De Anza ES 73 Electric Motors and Drives

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Instructor

Course Objectives

- Understand basic motor terminology
- Examine typical motor applications
- Examine various strategies to reduce energy usage in motors
- Assess the importance of sizing motors appropriately
- Examine the technology and benefits of high efficiency motors
- Examine variable frequency drives and other motor control devices
- Calculate life-cycle cost of motor retrofit and new construction options

Logistics

- Field Trip. TBD
- Reading assignments
- Two homework assignments
- Journal
- Sign up for "empt" listserve
- Contact Richard C. Celio, PE
  - rccelio@netscape.net
  - Voicemail 408 846-5411, check weekly

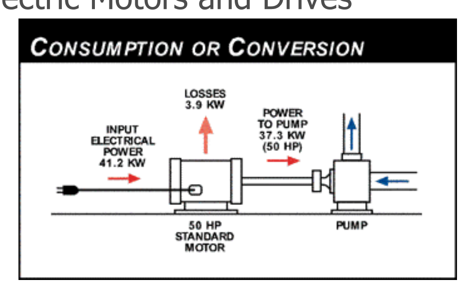
"Energy Management for Motor Driven Systems"

- Office of Industrial Technology (OIT)
- 800-862-2086 or www.oit.doe.gov Free!
- Chapters:
  - Read chapters 1,4,5,6,7,9
  - Review chapters 2,3,8
  - Special Attention to p 7-2 "Motor Master+"

"Energy Efficient Motor Systems"

- ACEEE, 2nd ed. Nadel, et al. 2002
- http://www.aceee.org/motors
- Chapter one on line
- Excellent Glossary on line

Electric Motors and Drives



- What is a Motor?
  - Machine that converts electrical power into mechanical power. In doing so, it consumes power also (3.9kW in the picture).

Energy Policy Act

- % of National Energy Use
  - 60 % of Nation's electricity as input
  - "A sizable percentage (15-25 %) of U.S. electricity can be saved by optimizing the performance of electric motors and their associated wiring, power conditioning equipment, controls, and transmission components" (American Council for an Energy Efficient Economy 2002)
- Energy Policy Act (EPAct) 1992
  - Federal Legislation, Bush (#41) signed into law
  - Establishes minimum-efficiency standards for specific motors less than 200 hp.
- NEMA (National Electrical Manufacturers Association)
  - Sets industry standards for electrical equipment

How Are Motors Used?

How Are Motors Used?

- Residential
  - "Fractional" small motors for appliances
- Commercial
  - Pumps, fans, compressors for HVAC, lifting
- Industrial
  - The above plus, presses, conveyance, etc.

% of Electric Load Consumed By Motors in Industry	
Petroleum/Chemical	92.4%
Paper	90.1%
Food	86.7%
Textile	82.4%

Key Definitions

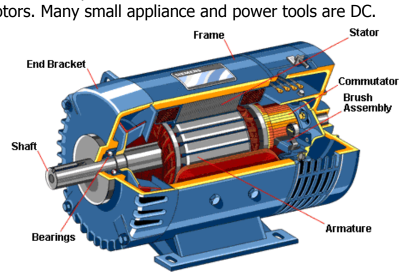
- Horsepower = 746 watts or 33,000 ft-lb/minute. Used for rated output of a motor.
- Torque = The twisting force exerted by the shaft of the motor. Measured in ft-lbs
- kW v kWh (power vs energy)

Power Factor

- Ratio of Real Power to Apparent Power
  - Power Factor = Real Power (W)/Apparent Power (VA)
- Induction motors can contribute to poor power factor.
- Utilities Penalize Customers for low power factor (See rate schedule for details.)

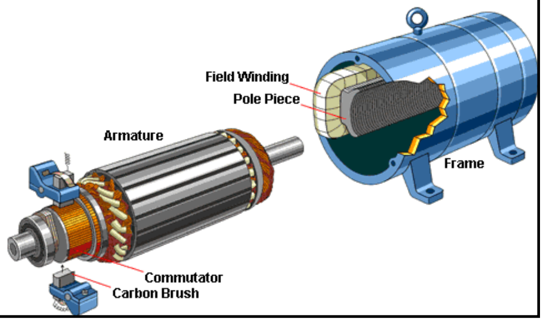
Types of Motors - DC.

- DC motors
  - Good for speed control since speed varies with voltage. Large DC motors are expensive to maintain and not as efficient as induction motors. Many small appliance and power tools are DC.



Types of Motors - DC.

- DC motors
  - Armature rotates between the poles of the field windings.



Types of Motors - AC

- Fractional HP (less than 1 hp)
  - Tend to have poor power factor and efficiency
- AC motors
  - Induction/Asynchronous
    - "Squirrel Cage" motor most common. Simple, reliable, and efficient. Are asynchronous because of slip.
  - Synchronous
    - Complex rotor design eliminates slip. Good for constant low speed applications. Good efficiency but more expensive.

Types of Motors - AC

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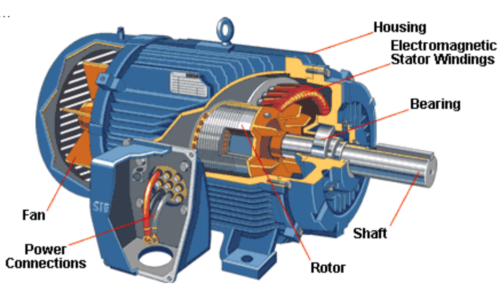
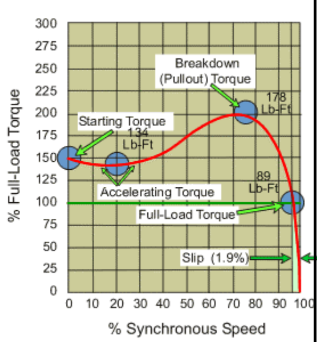


Motor Parts

- Rotor – The part of the motor that rotates!
- Stator – Non rotating magnetic section of a motor
- Bearings – The supports that hold the revolving shaft
- Fan – motor cooling
- Insulation – separate electric components
- Enclosure – motor housing type
  - ODP – Open drip proof – common
  - Splashproof and Weather protected --same as above with angled vents to avoid drips
  - TEFC – Totally enclosed fan cooling – exterior fan

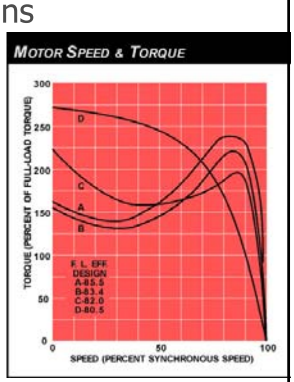
Motor Specifications

- Torque vs Speed
  - The motor torque speed curve must match the load torque requirments.
  - If the load torque exceeds the motor curve the motor will stall and possible burn out.



Motor Specifications

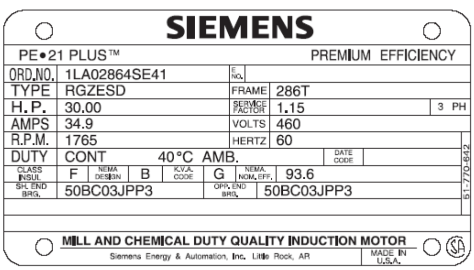
- NEMA Design
  - Induction motor standards for different load conditions
  - A, B, C, D
    - Design B is the most common. Others are for loads with different torque requirements



Specification - Nameplate Data

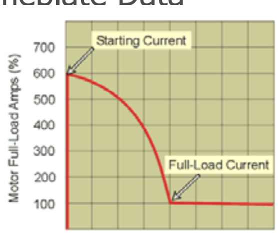
Catalog #	
Specification #	
Frame #	RPM
HP (output)	Phase
Volts	Class
Amps	Service Factor
Rating	Nema Nom. Eff %
	Power Factor %

Specification - Nameplate Data



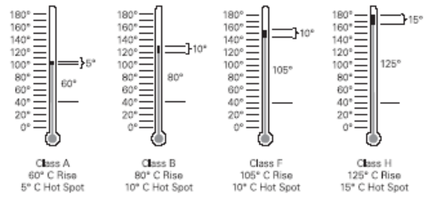
Specification - Nameplate Data

- FLA = Full load amps or what you would expect the motor to use.
- LRA = Locked rotor amps or starting inrush current.
- Service Factor
  - If the service factor is higher than one, the motor can "harder" without failing. Does impact insulation life.



Typical curve for NEMA Type B Higher starting currents may require NEMA type A. Caution must be used to avoid tripping overcurrent protection on startup.

Specification - Nameplate Data



- Insulation Class,
  - Heat will eventually cause the winding insulation to fail. Different insulation material will be used for different application.

Motor Slip

Synchronous Speed= The difference in RPM between the rotational speed of the magnetic field and the actual RPM of the rotor and shaft at a given RPM

$$\frac{120 \times \text{frequency in HZ}}{\text{\# of poles}}$$

Example:

(120 x 60)/4 poles = 1800 rpm

Actual (measured) is 1740 to 1780 rpm

Motor Slip

Or in percentage:

$$\text{Slip} = \frac{1800 - 1740}{1800}$$

= 3.3%

Where 1800 rpm = synchronous speed or no load speed

And 1740 = Output speed under load

Energy Consumption

Energy Use Equation*

kWh =

$$\frac{\text{horsepower} \times 0.746\ \text{kW/hp} \times \text{hours of operation}}{\text{Motor efficiency (\%)}}$$

- Assumes average hp load. Since load can vary significantly, one can use a load factor LF (usually between 25-75%)

OR if you know the volts - V (line to line) and amps - I

kWh =

$$\frac{V \times I \times PF \times 1.73 \times LF \times \text{hours}}{\text{Efficiency}}$$

NOTE: 1.73 is for three phase motors only. For single phase, use 1.0

Energy Consumption

Assume: 10 hp, Running full time 24 hours 7 days week, 8760 hours per year with Standard Efficiency = 90.8%

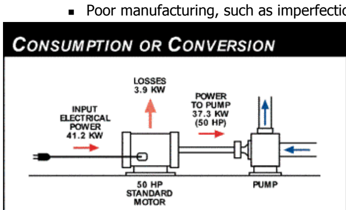
$$= \frac{10\ \text{hp} \times 0.746\ \text{kW/hp} \times 8760\ \text{hrs/yr}}{.908}$$

= 71,970 kWh/yr

Calculate the energy for the 10HP if it runs 65 hrs per week with an average load factor of 72%.

Motor Losses

- Electrical (Power Losses)
  - I^2R losses (current x resistance), Increases with load
- Magnetic
  - Eddy currents and stray voltage, Improved by using more iron in the motor
- Mechanical
  - Bering Friction, Windage losses, Slip
- Stray Loss
  - Poor manufacturing, such as imperfections in the air gap.



Efficiency = Output/Input

$= P_{out}/P_{in}$

$= (1-P_{Loss}/P_{in})$

For example given…

% = (1-3.9/41.2) x 100

= 90.5%

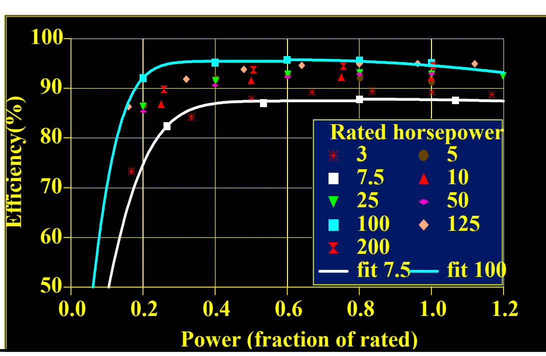
Energy Efficient Motors

- Electricity accounts for nearly 98% of the lifetime cost of electric motors.
- Improved design, materials, and manufacturing reduces losses.
- Other benefits include:
  - Increased reliability
  - Higher service factor
  - Longer insulation and bearing lives
  - Less waste heat and vibration
  - Often longer warranty
  - Improved power factor

Motor Efficiency

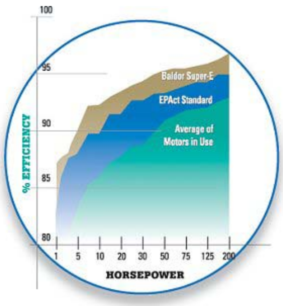
- Nominal Efficiency
  - "Average" expected efficiency
  - Not all motors are exactly the same. There are variations in the manufacturing
- Minimum Efficiency
  - Guaranteed by manufacturer "Worst Case"
- Standard Efficiency Motors
  - Lower first cost
  - Older motor population

Motor Efficiency Curves



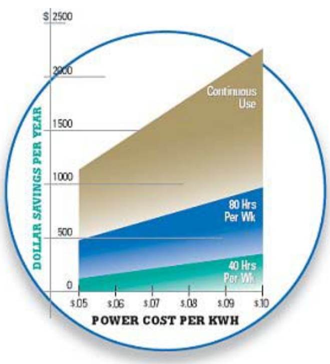
Motor Efficiency Standards

- EPAct Motors
  - New standard effective 1997 (1-200 hp)
- CEE -- Consortium for Energy Efficiency – Non profit organization. (www.cee1.org)
- NEMA – Broader definition includes more motors
  - June 2001 "Better than EPAct" NEMA special designation for premium (1-500 hp) motors.



Energy Efficient Motors

- Savings using a 40-horsepower Baldor Super-E® - 94.5% efficiency Compared with an average industrial motor - 88% efficiency.



Energy Efficient Motors Applications

- Where is it economical to use EE Motors? Some possibilities…..
  - New Construction
  - Large Renovation projects
  - Retrofit Frequently used motors (hrs/yr) We'll do payback analysis!
  - Improperly sized motors
  - Alternative to rewinding
  - Failed motors

Motor Load

- Constant Speed, Constant Torque
  - Bathroom fan
  - Circulation Pump
  - Constant Volume Air Systems
- Best Opportunities
  - Turn off!
  - More efficient motors

Motor Load

- Constant Speed, Variable Torque loads
  - Escalator – Same Speed no matter what
- Variable Speed, Variable Torque loads
  - Train- High torque to start, low to run

Motor Load

- Cube Law – Power required is proportional to the cube of the flow

"If the fan speed is doubled, the power requirement grows eight fold."

or

"Reducing speed of a fan by 20% reduced the power requirement by half"

Oversized Motors

- ◆Loads change as buildings age.
- ◆Peak motor efficiency is around 75% of load.
- ◆Efficiency decreases rapidly below 25% of load especially for smaller motors.
- ◆Motors can be tested by an electrician.

Motor Resources

- ◆ Motormaster + 3
http://www.energy.wsu.edu/cfdocs/mmdownload/register.cfm
Download free
Large documentation File

- ◆ Resources
  - http://www.oit.doe.gov/bestpractices/motors/ U.S. D.O.E.
  - Htttp://www.motorsmatter.org
  - http://www.energy.copper.org/motor-text.html
  - www.subscribeforfree.com (code NP26P) Energy User News

- ◆ Example Manufacturers
  - http://www.emersonmotors.com/
  - http://www.geindustrial.com/
  - http://www.baldor.com/

Factors Influencing Decision Making*

- ◆Limited Information
- ◆Limited Access to Capital
- ◆Payback Gap
- ◆Low Priority Assigned to Energy Matters
- ◆Transaction Costs/Staff Time
- ◆Misplaced Program Emphasis
- ◆Lack of Internal Incentives

*From ACEEE "Energy Efficient Motor Systems" 2002

Motor Action Plan

- Management Commitment
- Energy Coordinator
- Staff “buy – in”
- Energy Data
- Energy Surveys
- Analyze data and surveys
- Set goals
- Develop a plan
- Implement plan
- Evaluate results

Review

- Course Objectives
- Basic terminology
- Motor parts
- Simple Calculation
- Energy Efficient Motors
- Homework assignment
- Reading material