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PUMPS & SYSTEMS WEBINAR SERIES

Motor Efficiency Improvements for Pumping Applications

Brent McManis, P.E.

Industry Engineering Manager

Baldor Electric: A Member of the ABB Group

• Participants are in a listen-only mode.

• To ask a question during the event, use the chat feature at the bottom left of your screen. Technical questions will be answered by ReadyTalk. Questions for our speakers can be asked at any time and will be answered during the Q&A at the end of the session.

• Visit pump-zone.com in the coming days to view the answers to all of the questions asked during the Q&A session.

• Visit pump-zone.com in the coming days to access the recording of the webinar.

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Our mission is to be the best (as determined by our customers) marketers, designers and manufacturers of industrial electric motors, drives and mechanical power transmission products.

Our Strategy

To produce the highest quality, energy-efficient products available in the marketplace and sell them to a broad base of value-minded customers.

$$V_p = \frac{Q_p \times S_p}{C \times T}$$

Vp = perceived Value **Qp = perceived Quality** **Sp = perceived Service**

C = Cost **T = Time**

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Motor Efficiency Improvements for Pumping Applications

- Energy Savings Potential
- Rules/Regulations
- Motor Retrofits
- New Motor Technology

ABB

- 145,000 employees in about 100 countries
- $42 billion in revenue (2013)
- Formed in 1988 merger of Swiss and Swedish engineering companies
- Predecessors founded in 1883 and 1891
- Publicly owned company with head office in Switzerland

ABB – 5 Global Divisions

Power Products

36,000 employees

Power Systems

20,000 employees

Discrete Automation and Motion

29,000 employees

Low Voltage Products

31,000 employees

Process Automation

28,000 employees

- ABB's portfolio covers:
  - Electricals, automation, controls and instrumentation for power generation and industrial processes
  - Power transmission
  - Distribution solutions
  - Low-voltage products
  - Motors and drives
  - Intelligent building systems
  - Robots and robot systems
  - Services to improve customers productivity and reliability

Discrete Automation and Motion – Business Units[1)]

Together, we drive our customer's industrial productivity and energy efficiency

Drives and Controls

- Low voltage AC drives from 0.12 to 5'600 kW
- DC Drives from 4 kW to 15'000 kW
- Medium voltage drives from 315 kW to more than 100 MW
- PLCs, HMIs, and input/output devices
- Motion control
- Software tools
- Energy saving tools
- Service

Power Conversion

- Advanced power electronics
- Converter products
- Wind turbine drives
- Solar inverters
- Excitation and synchronizing systems
- High power rectifiers
- Power quality products
- UPS
- Traction converters
- Charging infrastructure for EV
- Service

Motors and Generators

- Low voltage motors from 0.25 to 1'000 kW
- High voltage motors and generators up to 70 MW
- High speed motors
- Traction motors
- Wind power generators
- Diesel generators
- Gas and steam turbine generators
- Hydro generators, tidal waves, etc.
- Mechanical power transmission
- Service

Robotics

- Industrial robots
- Robot controllers and software
- Industrial software products
- Application equipment and accessories
- Robot automation systems for automotive, foundry, packaging, metal, solar, wood, plastics, etc. industries
- Service

Number 1 or 2 in all markets where we operate

[1)] New BUs structure starting January 1st, 2013

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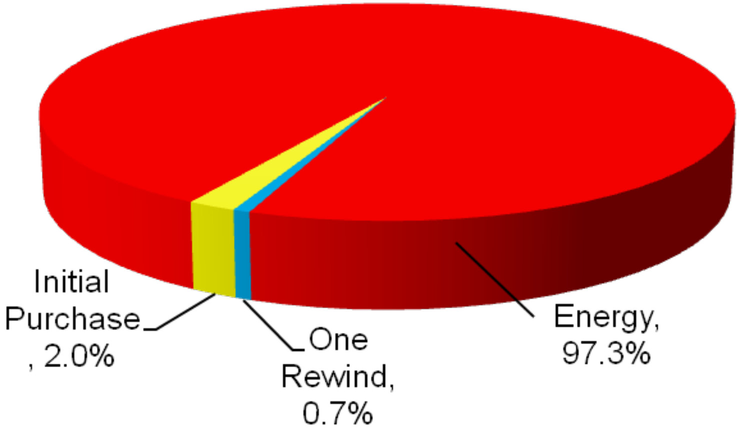
The Efficiency Story

Motor Efficiency Background/Rules/Regulation

$$

Lifetime Motor Costs

- **Almost 30 percent of all electricity generated in the United States is used to run electric motors.[1]**
- **For industrial companies, electric motor-driven systems consume 63 percent of the electricity used. [1]**
- **The cost of electricity to run an electric motor represents more than 97 percent of its lifetime cost.**



Lifetime Cost of a Motor

(1) Department of Energy - Market Opportunities Assessment 2002

Energy Cost

- Cost of 100 hp motor around $5,000
- Energy cost is about $0.07/kW-hr
- Cost to run the motor for one day

100 hp * 0.746 kW/hp * 0.07 $/kW-hr * 24 hrs =

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# of days for energy cost = purchase price?

40 Days!

Motor Efficiency Terminology

NEMA MG-1		IE-60034-10
EPACT Efficiency	Table 12-11	IE-2
NEMA Premium® Efficiency	Table 12-12 Table 12-13	IE-3
Super Premium Efficiency (proposed)	TBD	IE-4 IE-5

U.S. Motor Efficiency Regulations

1992

- Energy Policy Act 1992 (EPACT 92)
- Established min efficiency standard for motors
- NEMA MG-1 Table 12-11

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- 1-200 HP TEFC and ODP *General Purpose*

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- Federal Energy Management Program (FEMP)
- All motors in federal facilities must meet NEMA Premium efficiency levels.

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2007

- Energy Independence and Security Act (EISA) of 2007
- Amended EPAct 1992
- Set standards for a broader scope of motors

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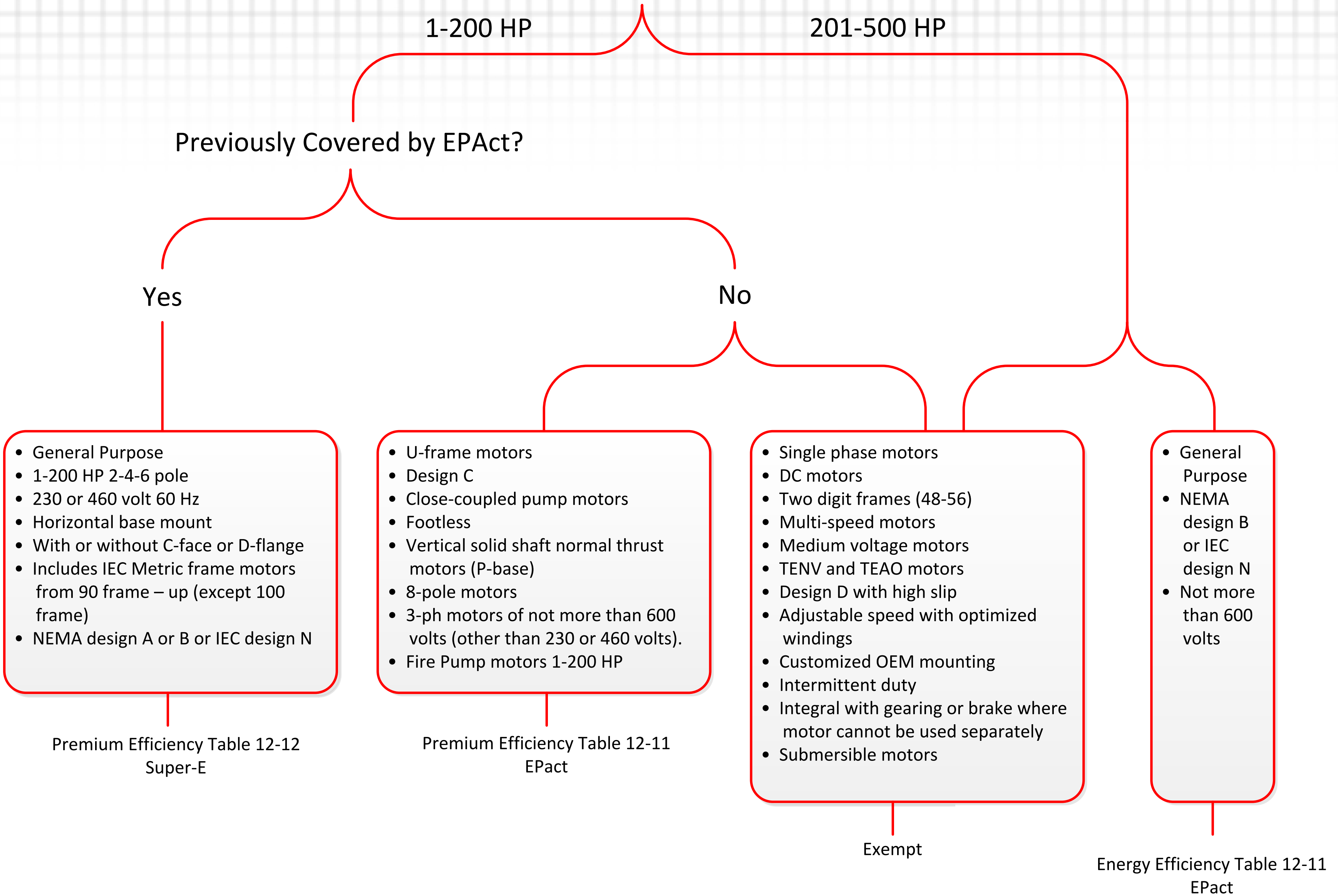
• Energy Independence and Security Act of 2007



• Energy Independence and Security Act of 2007

- **1-200 HP**
  - **Previously Covered by EPAct?**
    - **Yes**
      - General Purpose
      - 1-200 HP 2-4-6 pole
      - 230 or 460 volt 60 Hz
      - Horizontal base mount
      - With or without C-face or D-flange
      - Includes IEC Metric frame motors from 90 frame – up (except 100 frame)
      - NEMA design A or B or IEC design N

      Premium Efficiency Table 12-12
      Super-E
    - **No**
      - U-frame motors
      - Design C
      - Close-coupled pump motors
      - Footless
      - Vertical solid shaft normal thrust motors (P-base)
      - 8-pole motors
      - 3-ph motors of not more than 600 volts (other than 230 or 460 volts).
      - Fire Pump motors 1-200 HP

      Premium Efficiency Table 12-11
      EPact
- **No / 201-500 HP**
  - Single phase motors
  - DC motors
  - Two digit frames (48-56)
  - Multi-speed motors
  - Medium voltage motors
  - TENV and TEAO motors
  - Design D with high slip
  - Adjustable speed with optimized windings
  - Customized OEM mounting
  - Intermittent duty
  - Integral with gearing or brake where motor cannot be used separately
  - Submersible motors

  Exempt
- **201-500 HP**
  - General Purpose
  - NEMA design B or IEC design N
  - Not more than 600 volts

  Energy Efficiency Table 12-11
  EPact

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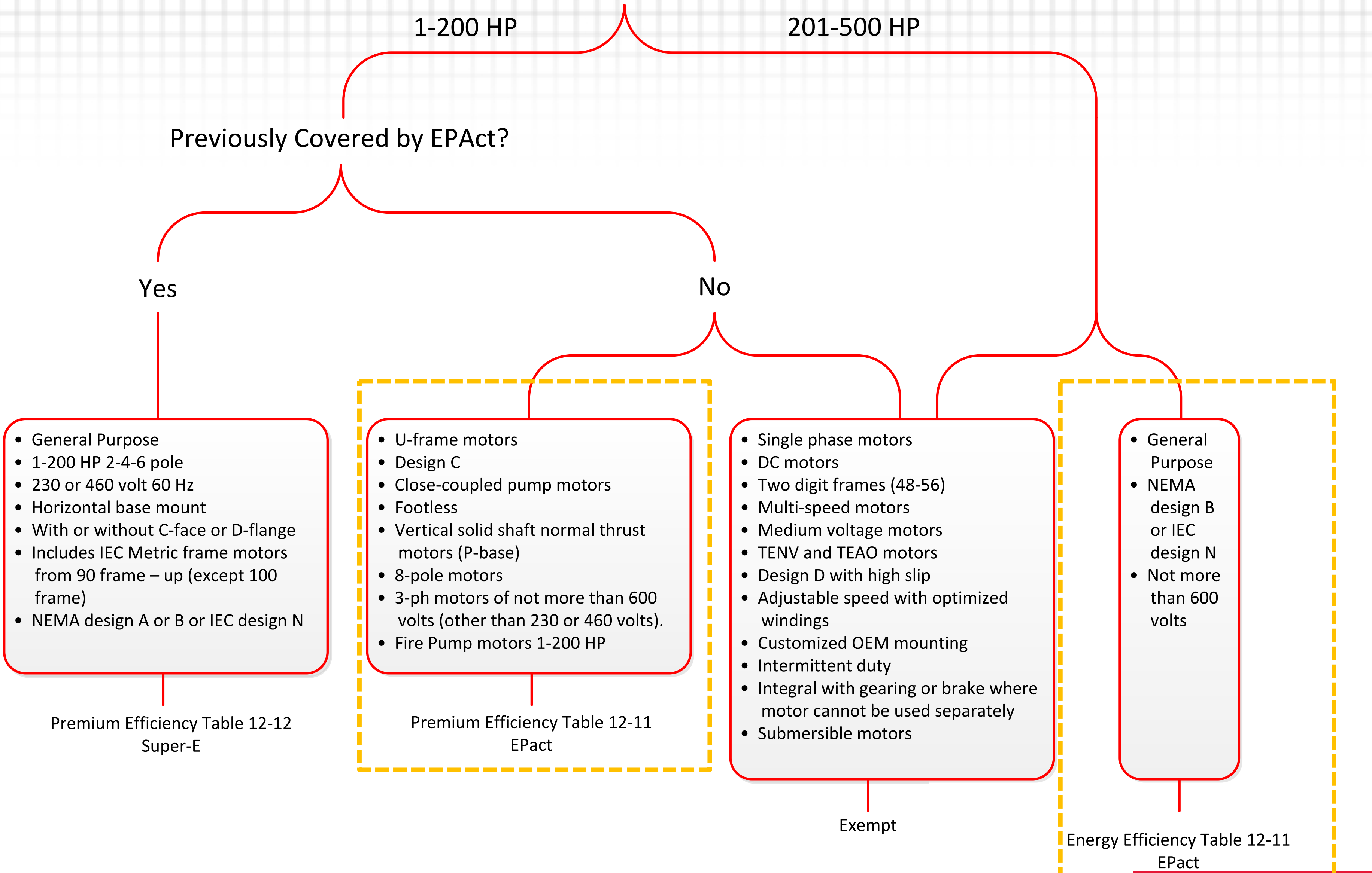

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- EISA Effective
- Added EPACT eff requirement to more motors
- Raised levels on EPACT motors to NEMA Premium®

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2015

- Small motor regulation production requirement effective 9 Mar 2015

U.S. Motor Efficiency Regulations

2009	2010	2015	2016
• Small Electric Motor Regulation Established	• EISA Effective • Added EPACT eff requirement to more motors • Raised levels on EPACT motors to NEMA Premium®	• Small motor regulation production requirement effective 9 Mar 2015	• Integral Horsepower Rule expansion of EISA effective 1 Jun 2016

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New: Small Motor Rule

- Effective 9 March 2015 – Must Stop Manufacturing & Importing

- Small Motor Regulation Scope
  - Open Construction
  - 2-Digit Frame Number (42, 48, 56 frame) or Equivalent IEC Frame
  - 2, 4, 6 Pole
  - ¼ - 3 HP or Equivalent KW
  - Polyphase, Cap Start Induction Run, Cap Start/Cap Run
  - General Purpose
  - Average Efficiency Levels Set by DOE, not NEMA Nominal Levels

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2016

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New: Integral HP Motor Rule

- Expands Energy Independence & Security Act of 2007
- Effective 1 Jun 2016
- Most motors will be covered at NEMA Premium Efficiency Levels (IE3)
- Manufacturers must stop production 1 Jun 2016 - existing inventory may be sold

Compare IHP Rule to EISA

Motor Type	EISA	New Integral HP Rule
1-200 HP Subtype I	Premium Efficient NEMA MG 1, Table 12-12	Premium Efficient NEMA MG 1, Table 12-12
1-200 HP Subtype II	Energy Efficient NEMA MG 1, Table 12-11	Premium Efficient NEMA MG 1, Table 12-12
201-500 HP	Energy Efficient NEMA MG 1, Table 12-11	Premium Efficient NEMA MG 1, Table 12-12,13
56 Frame Enclosed	Exempt	Premium Efficient NEMA MG 1, Table 12-12
Custom Configurations	Exempt	Premium Efficient NEMA MG 1, Table 12-12
1-200 HP Fire Pump Motors	Energy Efficient NEMA MG 1, Table 12-11	Energy Efficient NEMA MG 1, Table 12-11

Motors covered under IHP Rule

The motors regulated under expanded scope meet the following nine characteristics:

1. Is a single speed motor
2. Is rated for continuous duty
3. Squirrel cage rotor
4. 3-phase line power
5. Has 2-, 4-, 6-, or 8-pole configuration
6. Is rated 600 volts or less
7. Has a three or four-digit NEMA frame size (or IEC metric equivalent) or an enclosed 56 NEMA frame size (or IEC metric equivalent)
8. 1 – 500 HP
9. NEMA design A, B or C or IEC design N or H electric motor

Motors added previously not covered by EISA

- What is covered:
  - NEMA Design A motors from 201-500 HP
  - Electric motors with moisture-resistant windings, sealed or encapsulated windings
  - Partial electric motors
  - Totally-enclosed non-ventilated (TENV) electric motors
  - Immersible electric motors
  - Integral brake electric motors
  - Non-integral electric brake motors
  - Electric motors with non-standard endshields or flanges
  - Electric motors with non-standard base or mounting feet
  - Electric motors with special shafts
  - Vertical hollow shaft electric motors
  - Vertical medium and high thrust solid shaft electric motors
  - Electric motors with sleeve bearings
  - Electric motors with thrust bearings

Motors not covered under IHP rule

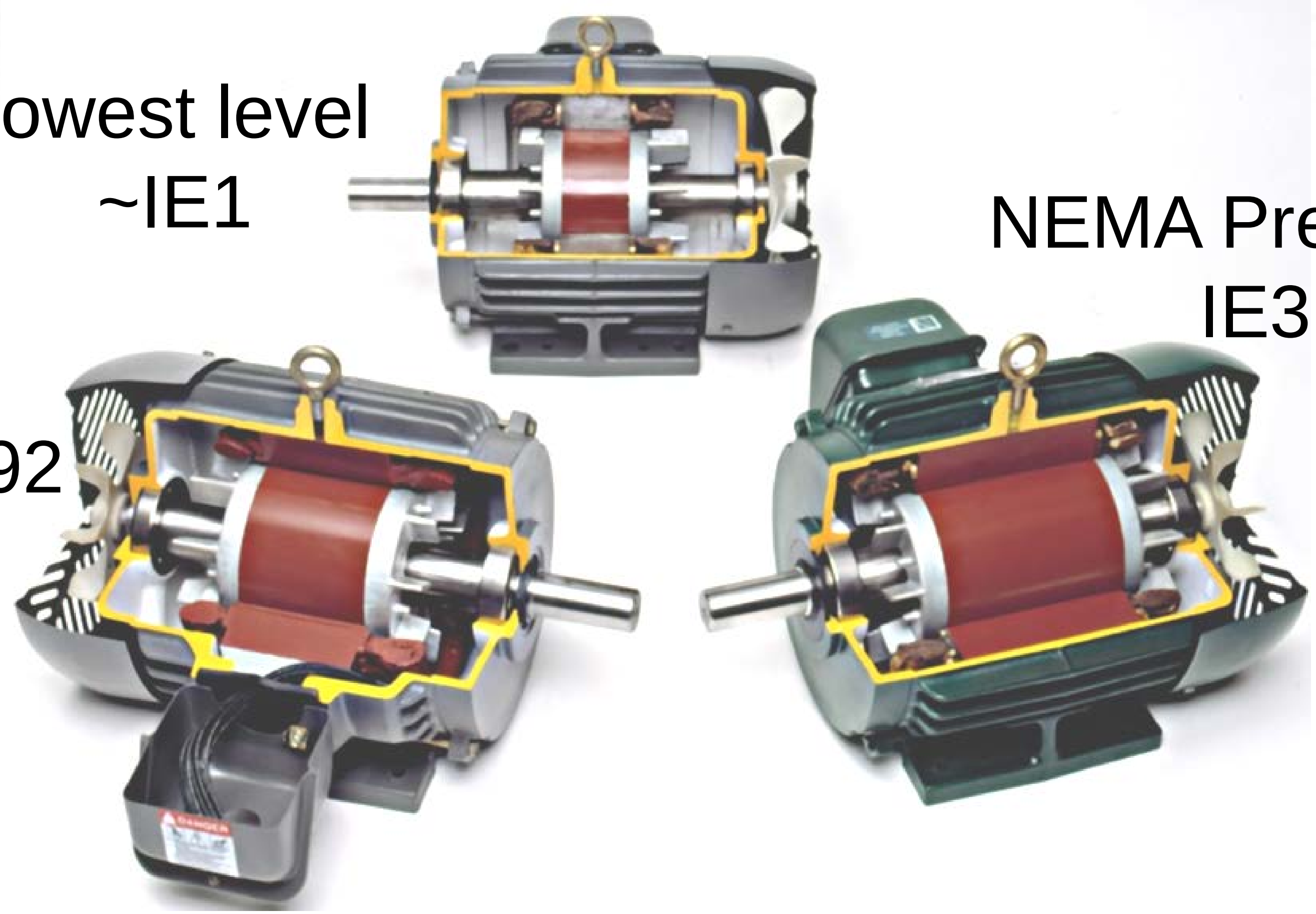
- What is not covered:
  - Single phase motors (Small Motor Rule)
  - DC motors
  - Two digit frames (42 – 48)
  - Multi-speed motors
  - Medium voltage motors
  - TEAO motors
  - Submersible motors
  - Water-cooled motors
  - Intermittent duty motors
  - Stator-rotor sets
  - Design D motors

Impact on End Users

Lowest level
~IE1

NEMA Premium®
IE3

EPAct 92
IE2



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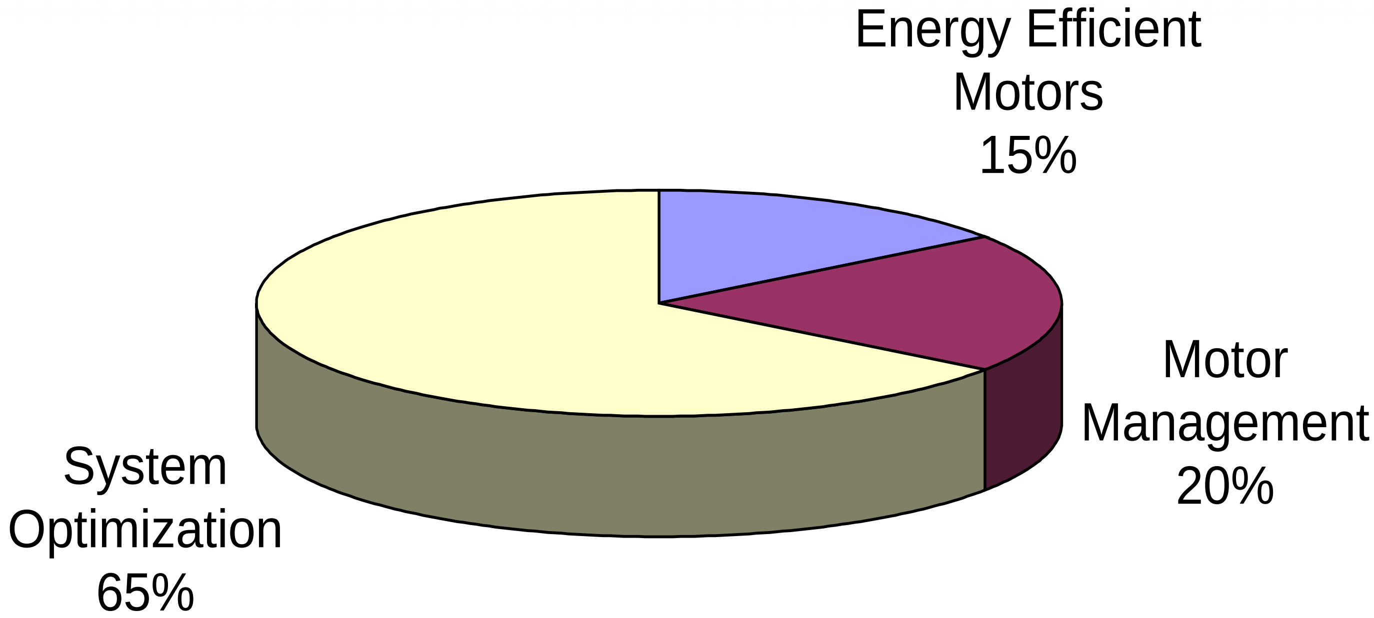
Industrial Motor System Savings Potential



Source: US Dept. of Energy; “United States Industrial Motor-Driven Systems Market Assessment: Charting a Roadmap to Energy Savings for Industry”

Legacy Motor Retrofits and Upgrades

- Why upgrade?
  - Energy efficiency
  - Reliability/maintainability
  - Variable speed control

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Motor Retrofit Case Study

- Background
  - Plant has installed base of circa 1950 vintage induction motors
  - Motors have been well maintained, energy efficiency becoming more important

Savings potential with modern motors:

HP	Legacy Motor		New Motor		Annual Savings
	Eff	Annual Energy Cost	Eff	Annual Energy Cost	
900	0.89	$ 211,227	0.947	$ 198,513	$ 12,714
600	0.87	$ 144,055	0.939	$ 133,470	$ 10,586

Assumptions:

- Energy cost 0.07 /kWh
- Operating time 4,000 hours/year
- Old motor eff estimated at - 4 NEMA bands

+ additional losses for rewind

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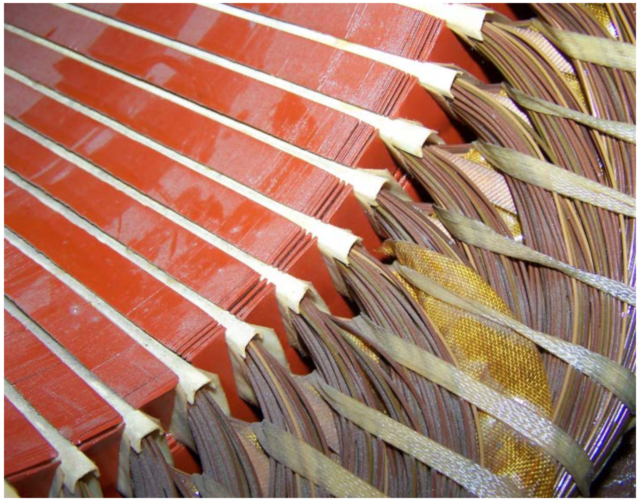
Motor Retrofit Case Study

- Challenges
  - Motor design philosophy and materials have changed in the past 50 years
  - Additional active material:
    - Winding
    - Rotor
    - Stator core
    - Improved electrical steel
    - Thinner laminations
  - Fan design (low loss)
  - Manufacturing processes - quality assured
  - Optimized material utilization - experience design
  - Result is a more efficient motor that generates less loss (heat)
  - The bottom line, motor physical shape has changed



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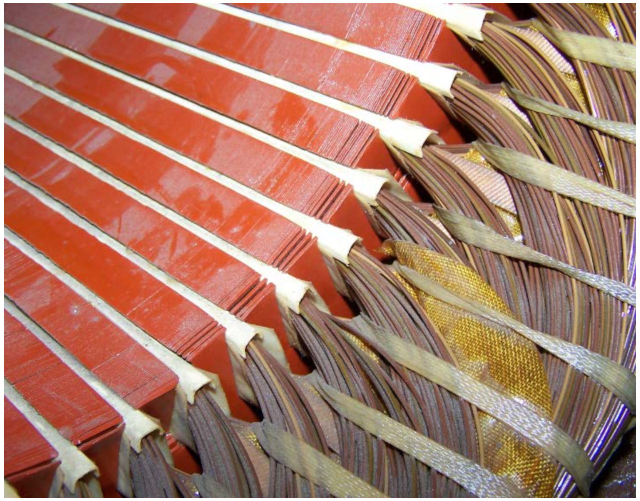

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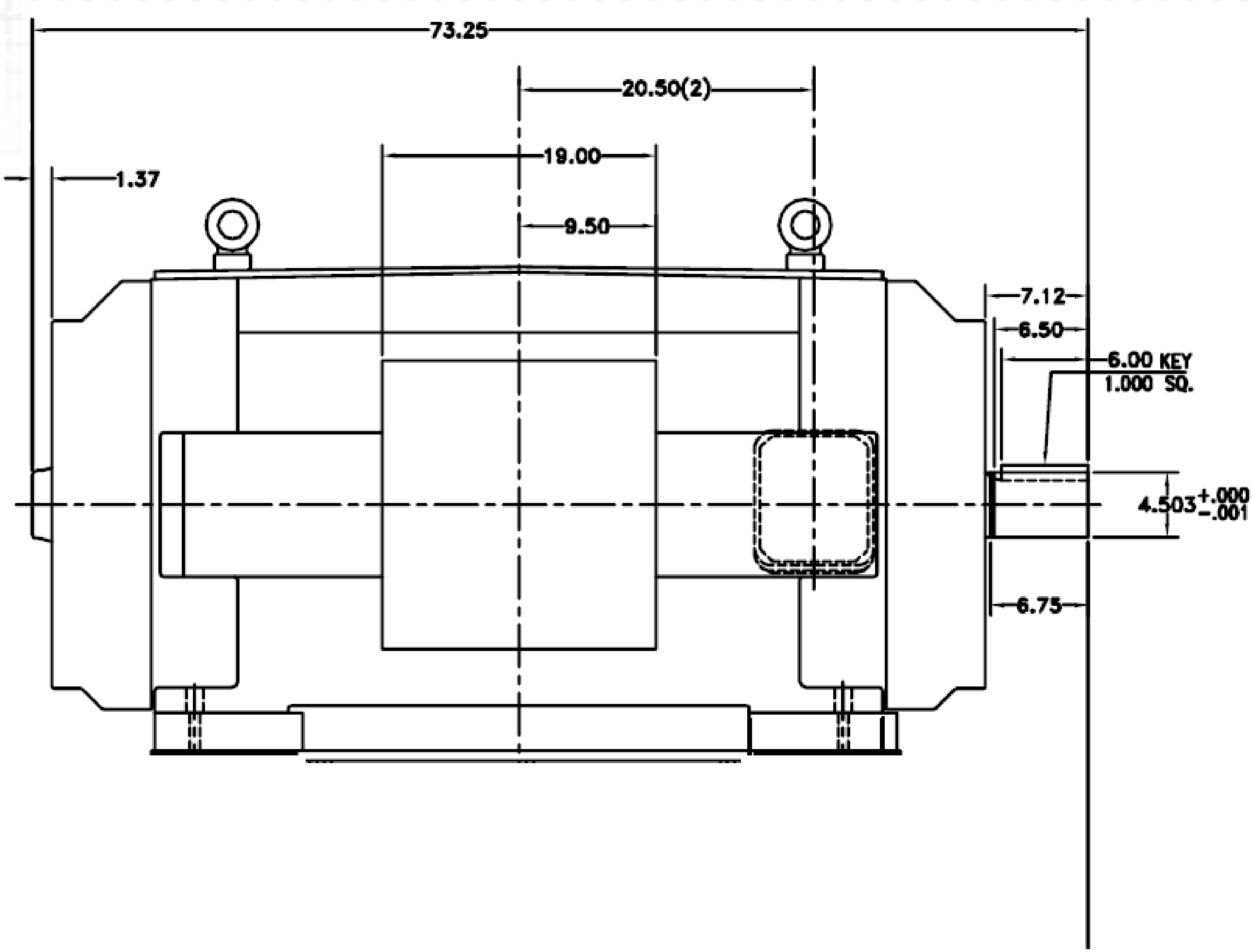
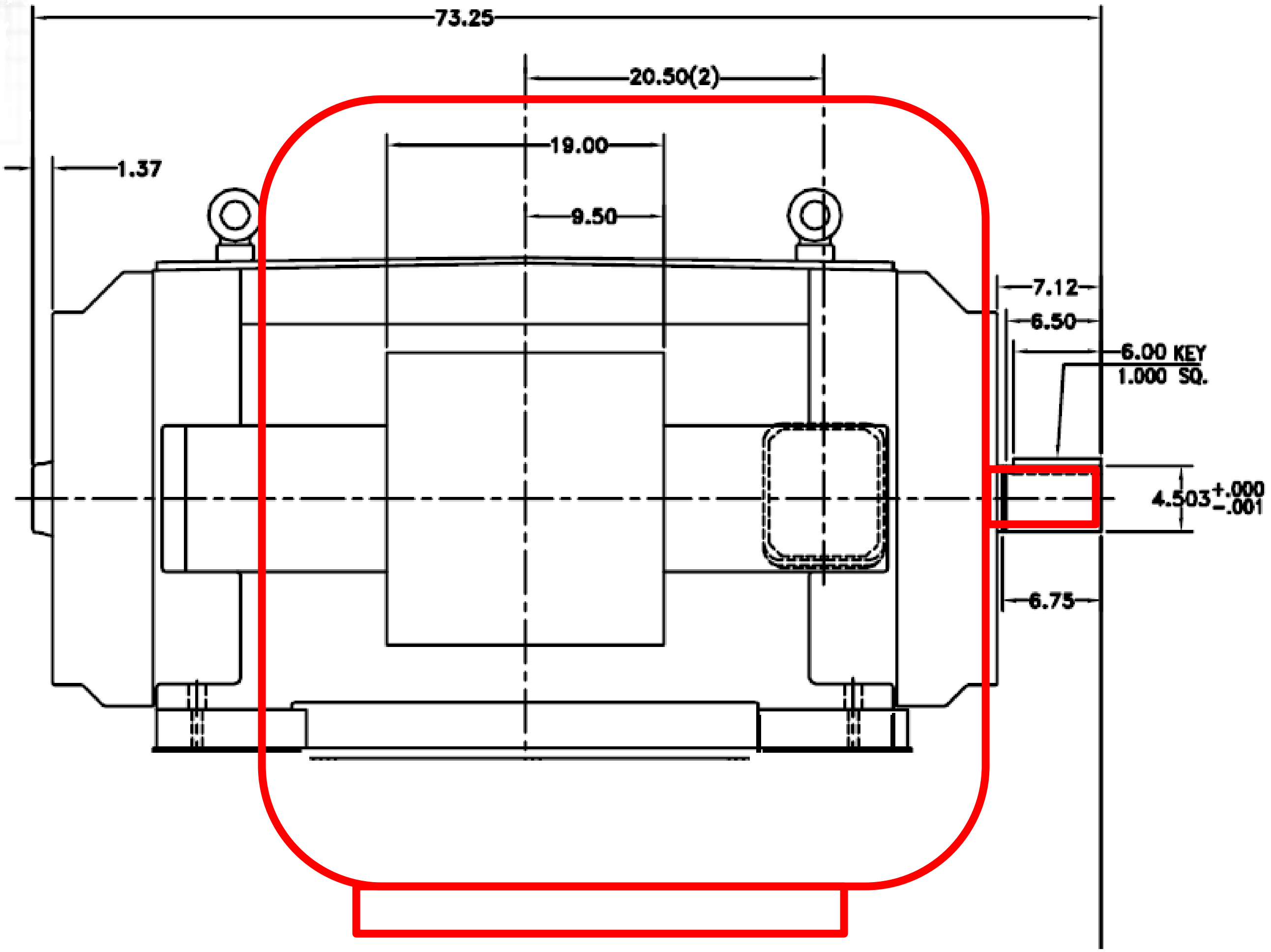


600 HP
900 RPM
2,300 V
E5812
Frame
ODP

Motor Retrofit Case Study



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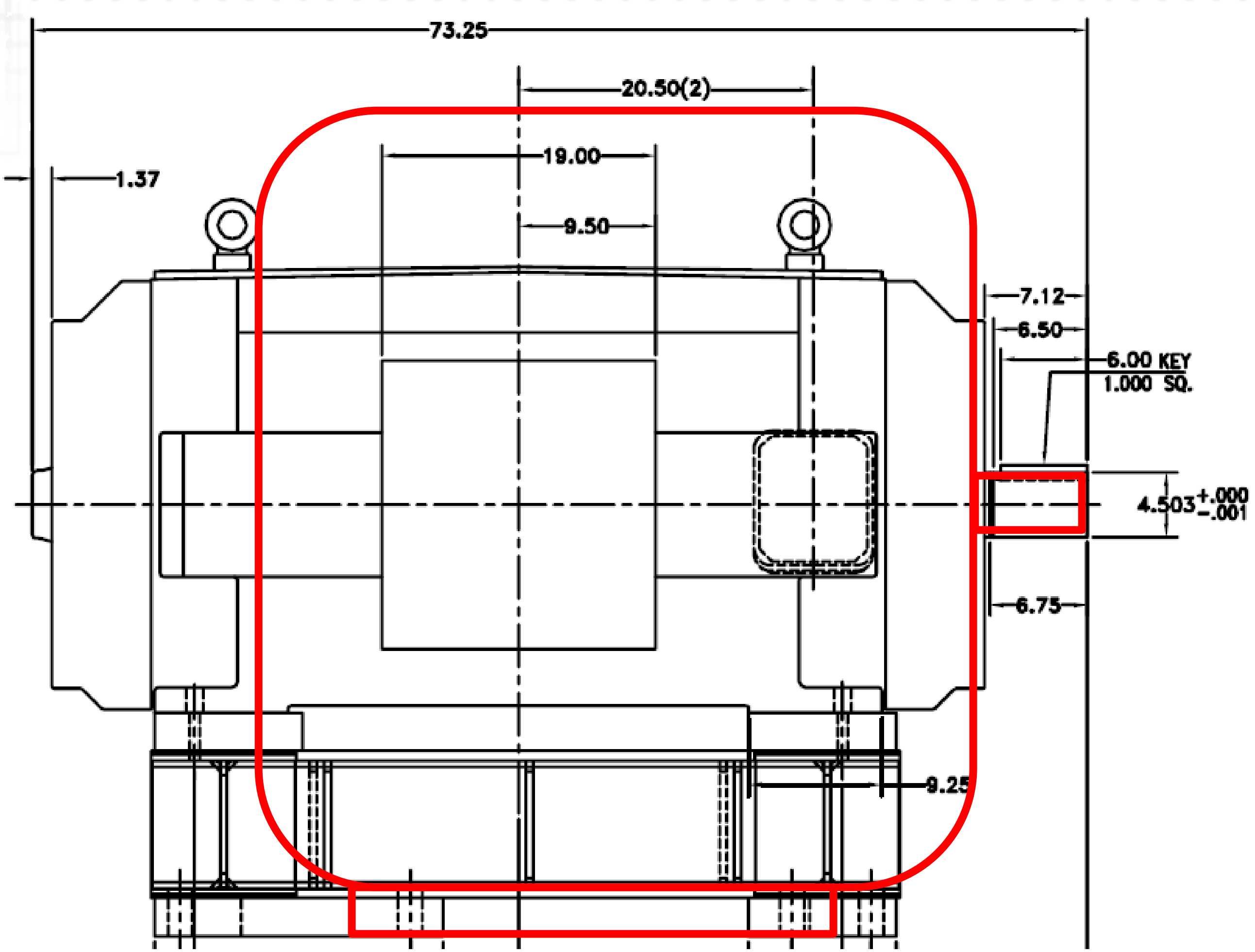

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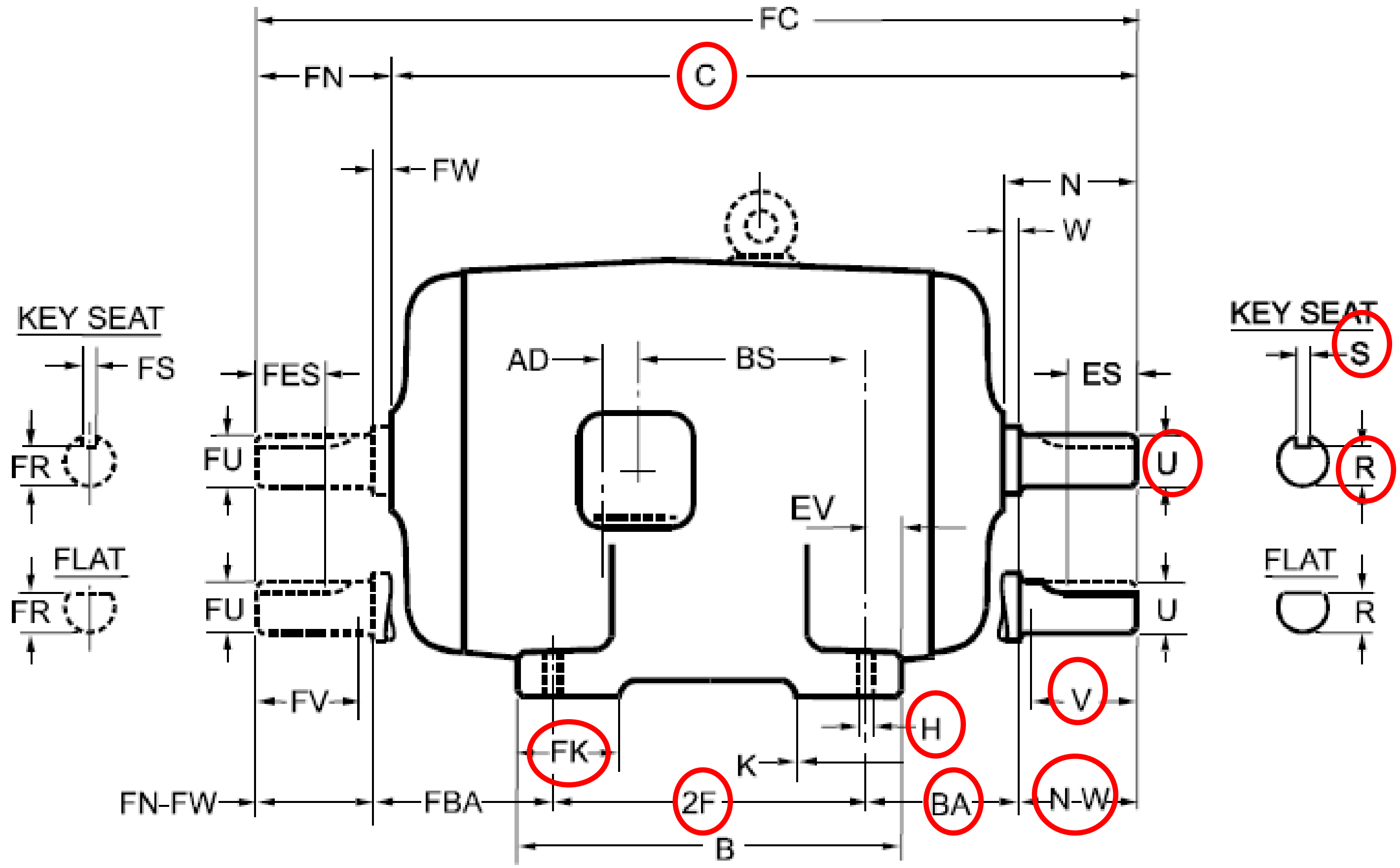
Critical Information



XBA = BA + N - W

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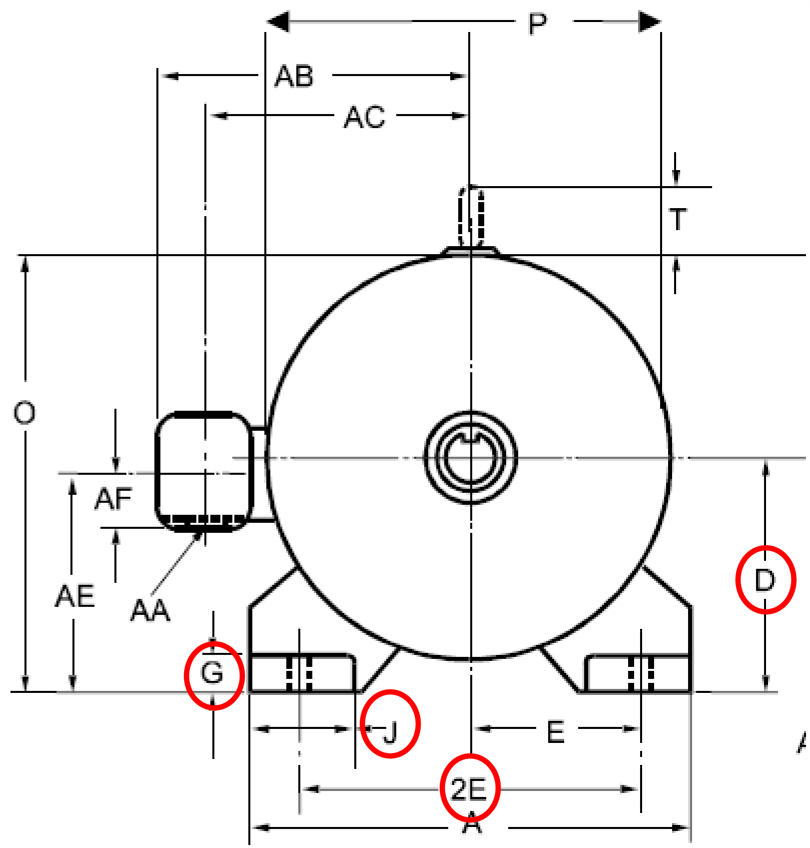

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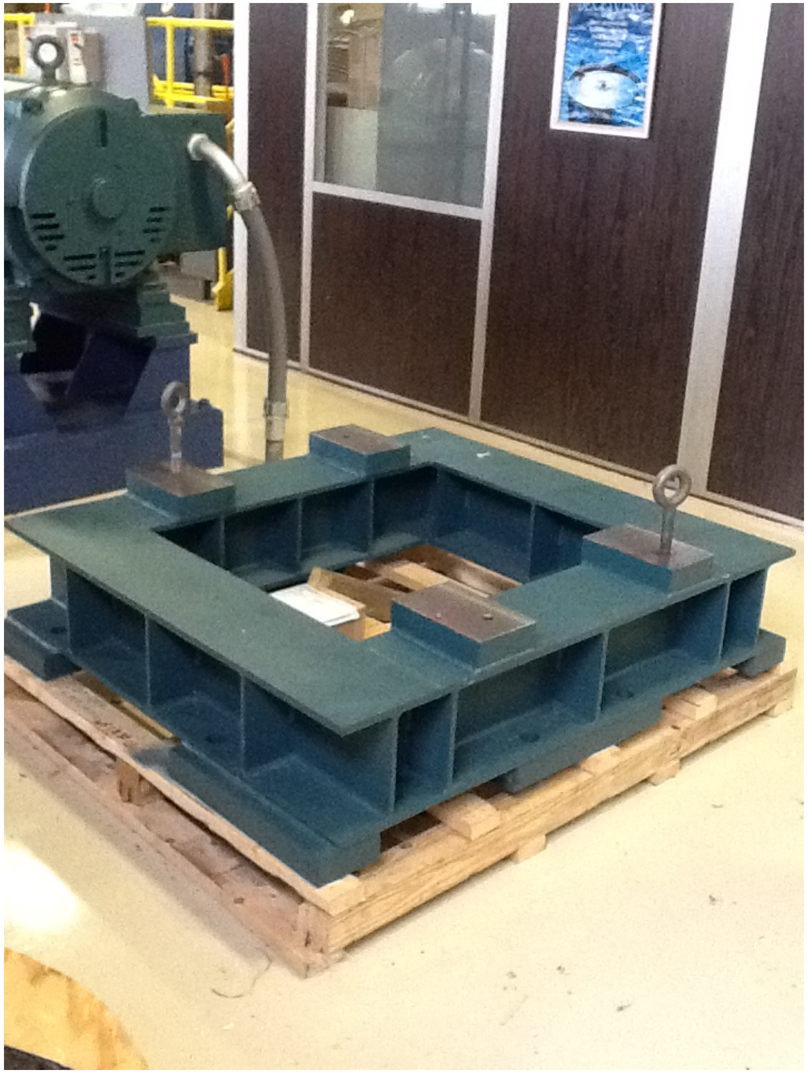
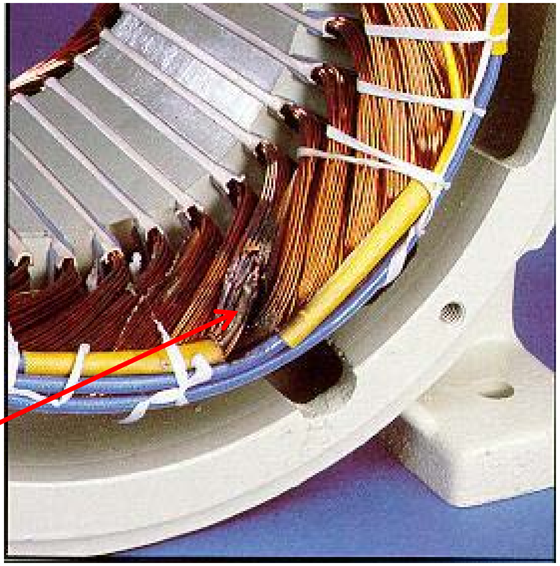


Critical Information

- Motor dimension sheet
- Foundation details
  - Sole plate/transition plate details
- Envelope dimensions
  - Height/width restrictions
- All connection points
  - Main conduit box connections
  - Coupling guards
  - Oil piping
  - Heat exchangers
  - Others…
- Engage your motor vendor
  - There is never enough information.
  - Drawings / Pictures / Details.
- VFD Operation?

Considerations for Motors Used on VFDs

- Stator Issues –
  - Impedance mismatch between drive and motor
  - Carrier frequency/switching frequency
  - **Reflected waveform** can cause voltage doubling at the motor
  - **dV/dT** – Rise time of IGBTs
  - Voltage spikes
- Insulation failure
  - Highest voltage stress occurs between the turns in the first one or two coils in a phase group



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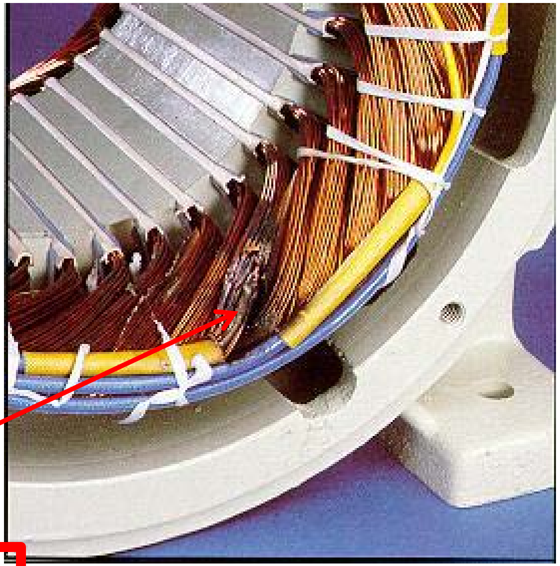

- **<u>Insure motor meets requirements of NEMA MG-1, Part 31.4.4.2</u>**
  - Voltage stress, suitable for:
    - 3.1 PU @ 0.1 µS – Max 600V
    - 2.04 PU @ 1 µS – Above 600V

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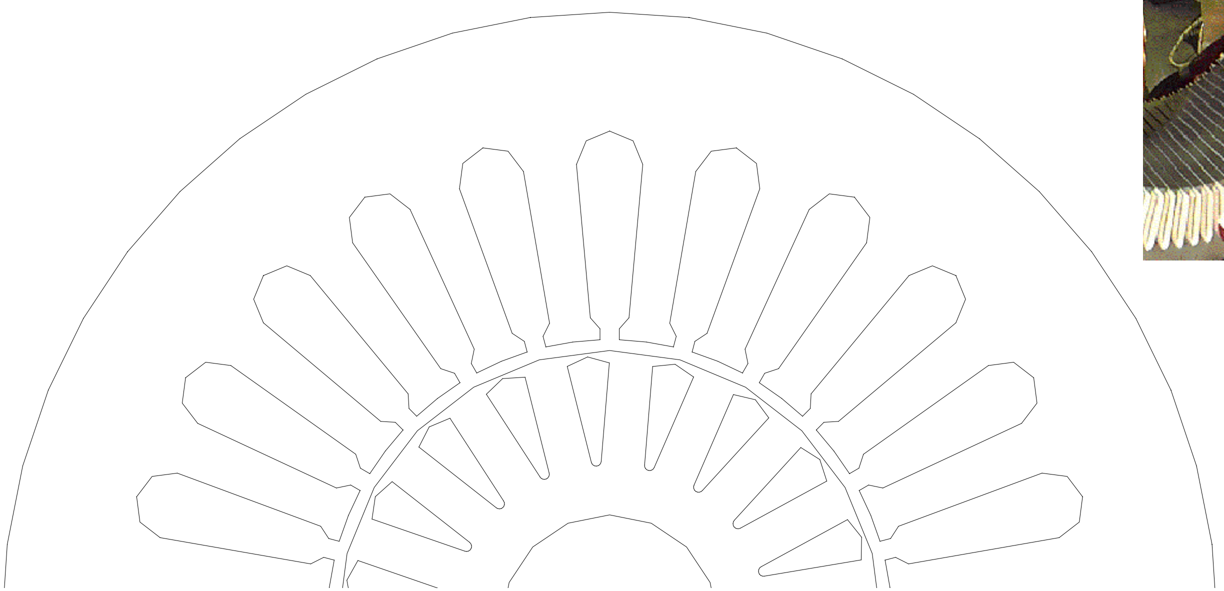
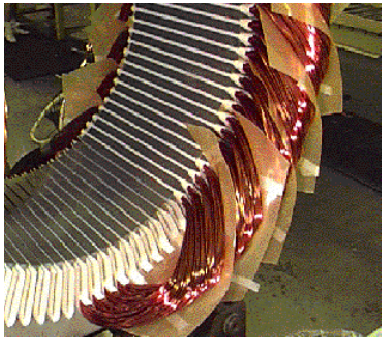
New Motor Technology – Beyond NEMA Premium

- Current induction motor technology
- Permanent motor technology
- Synchronous reluctance technology

Current Technology: Induction Motors

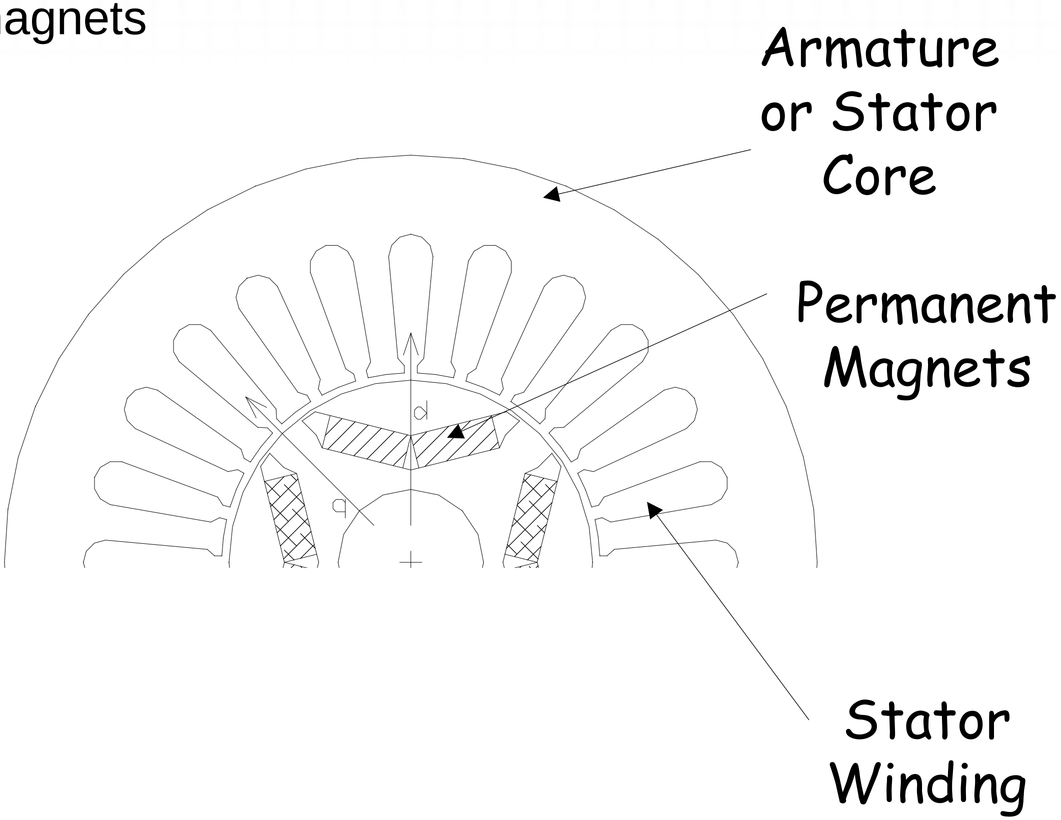
- Distributed stator lamination slots and winding
- Stator is pressed into cast iron motor frame
- Squirrel cage rotor (cast or fabricated) with Al or Cu.





Interior Permanent Magnet (PM) AC Motors

- Typical Interior Magnet PM AC Motor cross section
- Rotor field from permanent magnets
- No slip (synchronous)
- Very low rotor losses
- Requires VFD



PM Motor comparison to IM

Frame Type	NEMA Cast Iron		Laminated Steel
Rotor Type	Induction		Interior PM
Enclosure	TEFC	TEFC	TEBC
HP @ 1750 RPM	20	100	100
Frame Size	256T	405T	FL2586
lbs/HP	16.25	11.60	5.32
F.L. Amps	25.5	115	103.5
F.L. Power Factor	78.9%	86.4%	93.4%
kW Losses	1.116	4.381	2.4
F.L. Efficiency	93.0%	94.5%	96.9%
Rotor Inertia	2.42 lb-ft^2	26.1 lb-ft^2	4.9 lb-ft^2
Temp Rise	80 C	80 C	77.6 C

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F.L. Power Factor	78.9%	86.4%	93.4%
kW Losses	1.116	4.381	2.4
F.L. Efficiency	93.0%	94.5%	96.9%
Rotor Inertia	2.42 lb-ft^2	26.1 lb-ft^2	4.9 lb-ft^2
Temp Rise	80 C	80 C	77.6 C

PM Motor comparison to IM

Frame Type	NEMA Cast Iron		Laminated Steel
Rotor Type	Induction		Interior PM
Enclosure	TEFC	TEFC	TEBC
HP @ 1750 RPM	20	100	100
Frame Size	256T	405T	FL2586
lbs/HP	16.25	11.60	5.32
F.L. Amps	25.5	115	103.5
F.L. Power Factor	78.9%	86.4%	93.4%
kW Losses	1.116	4.381	2.4
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PM Motors, the next generation

- Past development has focused on power density and meeting specific application needs
- Optimizing efficiency has not been primary goal
- PM designs require VFD with special control firmware
- What if application doesn't need VFD?
- Can we use this technology to get to the next efficiency levels (IE4)?

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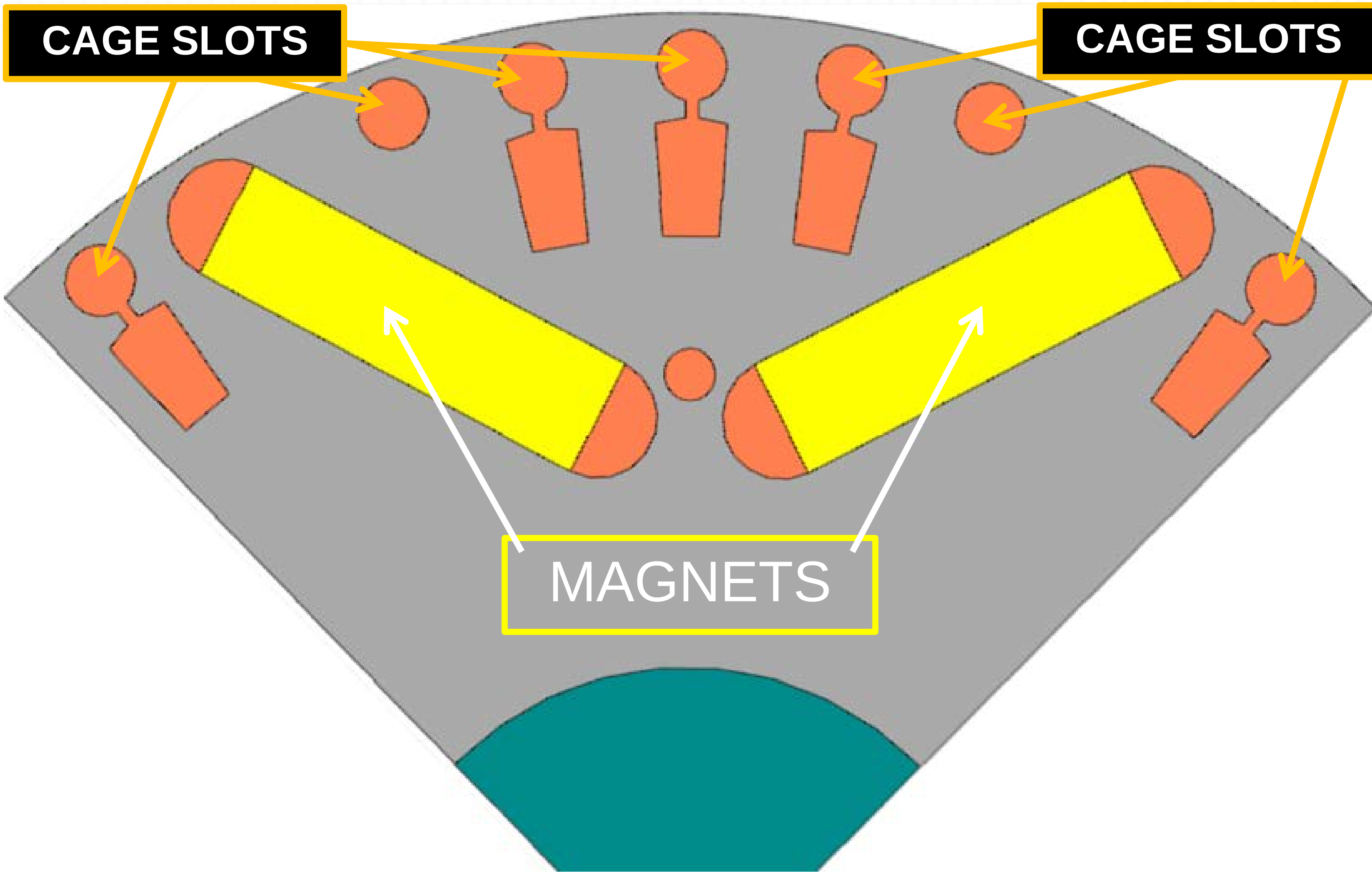
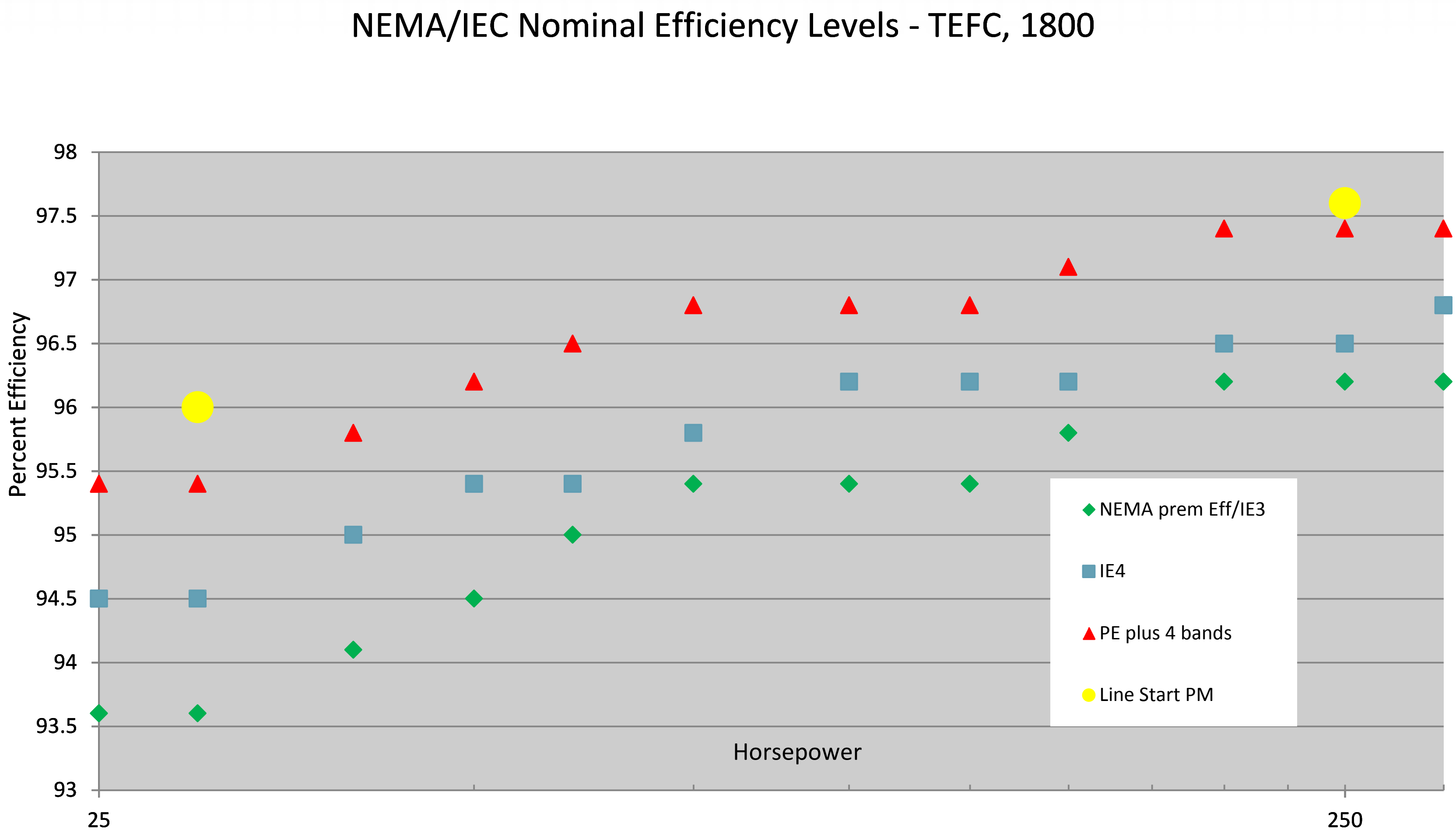
Line Start PM Motors



Line Start PM Motor Efficiency



“New” Technology - Synchronous Reluctance

- Not a new idea (1923)
- No suitable starting method available (VFD)
- Initial work with technology could not demonstrate superior torque performance
- Advances in drive technology and design have overcome initial obstacles

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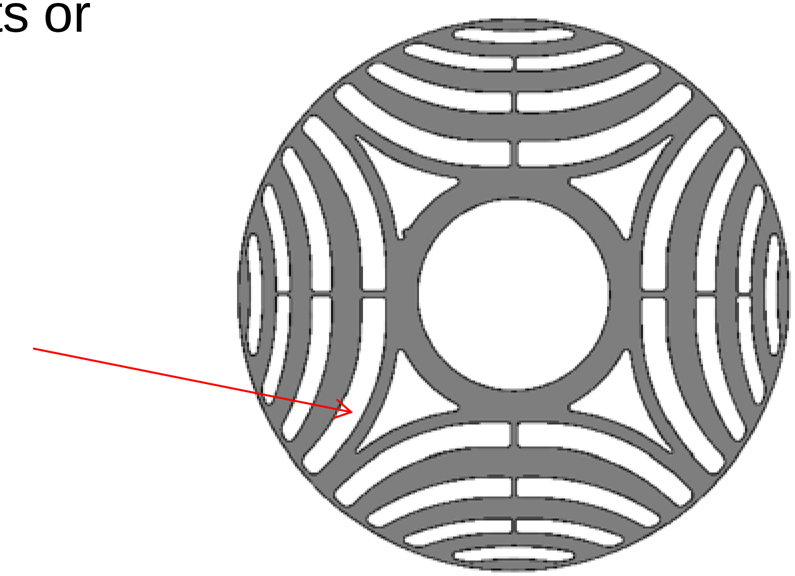
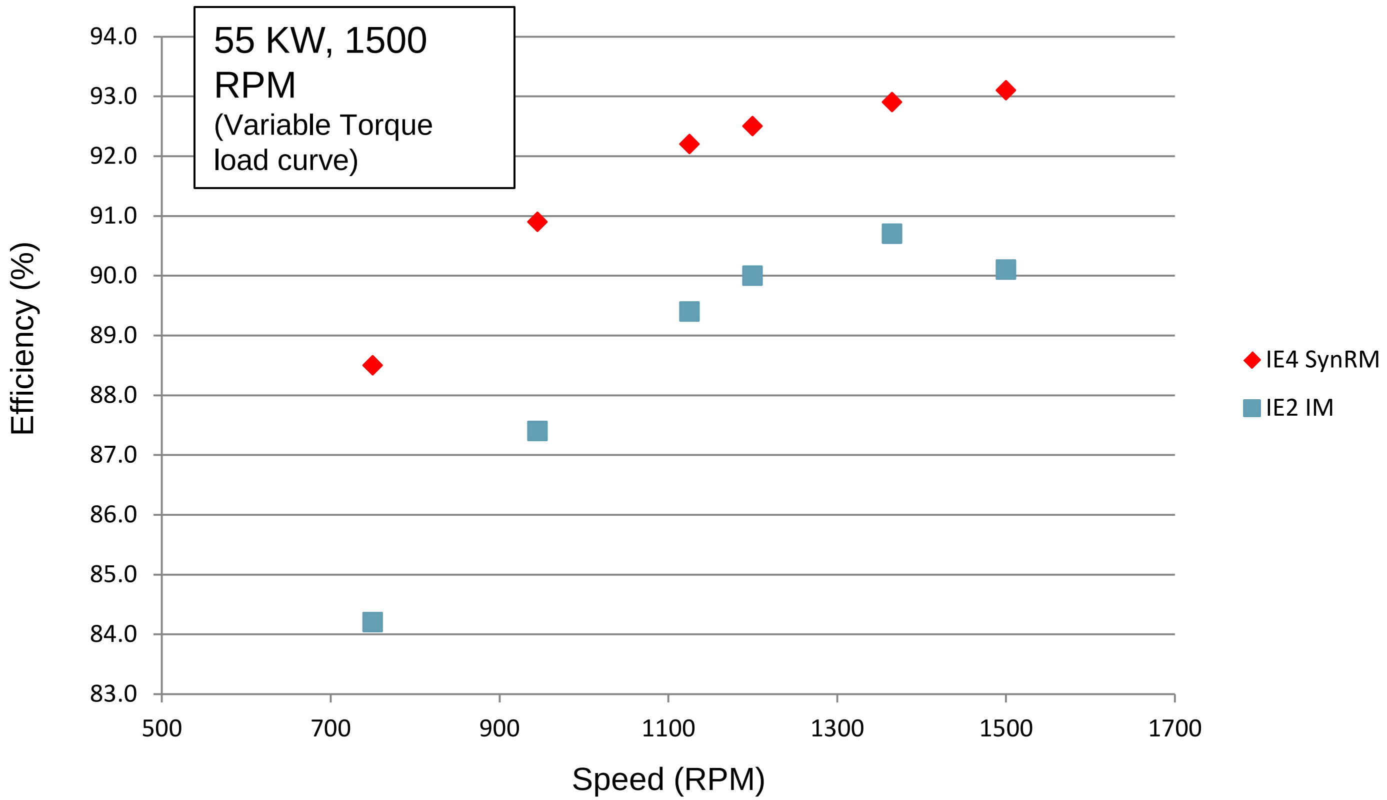
Synchronous Reluctance

- Distributed, symmetric stator lamination and winding (same as induction motor)
- Rotor is simple design, no magnets or cage
- Designed to create areas of high reluctance

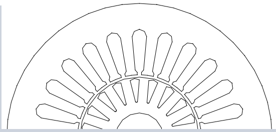


Synchronous Reluctance - Performance

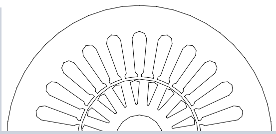
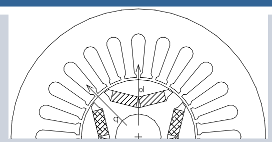
- Comparison testing of "packaged" SynR motor/drive w/ IEC IE2 Induction motor/drive as function of speed



New Motor Technology Comparison

Induction

Simple construction
Proven technology
Industry standard
Low cost
Efficiency gains at max
Rotor loss
Low power density

New Motor Technology Comparison

Induction	Lam. Frame IPM
	
Simple construction	Higher power density
Proven technology	Very low rotor losses
Industry standard	Lower weights
Low cost	Could be designed to optimize Eff
Efficiency gains at max	Flexibility with frame length
Rotor loss	Magnet cost
Low power density	Loss of magnetism
	May require special inverter or feedback

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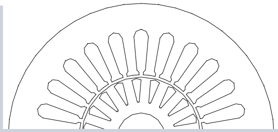
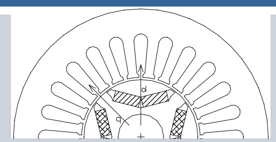
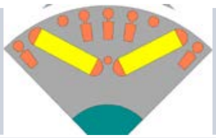
New Motor Technology Comparison

Induction	Lam. Frame IPM	Line Start PM
		
Simple construction	Higher power density	Very low rotor losses
Proven technology	Very low rotor losses	Does not require VFD
Industry standard	Lower weights	Can run on standard VFD
Low cost	Could be designed to optimize Eff	Higher power factor
Efficiency gains at max	Flexibility with frame length	Higher efficiency (IE4 and beyond)
Rotor loss	Magnet cost	Magnet cost
Low power density	Loss of magnetism	Loss of magnetism
	May require special inverter or feedback	Starting torque
		Torque ripple

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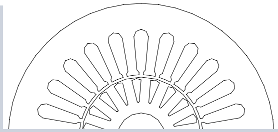
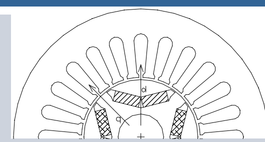
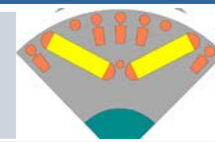
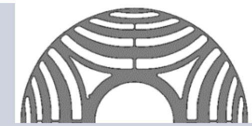
New Motor Technology Comparison

Induction	Lam. Frame IPM	Line Start PM	SyncR
			
Simple construction	Higher power density	Very low rotor losses	Very low rotor losses
Proven technology	Very low rotor losses	Does not require VFD	Lowest inertia
Industry standard	Lower weights	Can run on standard VFD	Simple rotor (cost)
Low cost	Could be designed to optimize Eff	Higher power factor	Lower weight
Efficiency gains at max	Flexibility with frame length	Higher efficiency (IE4 and beyond)	Can be optimized for eff or power density
Rotor loss	Magnet cost	Magnet cost	Cool running
Low power density	Loss of magnetism	Loss of magnetism	Requires VFD
	May require special inverter or feedback	Starting torque	Low power factor
		Torque ripple	

Motor Efficiency Improvements for Pumping Applications

- Energy Savings Potential
- Rules/Regulation
- Motor Retrofits
- New Motor Technology

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