Mechatronic Systems Design

MEC301

Asst. Prof. Dr.Ing.

Mohammed Nour A. Ahmed

mnahmed@eng.zu.edu.eg

https://mnourgwad.github.io

Lecture 7: Actuators Overview

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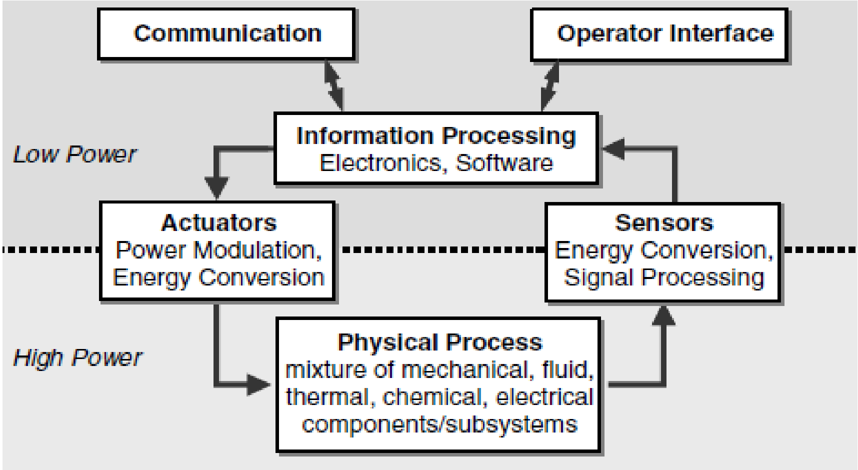
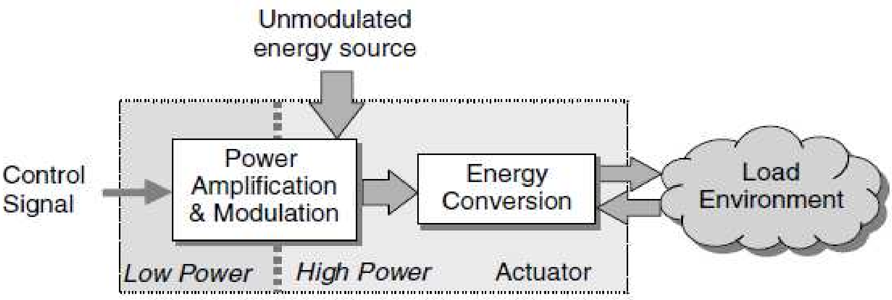
Zagazig University | Faculty of Engineering | Computer and Systems Engineering Department | Zagazig, Egypt

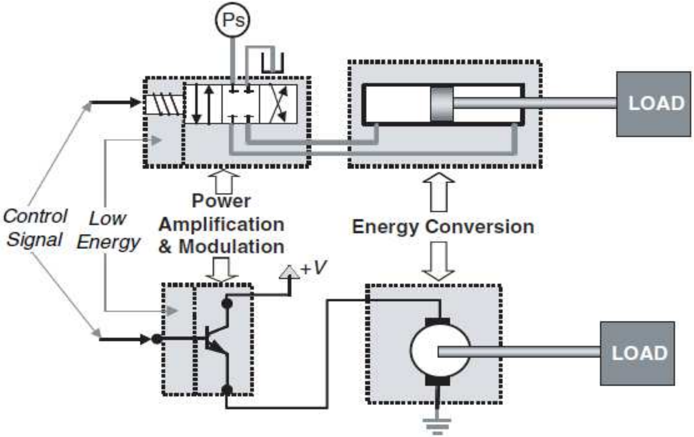
Mechatronics Diagram



Actuator Functional Diagram



Electrohydraulic & Electromechanical Actuators



Actuators

- Actuators (or drives) are essential elements of mechatronic systems. They are the muscles that provide the mechanical movements .

- Actuation is the result of a direct physical action upon the process, such as the application of a force.

- Actuators take low power signals transmitted from the computer and produce high power signals which are applied as input to the process

Actuators

- Electro-Mechanical
  - DC motors
  - AC motors
- Hydraulic and Pneumatic

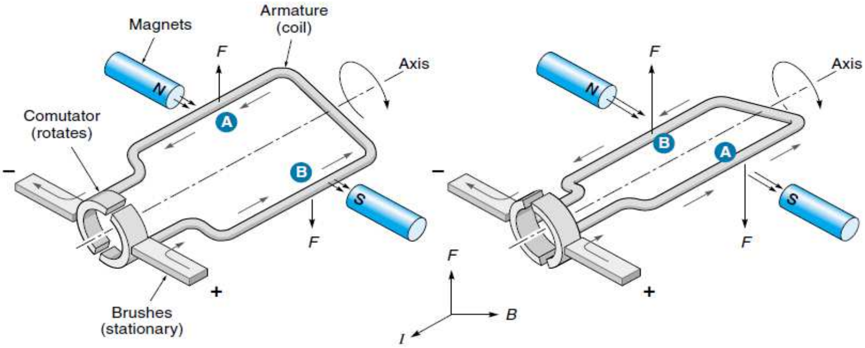
DC Motors

Introduction

- The electric motor is based on the principle that a current-carrying conductor will experience a physical force when in the presence of a magnetic field.

- The DC motor consists of a rotating armature and a stationary magnetic field.
  - The current in the armature, which must come through brushes, causes the rotating forces.
  - The stationary magnetic field is provided by either electromagnets (in which case, it is called a wound-field motor) or by permanent magnets.

Theory of Operation



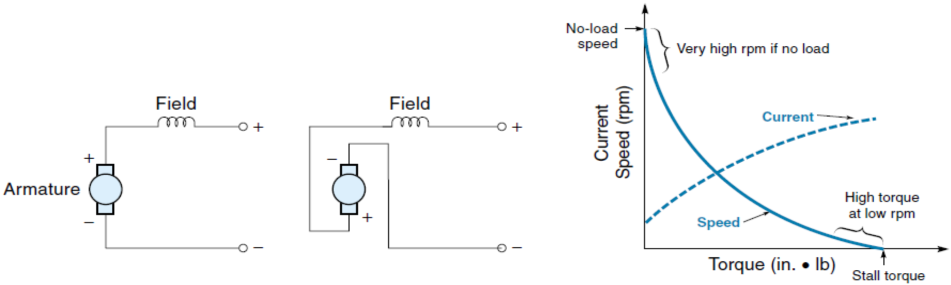
DC Brush Motors

- DC Brush motors are suitable for a wide variety of applications, especially for positioning and speed control.
- They do require an encoder for positioning applications.
- DC Brush motors are available in a great variety of sizes, up to several kilo watts. The speed range can be as high as 10,000 rpm. They run smoothly and relatively quiet.
- The major disadvantage of DC Brush motors are the brushes, which do wear out over time and need to be replaced.
- Another drawback is that DC Brush motors provide a relatively low torque in comparison to their size and weight.

DC Motor Types

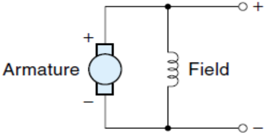
- Wound-field
  - The **series motor** has the armature and field windings connected in series. This type of motor is characterized by a high starting torque and a high no-load speed but poor speed regulation (the speed changes considerably if the load changes). Problem with no-load.
  - The **shunt motor** has the armature and field windings connected in parallel. This type of motor has much better speed regulation than does the series motor. Change input voltage might affect flux.
  - The **compound motor** has both series and shunt-type field windings and combines the good characteristics of both the series and shunt motors. However, they are more expensive and more difficult to control.

Series-Motor

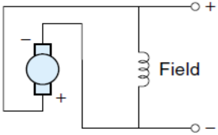


(a) Series motor circuit (b) Series motor reversed (c) Torque–speed curve for series motor

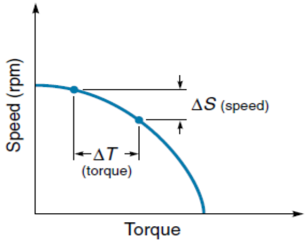
Shunt-Motor



(d) Shunt motor circuit

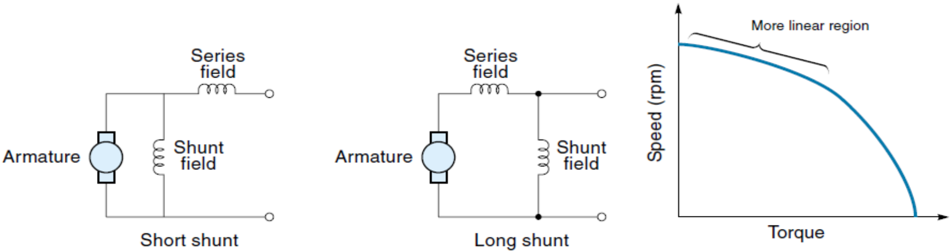


(e) Shunt motor reversed



(f) Torque–speed curve for shunt motor

Compound Motor

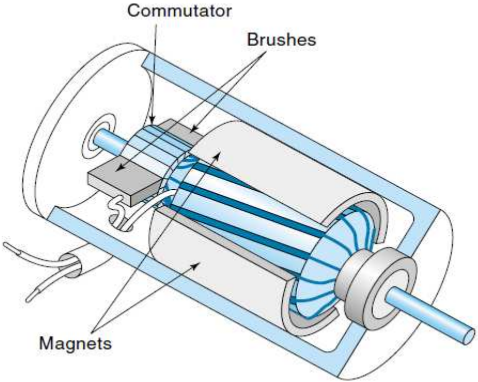


(a) Compound motor circuit (b) Torque-speed curve

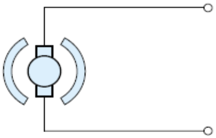
DC Motor Types

- Permanent magnet (PM) motors use permanent magnets to provide the stationary magnetic field.
    - This results in a very linear torque-speed curve, which makes it easy to calculate the motor speed for various load conditions and thus attractive for control system a applications.
    - Disadvantage is that the magnetic field will weaken after time and flux is constant. For large motors, flux might not be appropriate.

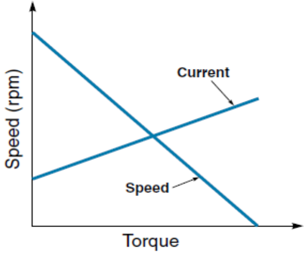
PM Motors



PM Motors



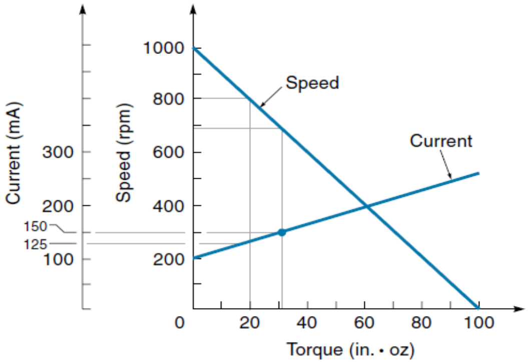
(a) PM motor symbol

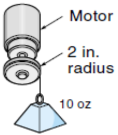


(b) PM motor torque-speed curve

Torque-Speed Curves

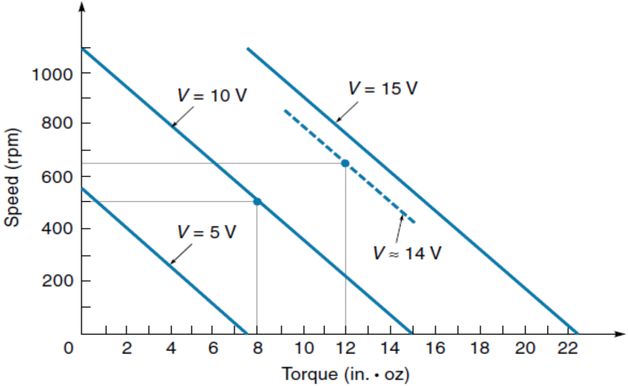
Use the torque-speed curve to find the motor speed and current for:
no-load, stall conditions, and lifting a 10-oz load with a 2-in radius pulley



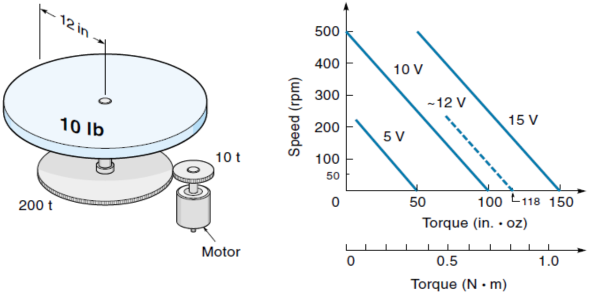


Example

Torque-speed curves shift by changing the supply voltage



DC Motor Example



A PM motor turns a large 60-cm diameter, 4.5-kg turntable through a 20 : 1 gear train . A particular requirement is that the turntable must be able to accelerate from a rest position to 90° in 0.2 s. Determine the necessary motor voltage.

DC Motor Example

$$T = I\alpha$$

$$I = \frac{1}{2}mr^2$$

$$\theta = \frac{1}{2}at^2$$

$$I = \frac{1}{2}4.5\ \text{kg}\ 30\ \text{cm}^2$$
$$= 2025\ \text{kg}\cdot\text{cm}^2 = 0.2025\ \text{kg}\cdot\text{m}^2$$

$$\alpha = \frac{2\theta}{t^2} = \frac{2(90^\circ)}{(0.2s)^2} \times \frac{\pi\ \text{rad}}{180^\circ} = 79\ \text{rad/s}^2$$

$$T = I\alpha = \frac{(0.2025\ \text{kg}\cdot\text{m}^2)}{20^2} \times \frac{(79\times 20)}{s^2} = 0.8\ \text{N}\cdot\text{m}$$

→ 12 Volts

DC Data Sheets

- Data Sheets provide all the needed information about the DC motor to be used.
- It is important for engineers to able to read the data sheets and find the needed information
- The following two slides provide examples of two data sheets

WOUND FIELD

EXPLOSION-PROOF

$^{1}/_{4}$–1 HP

TOTALLY ENCLOSED • FAN-COOLED

FEATURES

- ADJUSTABLE SPEED
- 90 V ARMATURE 50/100 V FIELD(3)
- CLASS F INSULATION
- 40ºC AMBIENT
- EXPLOSION-PROOF(1)
- FOR OPERATING FROM FULL WAVE SINGLE-PHASE RECTIFIED POWER (TYPE K)
- RIGID MOUNT C-FACE

HP	RPM	Enclosure	Frame ▪
1/4	3500	TEFC-XP	HM56HC
	2500	TEFC-XP	HB56HC
	1750	TEFC-XP	HB56HC ◆
	1150	TEFC-XP	HU56HC
1/3	3500	TEFC-XP	HG56HC
	2500	TEFC-XP	HU56HC
	1750	TEFC-XP	HB56HC ◆
	1150	TEFC-XP	HJ56HC
1/2	3500	TEFC-XP	HU56HC
	2500	TEFC-XP	HG56HC
	1750	TEFC-XP	HJ56HC ◆
	1150	TEFC-XP	HE56HC
3/4	3500	TEFC-XP	HU56HC
	2500	TEFC-XP	HJ56HC
	1750	TEFC-XP	HJ56HC ◆
1	3500(2)	TEFC-XP	HJ56HC
	2500(2)	TEFC-XP	HE56HC
	1750(2)	TEFC-XP	HE56HC ◆

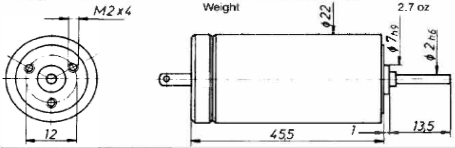
BERTSCH U.S. MICROMOTORS

Series 22-45 · 6 Watts · 10,000 RPM Dimensions – mm 1 mm = 0.0394 in

Magnet	AlNiCo	Efficiency	up to 85 %
Commutator	CuAg 0.1, 5 segments	Rotor Moment of Inertia	20 × 10^{-3} oz-in^2
Brushes	Graphite	Mechanical Time Const. appr.	20 ms
Bearings	Oilite	Weight	2.7 oz

Possible Combinations

Gear Heads	H 30, H 40, P 24
Tacho	20-08
Encoder	HEDS-5500



Recommended Operational Data

Speed	max. 10,000 rpm
Torque	0.7 oz-in
Temperature	-4° to +175° F

Type	22-45-30	22-45-20	22-45-16	22-45-14	22-45-12	22-45-10	22-45-08	
Voltage	3	6	9	12	18	24	36	V
No load speed	7,500	10,000	10,100	10,000	9,700	9,900	9,700	rpm
Resistance	0.8	2.5	4.5	6	14	28	65	Ohms
Stall torque	1.89	1.80	2.19	3.07	2.95	2.63	2.12	oz-in
No load current appr.	65	55	45	35	25	20	18	mA
Recommended current	1000	800	600	450	300	250	150	mA
Counter-EMF	0.51	0.77	1.15	1.56	2.34	3.15	4.78	mV/rpm
Speed/Torque Gradient	3980	5560	4510	3270	3420	3780	4740	rpm/oz-in

Gear Heads H 30 and H 40 with Oilite Bearings

Standard Gear Ratios

H 30:	20 : 1	60 : 1	200 : 1	600 : 1	2500 : 1	
H 40:	40 : 1	100 : 1	200 : 1	500 : 1	1000 : 1	2000 : 1

Gear Head	H 30	H 40	
Max. torque	30	42	oz-in
Max. Motor Speed	5000	7500	rpm
Max. Power	1	2	W
Max. Axial Load	36	54	oz
Max. Radial Load	36	36	oz
Weight with motor	4.2	5	oz

Brushless DC Motors

- Brushless DC motors (BLDC) use permanent magnets (instead of coils in the armature/rotor) and therefore do not need brushes.

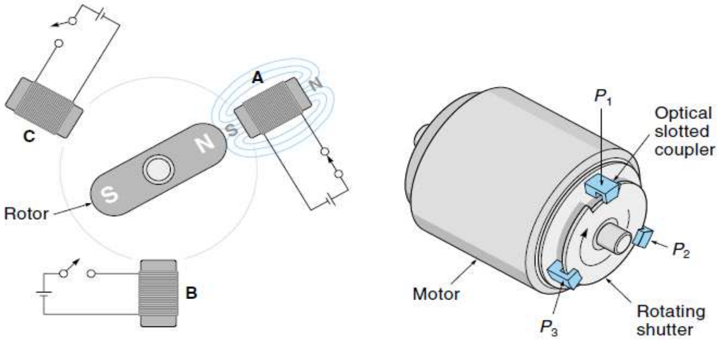
- The field coils are switched on and off in a rotating sequence that pulls the rotor around. They have built-in sensors that direct when the individual field coils are to be switched on and off.

- They are available in a wide power range and they can operate at very high speeds up to 30,000 rpm.

- They are able to generate high torque for a given size.

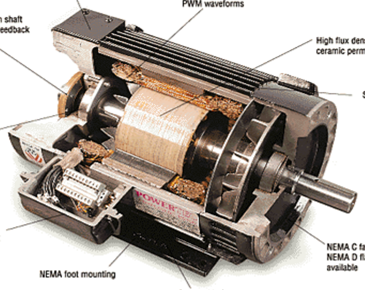
- DC brushless motors are the most widely used motor technology for servo applications.

Brushless DC Motors



(a) Field coil arrangement (b) Rotating shutter and sensors

Brushless DC Motors



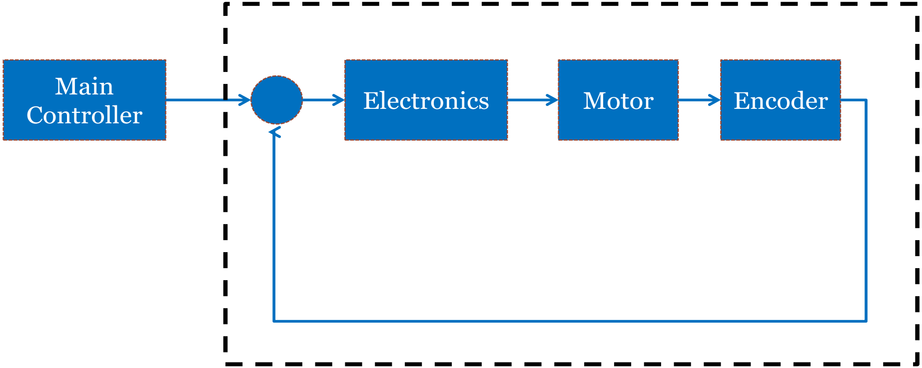
Brushless DC Motors

- Advantages: Reliable, high-performance motor technology - long-life, virtually maintenance free, cooler running, low acoustic. They run relatively smooth and quiet; they do not require mechanical brushes for commutation

- Disadvantage: High price due to the use of rare-earth magnetic materials to generate torque. They also require fairly complex and thus more expensive amplifiers.

Servo Motors

- Servo motors have built-in shaft encoder
- Data sheets provide the required pulses for specific speed and/or position



Stepper Motors

Stepper Motors

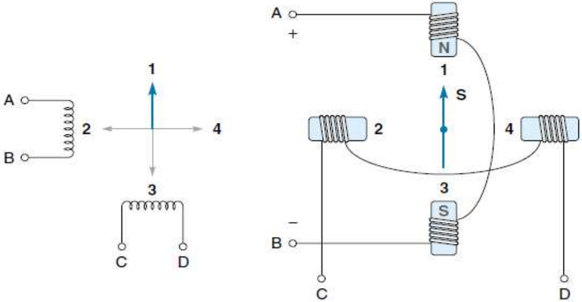
- Stepper motors are basically DC brushless motors. However, they do not require an encoder for position feedback: They rotate in fixed steps as related to number of degrees.

- Stepper motors produce a high torque for a given size and weight. However, the available torque from stepper motors drops dramatically with higher speed.

- Their maximum speed around of 5000 rpm at very low torque.

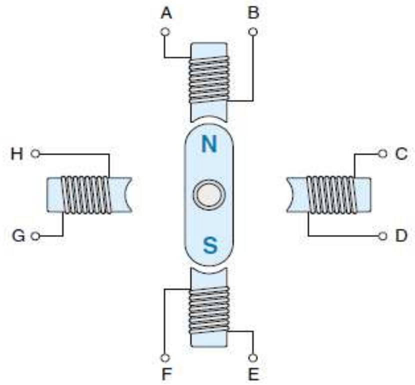
- The power range of stepper motors is up to several hundred watts, but hardly above that level. The major drawback of stepper motors is the noise and vibration they produce. Especially vibration can effect the lifetime of a mechanical system significantly.

Two-Phase (Bipolar) Stepper Motor

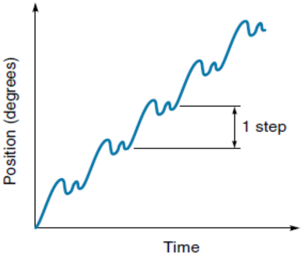


(a) Symbol (b) Wiring diagram

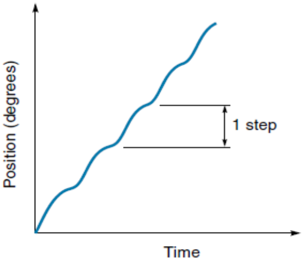
Four-Phase (Unipolar) Stepper Motor



Modes of Operation



Single Step

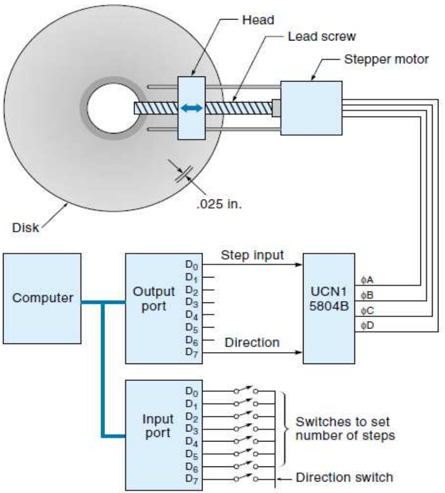


Slew

Data Sheets

PF35 Series		Models					
		PF35-48				PF35-24	
Excitation Mode		2-2					
Step Angle	(°)	7.5				15	
Step Angle Tolerance	(%)	±5					
Steps per Revolution		48				24	
Rating		Continuous			Intermittent	Continuous	
Letter Designator		C	D	Q	C	C	D
Winding Type		Unipolar	Unipolar	Bipolar	Unipolar	Unipolar	Unipolar
DC Operating Voltage	(V)	12	5	5	24	12	5
Operating Current	(mA/ø)	133	313	310	266	133	313
Winding Resistance	(Ω/ø)	90	16	17	90	90	16
Winding Inductance	(mH/ø)	48	8.9	12	48	48	8.9
Holding Torque	(oz-in)	2.78		3.25	3.88	2.08	
Rotor Inertia	(oz-in^2)	24.1×10^{-3}					
Starting Pulse Rate, Max.	(pps)	500		400	680	310	
Slewing Pulse Rate, Max.	(pps)	530		500	770	410	
Ambient Temp Range, Operating	(°C)	−10–+50					
Temperature Rise	(°C)	55			–	55	
Weight	(oz)	2.8					

Example: Hard Drive Application

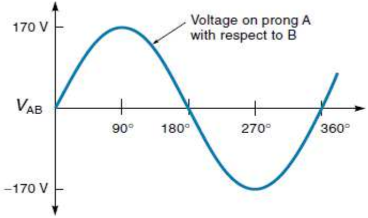


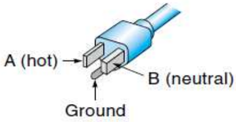
AC Actuators

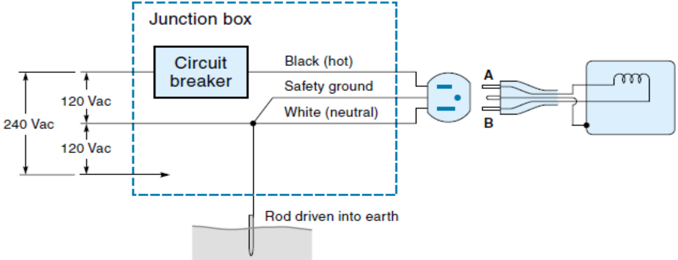
AC Motors

- The AC induction motor is the most widely used type of electric motor in the modern world.
- AC motors are by nature constant speed and therefore are mostly used for constant speed applications.
- They are popular because they can provide rotary power with high efficiency, low maintenance, and exceptional reliability—all at relatively low cost.
- They can be used for speed and torque control applications. However, they are rarely used for positioning applications.
- AC motors are low-cost when they are used for constant speed applications. However, advanced electronic controls add to the total system costs

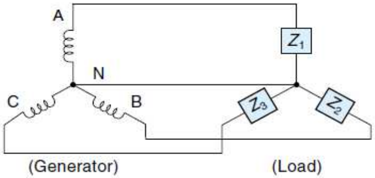
Single-Phase AC Motors

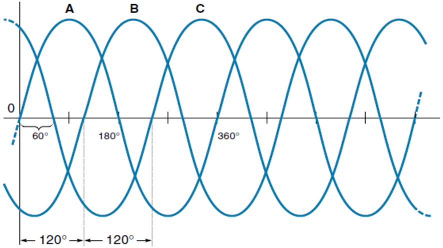






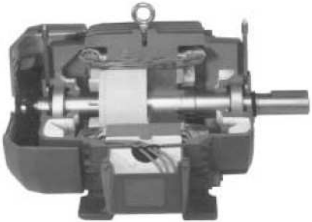
Three-Phase Motors





Induction Motors

(a) Frame Stator Rotor

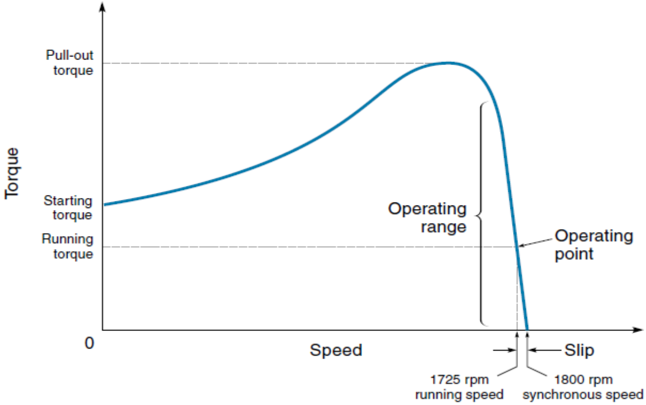


(b) Assembled motor

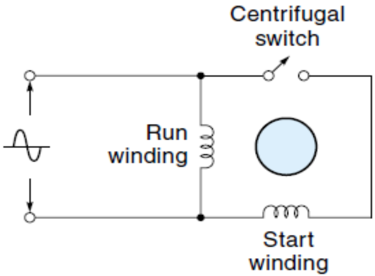
Induction Motors: Theory of Operation

- The theory of operation of the AC induction motor has some similarities to that of the stepper motor or BLDC (brushless DC motor).
  - With stepper motors and BLDCs, special switching circuits are required to turn the field windings on and off.
- The AC motor also works by rotating the stator field, but it makes use of the natural alternating nature of the AC wave to turn the field coils on and off sequentially.
- The AC induction motor does not need brushes because the rotor is essentially a passive device that is continuously being pulled in one direction.

Torque-Speed Curve



Single-Phase Motors Cannot Self-Start



Summary

- DC Motors can be divided into: Wound-field and Permanent magnet

- Wound field motors.
  - The series motor
  - The shunt motor
  - The compound motor

- PM motors use permanent magnets to provide the stationary magnetic field.

- Stepper motors are type of DC motors that do not require a feedback sensor

Summary

- The most common type of AC motor is the induction motor.
- AC motors advantages over DC Motors
  - Lighter in weight, more reliable, less expensive, and require less routine maintenance.
- Three-phase motors provide high-power and are self-starting, but require three-phase power
- AC motors are in general constant speed

Thanks for your attention.

Questions?

Asst. Prof. Dr.Ing.
Mohammed Nour A. Ahmed
mnahmed@eng.zu.edu.eg
https://mnourgwad.github.io

Robotics Research Interest Group (zuR^{2}IG)
Zagazig University | Faculty of Engineering | Computer and Systems Engineering Department | Zagazig, Egypt

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