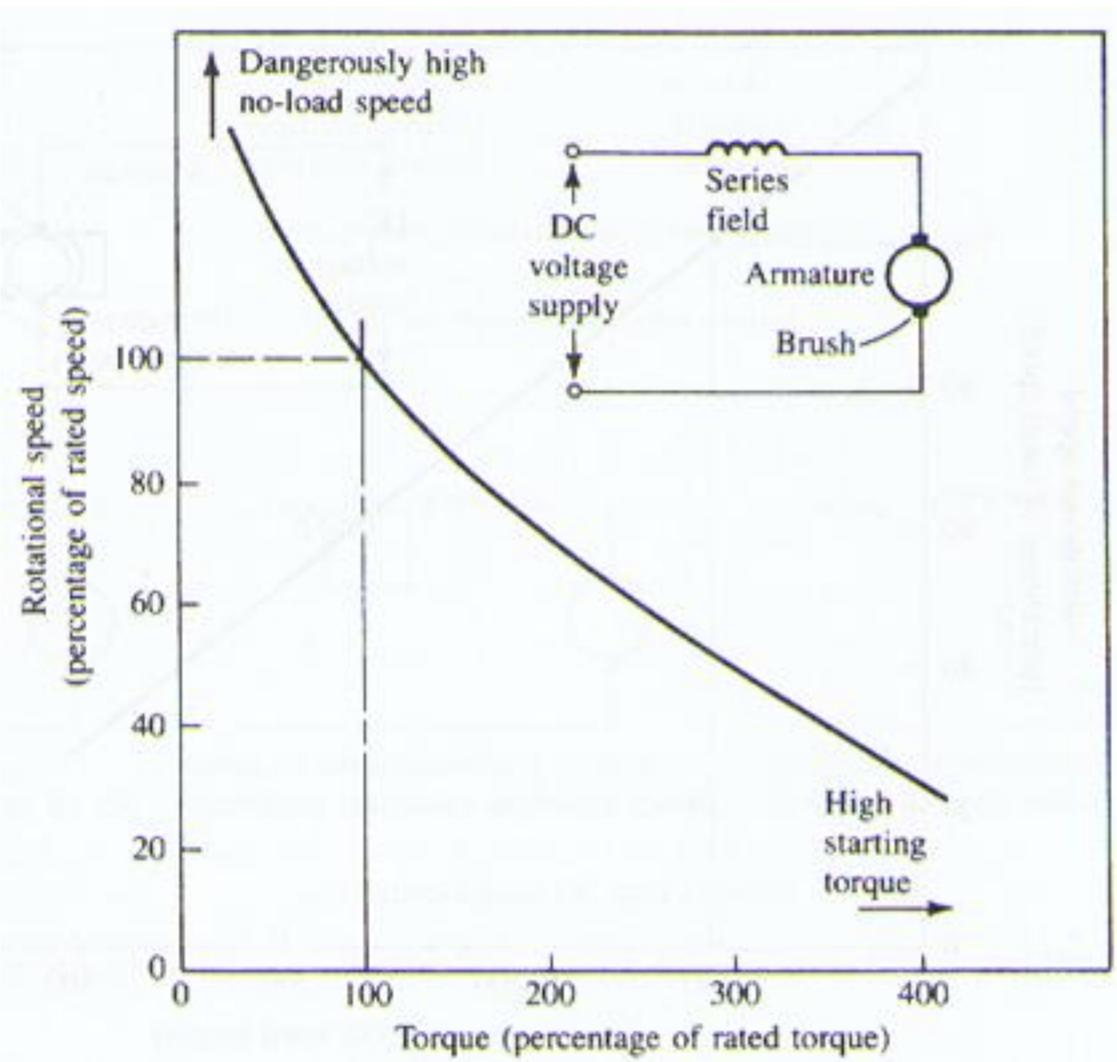
Permanent magnet motors are used extensively for low torque/horsepower applications. Because they have no electromagnets for field generation, they have less wiring than either series or shunt-type motors, and their reliability is therefore improved. The starting characteristics of PM motors are excellent, meaning they have a high starting torque. Due to both of these performance features they find wide use in small, battery-operated electronic appliances, toys, etc.

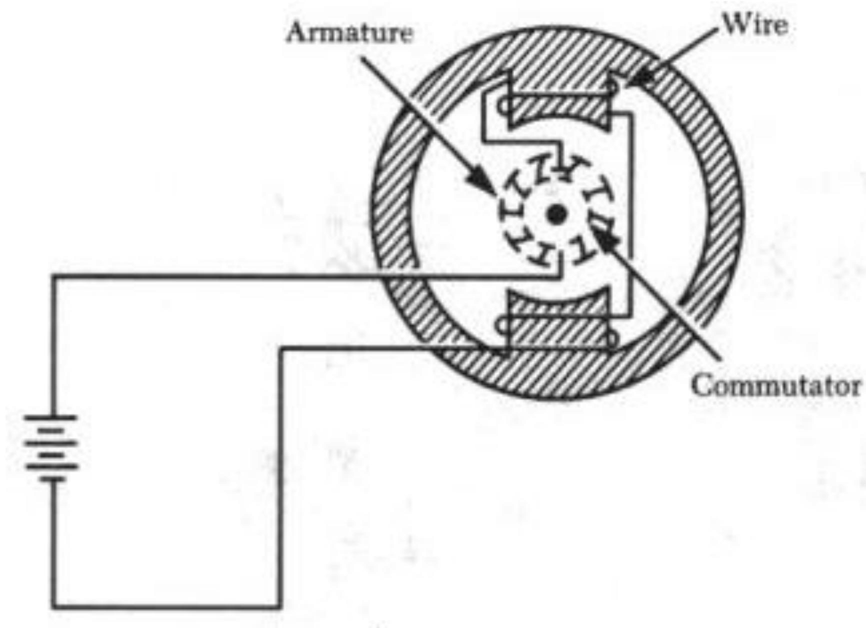
Small permanent magnet (PM) motor



Series DC Motors

Series DC motors are used where very high starting torques are needed. Therefore they are employed very effectively in traction applications, cranes, hoists, etc. Their speed regulation, however, is not very good, as speed decreases with an increase in load (see figure below). If the load on a series motor is very small, the speed becomes very high leading to possible motor run-away and rotor destruction. For this reason, series motors should always be connected to the load or geared, never belted.

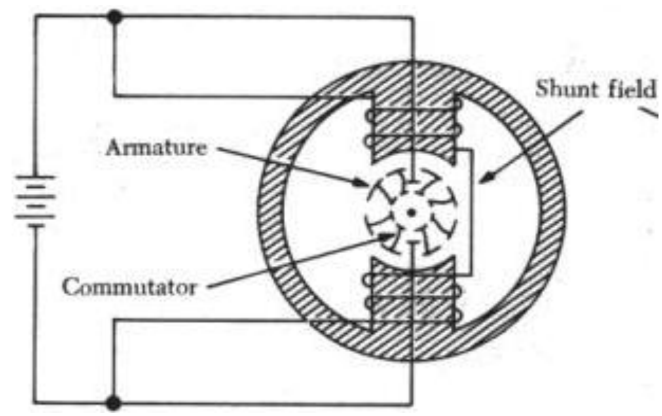


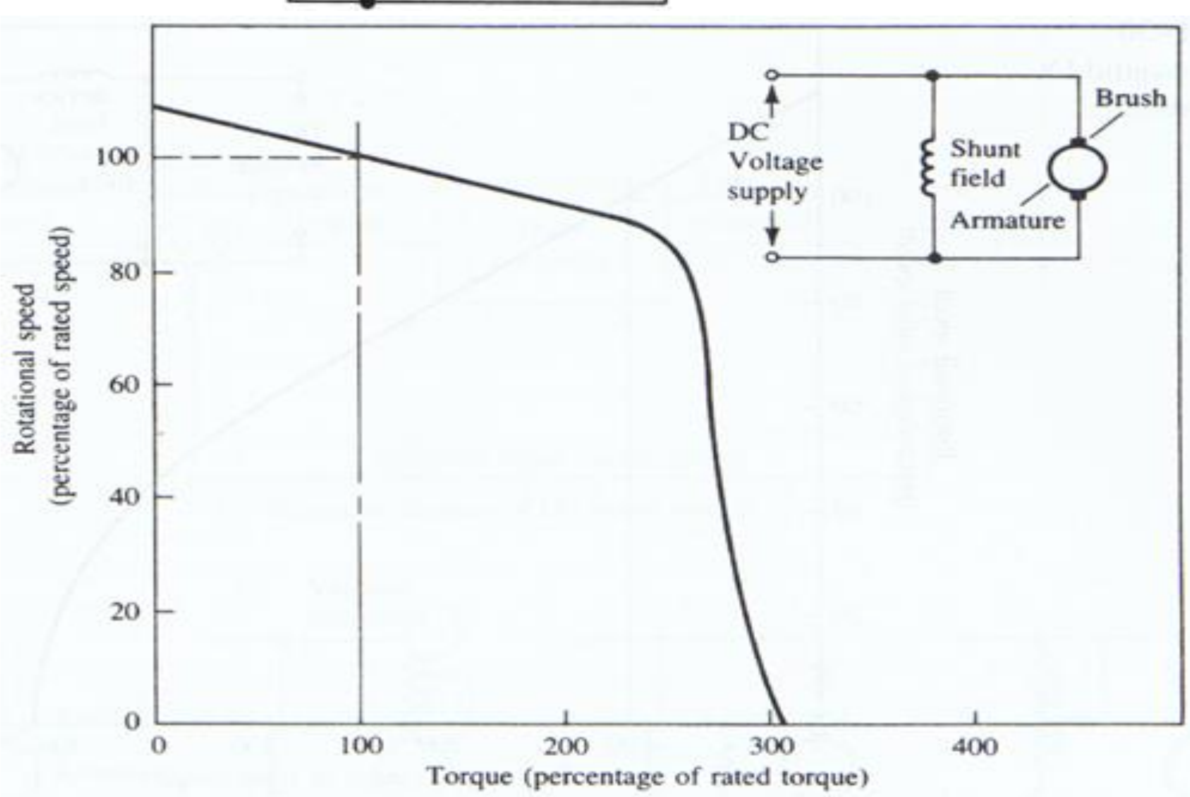


Series DC Motor Diagram

Shunt DC Motor

Shunt DC motors are used where good speed regulation is needed since the drop in speed from no load to full load seldom exceeds 5 percent. They are also employed where a considerable range of speeds will be encountered; the speed of the shunt motor can be easily varied using field control. They have a poor starting torque but a very high starting current, which necessitates the use of starting devices to limit their inrush current.





Types of AC Motors

Synchronous AC Motors

Synchronous AC motors are typically used to run very heavy loads in industrial applications. They were also used formerly and extensively in timing circuits because they run at a particular set speed called the synchronous speed, which is directly proportional to the frequency of the ac power supply.

It is given by the following equation:

$$\mathbf{N_s = \frac{f \times 60}{p}}$$

where,
N_s = synchronous speed (rev/min)
f = frequency of the line current (Hz)
p = pairs of poles per phase (2poles=1pair)

Synchronous motors also have the important characteristic of correcting the power factor of systems that contain large induction motors. Another highlight of synchronous motors is their high starting torque.

One of the disadvantages of synchronous motors is the fact that they will not start rotating on their own when power is first applied. Therefore, most synchronous motors are equipped with an induction squirrel-cage motor attached to the rotor in order to start.

Induction Motors

- Squirrel-Cage Induction Motor
- Wound-Rotor Induction Motor

Squirrel-Cage Induction Motor

- Most common type of motor used in the industry
- Offers a reasonably good starting torque and speed regulation
- Widely available and relatively inexpensive
- Low maintenance operation
- Performs well in multiple-speed applications with external frequency drive

The difference in speed between the synchronous speed of the motor (same as the synchronous speed for a synchronous motor) and the actual rotor speed is called the slip s,

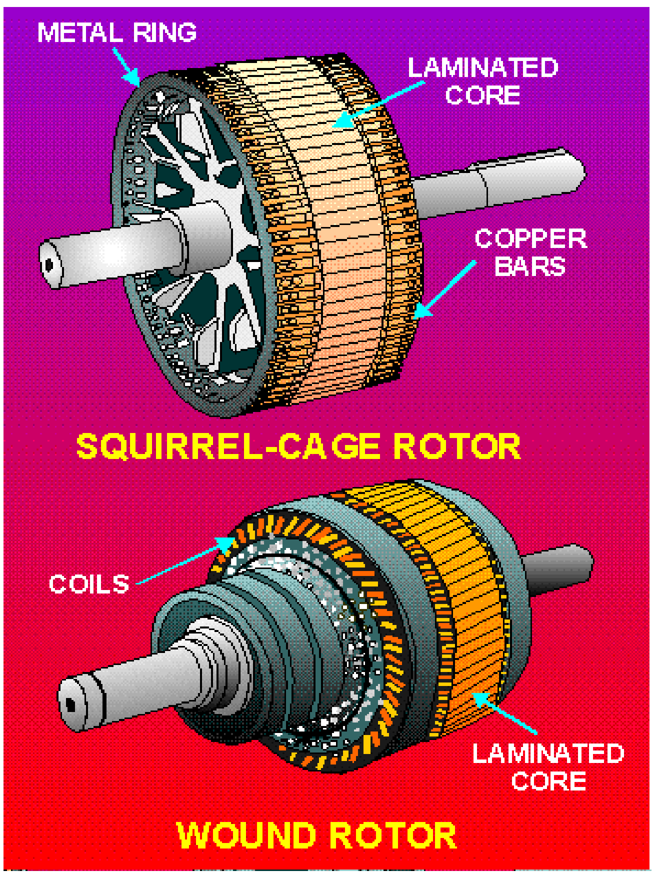
$$s = \frac{N_s - N}{N_s}$$

where,
s = slip
$\mathbf{N_s}$ = synchronous speed
N = actual rotor speed

Wound-Rotor Motor

- Very similar to the squirrel-cage induction motor
- Construction optimized to provide a higher starting torque
- Draws small amount of starting current
- Reduced full load speed as compared to squirrel-cage motor
- Reduced efficiency because of external resistance
- Because of the use of brushes to introduce external rotor resistance at start-up, has higher maintenance costs than the squirrel-cage motor

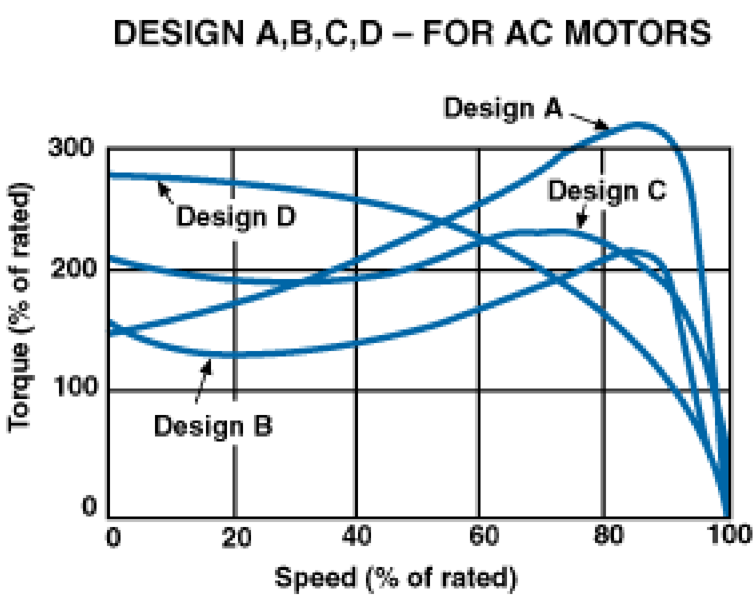
This last characteristic is a major drawback in industrial environments; since the modern squirrel-cage motor can perform as well or better than a wound-rotor motor when coupled with a frequency drive, its use has decreased with time.



Construction of Squirrel-Cage and Wound-Rotor Motors

NEMA Induction Motor Classification

Classification	Starting Torque%	Breakdown Torque %	Starting Current	Slip	Typical Application
Design B Normal starting torque and normal starting current	100 - 200	200 - 250	Normal	< 5%	Fans, blowers centrifugal pumps and compressors, etc., where starting torque requirements are relatively low
Design C High starting torque and normal starting current	200 - 250	200 - 250	Normal	< 5%	Conveyors, stirring machines, crushers, agitators, reciprocating pumps etc., where starting under load is required
Design D High starting torque and high starting current	275	275	Low	> 5%	High peak loads, loads with flywheels such as punch press, shears, elevators, extractors, winches, hoists, oil well pumping and wire drawing machines



Stepper Motors

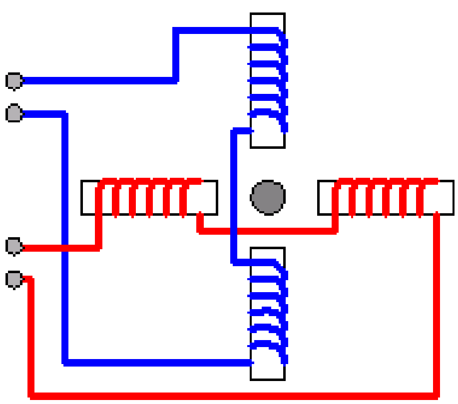
Characteristics:

Stepper Motor

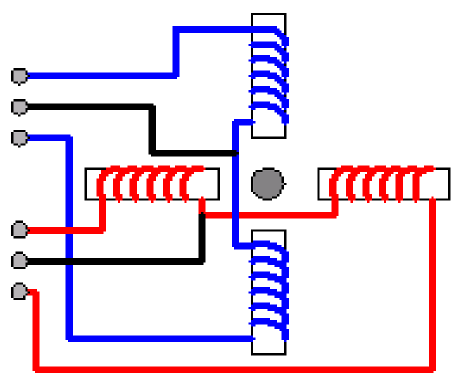
- Used generally for small torque applications
- Provide precise positioning without feedback
- Display incremental motion in their movement
- Continuous rotation achieved at high switching frequencies
- Readily integrated with computers and digital circuits

Types of Stepper Motors:

Bipolar Design



Unipolar Design



Lesson 6

Sequential Process Control

A sequential process control system is one in which a series of sequential operations need to be tightly controlled to achieve a desired outcome. This type of process control is typically employed in the manufacture of products in an assembly line and has thus become an important field of control engineering.

The typical sequential process contains variables that need to be monitored and variables that need to be controlled. The measure of the two different kinds of variables is then provided to the control mechanism by means of input and output devices.

Input Devices

Variables that impact the condition of the controlled variable are furnished to the system by input devices. There are many different kinds of input devices, some of which are:

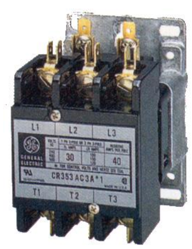
Limit Switches   *Pushbutton Switches*   *Photoelectric Sensors*

Proximity Sensors *Timers* *Etc. ...*

Output Devices

Those variables that need to be controlled are manipulated using output devices. Again, there are many kinds of output devices used in sequential process control. Some of the them are:

Audible Alarms *Visible Alarms* *Contactors* *Frequency Drivers*



Motors *Fans and Blowers*

Process Controllers

Types of Controllers

Even though there are many different kinds of process controllers, they can be classified into two main groups:

- Analog controllers
- Digital controllers

Analog Controllers

Analog controllers provide a continuous control signal and monitor all input variables continuously. They are typically used for controlling one or, at most, only a few control variables. They are inexpensive and can be used in conjunction with digital controllers for increased versatility.

Especially popular are the PID controllers. These types of controllers incorporate a proportional gain, an integral gain, and a derivative gain adjustment to accurately control the specified variable according to the desired criteria.

PID Controller

Digital Controllers

Digital controllers are more sophisticated and expensive than analog controllers. They are able to monitor and control tens or even hundreds of variables simultaneously. Digital controllers can be used together with computers to interface efficiently with those in charge of the production process such as operators, technicians and engineers.

Digital controllers, unlike analog controllers monitor their inputs and control their outputs periodically, not continuously. The period is called the scan time and can be very short. Most modern digital controllers scan their inputs many times per second.

The most popular type of digital controller is the PLC, which stands for Programmable Logic Controller. PLCs use a programming language, which relies on a schematic representation of the control system called Ladder Logic.

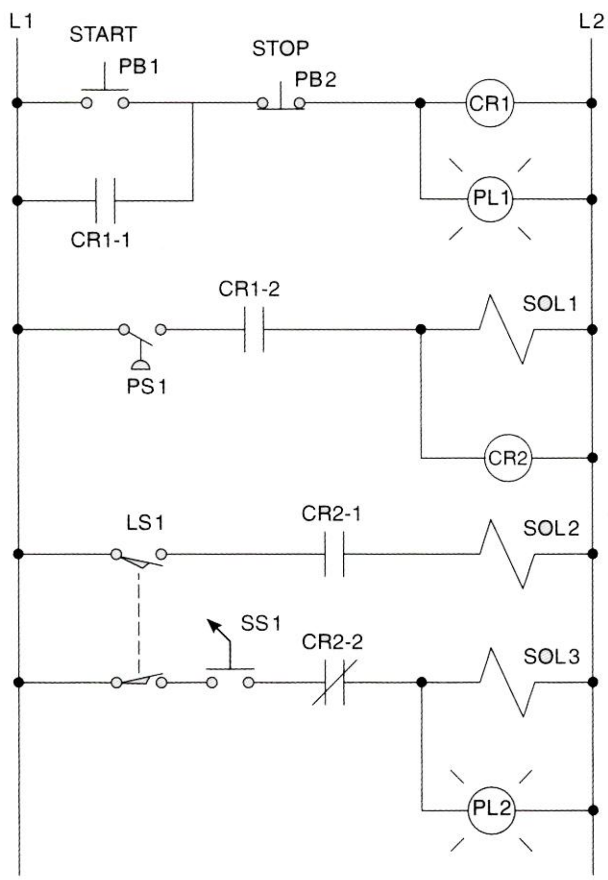
PLCs

Ladder Logic

The ladder diagram is simply a special schematic representation of the hardware making up the control system and its connection that makes the event sequence description clear. It attempts to represent both the system hardware and the process controller.

It is called a ladder diagram because the various circuit devices are connected in parallel across two lines forming something that looks like a ladder. Each parallel connection forms a "rung" of the ladder.

Example of a Ladder Logic Diagram



Lesson 7

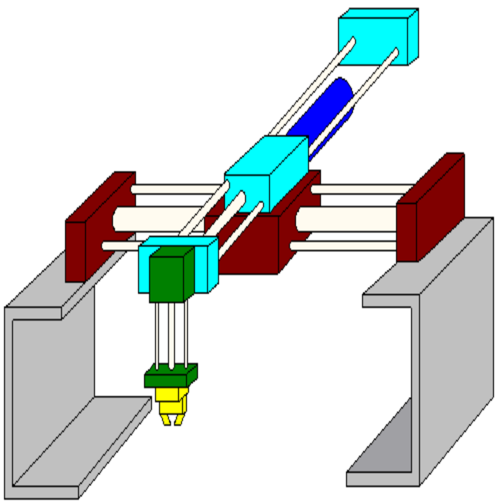
Introduction to Robotics

Types of Robots

Robots can be classified according to the way they move, what type of coordinate axes they use and the location and arrangement of their joints. Accordingly, we have the following types:

Cartesian:

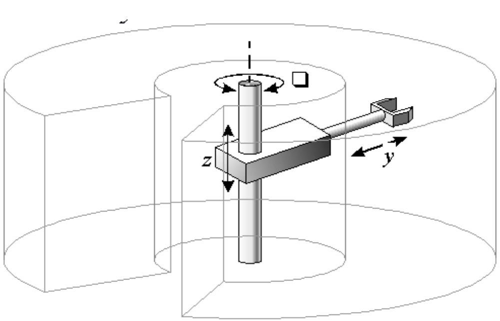
Cartesian robots use a Cartesian (three perpendicular axes) coordinate system to move. They are used extensively for overhead work and where fast movement is desired.



Industrial Cartesian Robot

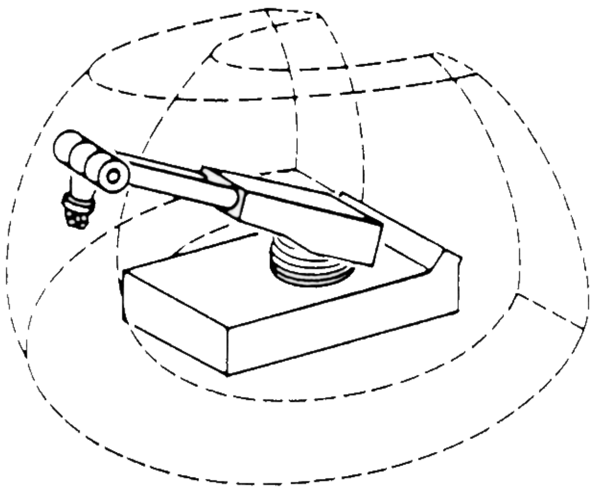
Cylindrical:

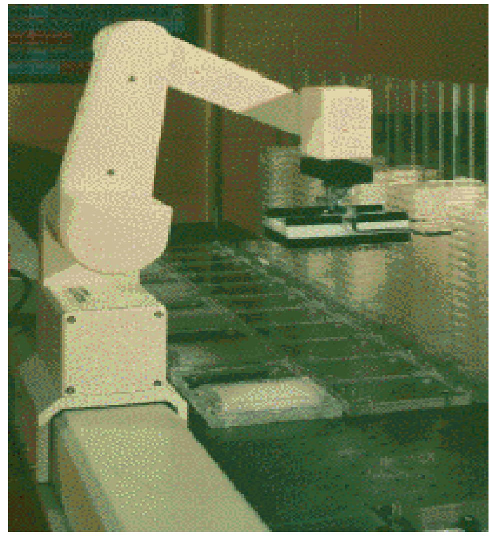
Cylindrical robots use two perpendicular axes and a rotational axis to control their movement.



Polar:

Polar robots use two rotational axes and a linear axis to achieve motion.

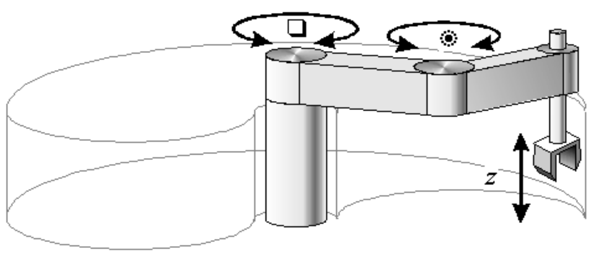




Industrial Polar Robot

SCARA:

Scara stands for Selective Compliance Assembly Robot Arm. They basically consist of jointed arms in a horizontal configuration (as opposed to a vertical configuration as with the jointed arm robot).



Industrial SCARA robot

Articulated:

Jointed arm or articulated robots use sets of joints to achieve their desired movement, just like the arm of a human being. The joints are usually arranged in a vertical configuration.

Industrial Articulated Robot

Types of Robot Controls:

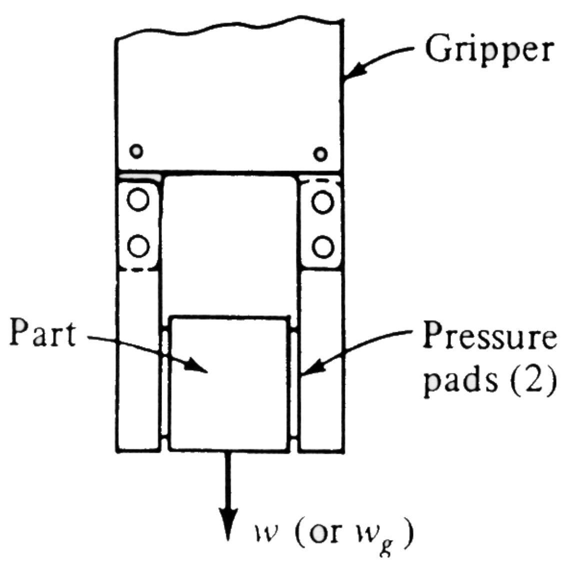
- Playback with point-to-point Control: This is the most commonly used control method in the industry. You simply enter the initial and final coordinates, and the robot moves according to a set of self-determined algorithms to achieve the end position from the initial position.
- Playback with continuous path control: In this method, you actually program the path that the robot will take to achieve the desired movement from the initial to the final coordinates.
- Intelligent robots: Usually, this method requires vision systems in order for the robot to guide itself through a set of prescribed motions.

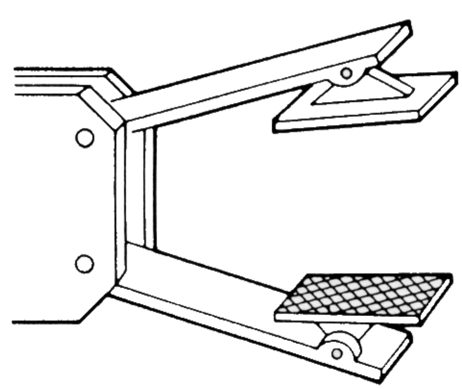
Types of Robotic Mechanical Grippers:

One of the most important characteristics of any robot is the device it uses to handle objects, parts, etc. There are many different kinds of gripping devices, but they can be classified into three major groups:

Friction Grippers:

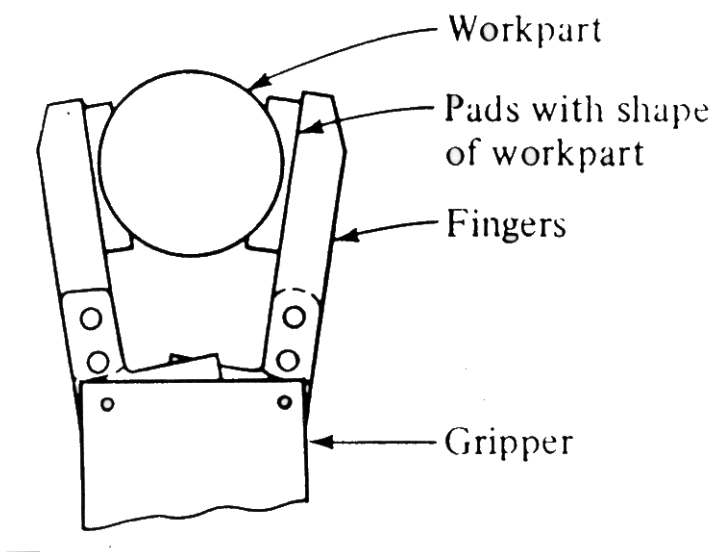
Friction grippers (see figures below) use the force of friction between the gripping element and the object to hold on to the part that is being moved. As such, they are typically used to hold light objects or where objects with high fragility are encountered.

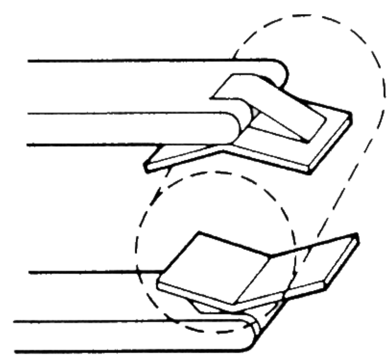


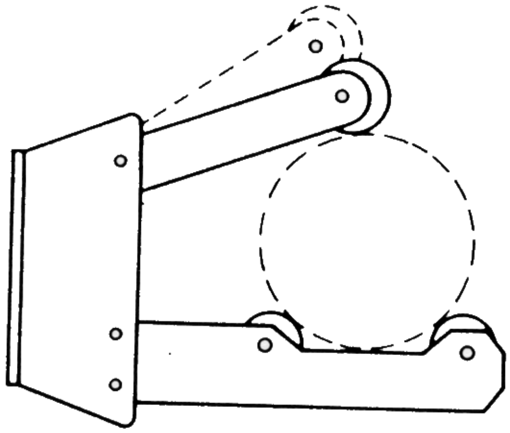


Physical Constriction:

Physical constriction grippers actually hold an object tightly in between vise-like “fingers” to manipulate parts, etc. They can be used to hold objects very securely, or in the movement of heavy parts, machinery and other critical goods.



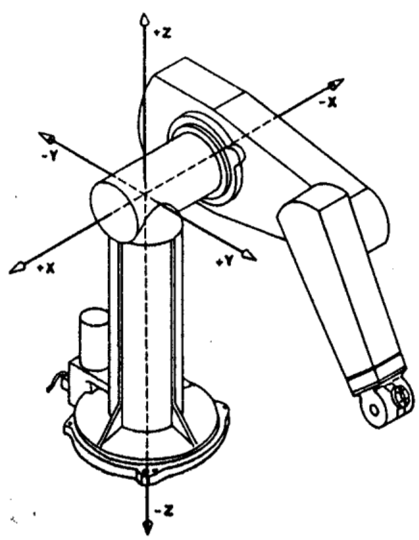




Other:

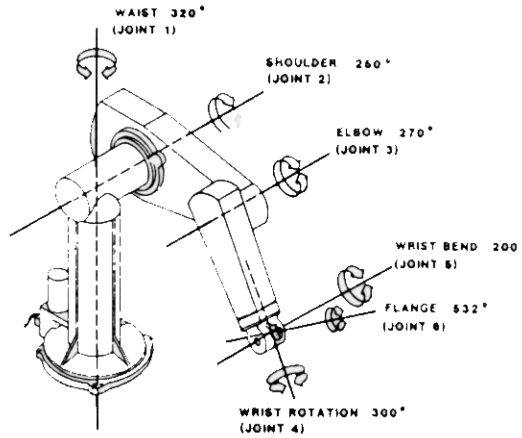
These types include devices for holding objects based on principles such as vacuum, magnetism, adhesives, hooks, scoops, etc.

Robot Coordinate Systems:

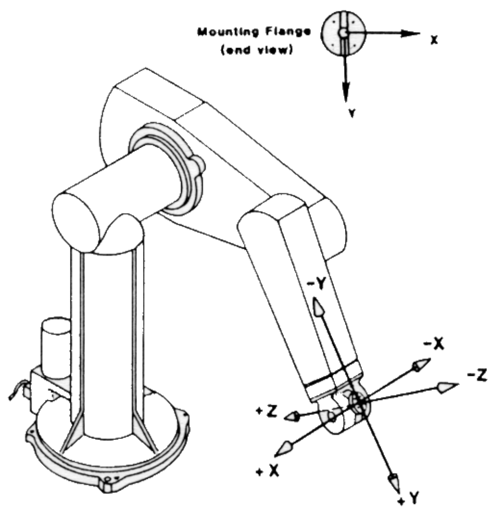


World Coordinates

Joint Coordinates



Tool Coordinates



References

Bartelt, Terry. Industrial Control Electronics. 2nd ed. New York: Delmar, 2001.

Fink, Donald G., ed. and H. Wayne Beaty, ed. Standard Handbook for Electrical Engineers. New York: McGraw-Hill, 1993.

Harter, James H. Electromechanics: Principles, Concepts and Devices. New York: Prentice Hall, 1995.

Resnick, Robert, David Halliday, and Kenneth S. Krane. Physics. 2nd ed. New York: John Wiley & Sons, 1992.

Sadiku, Matthew N.O. Elements of Electromagnetics. 2nd ed. New York: Saunders College Publishing, 1994.