Demand-Side Management Technology Workshop: Motors and Variable Frequency Drives

Sponsored by

Basin Electric Power Cooperative

with Western Area Power Administration

April 6, 2009

Bismarck, ND

Agenda

8:00 - 8:30 a.m.	***Registration***
8:30 - 8:45 a.m.	***Welcoming Remarks***
8:45 - 9:00 a.m.	***Determining Key Take-Aways***
9:00 - 10:15 a.m.	***Motors and VFD Technology Road Map***
10:15 - 10:30 a.m.	***Refreshment Break***
10:30 -12 Noon	***Motors and VFD Case Studies***
Noon - 1 p.m.	***Lunch break*** *- Motor Technology Demonstrations*
1:00 - 2:00 p.m.	***Motor Program Strategies***
2:00 - 3:00 p.m.	***Deploying a Motors Program to Your Customers***
3:00 - 3:15 p.m.	***Refreshment Break***
3:15 - 4:00 p.m.	***Technology Discussion Roundtable***
4:00 p.m.	**Closing Remarks and Adjourn**

Motors and VFD Technology Road Map

Katherine Johnson, Johnson Consulting Group with

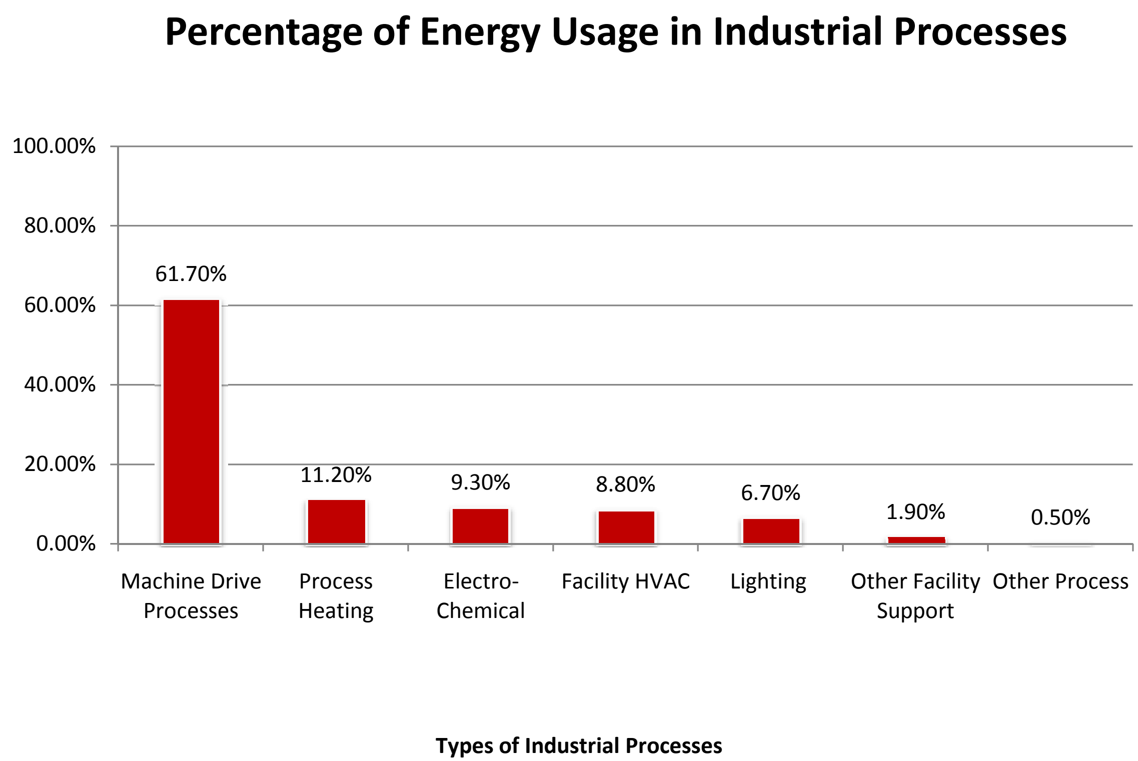
Mark Tsatsos, Marathon Electric

and Warren Bryan, L & S Electric

Why Motors Matter

- The Department of Energy (DOE) estimates that industrial electric motor-driven systems consume approximately 679 billion kWh annually or about 23% of all electricity in the US
- Motor systems are the single largest electric end use in the country. Motors offer a tremendous opportunity for energy savings, between 62 to 104 billion kilowatt hours (kWh) annually, according to the DOE estimates.

Energy Usage in Industrial Processes



Source: EIA Motors Assessment Study, 1998

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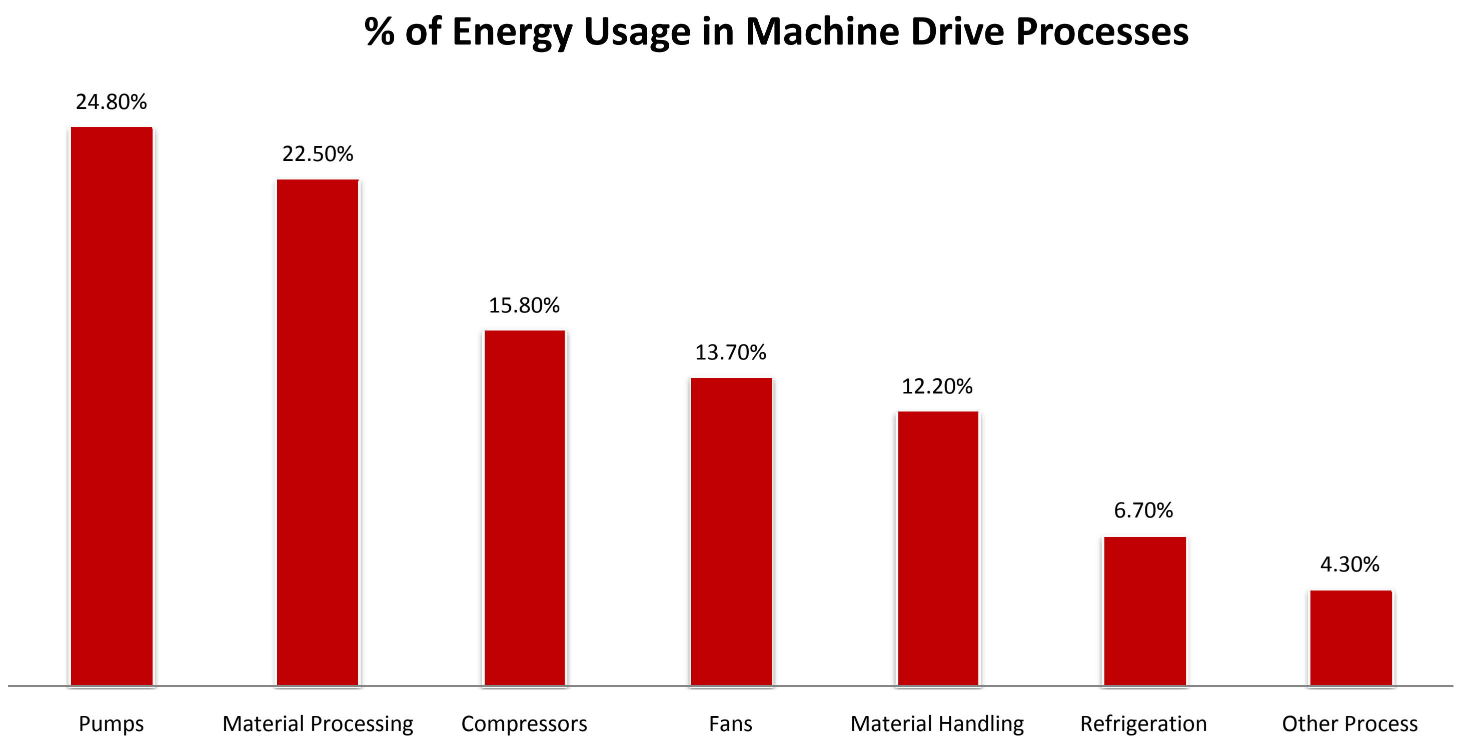
Energy Savings Potential for Motors and VFDs

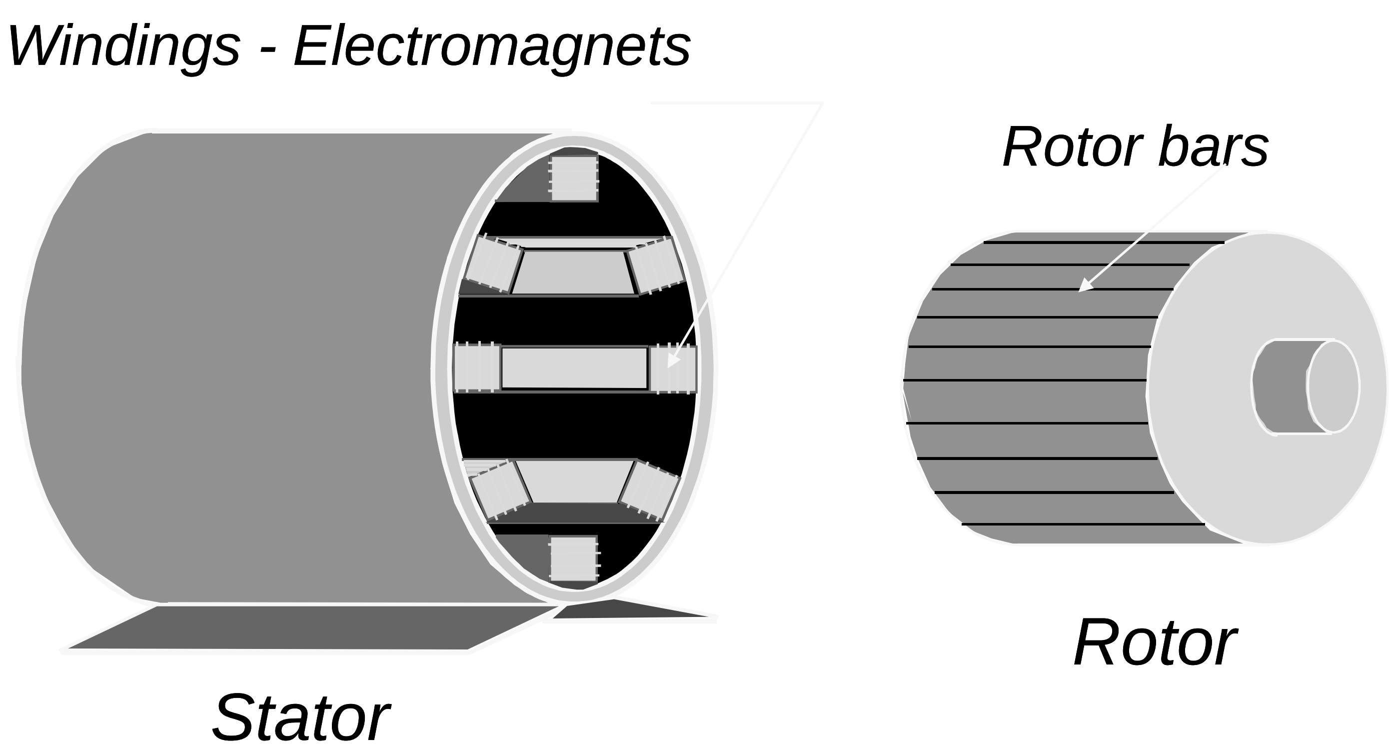


Source: EIA Motors Assessment Study, 1998

Motors Offer a Tremendous Savings Opportunity

- There is an installed base of motors in every manufacturing and commercial facility.
- The savings are often easily quantifiable
- They serve as an excellent entry point to discussions of larger system and facility savings

Three Phase Motor Construction



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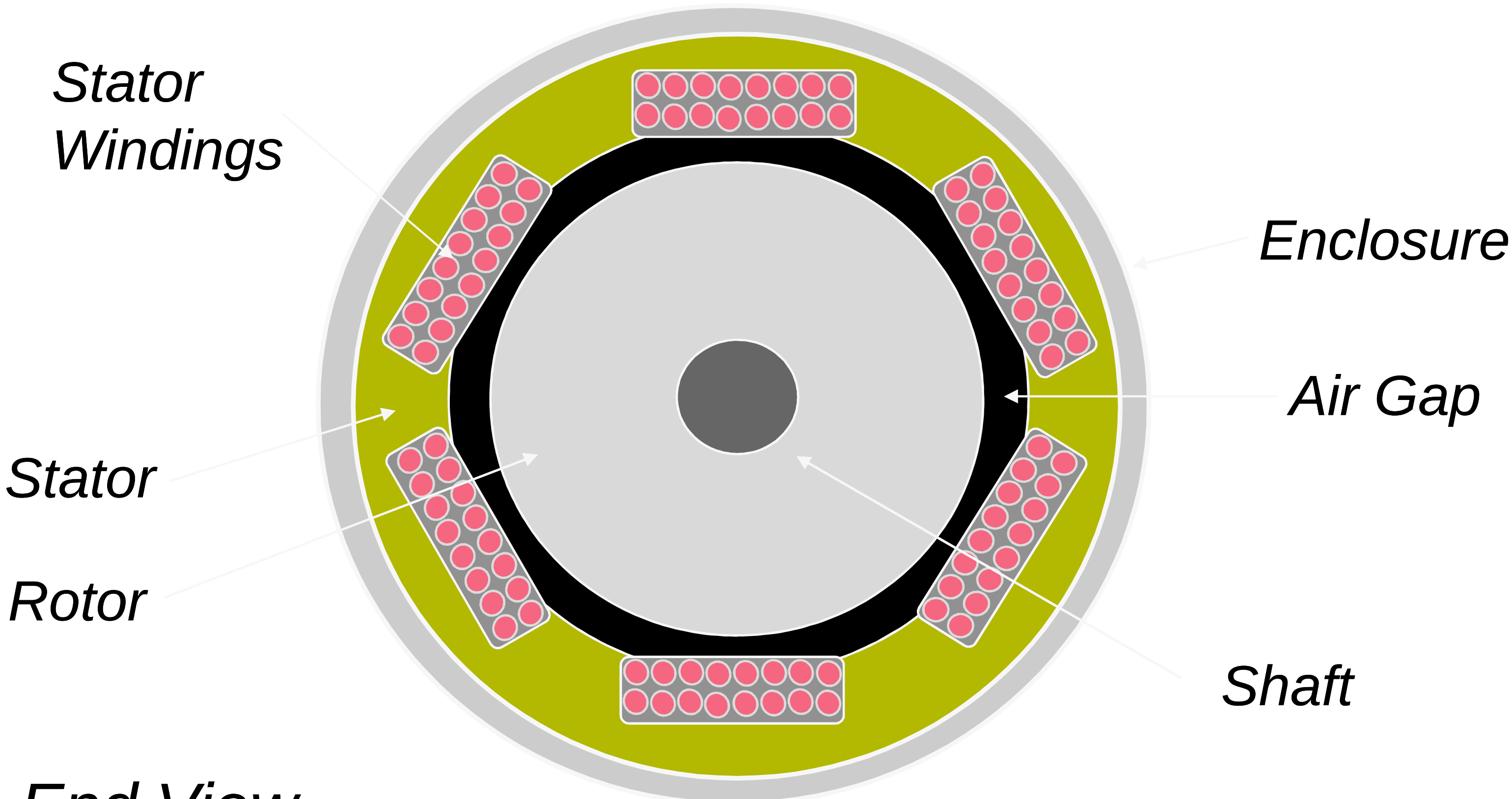
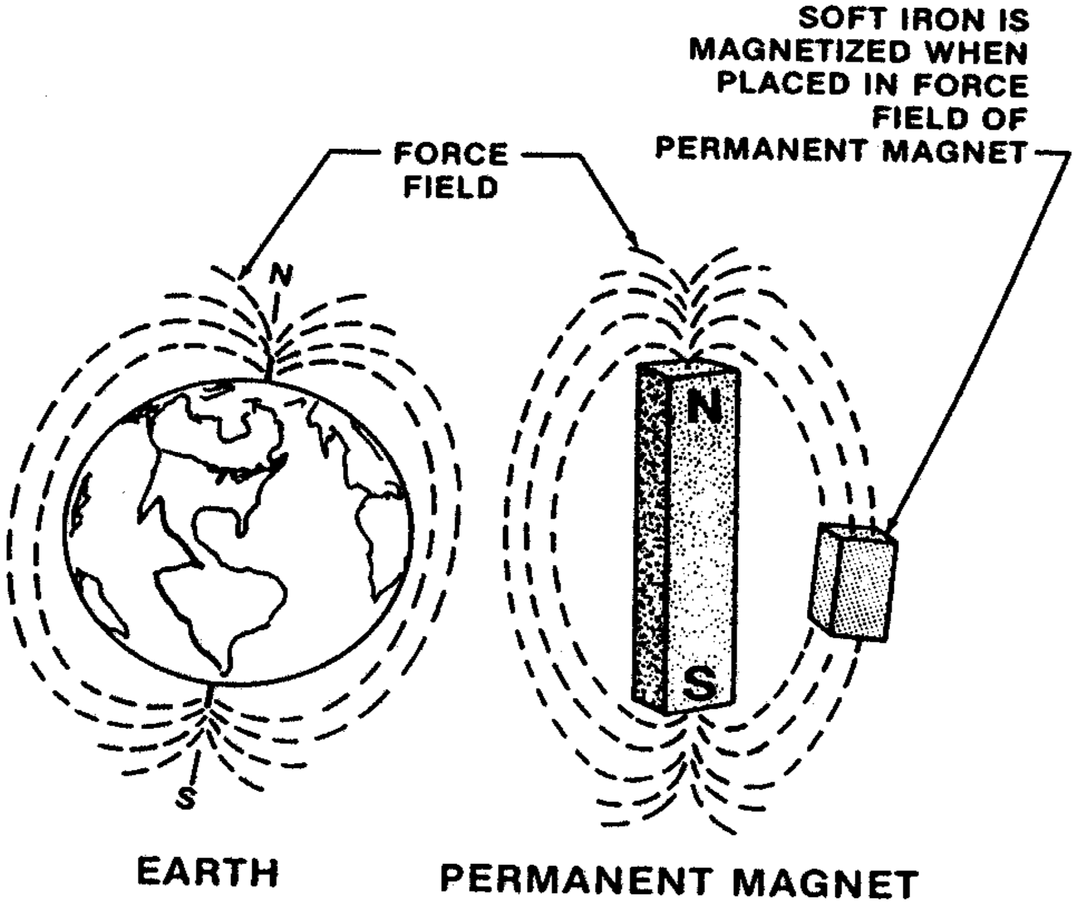
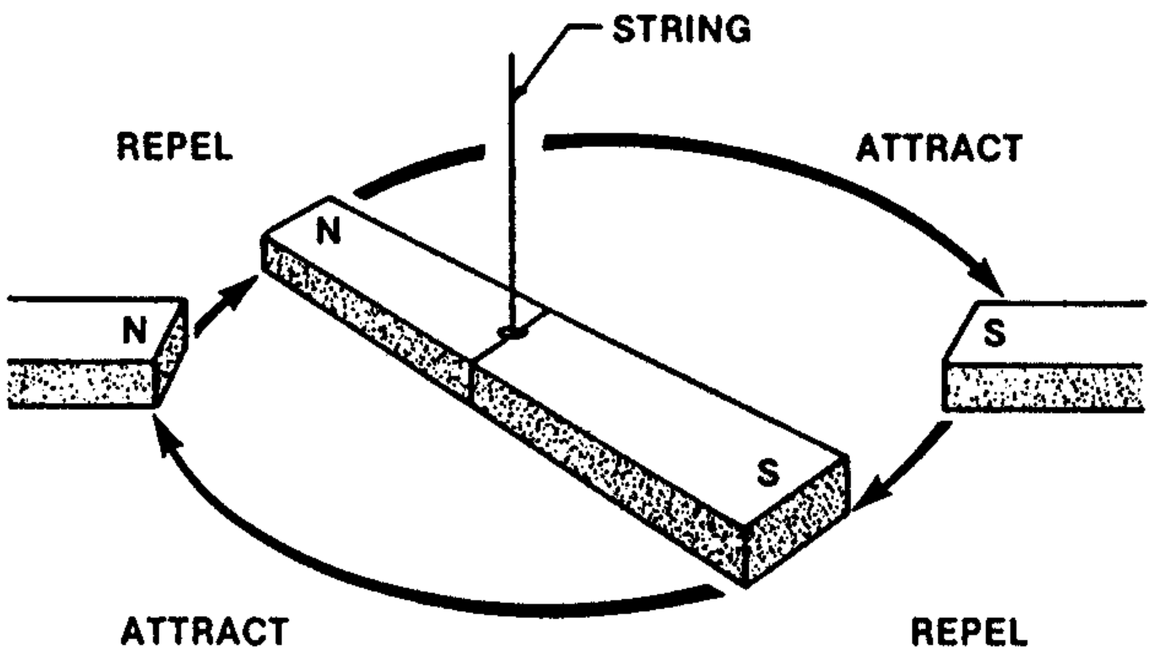


End View

Motor Operation



Motor Operation



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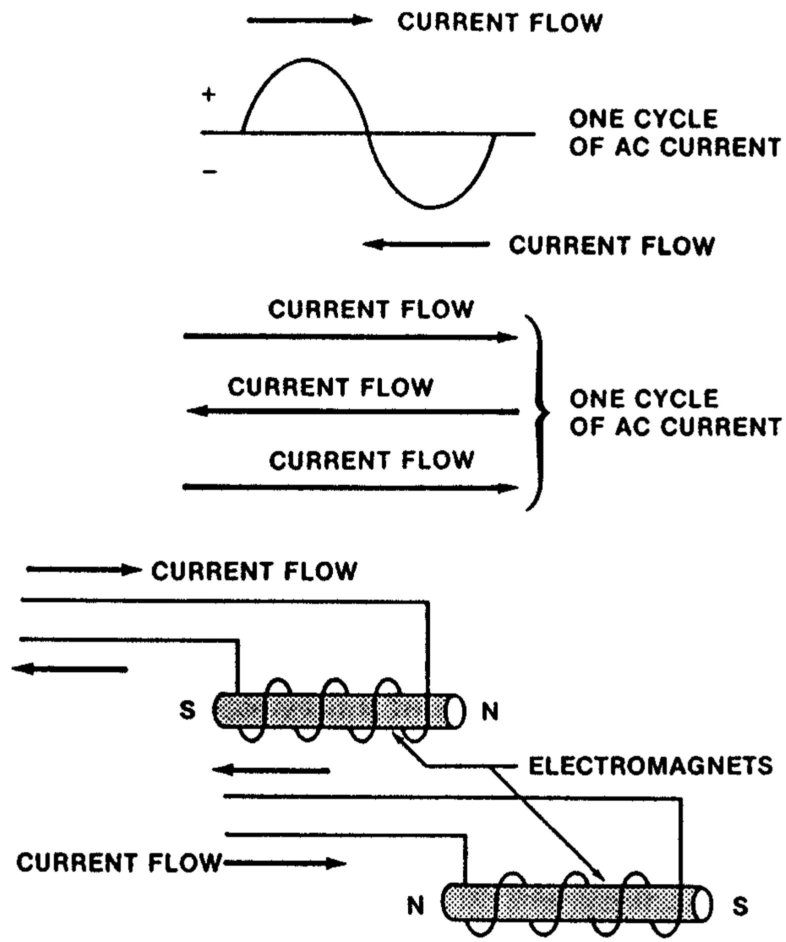
Motor Operation



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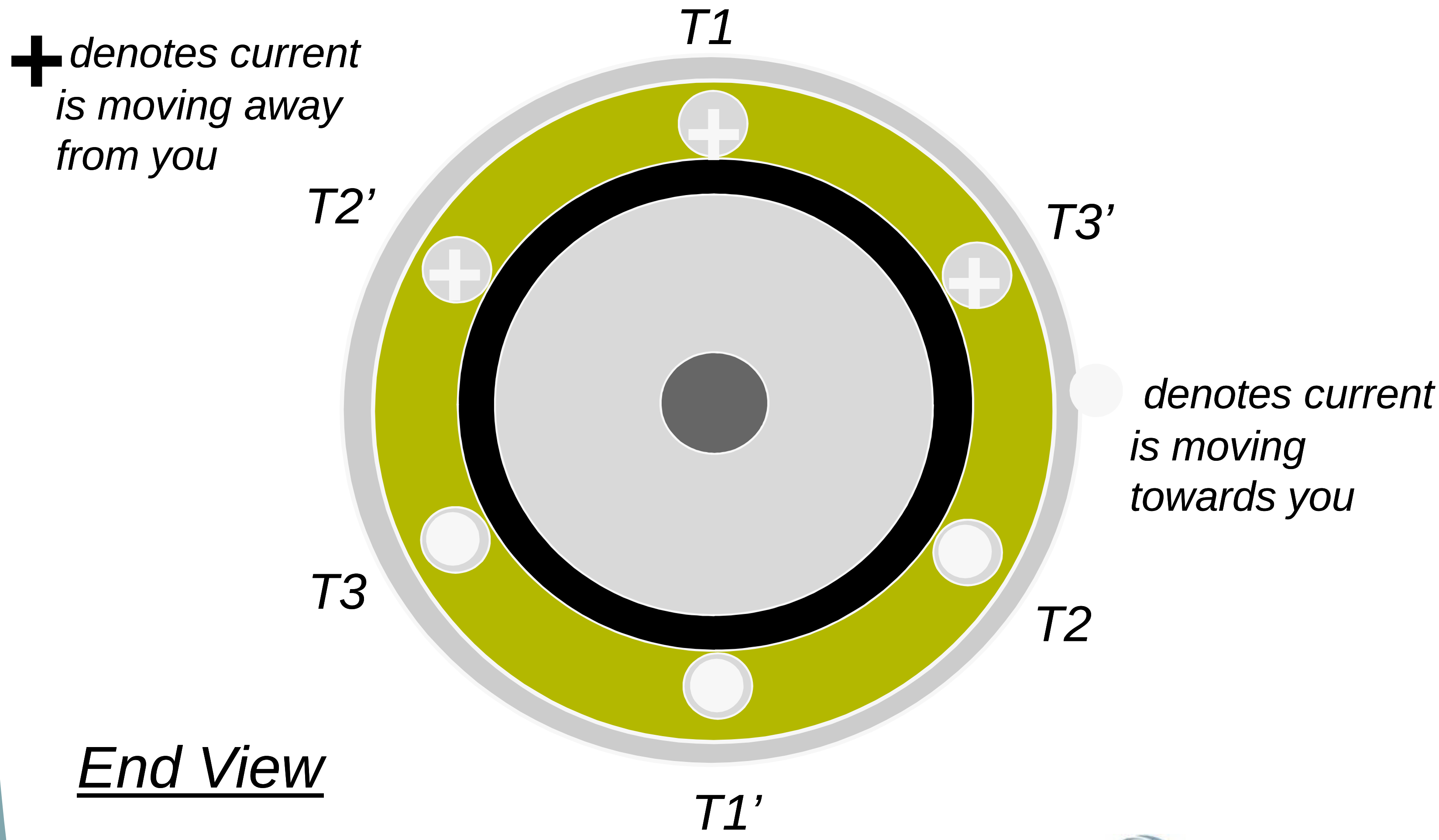

End View

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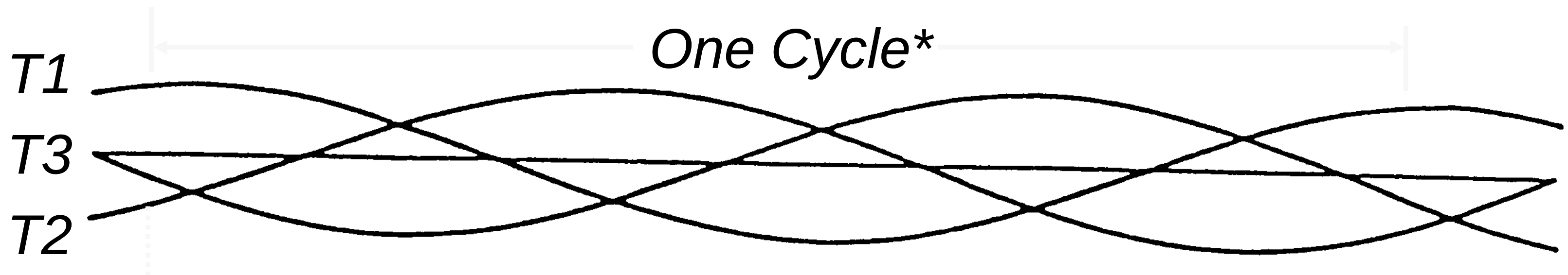
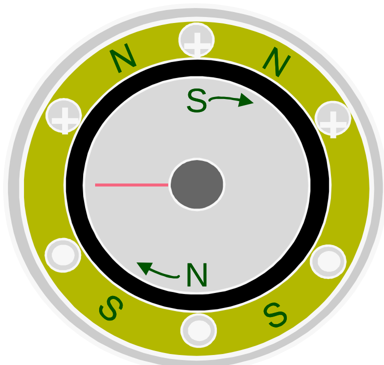
Rotation of the Motor





* - current waveform

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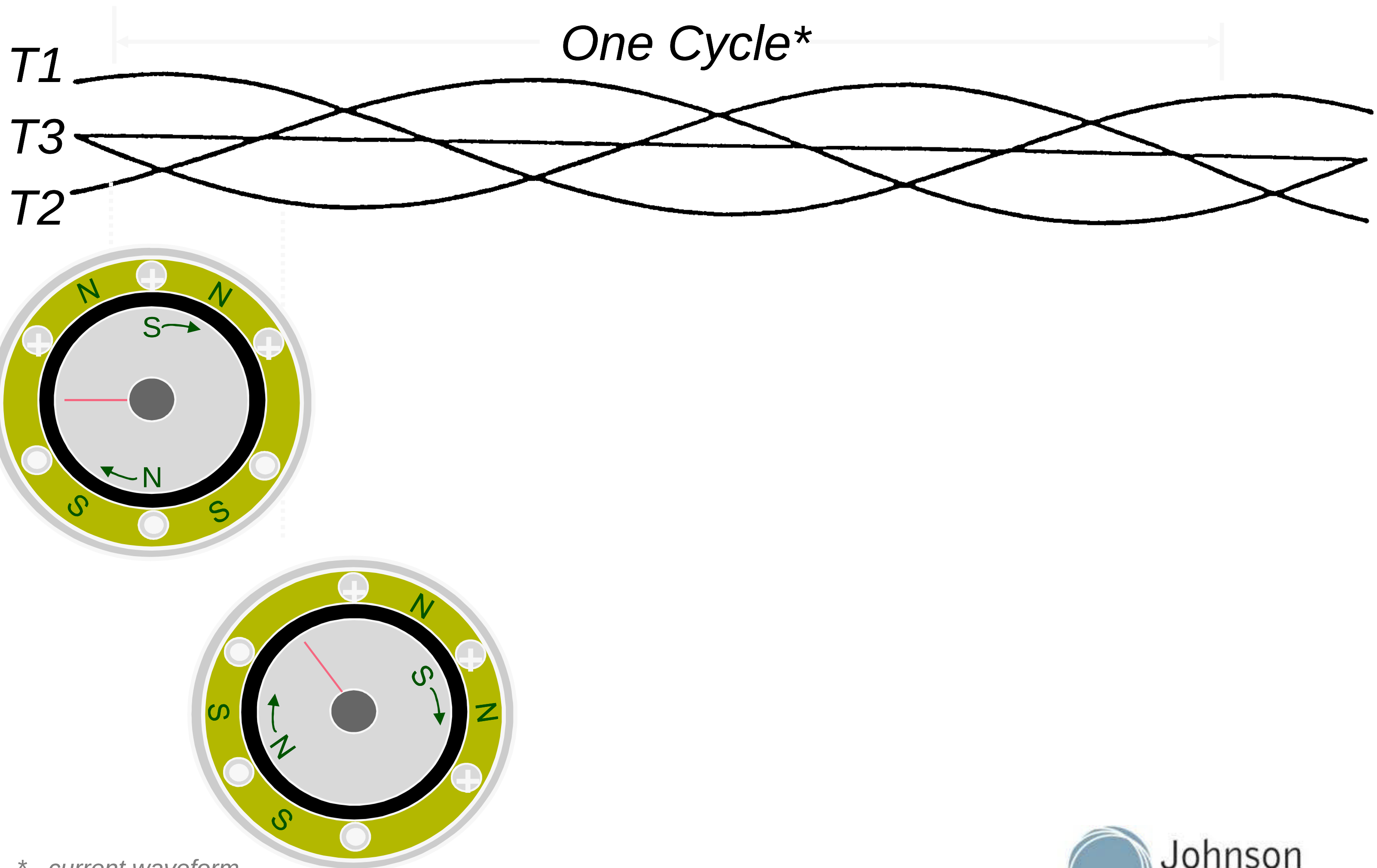

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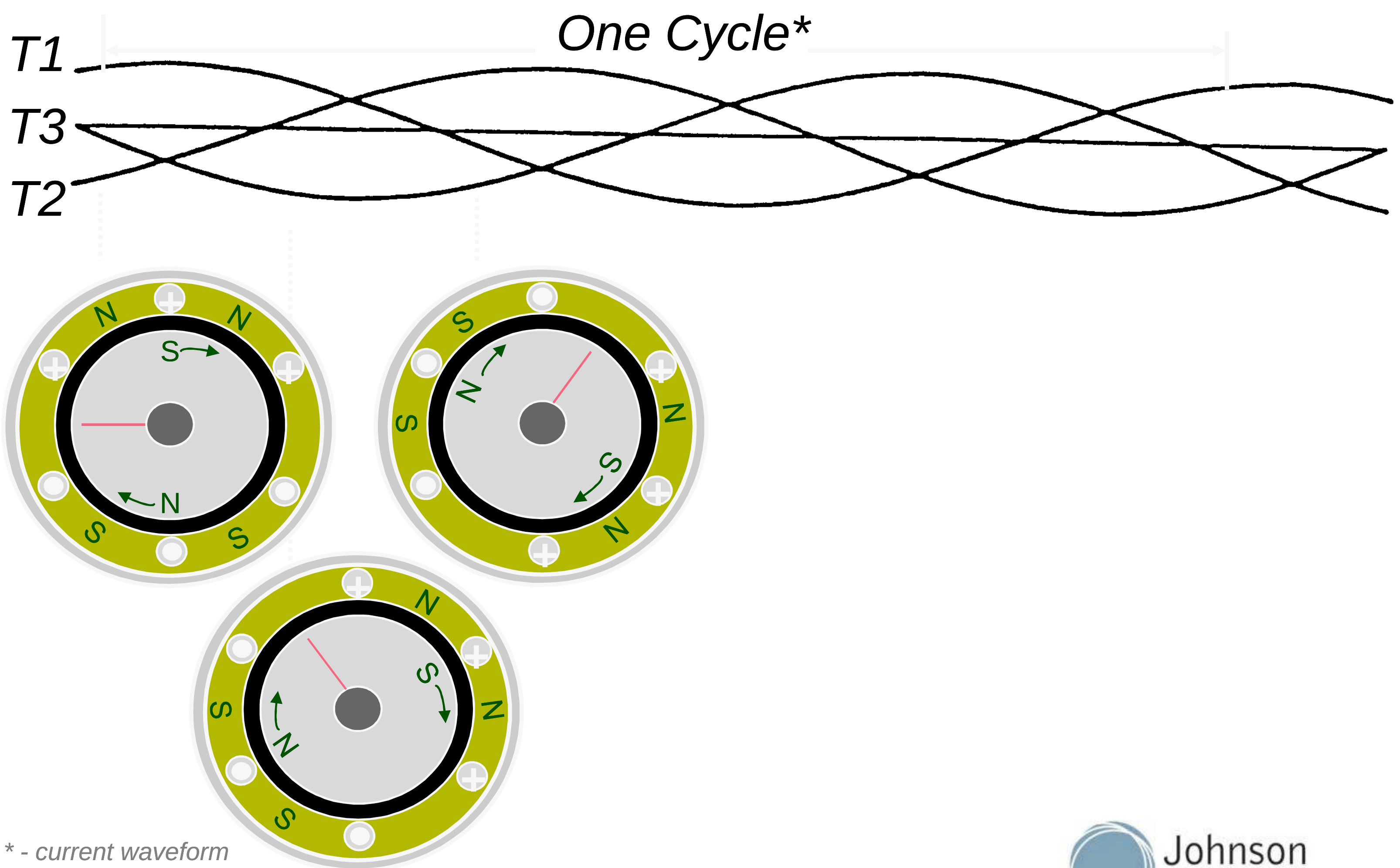

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Calculating Synchronous Speed of the Motor

$$N_o = \frac{120\,f}{P}$$

Calculating Synchronous Speed of the Motor

$$3600\,RPM = \frac{120\,f\,(60cycles)}{P(2\,poles)}$$

Motor Operation

- The number of poles and the frequency applied determine motor speed.
- Slip is the difference between the rotor speed and the rotating magnetic field in the stator.
  - When a magnetic field passes through the conductors of the rotor, the rotor takes on magnetic fields of its own. These rotor magnetic fields will try to catch up to the rotating fields of the stator. However, it never does -- this difference is slip.

Poles & Synchronous RPM @ 60Hz

Magnetic Poles	Synchronous RPM
2	3600
4	1800
6	1200
8	900

$$\frac{7200}{P} = \text{Synchronous RPM}$$

$$\frac{7200}{\text{Synchronous RPM}} = P$$

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Motor Efficiency

- Electric motors convert electrical energy into mechanical energy. Like all electromechanical equipment, motors consume some "extra" energy in order to make the conversion.
- Efficiency measures how much *total energy* a motor uses in relation to the rated power delivered to the shaft.
- Energy efficiency can reduce lifetime operating cost:
  - The annual energy cost of running a motor is usually many times greater than its initial purchase price.
  - When purchasing motors one must consider the total cost of ownership vs. initial purchase price.

Two Most Common Types of Motor Applications

- A ***TEFC*** enclosure on a motor means "Totally Enclosed, Fan Cooled": This motor is type the most commonly used motor in ordinary industrial environments. It costs only a few dollars more than the open motor, yet offers good protection against common hazards.
- An ***ODP*** enclosure on a motor means "Open, Drip Proof": ODP motors are relatively inexpensive motors used in normal applications.

Design Factors to Consider

- ***Motor Size.*** Size motors for efficiency. Motors should be sized to operate with a load factor between 65% and 100%.
- ***Operating Speed*****.** Select replacement energy-efficient motors with a comparable full-load speed for centrifugal load applications (pumps and fans).
- ***Inrush Current*****.** Avoid overloading circuits. Energy-efficient motors feature low electrical resistance and thus exhibit higher inrush currents than standard models.

Defining Motor Efficiency

- Electrical energy input is measured in Watts, while output is given in horsepower (hp). 1 HP = 746 watts.
- A motor's nameplate rating is based on output horsepower and is fixed for continuous operation at full load.
- Motor efficiency is expressed in the following ways:

$$\text{Efficiency, \%} = \frac{746 \text{ x Horsepower (output)}}{\text{Watts (input)}} \text{ x } 100$$

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Benefits of Energy Efficient and Premium Efficiency Motors

- Run cooler and are more likely to withstand voltage variations and harmonics better than less efficient motors.
- Have a slightly higher power factor on average than their standard counterparts.
- Operate more quietly than standard motors.
- Often have extended warranties on energy-efficient and premium-efficiency motors.

NEMA Motors- Recognized Energy Efficiency Standard

- NEMA Premium program ***assists purchasers*** identify higher efficient motors that will save them money and improve system reliability.
- NEMA Premium labeled electric motors will assist users to ***optimize motor systems efficiency***
- This will ***reduce electrical consumption*** thereby reducing pollution associated with electrical power generation.
- NEMA Premium motor program would save 5,800 gigawatts of electricity and prevent release of nearly 80 million metric tons of carbon into the atmosphere over the next ten years. *This is equivalent to keeping 16 million cars off the road.*

NEMA Specification

- NEMA Premium™ efficiency electric motor program scope is single-speed, polyphase, 1-500 horsepower, 2, 4, and 6 pole, squirrel cage induction motors, NEMA Design A or B, continuous rated. Products must meet or exceed the nominal energy efficiency levels.
- NEMA Premium™ efficiency levels are contained in NEMA Standards Publication MG 1- 2003, in Tables 12-12 and 12-13, respectively

EISA Basics

EISA is the acronym for the
Energy Independence & Securities Act

- This law was signed on December 19, 2007 and will be enforced beginning on December 19, 2010
- On December 19, 2010, motor manufacturers may not build motors that have a lower nameplate efficiency than the rules allow.
- Motors that are considered "finished goods" or are shipped from the factory before December 19, 2010 can be sold after December 19, 2010 because they were built before the deadline.

EISA Basics

General Overview of Levels

- General Purpose motors that today need to meet EPACT, will need to meet the NEMA
- Premium efficiency levels in 2010
- General Purpose motors that were exempt from EPACT because of voltage, mounting, etc
- will need to meet EPACT in 2010
- Motors that cannot be used in most applications, such as special shafts, blowers or
- nonstandard frequencies, are exempt from any regulations for efficiency.

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Specific EISA Rules

Exempt / Not Covered

Single phase
Special shaft extensions
TEBC, TEAO, DPFV, TENV
Special V/Hz inverter motors
Non-continuous duty
Design D
Phase converters
Multi-speed
50Hz
Two-digit frames (48, 56)

Must meet EPACT (Table 12-11)

Close Coupled Pump
Vertical Solid Shaft
Round body
Nonstandard Voltages, 60Hz
200-500hp
Firepump motors
U-frame

Must meet NEMA Premium (Table 12-12)

1-200hp
Design A & B
C-face, D-flange
Footed
Voltages covered by EPACT (60Hz)

Note: Frame size is not an exemption.
If a motor is an IEC frame, follow the rules just as if it was a NEMA Frame.
If a motor is above a NEMA frame (680), follow the rules just as if it was a 440 frame.

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Types of Energy “Losses”

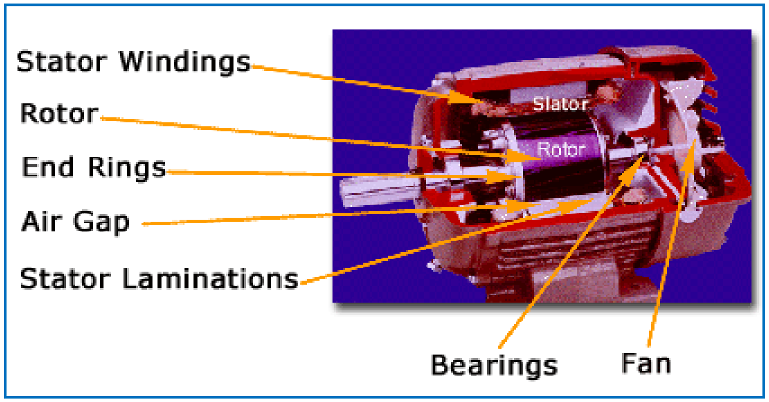
- “Losses” are the energy "fees" the motor charges in order to make its electrical-to-mechanical energy conversion. Their magnitude varies between the type and make of motors.
  - Power losses
  - Stray load losses
  - Magnetic core losses and
  - Friction and windage losses

Power and Load Losses

- Power losses appear only when the motor is operating under load.
  - They are more important, in terms of energy efficiency, than magnetic core losses and friction and windage losses, which are present even under no-load conditions (but the motor is running).
- Power losses, also called I^2R losses, are the ***most important*** and can account for more than one-half of a motor's total losses.
  - Power losses appear as heat generated by resistance to current flowing in the stator windings and rotor conductor bars and end rings.

Stator Losses

- Account for 66% of power losses
- But are able to be minimized by increasing the mass of stator windings. This lowers their electrical resistance
- Highly efficient motors typically contain about 20% more copper than standard efficiency models of equivalent size and rating.



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Rotor Losses

- Are reduced by decreasing the degree of slip. This is accomplished by increasing the mass of the rotor conductors and/or increasing their conductivity and by increasing the total flux across the air gap between rotor and stator.
- High- efficiency motors tend to have less slip (run faster) than standard-efficiency motors.
- Therefore, it is important to properly engineer the application of any motor.

Magnetic Losses

- Magnetic core losses arise from changes in magnetism such as eddy currents and magnetic saturation.
- Can account for up to 20% of total losses.
- Can be minimized with proper design, use of better materials and stringent quality control

VFD Overview

Electronic Motor Drives

- A motor drive controls the speed, torque, direction and resulting horsepower of a motor.
  - A DC drive typically controls a shunt wound DC motor, which has separate armature and field circuits.
  - An AC drive control AC induction motors, control speed, torque, and horsepower.

Adjusting Motor Operation

- Could adjust by the number of poles, but that requires rewinding, and result in a step change to the speed.
- So, for convenience, cost-efficiency, and precision, we change the frequency using variable frequency drives (VFDs)

Variable Frequency Drives

- Vary in the complexity of their designs, but the designs continue to improve.
- Come in smaller packages with each generation. The trend is for more features, better performance, and lower cost with successive generations
- Are increasingly becoming "plug and play." As electronic power components improve in reliability and decrease in size, the cost and size of VFDs will continue to decrease.

Source: **ABB Inc.** - Drives and Power Electronics

Benefits of Variable Frequency Drives

- VFDs are ideal for AC motor-driven application that does not need to be run at full speed.
- Divided into two groups: constant torque and variable torque.
  - Variable torque loads include centrifugal pumps and fans, which make up the majority of HVAC applications.
  - Constant torque loads include vibrating conveyors, punch presses, rock crushers, machine tools, and other applications where the drive follows a constant V/Hz ratio.
  - Energy savings potential of variable torque applications is much greater than that of constant torque applications

Performance Advantages of Variable Frequency Drives

Productivity: Process equipment is normally designed for future productivity increases. Changing speeds of production equipment can be costly and take a significant amount of time. With the application of VFD's to a production system an increase in the speed of the process can be easily accomplished.

Energy Savings: In many manufacturing processes the production volume changes. Changing production volumes utilizing mechanical means can be very inefficient. With VFD's the production volume can be achieved by changing the motor speed. This can save a significant amount of energy particularly in fan and pump applications because the shaft power is proportional to the flow rate to the power of three.

Performance Advantages of Variable Frequency Drives

Higher Quality: The application of VFD's can provide improved accuracy in the speed control of a process resulting in process optimization. The optimal process control leads to the best quality end product.

Advantage Over Line Starting: Operating an induction motor with a VFD has many advantages over line starting. A line started motor draws 6 to 10 times its rated current, heats up excessively, accelerates at an uncontrollable rate, and causes voltage disturbances on the supply lines feeding it. Line starting also causes undue stress on the connected machinery.

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