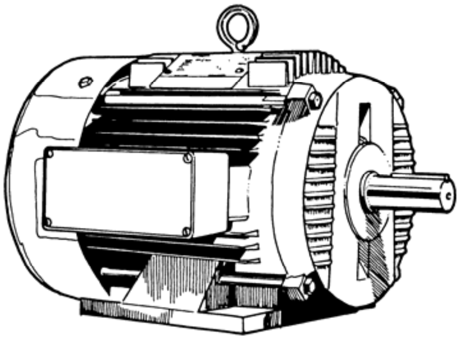
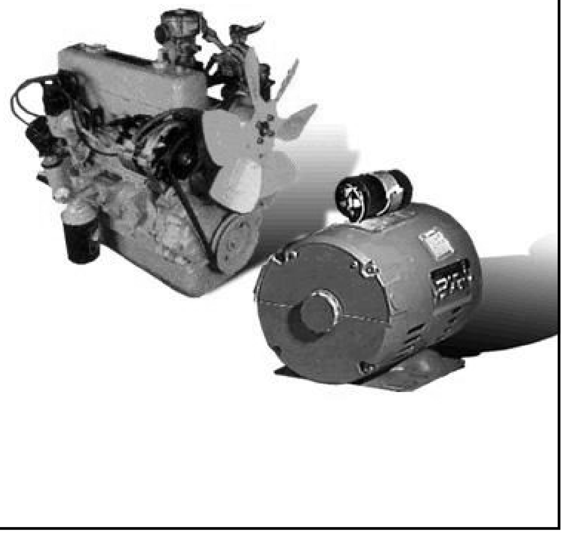
Motor Basics

AGSM 325



Motors vs Engines

- Motors convert electrical energy to mechanical energy.
- Engines convert chemical energy to mechanical energy.

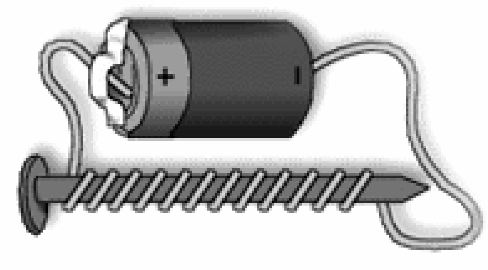


Motors

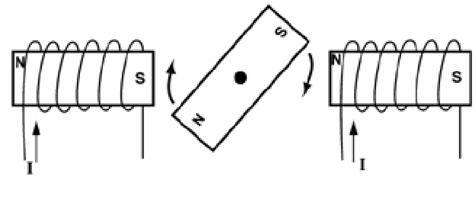
- Advantages
  - Low Initial Cost - $/Hp
  - Simple & Efficient Operation
  - Compact Size – cubic inches/Hp
  - Long Life – 30,000 to 50,000 hours
  - Low Noise
  - No Exhaust Emissions
  - Withstand high temporary overloads
  - Automatic/Remote Start & Control
- Disadvantages
  - Portability
  - Speed Control
  - No Demand Charge

Magnetic Induction

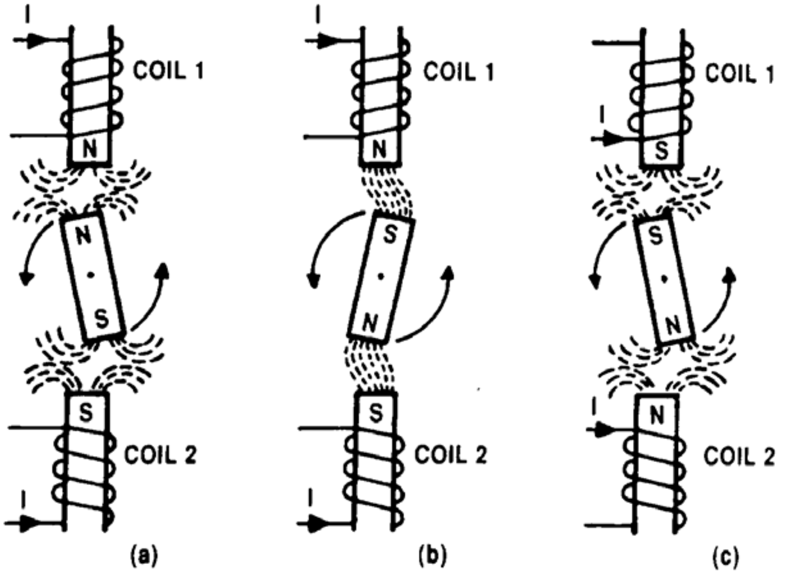
- Simple Electromagnet



- Like Poles Repel
- Opposite Poles Attract



Operating Principle

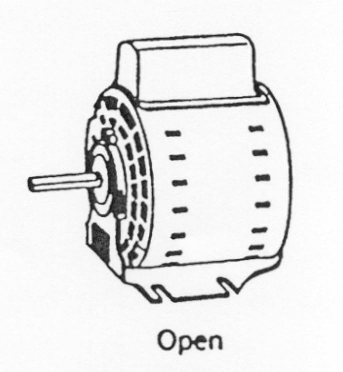


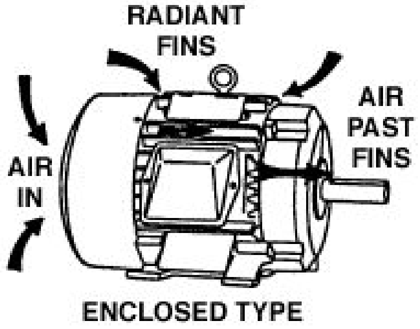
Motor Parts

- Enclosure
- Stator
- Rotor
- Bearings
- Conduit Box
- Eye Bolt

Enclosure

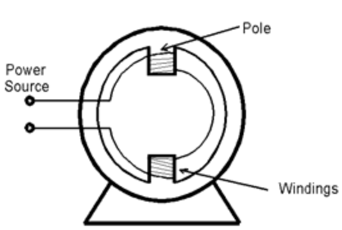
- Holds parts together
- Helps with heat dissipation
- In some cases, protects internal components from the environment.





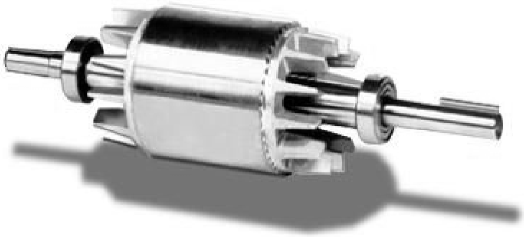
Stator (Windings)

- “Stationary” part of the motor sometimes referred to as “the windings”.
- Slotted cores made of thin sections of soft iron are wound with insulated copper wire to form one or more pairs of magnetic poles.



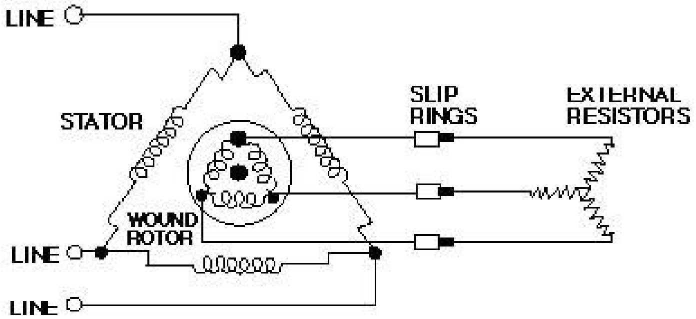
Rotor

- “Rotating” part of the motor.
- Magnetic field from the stator induces an opposing magnetic field onto the rotor causing the rotor to “push” away from the stator field.



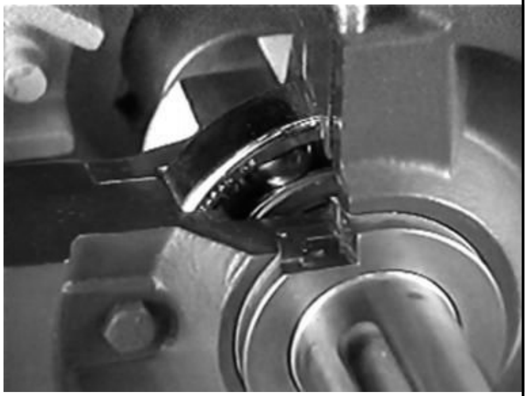
Wound Rotor Motors

- Older motor designed to operate at “variable speed”
- Advantages
  - Speed Control, High Starting Torque, Low Starting Current
- Disadvantages
  - Expensive, High Maintenance, Low Efficiency



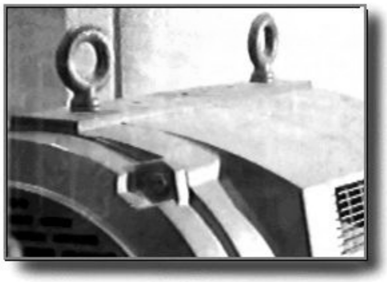
Bearings

- Sleeve Bearings
  - Standard on most motors
  - Quiet
  - Horizontal shafts only
  - Oil lubricated
- Ball (Roller) Bearings
  - Support shaft in any position
  - Grease lubricated
  - Many come sealed requiring no maintenance



Other Parts

- Conduit Box
  - Point of connection of electrical power to the motor's stator windings.
- Eye Bolt
  - Used to lift heavy motors with a hoist or crane to prevent motor damage.

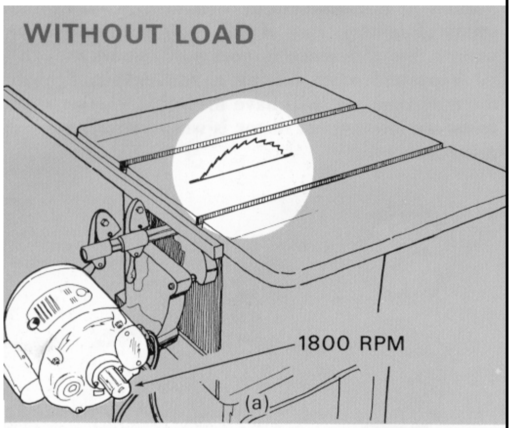


Motor Speed

- Synchronous Speed
  - Speed the motor’s magnetic field rotates.
  - Theoretical speed with not torque or friction.
- Rated Speed
  - Speed the motor operates when fully loaded.
  - Actual speed at full load when supplied rated voltage.

Synchronous Speed

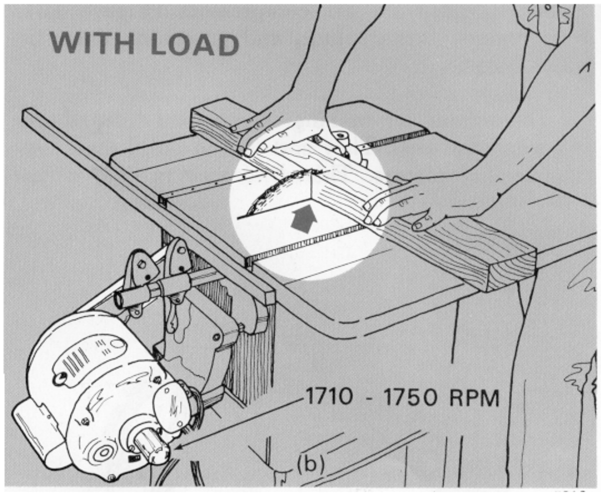
- Theoretical Speed
- A well built motor may approach synchronous speed when it has no load.
- Factors
  - Electrical Frequency (cycles/second)
  - # of poles in motor



$$\text{Synchronous Speed} = \frac{120 \times \text{Frequency}}{\text{\# of Poles}}$$

Rated Speed

- Speed the motor runs at when fully loaded and supplied rated nameplate voltage.



Motor Slip

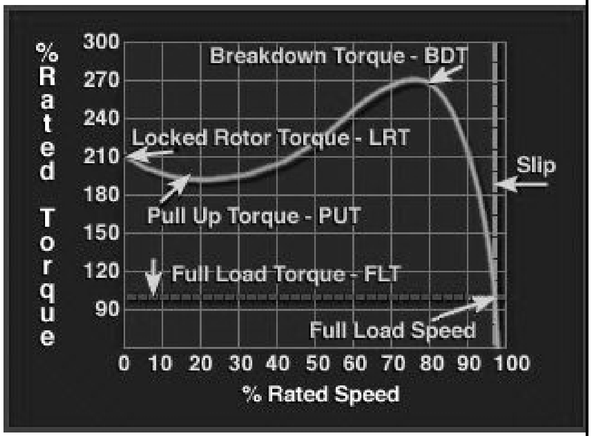
- Percent difference between a motor's synchronous speed and rated speed.
- The rotor in an induction motor lags slightly behind the synchronous speed of the changing polarity of the magnetic field.
  - Low Slip Motors
    - "Stiff"….High Efficiency motors
  - High Slip Motors
    - Used for applications where load varies significantly…oil pump jacks.

Torque

- Measure of force producing a rotation
  - Turning Effort
  - Measured in pound-feet (foot-pounds)

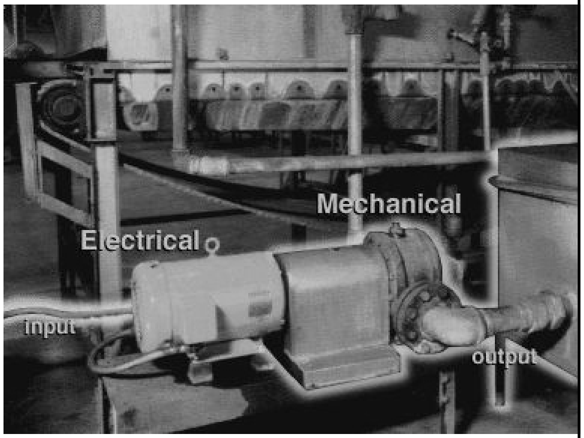
Torque-Speed Curve

- Amount of Torque produced by motors varies with Speed.
- Torque Speed Curves
  - Starting Torque
  - Pull Up Torque
  - Breakdown Torque



Motor Power

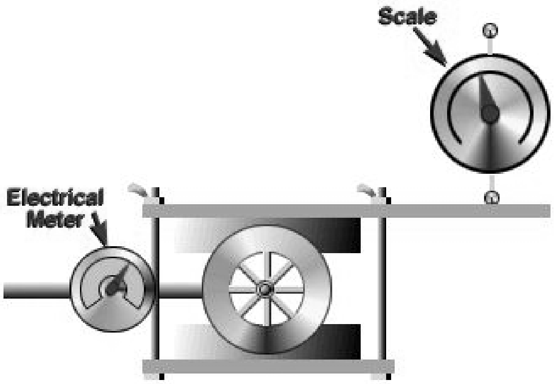
- Output Power
  - Horsepower
  - Amount of power motor can produce at shaft and not reduce life of motor.
- Input Power
  - Kilowatts
  - Amount of power the motor consumes to produce the output power.



Calculating Horsepower

- Need Speed and Torque
- Speed is easy
  - Tachometer
- Torque is difficult
  - Dynamometer
  - Prony Brake

HP = RPM x TORQUE / 5252



Watt’s Law

- Input Power
- Single Phase
  - – Watts = Volts X Amps X p.f.
- Three Phase
  - – Watts = Avg Volts X Avg Amps X p.f. X 1.74

Example

- Is a 1 Hp 1-phase motor driving a fan overloaded?
  - – Voltage = 123 volts
  - – Current = 9 amps
  - – p.f. = 78%
- Watts = Volts X Amps X p.f.

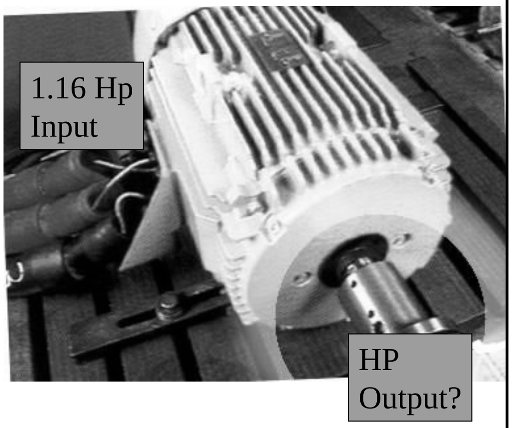
  Watts = 123 volts X 9 amps X 0.78 = 863.5 Watts

  864 Watts / 746 Watts/Hp = 1.16 Hp
- Is the motor overloaded?

Electrical = Input

- We measured Input
- Motors are rated as Output
- Difference?
  - Efficiency
- If the motor is 75% efficient, is it overloaded?
- Eff = Output / Input
- Output = Eff X Input

  0.75 X 1.16 Hp = 0.87 Hp
- The motor is NOT overloaded



Example #2

- Is this 10 Hp, 3-phase motor overloaded?
  - Voltages = 455, 458, and 461 volts
  - Currents = 14.1, 14.0 and 13.9 amps
  - P.f. = 82%
- Watts = Volts$_{avg}$ X Amps$_{avg}$ X p.f. X 1.74

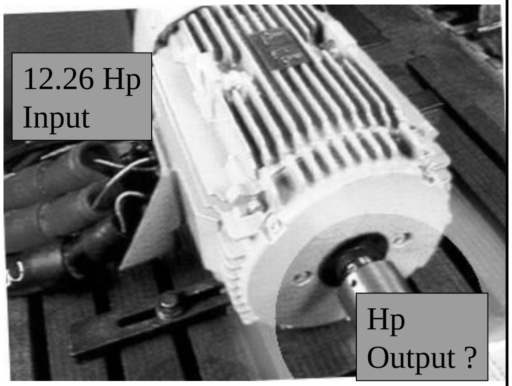
  Watts = 458v X 14a X 0.82 X 1.74 = 9148.6 Watts

  9148.6 Watts / 746 Watts/Hp = 12.26 Hp
- Is the motor overloaded?

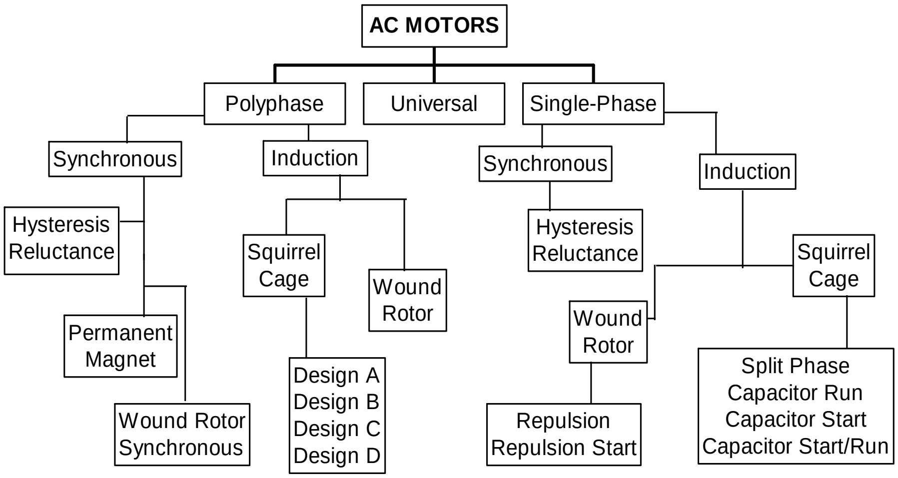
Example #2

- We measured Input
- Motor is rated as Output
- Difference?
  - Efficiency
- If the motor is 90% efficient, is it overloaded?
- Eff = Output / Input
- Output = Eff X Input

  0.90 X 12.26 Hp = 11.0 Hp
- The motor IS overloaded!
- How bad is the overload?

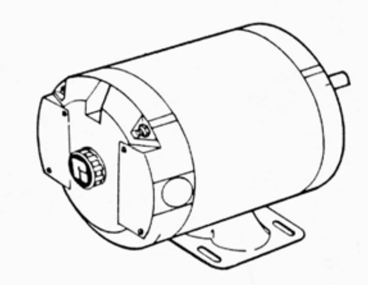


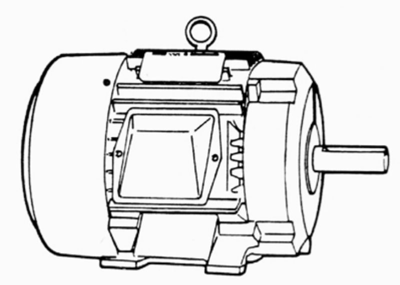
Motor Types
CLASSIFICATION OF MOTORS



- **AC MOTORS**
  - Polyphase
    - Synchronous
      - Hysteresis Reluctance
      - Permanent Magnet
      - Wound Rotor Synchronous
    - Induction
      - Squirrel Cage
        - Design A
Design B
Design C
Design D
      - Wound Rotor
  - Universal
  - Single-Phase
    - Synchronous
      - Hysteresis Reluctance
    - Induction
      - Wound Rotor
        - Repulsion
        - Repulsion Start
      - Squirrel Cage
        - Split Phase
        - Capacitor Run
        - Capacitor Start
        - Capacitor Start/Run

Synchronous vs Induction Motors



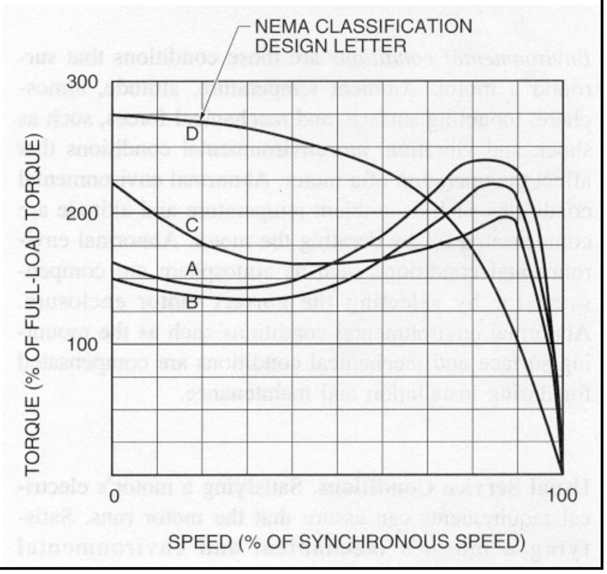


- Synchronous Motors
  - Turn at exactly the same speed as the rotating magnetic field.
  - 3600 rpm, 1800 rpm, etc.

- Induction Motors
  - Turn at less than synchronous speed under load.
  - 3450 rpm, 1740 rpm, etc.

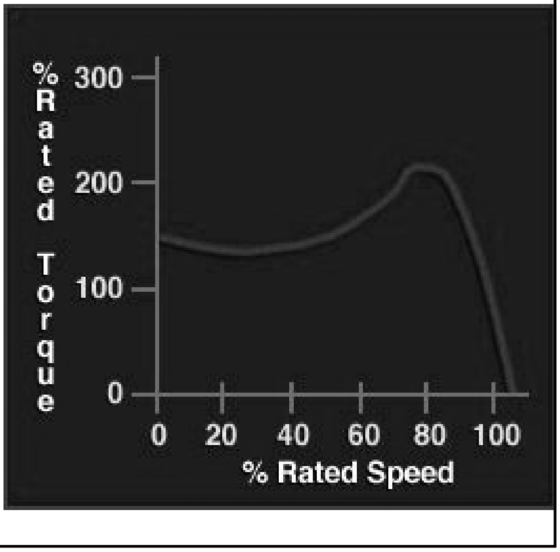
NEMA 3 Phase Motors

- 3 Phase Induction Motors
- NEMA Torque-Speed Design Types
  - A,B,C,D,E



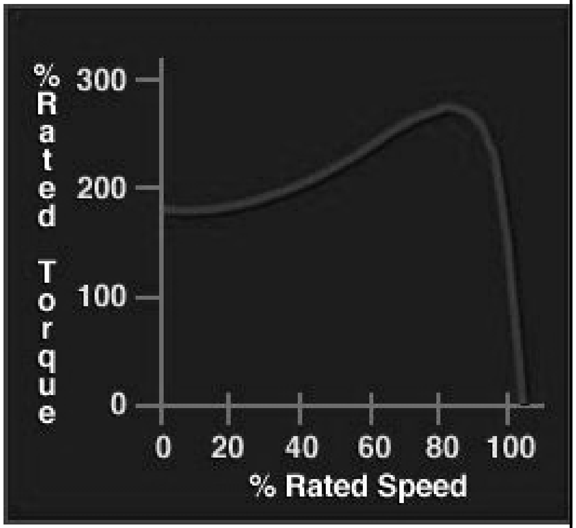
Design Type B

- Today's "Standard" 3-Phase Motor
- Good Starting Torque
  - In-rush amps 4-6 times full load amps
  - Good breakdown-torque
  - Medium Slip



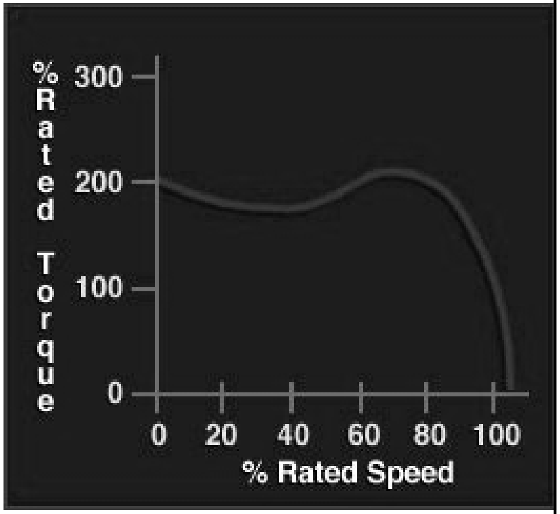
Design Type A

- The "old" Standard
- Higher starting torque than "B".
- Higher in-rush current (5-8 times full load amps)
- Good breakdown torque



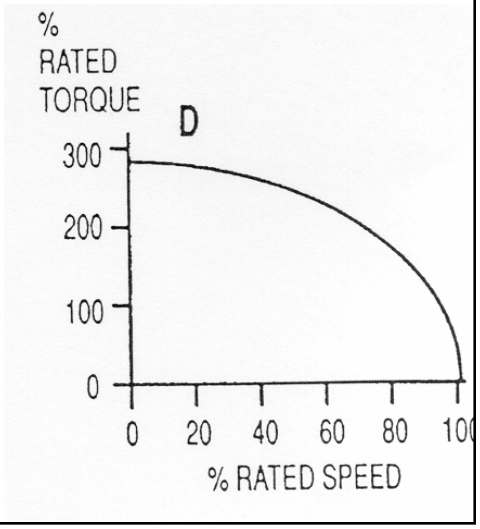
Design Type C

- Common OEM equipment on reciprocating pumps, compressors and other "hard starting" loads.
- High starting torque
- Moderate starting current (5-8 times FLA)
- Moderate breakdown torque



Design Type D

- Common on applications with significant loading changes as a machine operates.
- Impact Loads
  - Punch Presses, Metal Shears, etc.
  - Pump Jacks



Design Type E

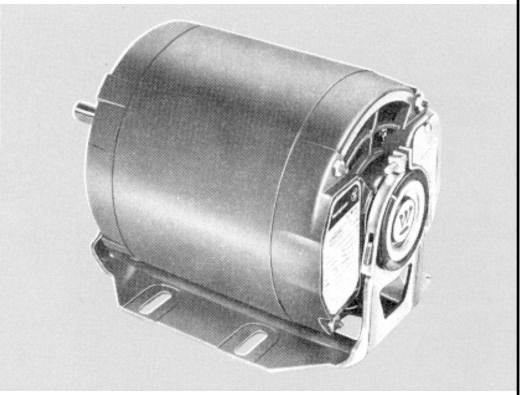
- Newest NEMA Category
- Newer ultra-high efficiency motors
  - Higher Starting Torque
  - Higher Starting Current (8-12 times Running)
  - Ultra Low Slip (Higher Rated Speed)

Single Phase Induction Motors

- Are not “self starting”
  - Require a starting mechanism.
- The name generally describes its “starting mechanism”.
  - Split Phase
  - Capacitor Run
  - Capacitor Start
  - Capacitor Start-Capacitor Run
  - Shaded Pole
  - Synchronous
  - Universal

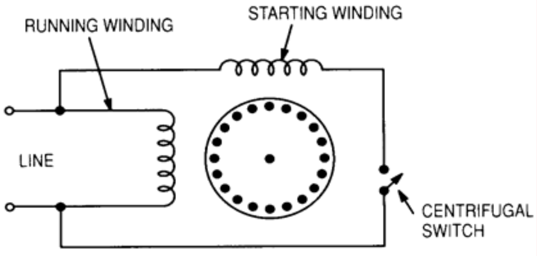
Split Phase Motor

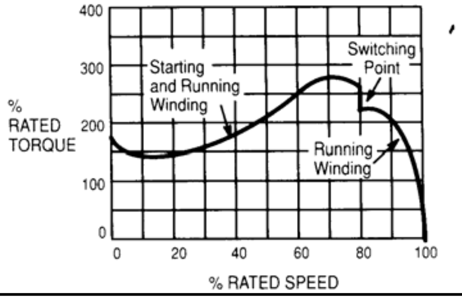
- Common small single phase motor
  - Good Starting Torque
  - Moderate Efficiency
  - Moderate Cost
- Small conveyors, augers, pumps, and some compressors
- 1/20th to ¾ Hp, available to 1.5 Hp



Split Phase Motor

- Starting winding in parallel with Running winding
- Switch operates at 70-80% of full speed.
- Centrifugal Switch
  - Sticks Open
  - Sticks Shut



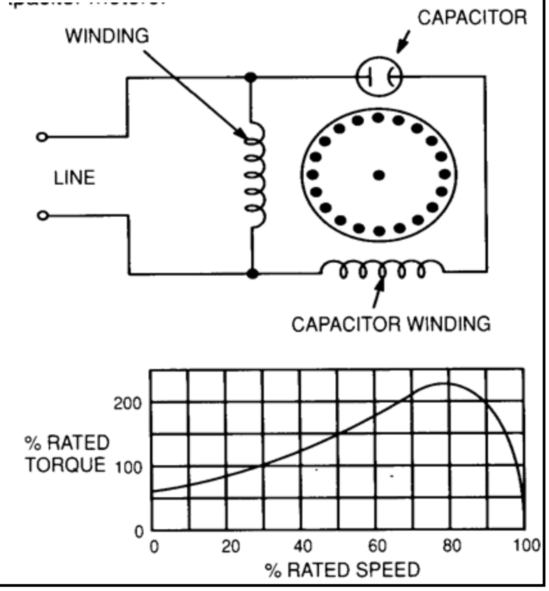


Capacitor Run Motor (Permanent Split Capacitor or PSC)

- Primarily a fan and blower motor.
- Poor starting torque
- Very low cost motor.

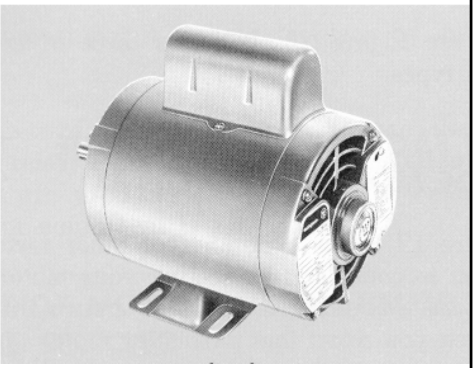
Permanent Split Capacitor (PSC)

- Capacitor in "Capacitor Winding"
  - Provides a "phase shift" for starting.
  - Optimizes running characteristics.
- No centrifugal switch



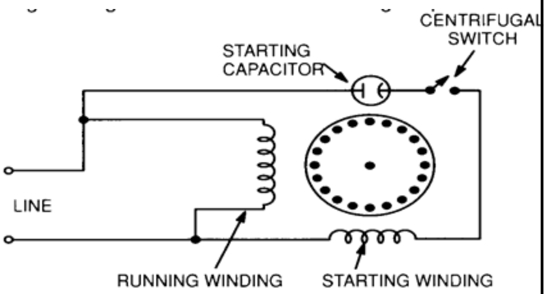
Capacitor Start Motor

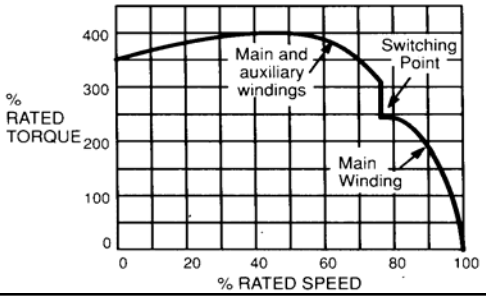
- Larger single phase motors up to about 10 Hp.
- A split phase motor with the addition of a capacitor in the starting winding.
- Capacitor sized for high starting torque.



Capacitor Start Motor

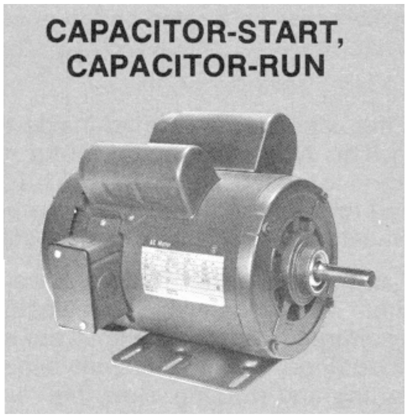
- Very high starting torque.
- Very high starting current.
- Common on compressors and other hard starting equipment.





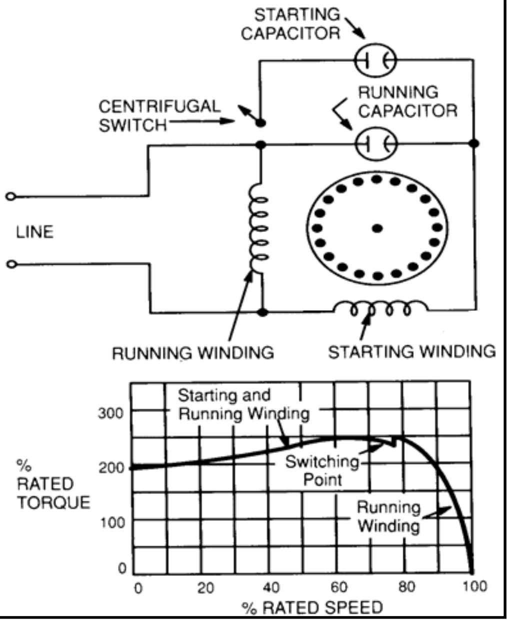
Capacitor Start-Capacitor Run

- Both starting and running characteristics are optimized.
  - High starting torque
  - Low starting current
  - Highest cost
- For hard starting loads like compressors and pumps.
- Up to 10 Hp or higher is some situations.



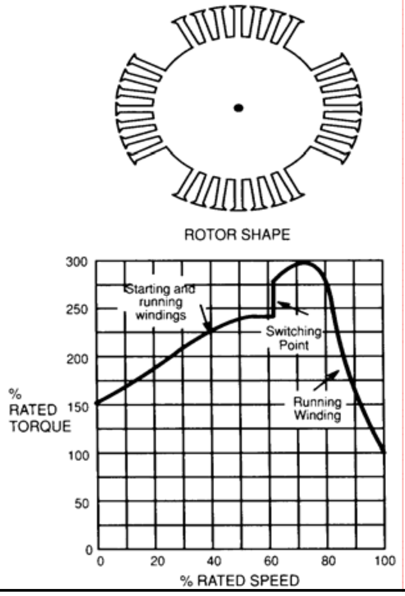
Capacitor Start-Run Motor

- Larger single phase motors up to 10 Hp.
- Good starting torque (less than cap start) with lower starting current.
- Higher cost than cap start.



Synchronous Motor

- Special design for “constant speed” at rated horsepower and below.
- Used where maintaining speed is critical when the load changes.



Universal Motor

- Runs on AC or DC
- Commutator and brushes
- Generally found in portable power tools.
- Lower Hp sizes

Universal Motor

- Very high starting torque.
- Higher torque on DC than AC (battery operated tools)
- The higher the rpm, the lower the torque.