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 no 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

\[
HP = \frac{RPM \times TORQUE}{5252}
\]
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
  \[ 0.75 \times 1.16 \text{ Hp} = 0.87 \text{ Hp} \]
• 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
  \[ \text{Watts} = 458v \times 14a \times 0.82 \times 1.74 = 9148.6 \text{ Watts} \]
  \[ 9148.6 \text{ Watts} / 746 \text{ Watts/Hp} = 12.26 \text{ Hp} \]
• 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
  \[0.90 \times 12.26 \text{ Hp} = 11.0 \text{ Hp}\]
- The motor IS overloaded!
- How bad is the overload?

Motor Types
CLASSIFICATION OF MOTORS

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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

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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

• 1/20\textsuperscript{th} 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.