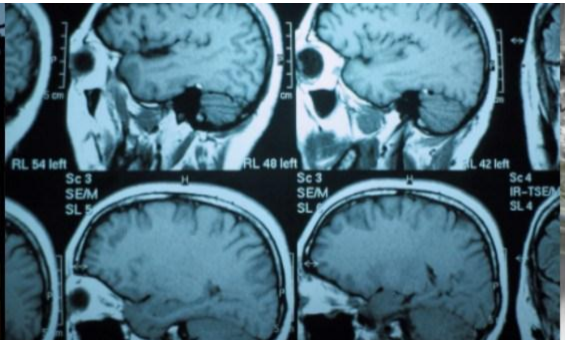
Motor Training
July 16th 2013

NEMA

The Association of Electrical and Medical Imaging Equipment Manufacturers


OUR GOAL

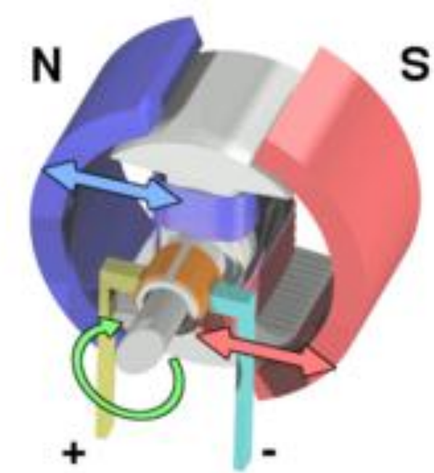
Collectively we believe there are significant energy savings opportunities to be had by increasing the use of high performance electric motors. By working together in the past we have achieved great success in transforming the motor market saving substantial Twh. Our goal is to increase the adoption of higher performing motors in a logical and realistic manner that builds on our past success saving additional energy, while maintaining the necessary service and utility for the motor users in the USA.

Our Roles

- NEMA Motor Section
  - Motor product and application experts
- DOE contractors
  - Rule process and evaluation experts
- DOE
  - Legal and procedure experts
- Efficiency advocates
  - Environmental and community positions

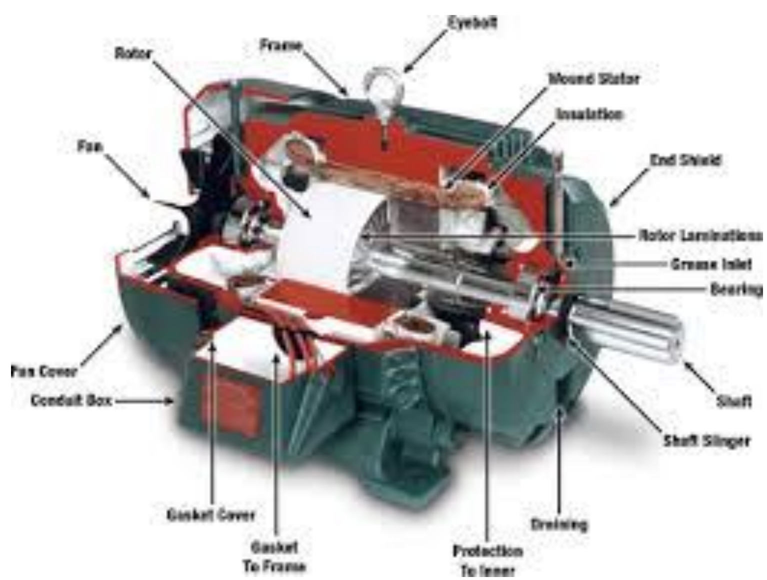
What are we going to cover today

- What is a and electric motor?
  - Terms we use
  - Industrial and commercial [1/4 to 500 HP]
- How does a motor convert electricity to rotating torque?
- Fundamentals
  - Electrical
    - Design options, power, testing and losses
  - Mechanical configuration
    - Mounting feet, flanges, shafts
  - Accessories



What are we going to cover today

- How is a motor's efficiency determined?
- How do US standards compare to the rest of the world?
- Review of existing motor efficiency rules
- Conclusions



Speakers

- John Malinowski – Baldor Electric / ABB
- Dan Delaney – Regal
- Dale Basso – WEG
- Rob Boteler - Nidec

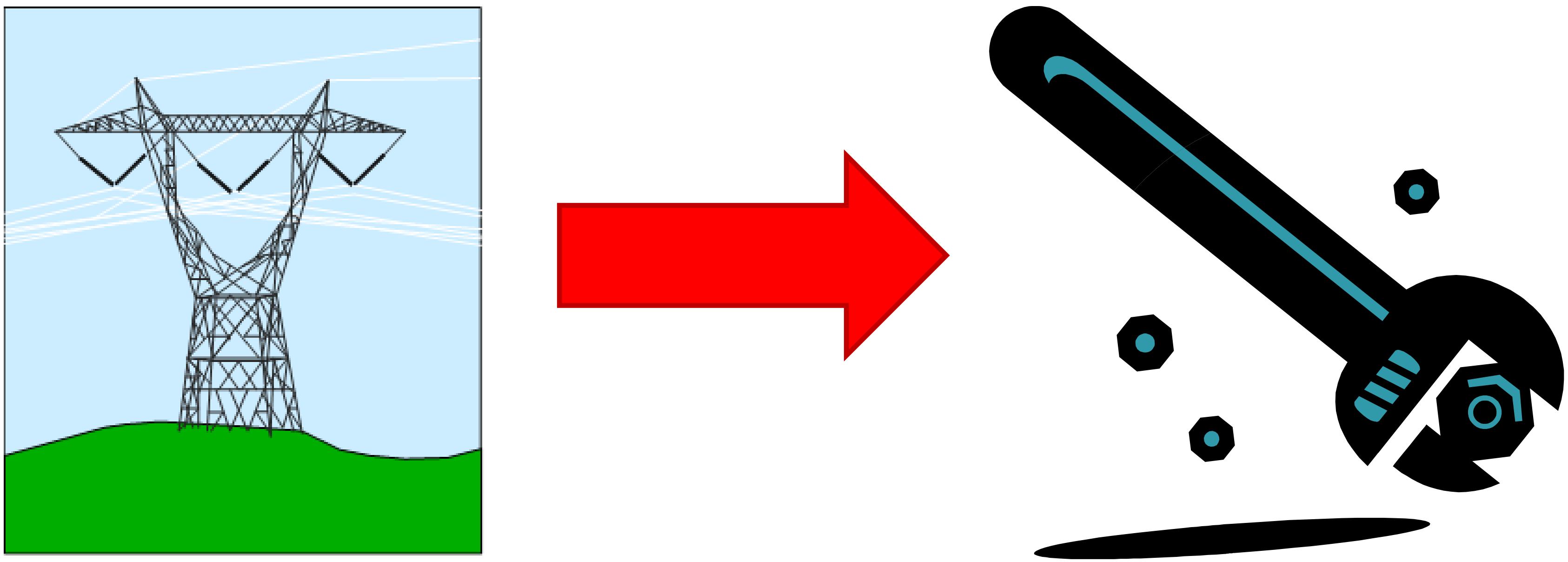
Fundamentals of Electric Motors

Agenda

- How a motor works
- Components
- Enclosures
- NEMA Dimensions
- Stators
- Rotors
- Bearings
- Accessories
- Efficiency
- Failure Modes
- Performance / Applications / Starting
- IEEE 841

What is a Motor?

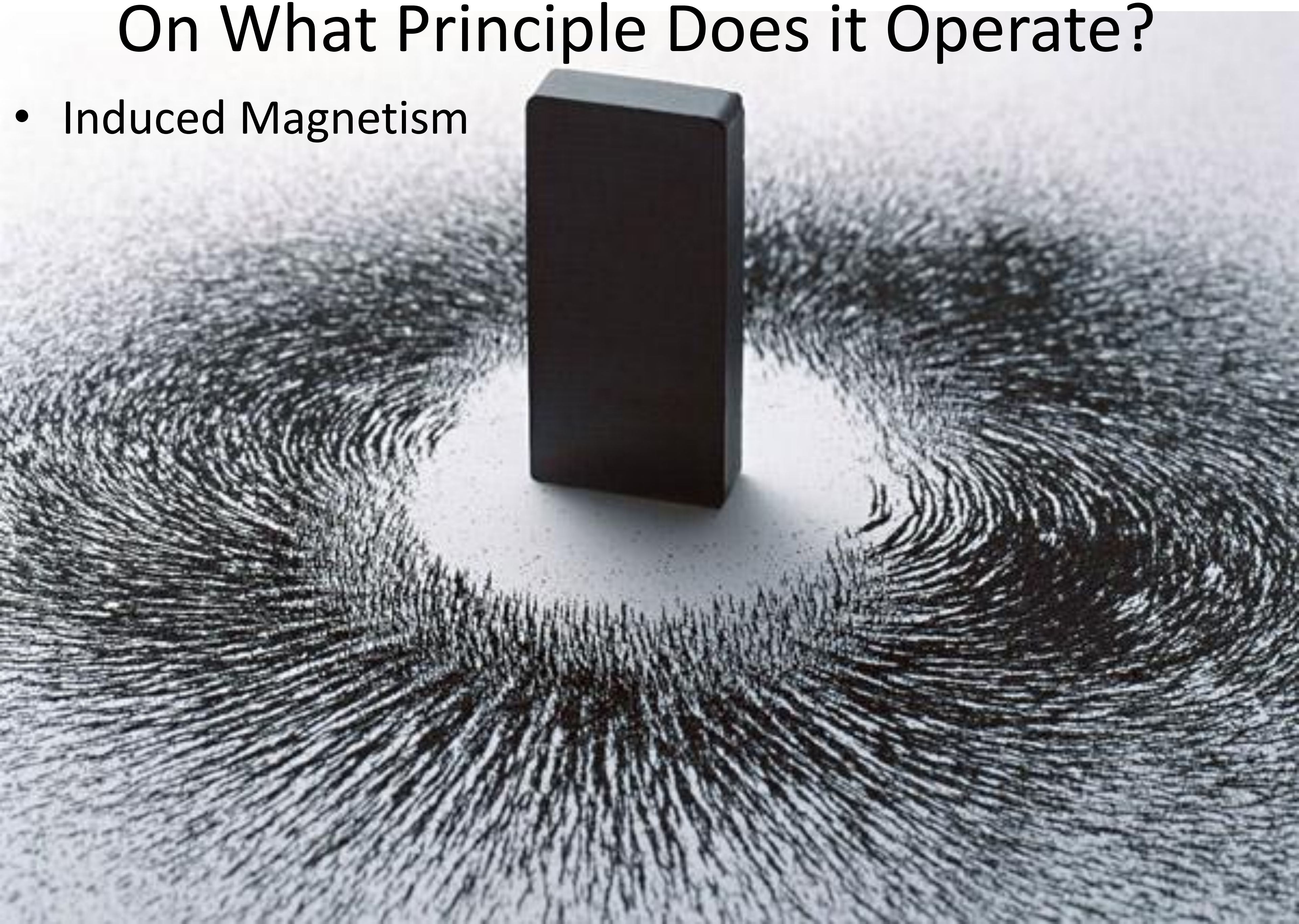
An Electric Motor Converts Electrical Power to Mechanical Power



How an Induction Motor Operates

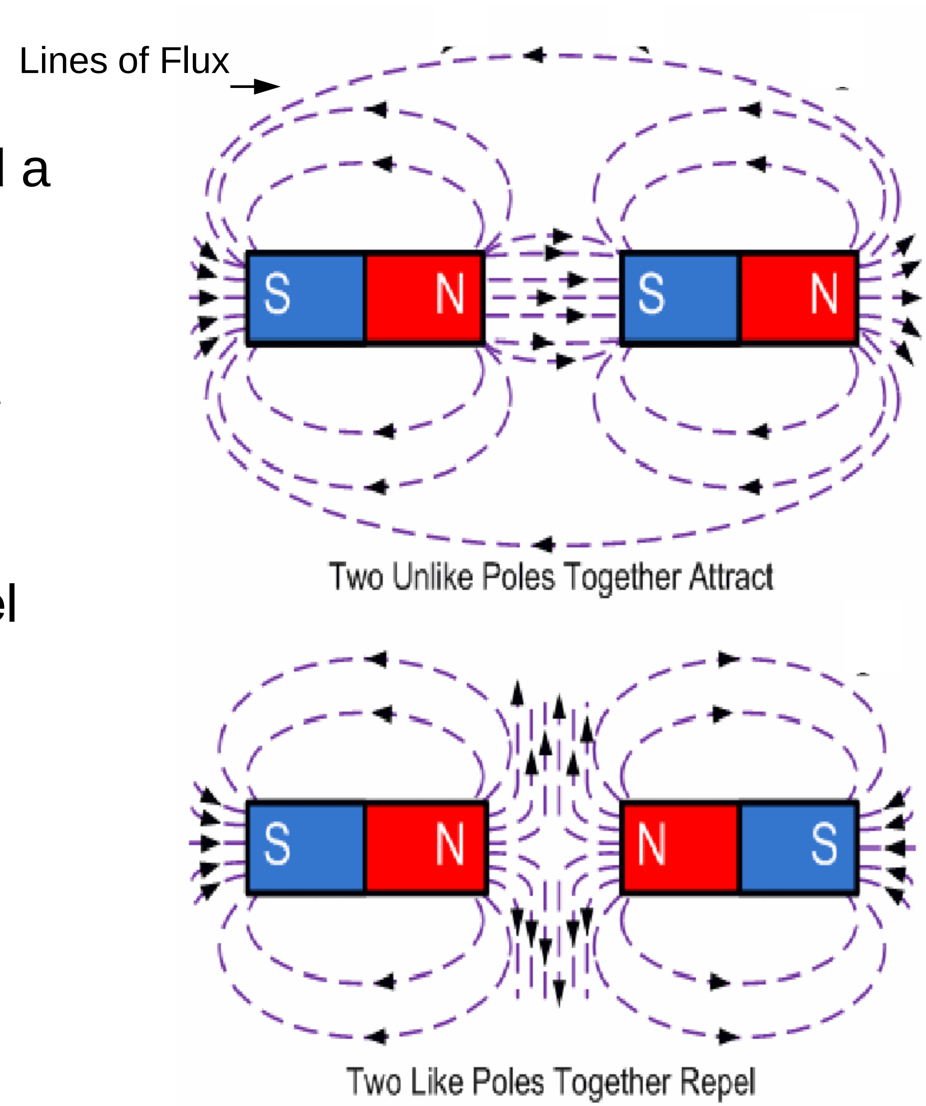
On What Principle Does it Operate?

- Induced Magnetism



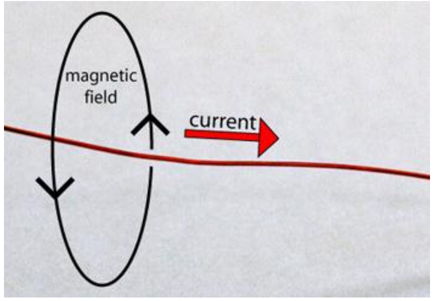
Permanent Magnet Basics

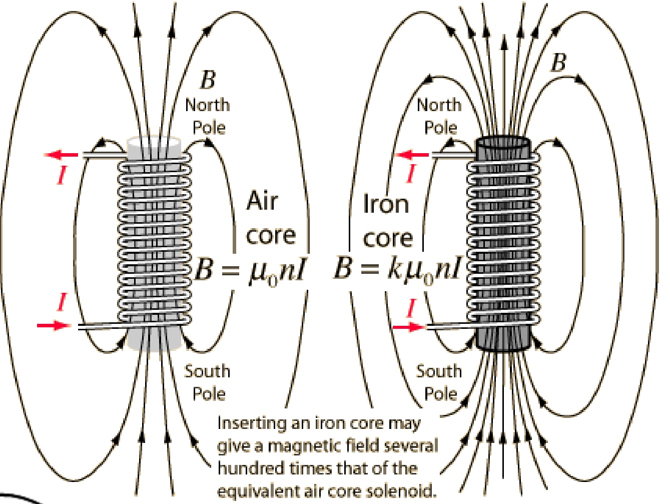
- Any magnet has a North and a South Pole
- “Opposite” poles of a magnet attract each other
- “Like” poles of a magnet repel each other.
- Motors use this principle of attraction and repulsion to rotate

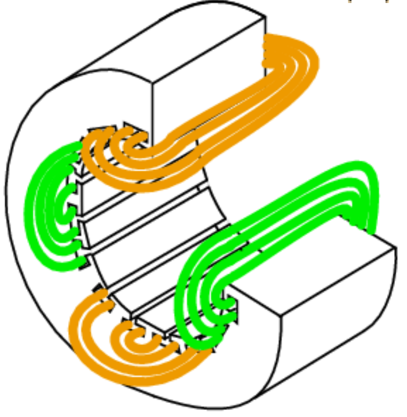


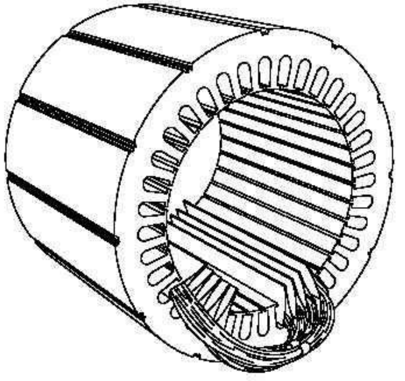
Induced Magnetic Fields

- A magnetic field (B) is produced any time an electric current is passed through a wire.
- The magnetic field around a singular straight wire is not very strong.
- A stronger field can be created by coiling the wire
- An even stronger field can be produced by coiling wire around a piece of **special** steel called “electrical steel”. This is called an Electromagnet.
- Coil “groups” laid in slots in electromagnetic material forms the stator of the motor

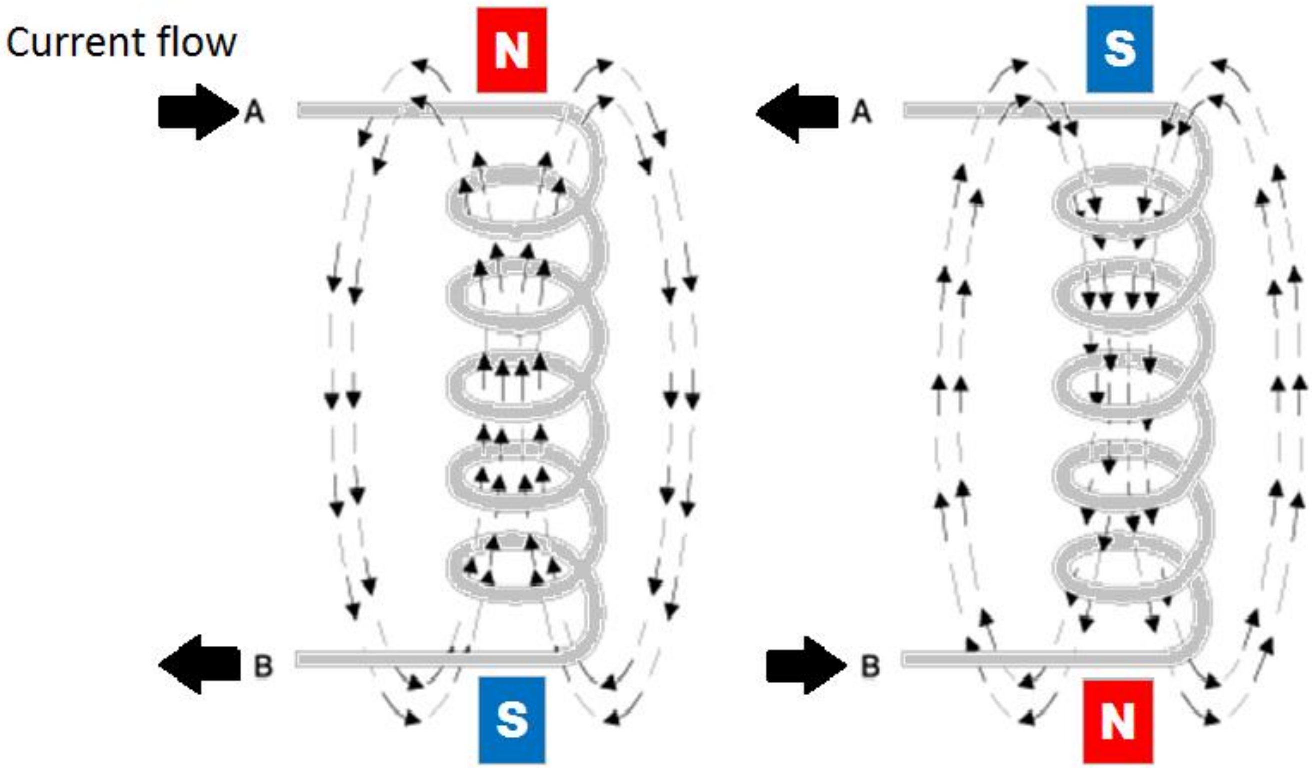






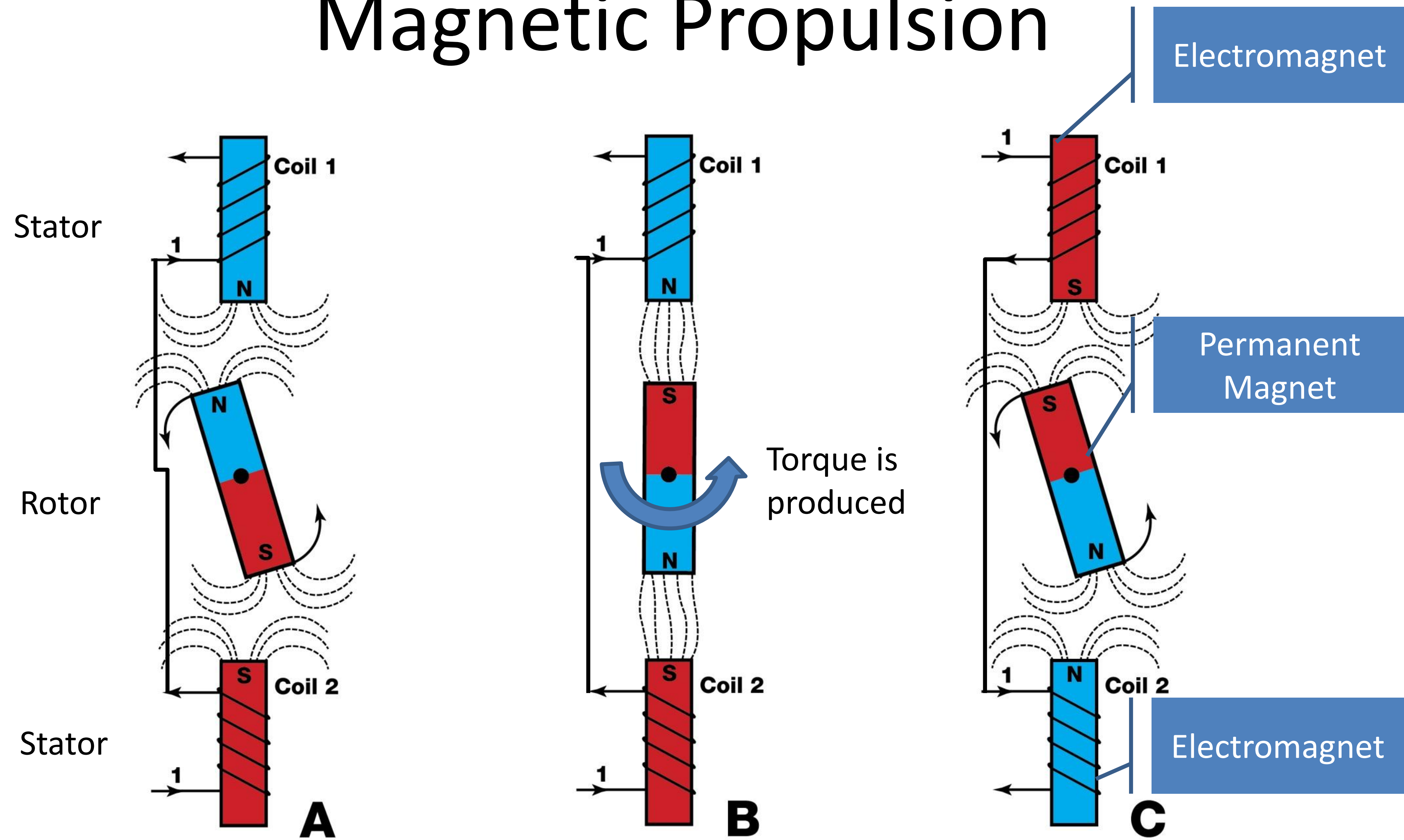


Alternating Current



- The poles of an electro-magnetic coil change polarity when the direction of current flow changes.

Magnetic Propulsion

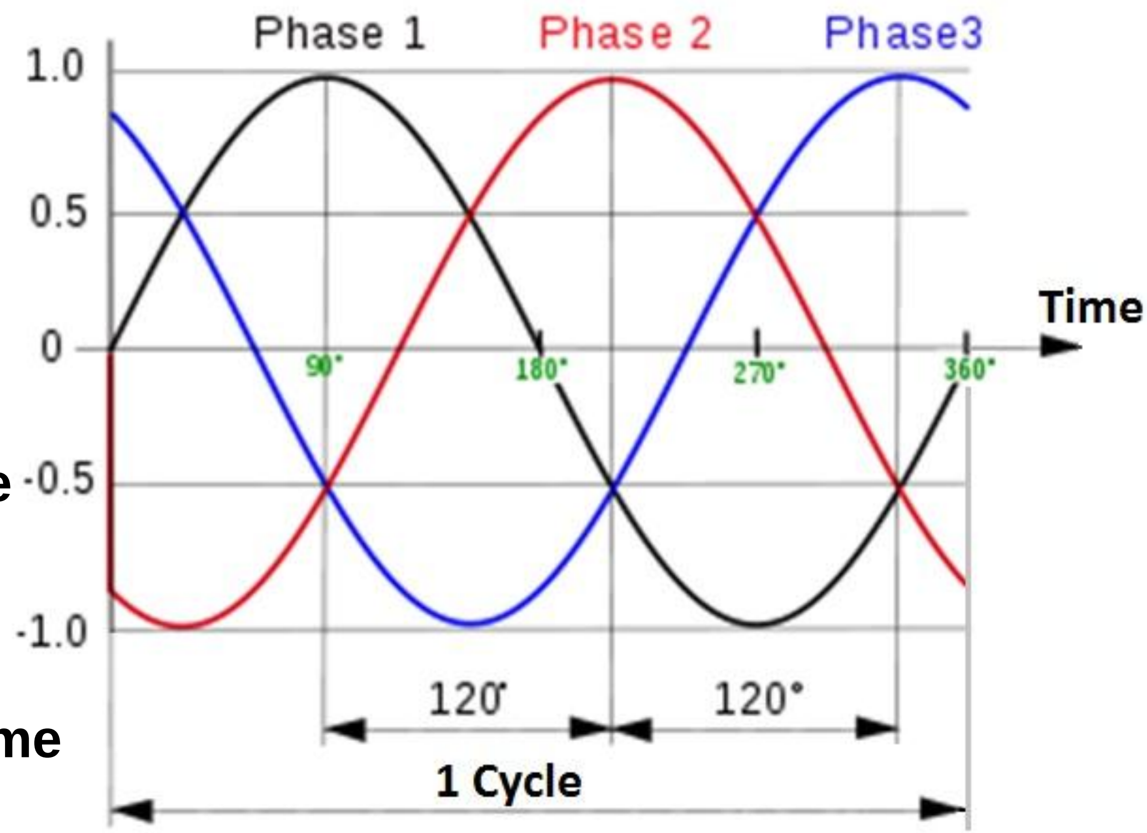


The principle of an induction motor is to induce magnetic forces into the rotor of the motor. A new generation of motors has permanent magnets imbedded in the rotor

Three Phase AC Power

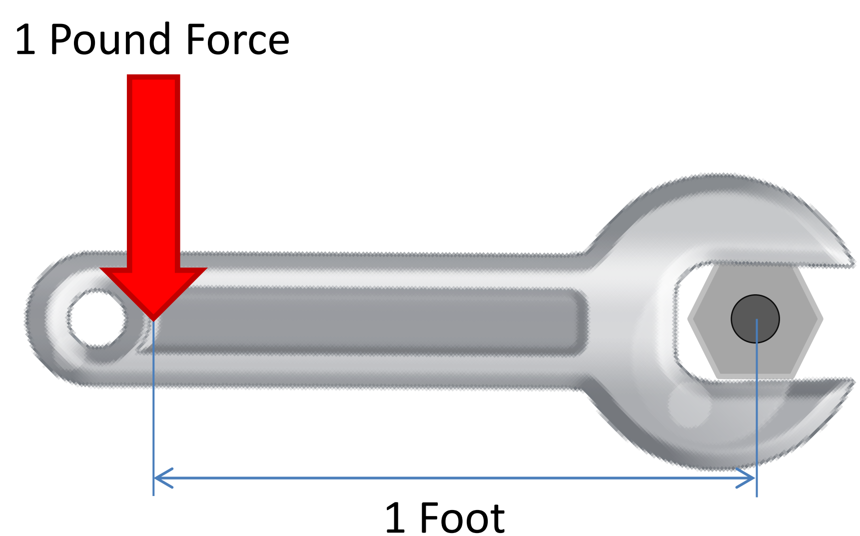
Why 3 phases?

- **It allows the most power transfer with the minimum number of conductors**
- **Three times the power transfer of a single phase system by adding only one conductor**
- **The sum of all three phase voltage at any instant of time is zero**



What is Torque?

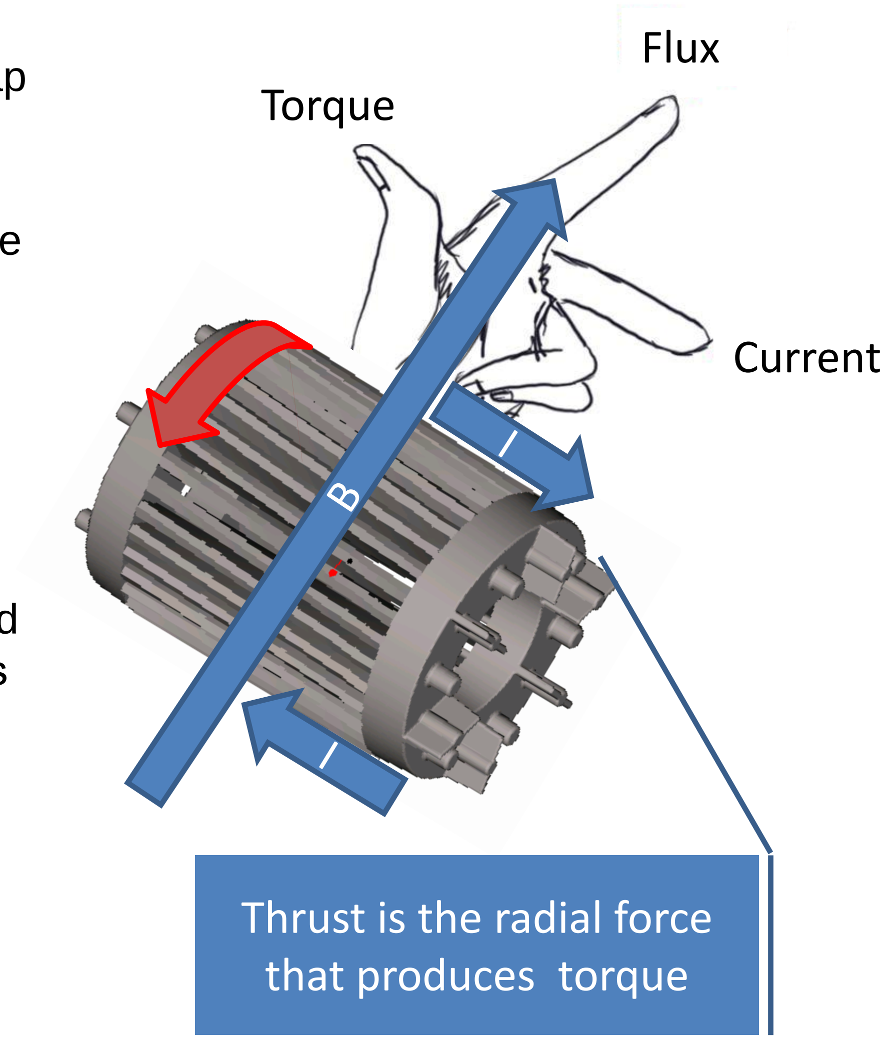
- Torque is a force applied at a distance from and perpendicular to an axis.



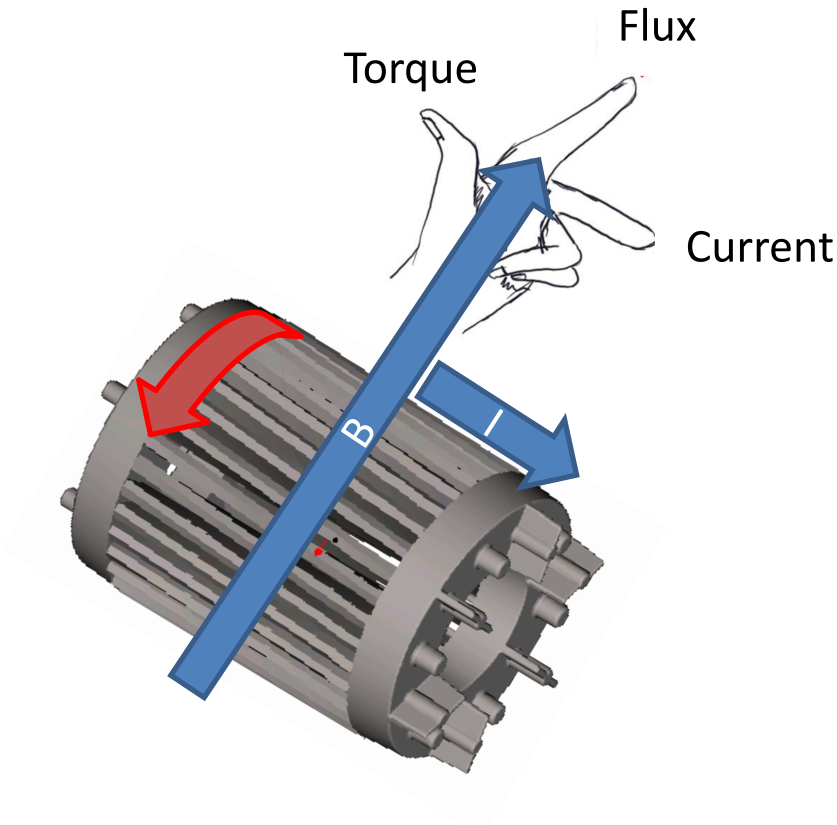
Torque = 1 Ft X 1 Lb = 1 Ft-Lb

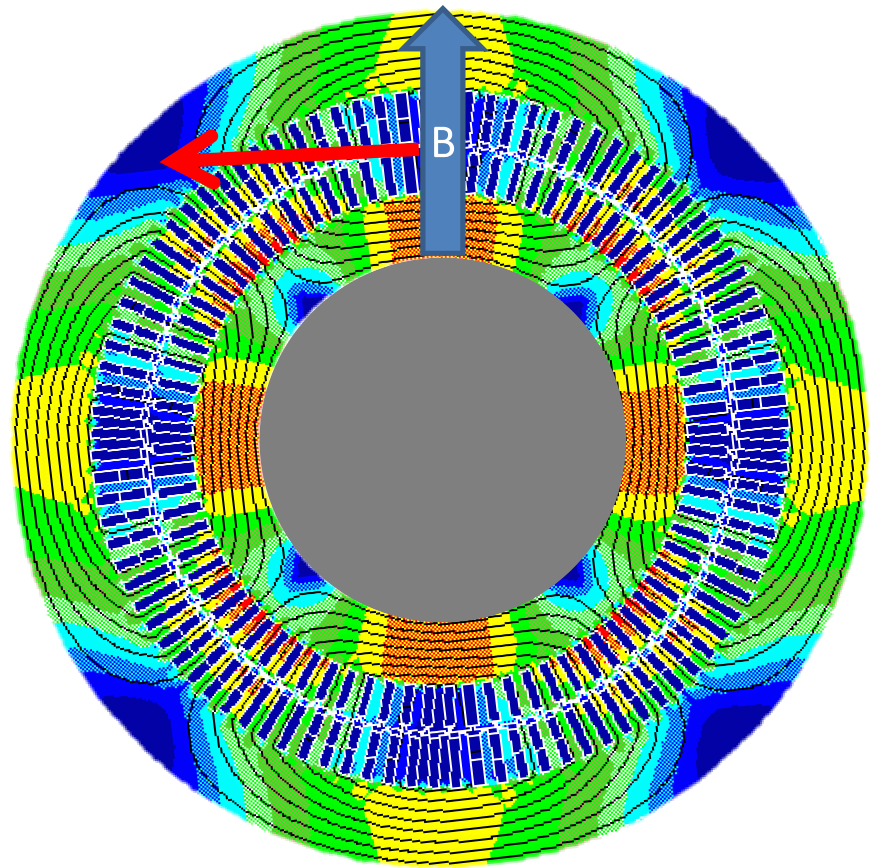
How is Torque Produced in the Rotor?

- Follows “Left Hand Rule”
- Rotating stator flux (B) sweeps through air gap
- The rotating magnetic field from the stator “cuts” through the rotor bars and induces current in them. The current flows through the bars to one of the end rings, through the bar on the opposite side of the rotor then returns through the other end ring etc.
- The current flowing through the rotor bar creates a magnetic field in the rotor that follows the stator’s magnetic field.
- The difference in speed between the rotor and the stator’s rotating magnetic field determines how many lines of magnetic flux cut through the rotor bar.
- The greater the difference in speed between rotor and stator, the more current that is induced in rotor and greater the force



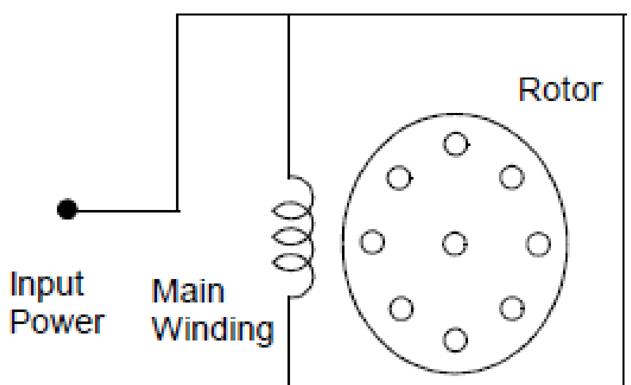
Four Pole Motor Torque Production



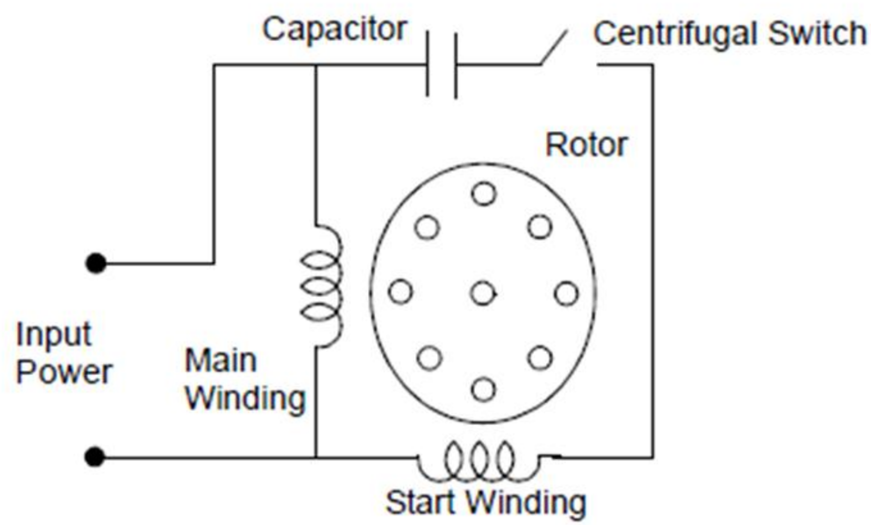


Single Phase Motors

- Single Phase induction motors cannot self start because they lack a rotating magnetic field.
- The starting mechanism is mainly an additional stator winding (start/Auxiliary winding)
- Up to 10hp

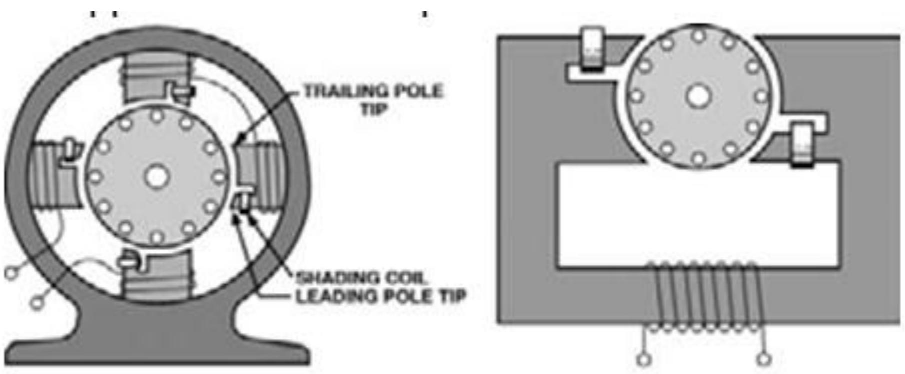


Single-Phase AC Induction Motor without Start Mechanism



Single-Phase AC Induction Motor with Start Mechanism

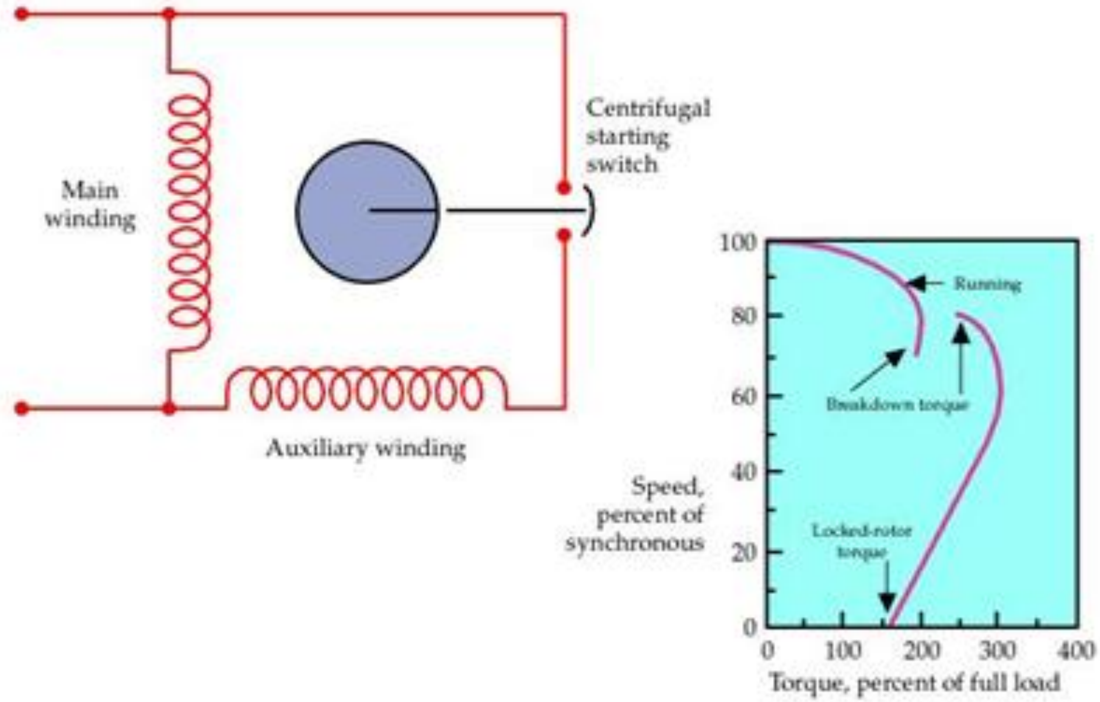
Single Phase Motors



(A) FOUR-POLE MOTOR

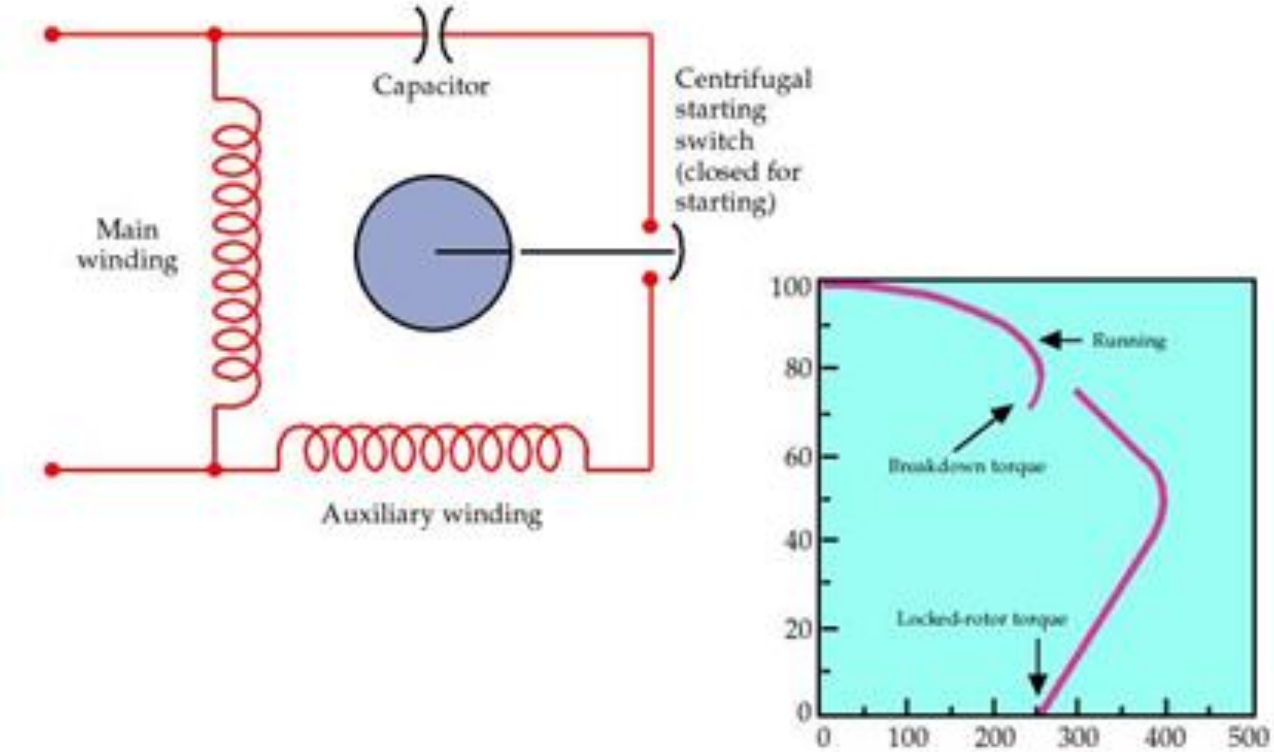
(B) TWO-POLE MOTOR

Single Phase Motors



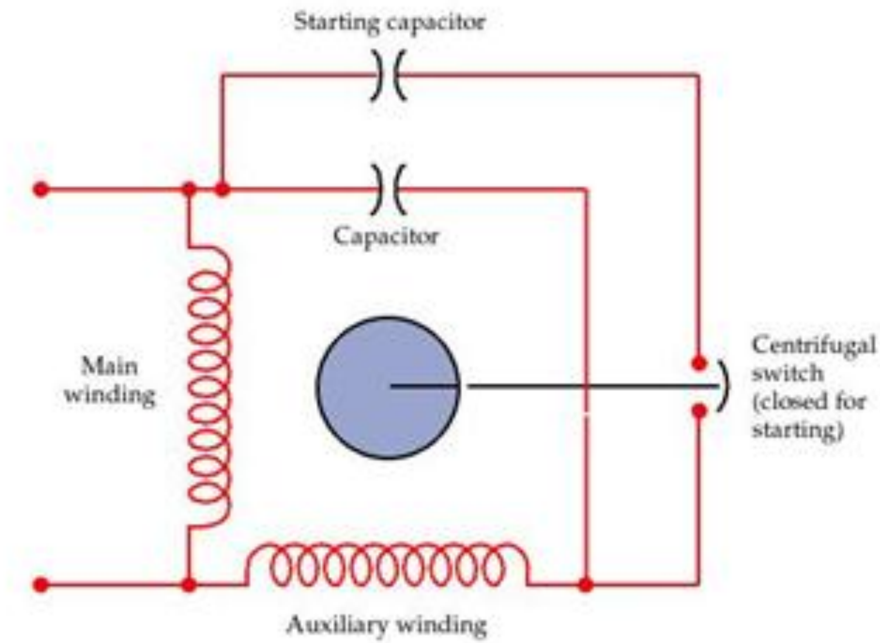
Split-phase squirrel cage induction motor

Single Phase Motors



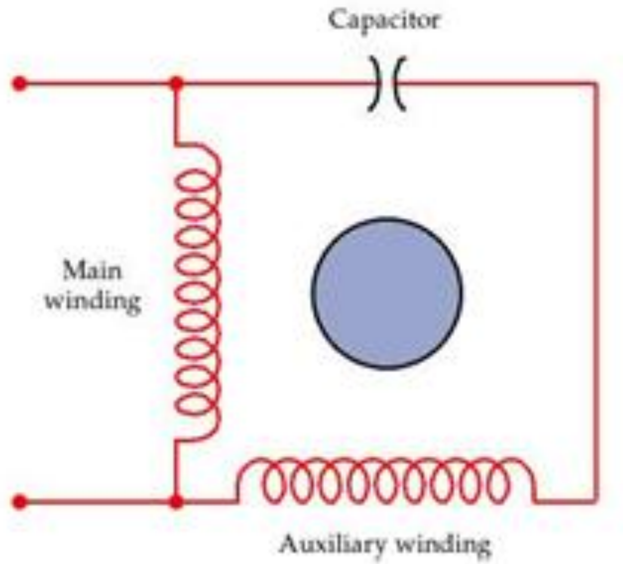
Capacitor-start induction-run

Single Phase Motors



Capacitor-start capacitor-run

Single Phase Motors



Permanent split-capacitor

Single-Phase Motors

Motor Type	Starting Ability (Torque)	Starting Current	Size HP	Voltage	RPM	REV?	Relative Cost	Notes	Uses
Shaded-pole Induction	Very Low, 0.5 – 1 x rt	Low	1/50 to 1/4	115	900, 1200 1800, 3600	NO	Very Low	Light duty, Low efficiency	Small fans, freezer blowers, arc welder blower, hair dryers
Split-Phase	Low, 1 – 1.5 x rt	High, 6 – 8 x rc	1/20 to 3/4	115 or 230	900, 1200, 1800, 3600	YES	Low	Simple construction	Fans, furnace blowers, lathes, small shop tools, jet pumps, small compressors
Permanent-Split, Capacitor-Induction	Very Low, 0.5 – 1 x rt	Low, 2 – r x rc	1/20 to 2	115 or 230	Variable 900 to 1800	YES	Low to Mid	Often custom designed	Fans, furnace blowers, air handling
Capacitor-Start, Induction-Run	High, 3 – 4 x rt	Medium, 3 – 6 x rc	1/6 to 10	115 or 230	900, 1200, 1800,3600	YES	Mid	Long service, easy care	Water systems, air compressors, ventilating fans, grinders, blowers, conveyors
Repulsion-Start, Induction-Run	High, 4 x rt	Low, 2.5 – 3 x rc	1/2 to 15	115 or 230	1200, 1800, 3600	YES	Mid	Handles big load changes well	Grinders, deep well pumps, silo unloaders, grain elevators, barn cleaners
Capacitor-Start, Capacitor-Run	High, 3.5 – 4 x rt	Medium, 3 – 5 x rc	1/2 to 15	115 or 230	900, 1200, 1800, 3600	YES	Mid	Good starting ability, efficiency	Pumps, air compressors, drying fans, large conveyors, feed mills

rc = Running Current

rt = Running Torque

Motor Terminology and Electrical Performance Characteristics

AC Power Supply Terms

- <u>Phase</u>: describes the type of AC power supplied (Single or Three). Does not apply to DC.

- <u>Frequency or Hertz (Hz)</u>: How many times a second the AC changes directions from positive to negative.

- <u>Voltage</u>: Defines the strength of the electric power

Typical Power Supply

Power	Phase	Cycle	Voltages
AC	Single	60	115 or 230
AC	Single	50	110, 208, 220 or 240
AC	Three	60	208, 230, 460, 575, 2300, 4160, 6600, or 13.8 kV
AC	Three	50	190, 380, 400, 415, 690, 4000 or 11 kV

Motor Performance Characteristics

- Speed / #Poles
- Horsepower
- Current
- Speed vs. Torque
- Service Factor

Motor Operating Speeds

- Mechanical speed tied to speed of rotating magnetic field in stator
  - Synchronous Speed $= \dfrac{120 \times \text{Frequency}}{\#\ \text{Poles}}$
  - Rotor lags behind - difference called “Slip”
  - Speeds at 60 Hz. - Full Load Speed is approximate

# Poles	Sync. Speed	Nominal FL Speed
2	3600 RPM	3550 RPM
4	1800 RPM	1750 RPM
6	1200 RPM	1150 RPM

Synchronous Speed (RPM)	# of Poles	Frequency (Hz)	Formula
3600	2	60	S = (120x60) / 2
1800	4	60	S = (120x60) / 4
1200	6	60	S = (120x60) / 6
900	8	60	S = (120x60) / 8
720	10	60	S = (120x60) / 10
3000	2	50	S = (120x50) / 2
1500	4	50	S = (120x50) / 4
1000	6	50	S = (120x50) / 6
750	8	50	S = (120x50) / 8
600	10	50	S = (120x50) / 10

What is Slip?

- Ratio between:

Full Load Speed and No Load Speed

$$\%\,\boldsymbol{Slip} = \left[\mathbf{1} - \left(\frac{\boldsymbol{Full\ Load\ RPM}}{\boldsymbol{No\ Load\ RPM}}\right)\right] \times \mathbf{100}$$

$$\%\,\boldsymbol{Slip} = \left[\mathbf{1} - \left(\frac{\mathbf{1750}}{\mathbf{1800}}\right)\right] \times \mathbf{100} = \mathbf{2.78}\%$$

Horsepower and Torque

Poles	Torque/Hp (lb/ft)	Speed @ 60Hz Synchronous
2	1.5	3600
4	3	1800
6	4.5	1200
8	6	900
10	7.5	720
12	9	600

$$HP = \frac{Speed \times Torque}{5252}$$

$$Torque = \frac{HP \times 5252}{Speed}$$

Rules of Thumb

Motor Amps per HP - (full load)

460v, a 3-phase motor draws 1.25 amps per HP

230v, a 3-phase motor draws 2.5 amps per HP

Effects of Voltage Variations on AC Motors

Low Voltage

1. Reduced starting torque - Motor may not be able to start load.
2. Reduced running torque - Current increases to produce 100% torque creating excessive heat. Increased heat causes premature insulation failure.
3. Speed decreases / Process interruption

High Voltage

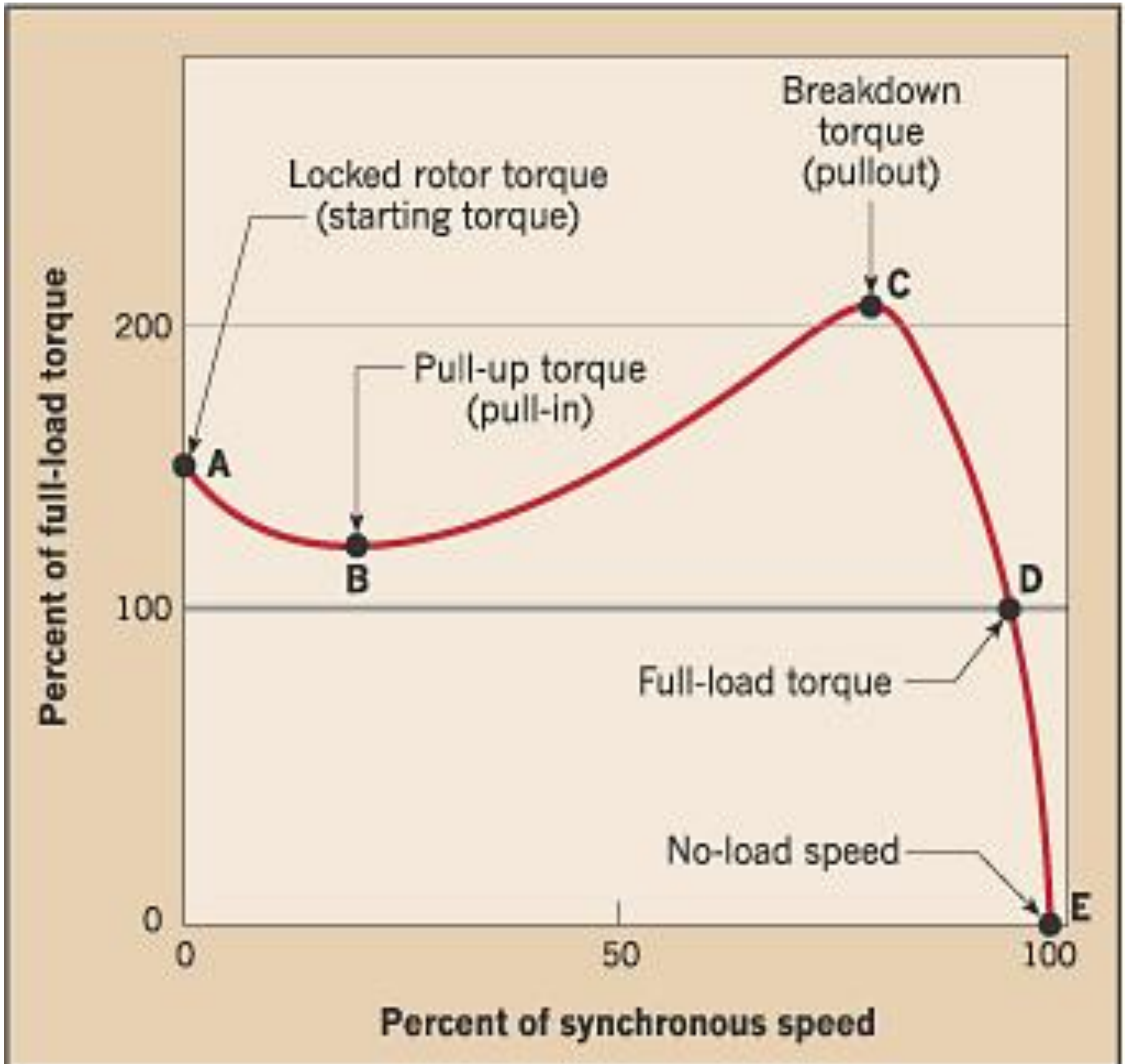
1. Increased starting current - Nuisance trip of overloads. Increased heat can cause insulation damage.
2. Increased starting and running torque.
3. Speed increases / Process interruption

- NEMA allows A +/- 10% voltage variation with no frequency variation.

Is it true?

- A motor, depending on its design can produce torque indefinitely without producing horsepower
- A motor cannot develop horsepower without first producing torque
- A motor needs to rotate to develop horsepower in order to do work

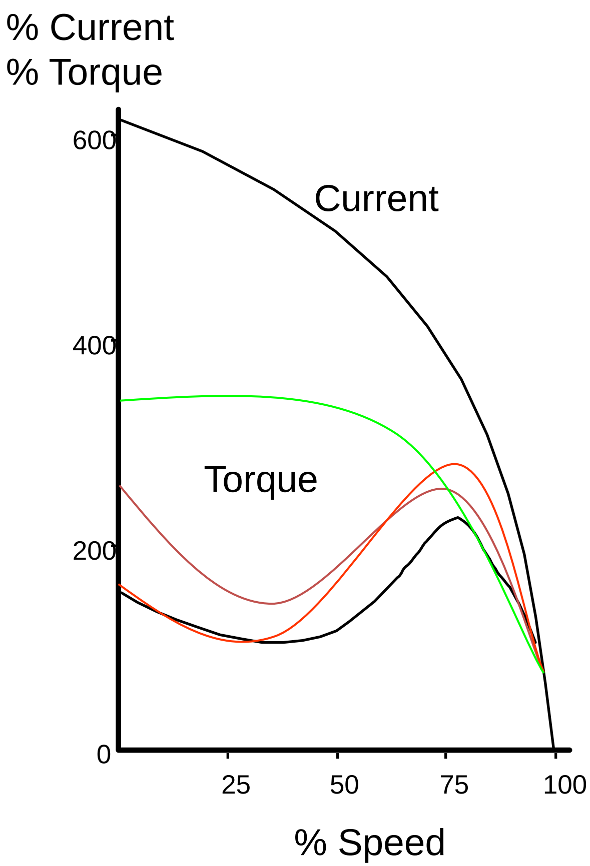
Motor Speed Torque Curve



Motor Designs

- The Material and Shape of the Rotor Bars Are the Main Factors in Obtaining Various Speed/Torque Curves
- NEMA Defines 4 Basic Types of Speed/Torque Characteristics for Induction Motors:
  - **DESIGN A**
  - **DESIGN B**
  - **DESIGN C**
  - **DESIGN D**
- The Stator Has Little to Do With the Shape of the Motors Speed/Torque Curve
- Different Rotors Could Be Used With the Same Stator to Change the Characteristic Shape

Typical Current & Torque Relationship for Squirrel Cage Induction Motor



Nema Des.	Starting Torque	LR amps	BD torq	FL slip	Applications
A	Normal	High	**High**	Low	Mach. Tools, fans
B	Normal	Normal	Normal	Normal	General Industrial
C	**High**	Normal	Normal	Normal	Conveyor
D	**Very High**	Low	n/a	**High**	Hoists

ROTOR DESIGN
Slot Shapes

Design A

- LRT Normal (90 – 100%)
- LRA High >650%
- BDT High >200%
- FL Slip Low

- Cross section of the bar is large (low resistance) and not too deep in the iron (low reactance).

ROTOR DESIGN
Slot Shapes

Design B

• LRT	Normal (80 – 100%)
• LRA	Normal ≈ 650%
• BDT	Medium ≈ 200%
• FL Slip	Low

- Similar to design A except the deeper bar results in lower inrush and slightly lower torques.

ROTOR DESIGN
Slot Shapes

Design C

- LRT High > 150%
- LRA Normal ≈ 650%
- BDT Medium ≈ 200%
- FL Slip Low – Med < 5%

- Design C utilizes a double cage slot. The high resistance of the upper cage delivers high starting torque.

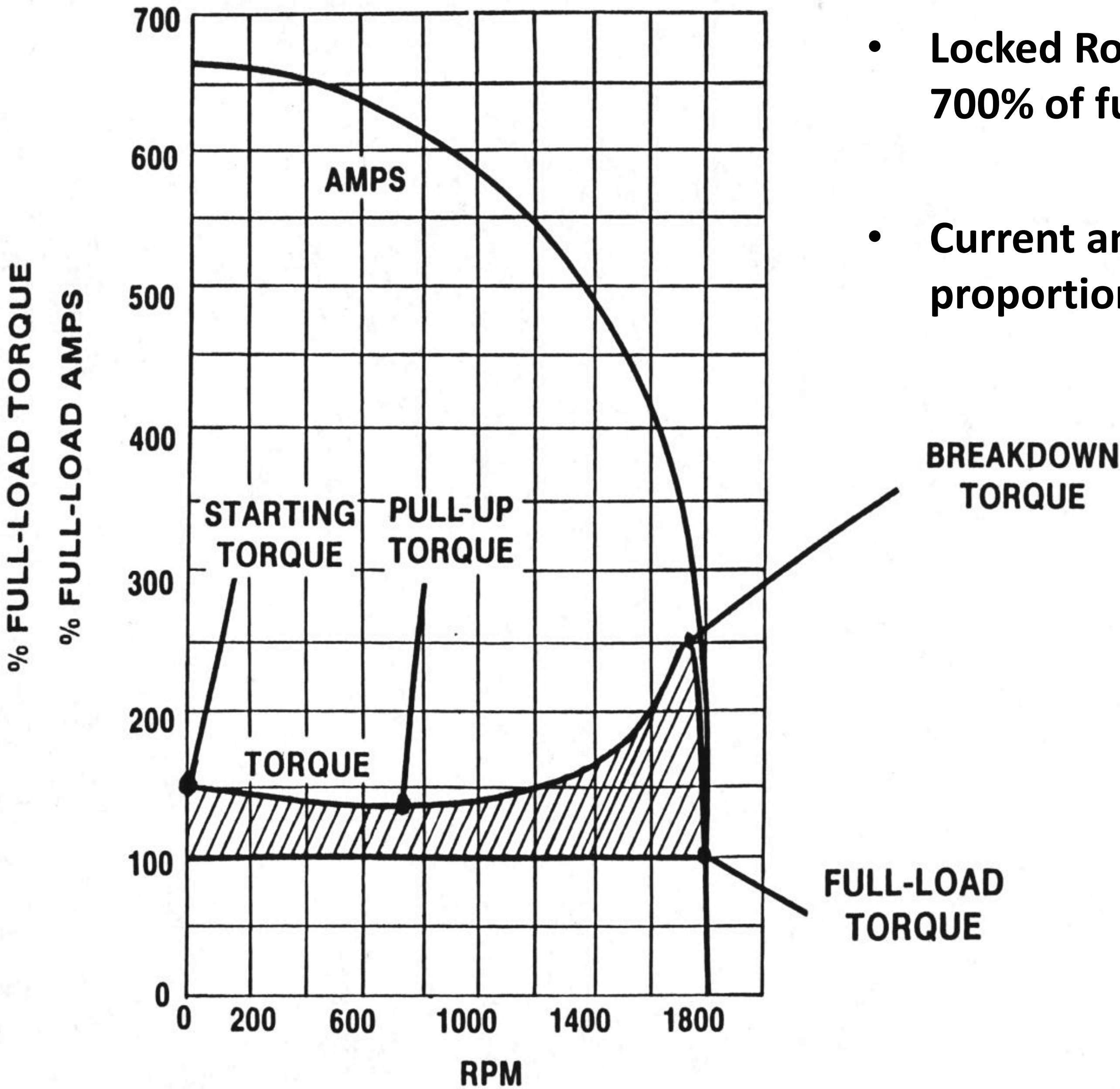
ROTOR DESIGN
Slot Shapes

Design D

- LRT Very High > 200%
- LRA Normal ≈ 650%
- BDT High > 200%
- FL Slip High (5 – 8%, 8 – 13%)

- Bar shape and brass or similar alloy is used for high resistance (high starting torque) and high slip.

Motor Starting - Inrush Currents



- **Locked Rotor Current typically 600 - 700% of full load**
- **Current and torque aren't proportional until near full load**

What is Large AC?

Per NEMA, Large Induction Machines include ratings <u>greater than</u>:

Sync. RPM	Motors-HP	Generators-kW
3600	500	400
1800	500	400
1200	350	300
900	250	200
720	200	150
600	150	125
514	125	100
450	ALL	ALL

NEMA MG 1 Part 20

Speed vs Torque
NEMA MG 1- 20.10

20.10.1 Standard Torque

The torques, with rated voltage and frequency applied, shall be not less than the following:

Torques	Percent of Rated Full-Load Torque
Locked-rotor*	60
Pull-up*	60
Breakdown*	175

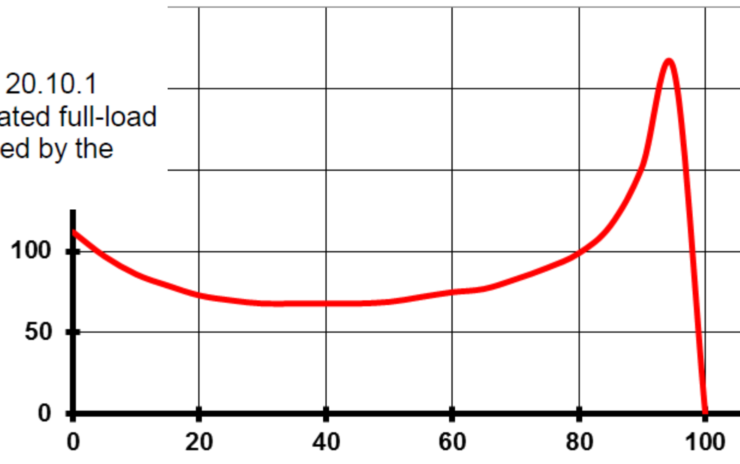
20.10.2 High Torque

When specified, the torques with rated voltage and frequency applied, shall not be less than the following:

Torques	Percent of Rated Full-load Torque
Locked-rotor	200
Pull-up	150
Breakdown	190

20.10.3 Motor Torques When Customer Specifies A Custom Load Curve

When the customer specifies a load curve, the torques may be lower than those specified in 20.10.1 provided the motor developed torque exceeds the load torque by a minimum of 10% of the rated full-load torque at any speed up to that at which breakdown occurs, with starting conditions as specified by the customer (refer to 20.14.2.3).



Speed vs Torque - Application

Constant Torque

- Reciprocating Compressor
- Reciprocating Pump
- Extruder
- Conveyer

Variable Torque

- Centrifugal Pump
- Centrifugal Compressor
- Fan

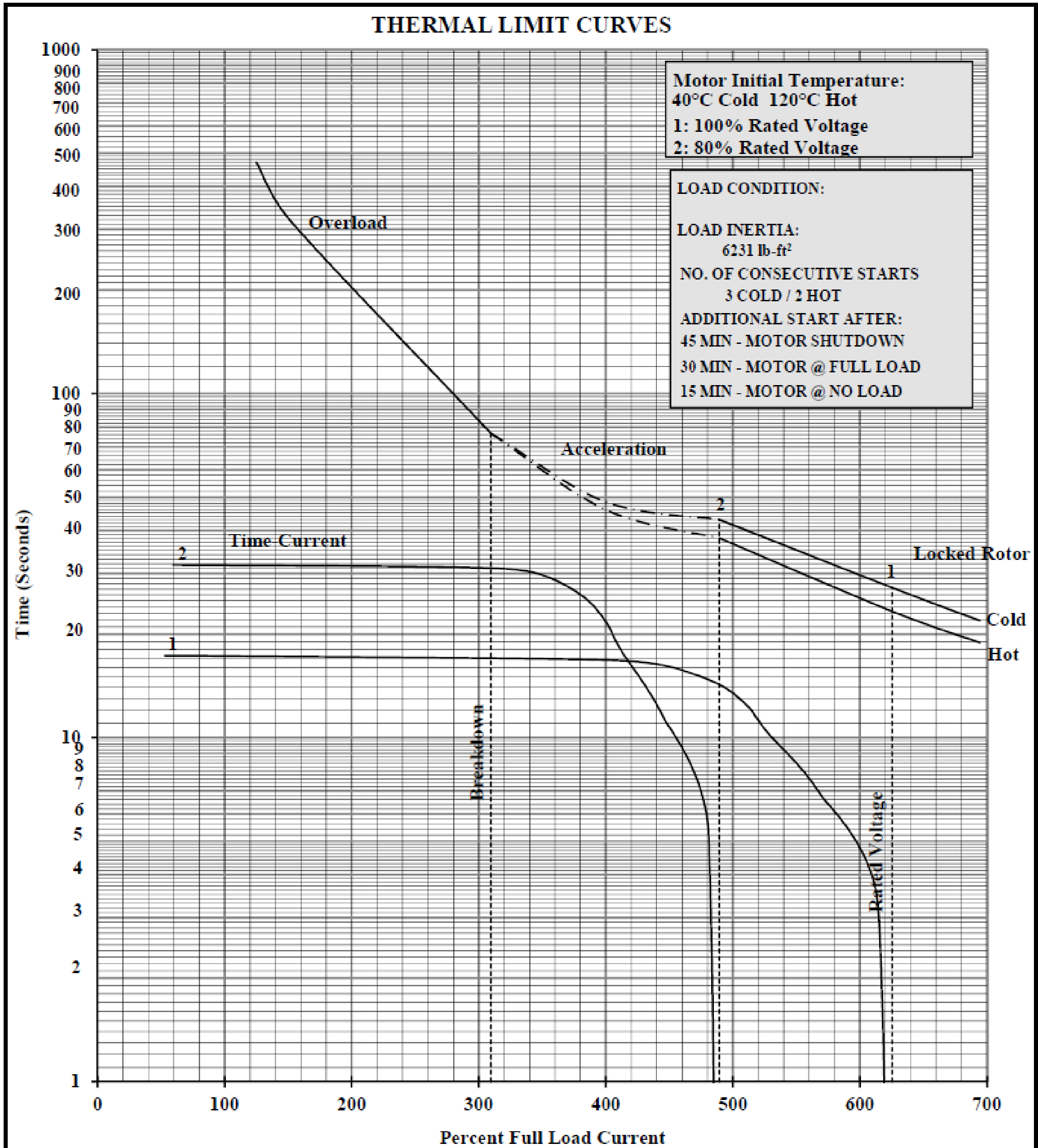
Application Characteristics

- Required HP, Speed, and Voltage
- Application (Type of Load)
- Starting / Running Method

Motor Starts

- **Every time a motor starts its components are subjected to mechanical and thermal stress.**
  - **Rotors**
  - **Winding insulation**

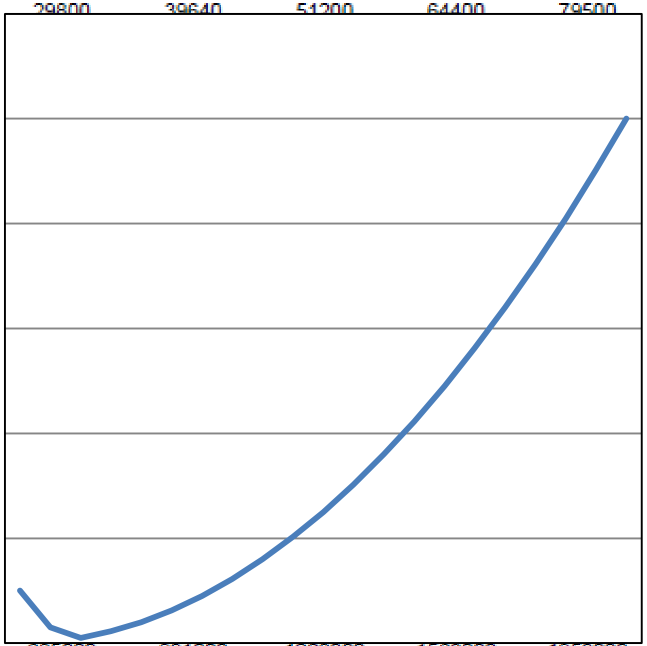
- **Number of starts per time should not be exceeded.**
  - **2 starts loaded with motor at ambient temperature**
  - **1 start loaded with motor at operating temperature**
  - **Followed by required cooling time**



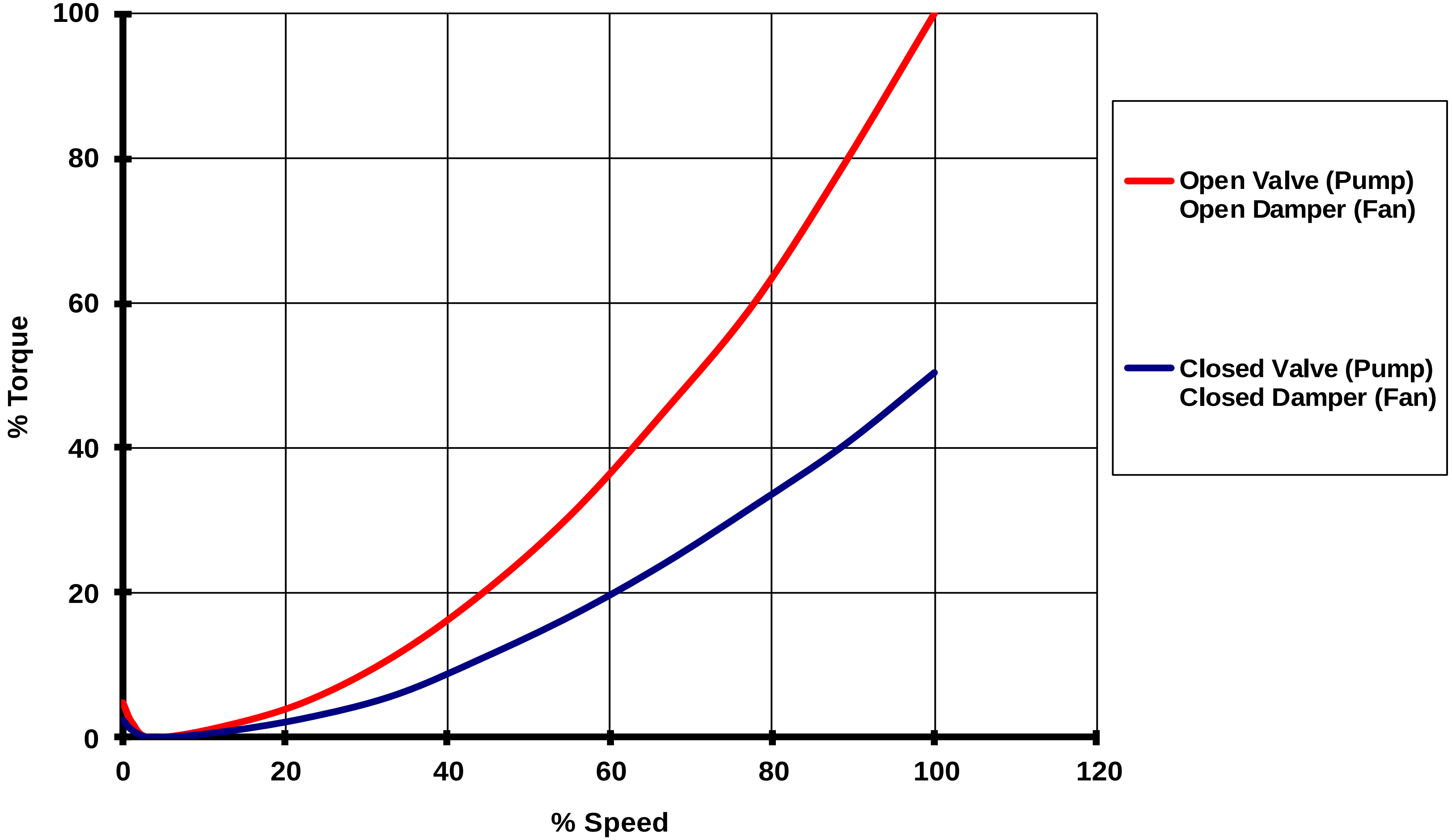
Consider the applied load inertia at the motor shaft……

Table 20-1
LOAD Wk^2 FOR POLYPHASE SQUIRREL-CAGE INDUCTION MOTORS*

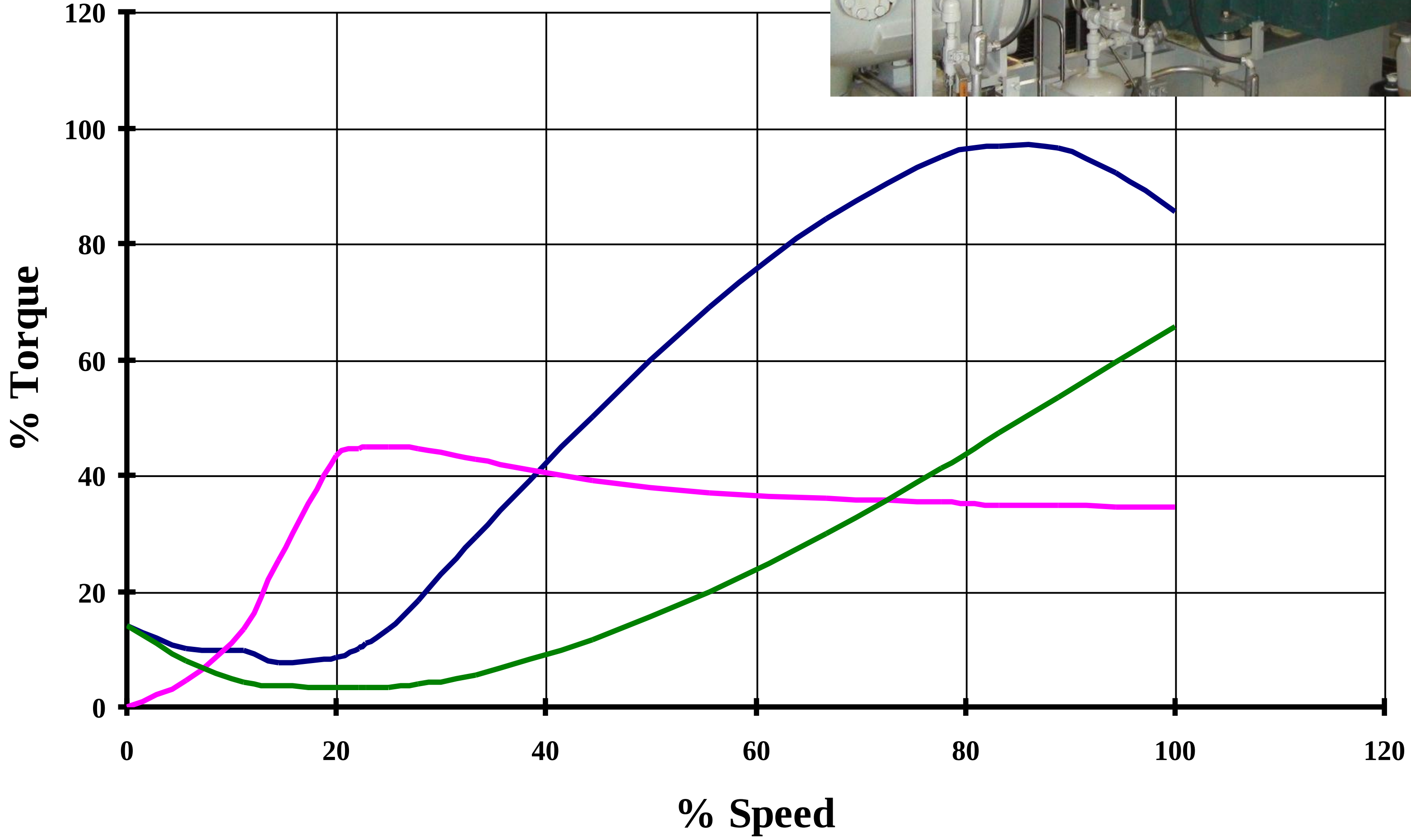
Hp	Synchronous Speed, Rpm											
	3600	1800	1200	900	720	600	514	450	400	360	327	300
	Load Wk^2 (Exclusive of Motor Wk^2), Lb-ft^2											
100	...	...	...	...	...	...	...	12670	16830	21700	27310	33690
125	...	...	...	...	...	...	...	15610	20750	26760	33680	41550
150	...	...	...	...	...	...	13410	18520	24610	31750	39960	49300
200	...	...	...	...	...	12060	17530	24220	32200	41540	52300	64500
250	...	...	...	...	9530	14830	21560	29800	39640	51200	64400	79500
300	...	...	...	6540	11270	17550	25530	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
350	...	...	...	7530	12980	20230	29430	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
400	...	...	4199	8500	14670	22870	33280	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
450	...	...	4666	9460	16320	25470	37090	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
500	...	...	5130	10400	17970	28050	40850	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
600	443	2202	6030	12250	21190	33110	48260	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
700	503	2514	6900	14060	24340	38080	55500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
800	560	2815	7760	15830	27440	42950	62700	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
900	615	3108	8590	17560	30480	47740	69700	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1000	668	3393	9410	19260	33470	52500	76600	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1250	790	4073	11380	23390	40740	64000	93600	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1500	902	4712	13260	27350	47750	75100	110000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1750	1004	5310	15060	31170	54500	85900	126000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2000	1096	5880	16780	34860	61100	96500	141600	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2250	1180	6420	18440	38430	67600	106800	156900	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2500	1256	6930	20030	41900	73800	116800	171800	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3000	1387	7860	23040	48520	85800	136200	200700	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3500	1491	8700	25850	54800	97300	154800	228600	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4000	1570	9460	28460	60700	108200	172600	255400	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4500	1627	10120	30890	66300	118700	189800	281400	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5000	1662	10720	33160	71700	128700	206400	306500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5500	1677	11240	35280	76700	138300	222300	330800	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6000	...	11690	37250	81500	147500	237800	354400	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7000	...	12400	40770	90500	164900	267100	399500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8000	...	12870	43790	98500	181000	294500	442100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9000	...	13120	46330	105700	195800	320200	482300	685000	931000	1223000	1563000	1953000
10000	...	13170	48430	112200	209400	344200	520000	741000	1009000	1327000	1699000	2125000
11000	...	...	50100	117900	220000	366700	556200	794000	1084000	1428000	1830000	2291000
12000	...	...	51400	123000	233500	387700	590200	844800	1155000	1524000	1956000	2452000
13000	...	...	52300	127500	244000	407400	622400	893100	1224000	1617000	2078000	2608000
14000	...	...	52900	131300	253600	425800	652800	934200	1289000	1707000	2195000	2758000
15000	...	...	53100	134500	262400	442900	681500	983100	1352000	1793000	2309000	2904000



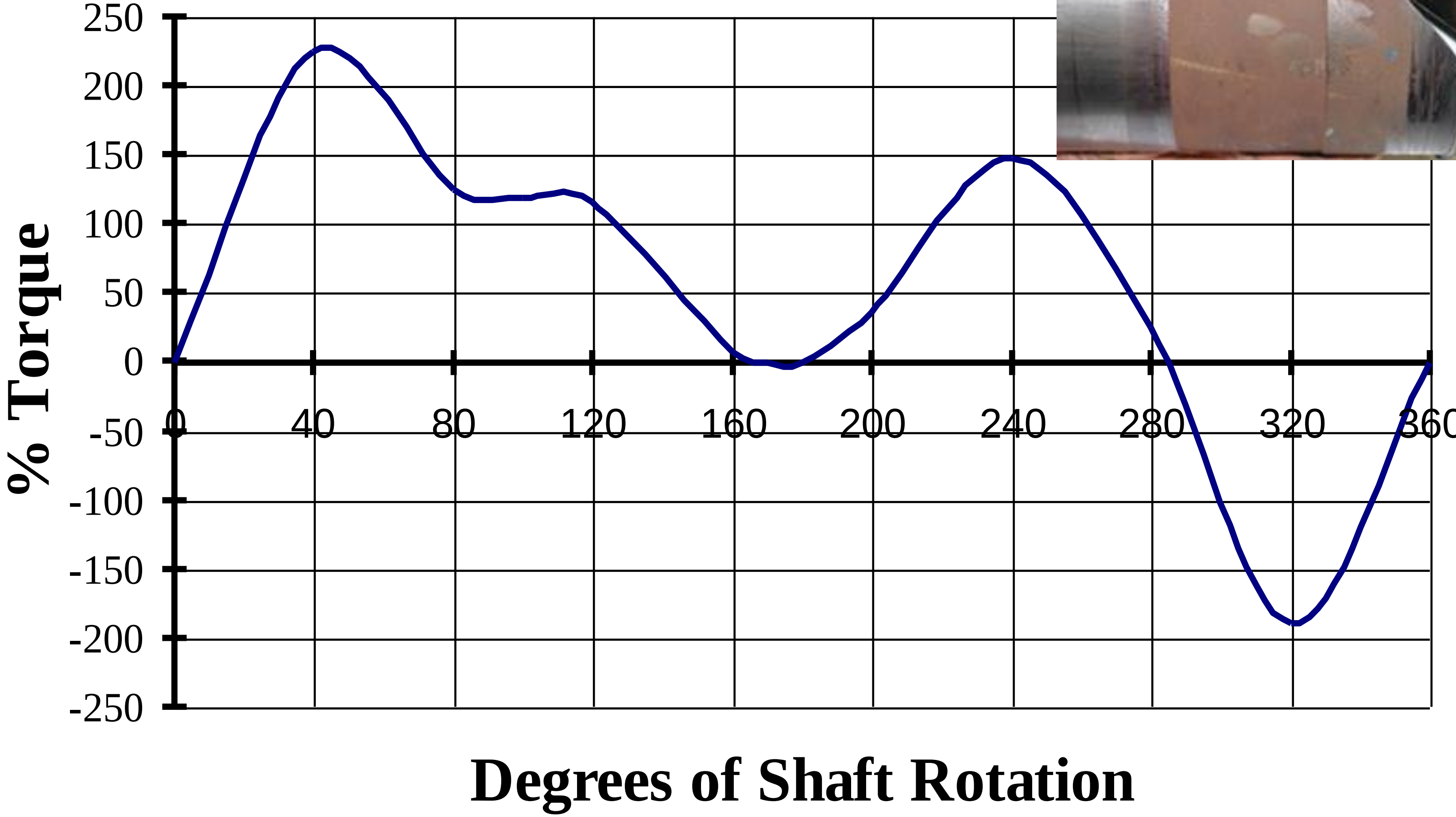
LOAD CURVES
Pump/Fan

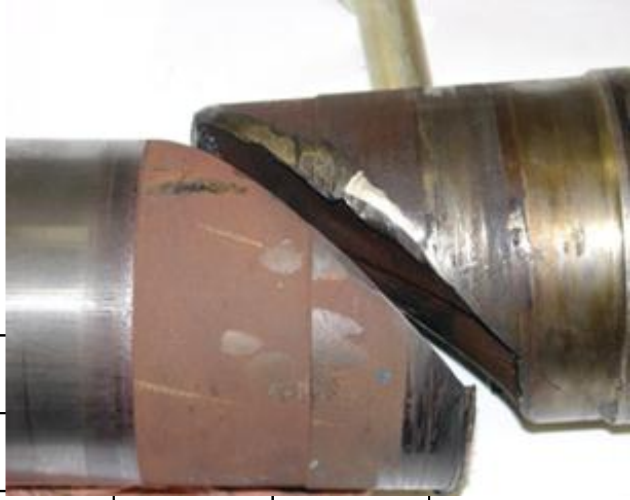


LOAD CURVES
Compressor

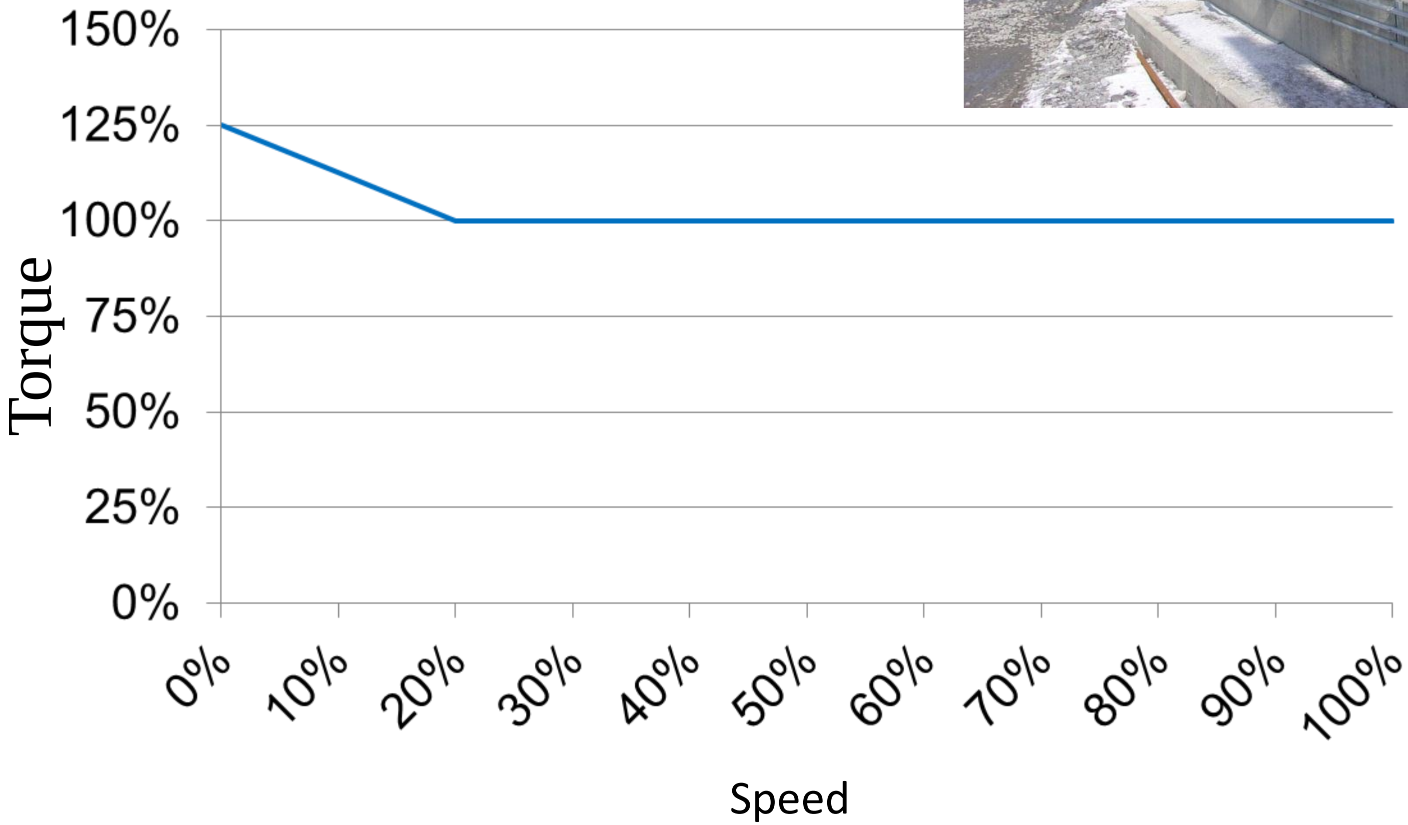


Reciprocating Compressor Torque Effort Curve





LOAD CURVES
Conveyor

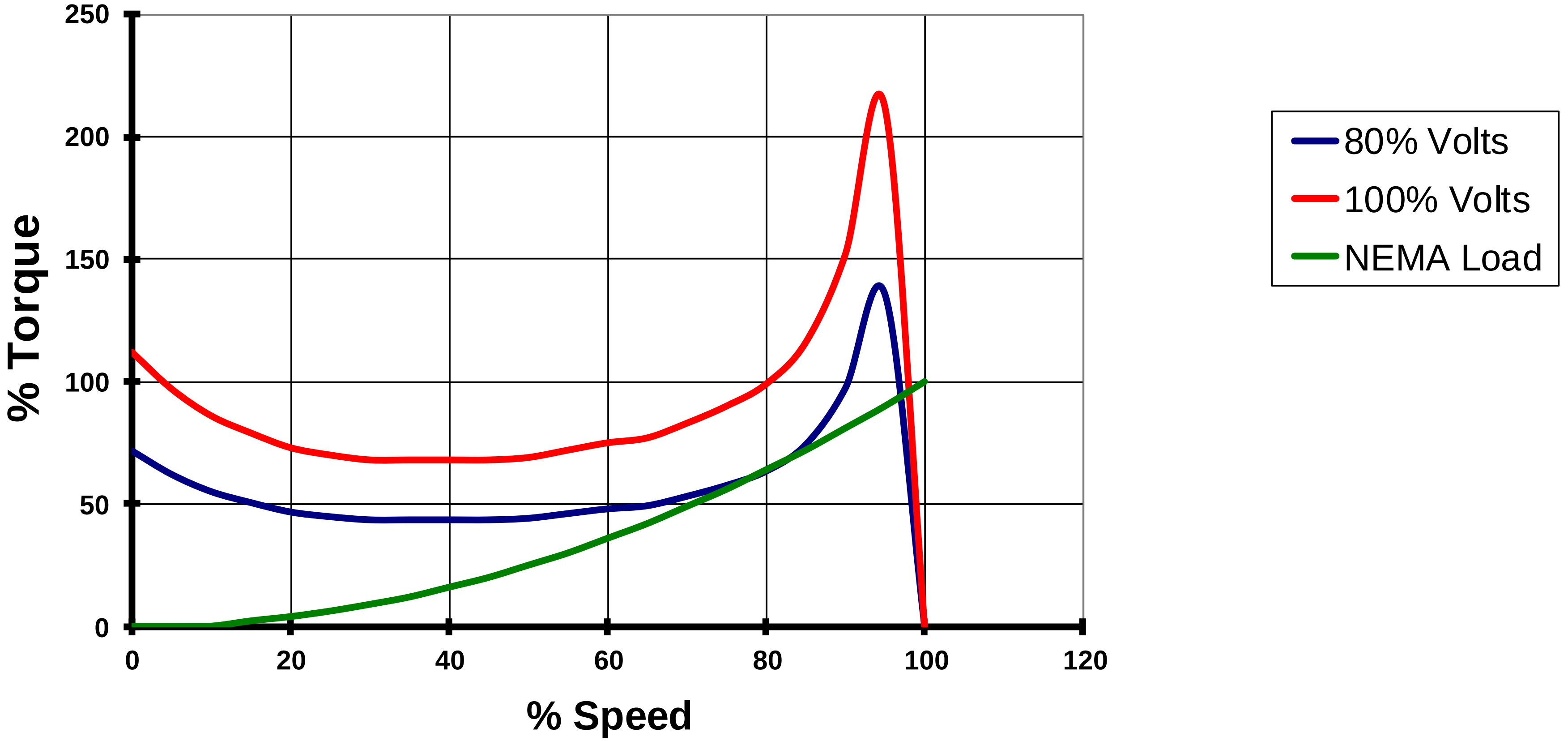


Starting Method

- Full Voltage
- Auto Transformer / Voltage Dip
- Current Limiting Soft Start
- Adjustable Speed Drive

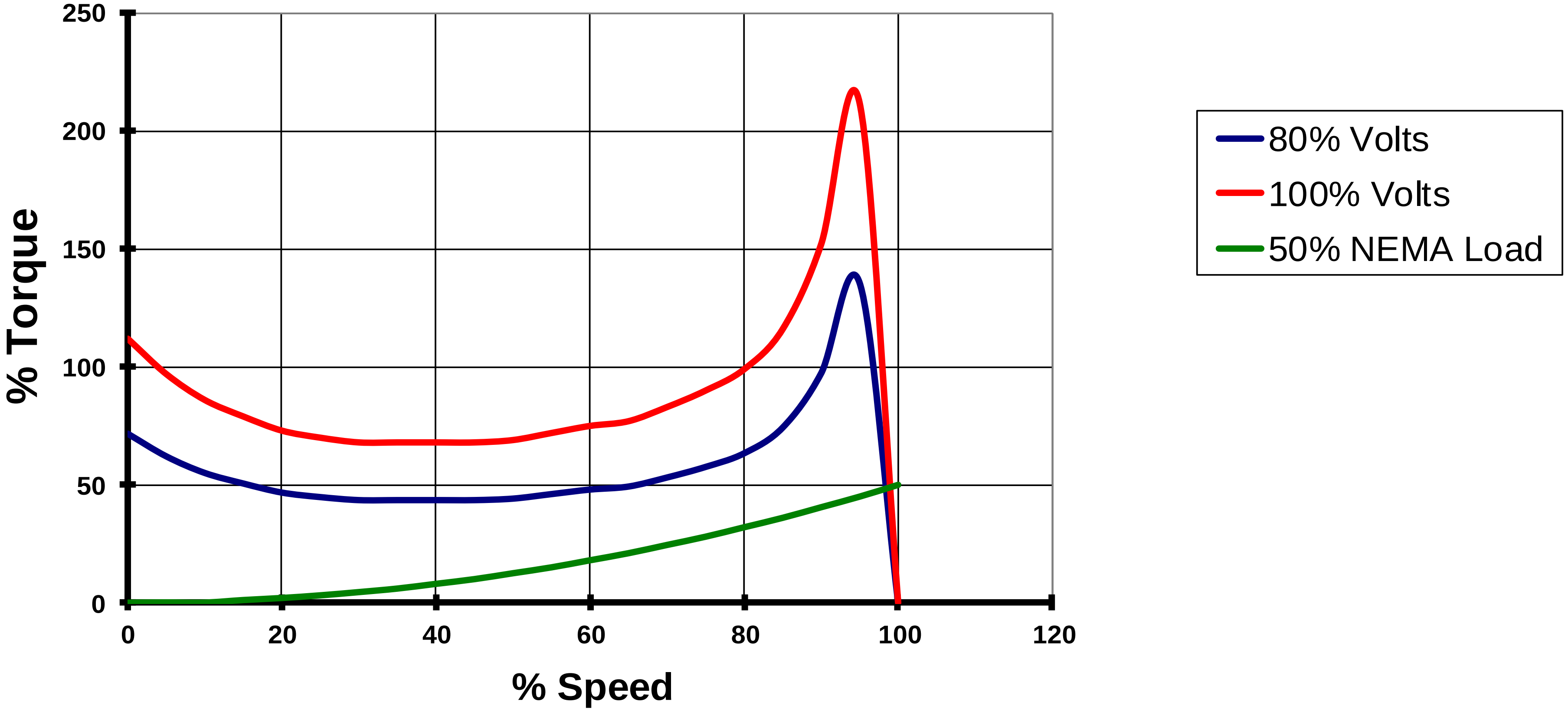
STARTING METHODS

Reduced Voltage - NEMA Load Curve



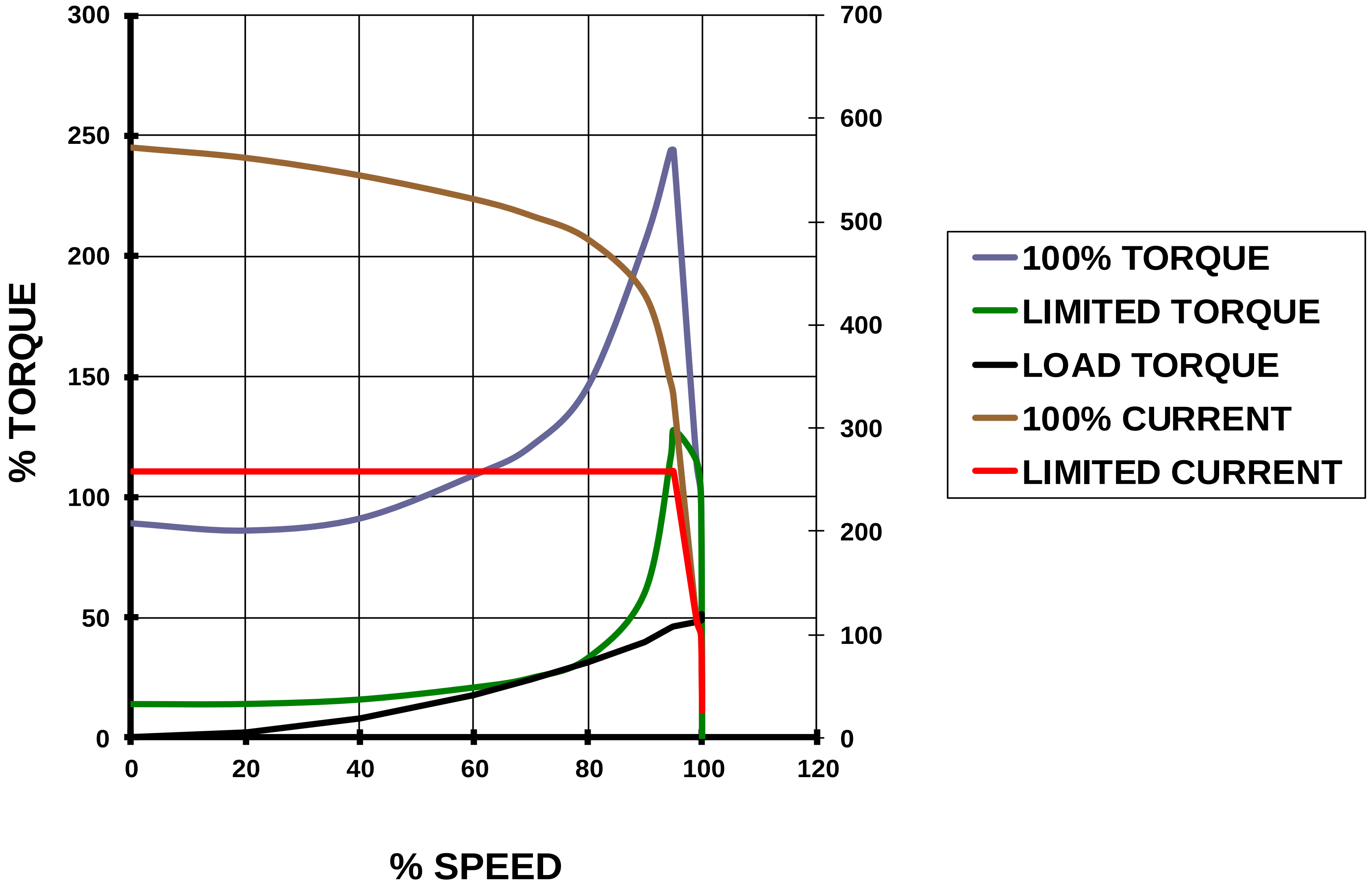
STARTING METHODS

Reduced Voltage - 50% NEMA Load Curve

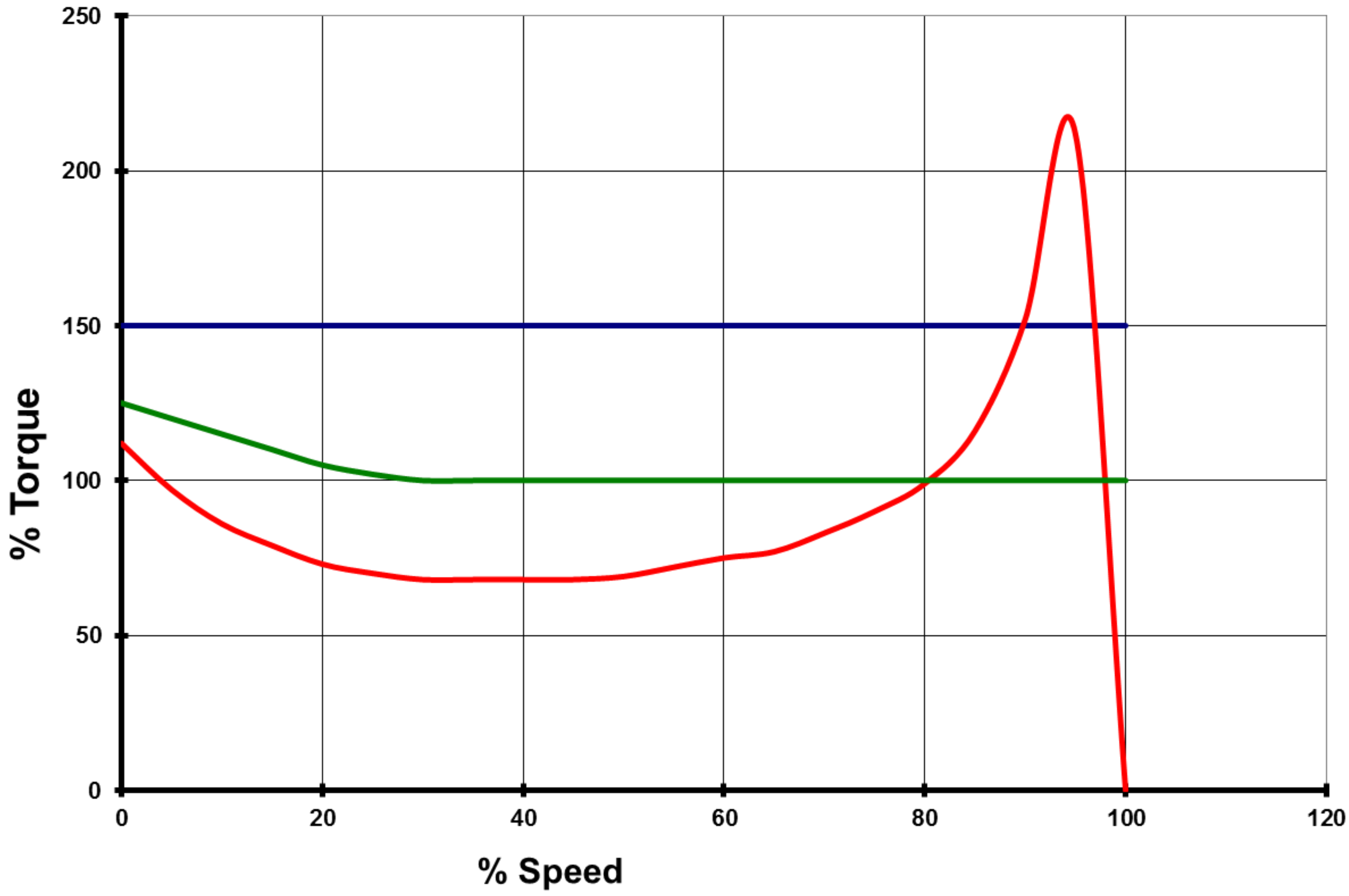


STARTING METHODS

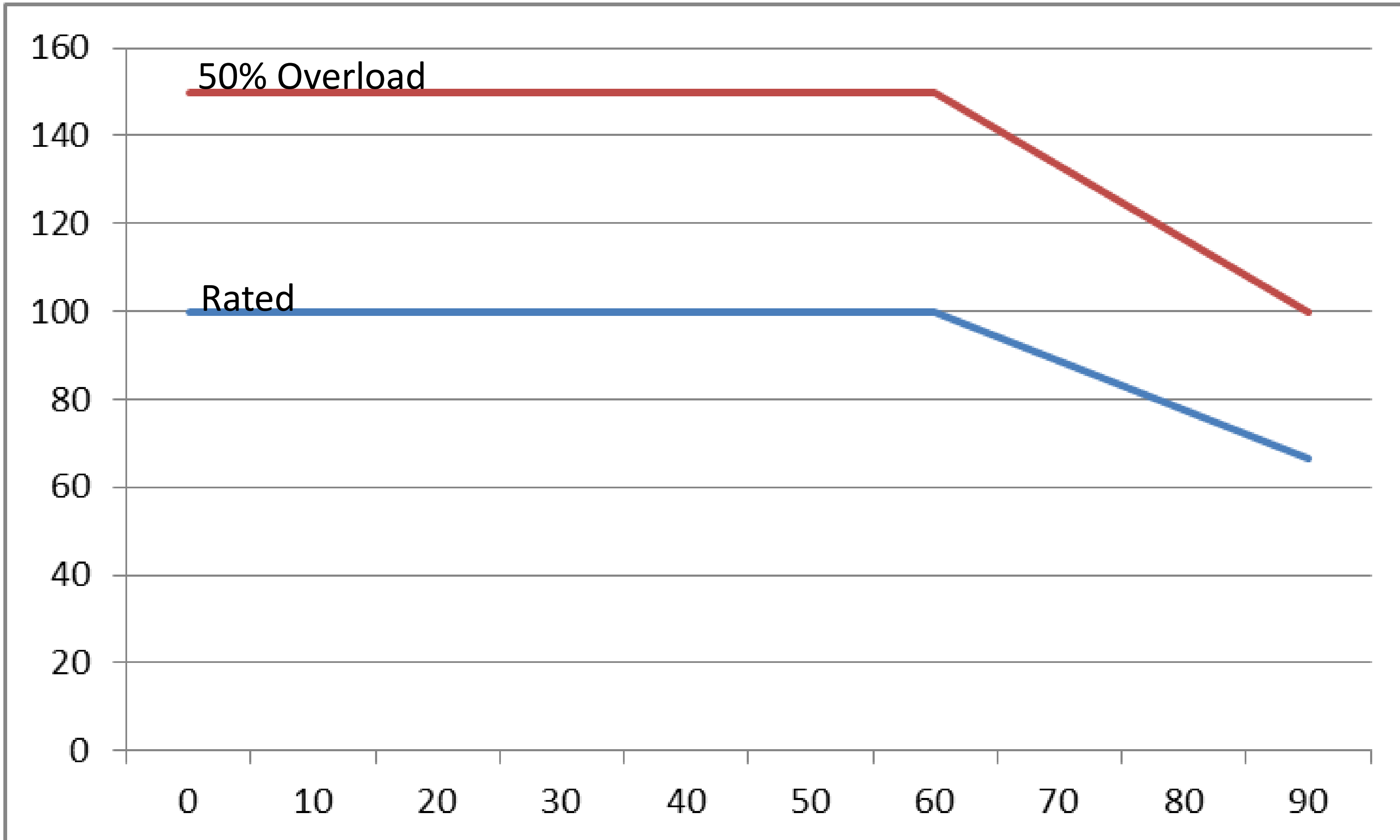
Current Limiting Soft-Start (250% FLA)



VFD Starting

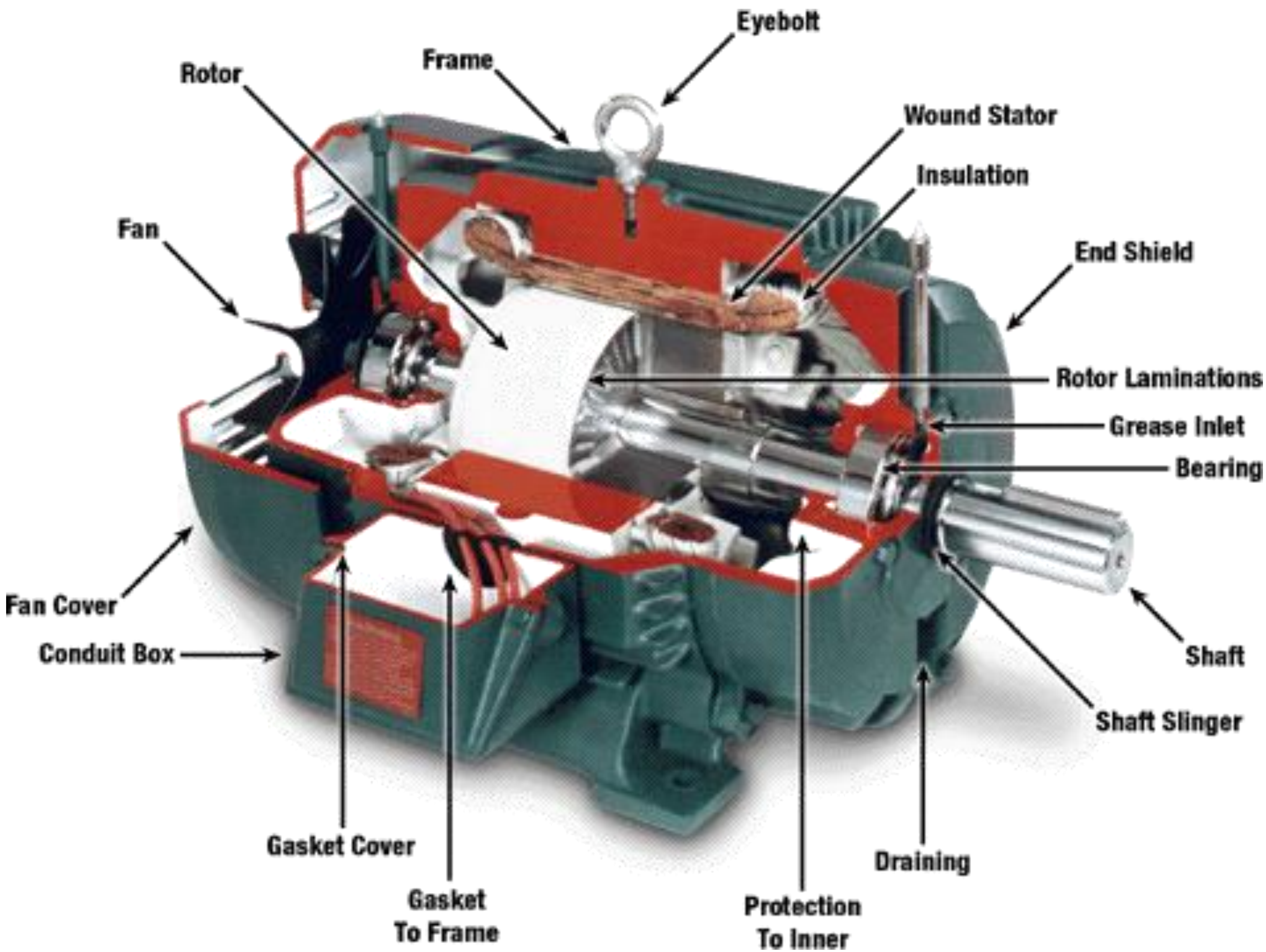


AC Motor Torque on Variable Frequency

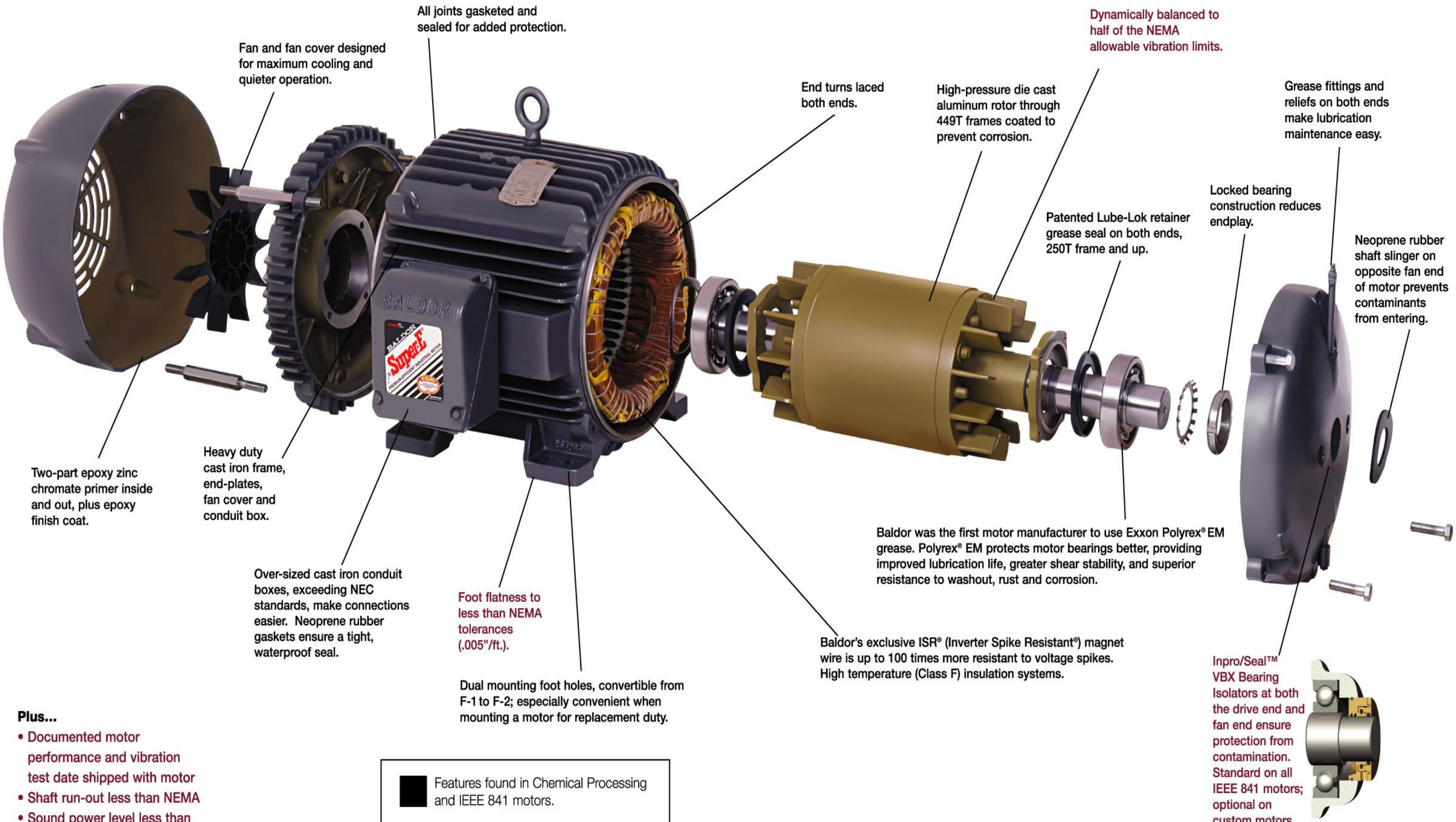


Motor Components

AC Motor Components



Severe Duty Motors: Built for Reliable Performance



Plus...
- Documented motor performance and vibration test date shipped with motor
- Shaft run-out less than NEMA
- Sound power level less than 90 dBA
- Five-year warranty

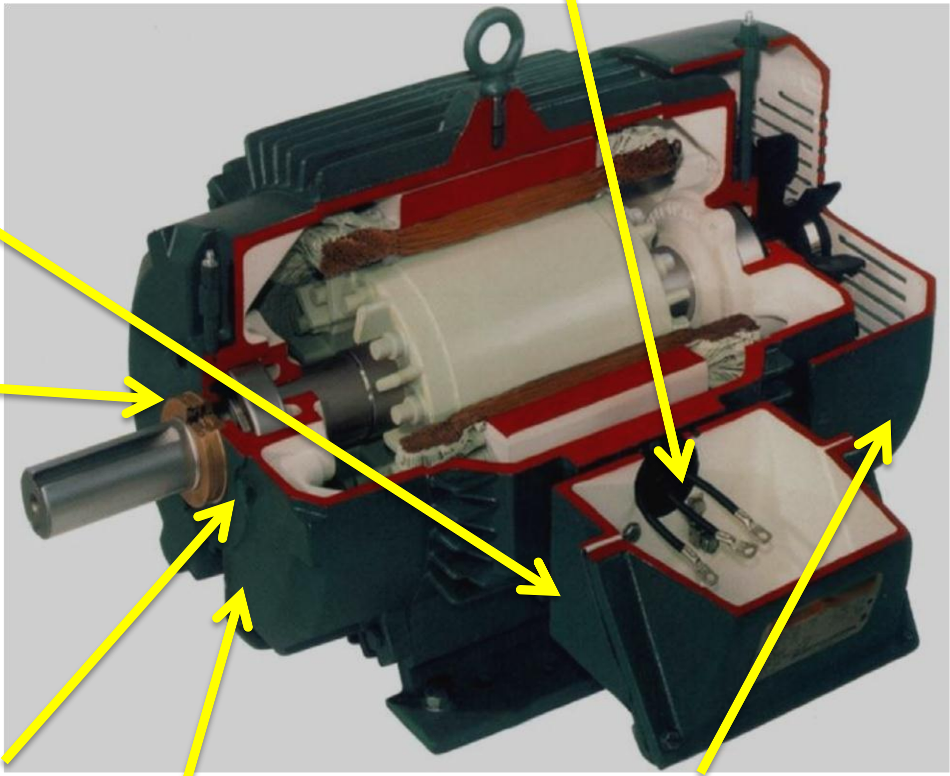
■	Features found in Chemical Processing and IEEE 841 motors.
■ (maroon)	Features found only in IEEE 841 motors.

Typical IEEE-841 Motor Construction

3 Flying leads

Side mounted
conduit box

Rotating
labyrinth seal



Cast iron frame ,endplates and
Bearing retainers

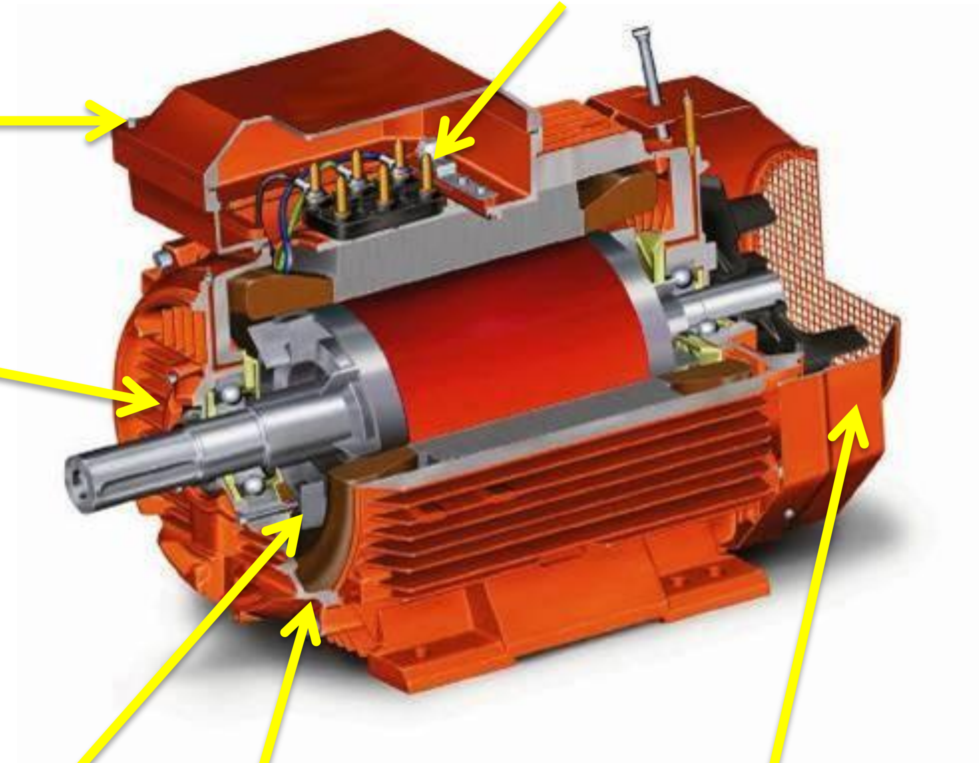
Cast iron fan cover

Typical IEC Motor Construction

6-terminal studs
Wye-Delta Start

Top mounted
conduit box

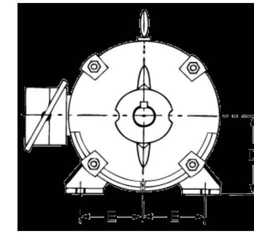
Lip seal on shaft,
not rotating
labyrinth seal



Sometimes frame, endplates and
bearing retainers are aluminum,
not cast iron

Stamped steel fan cover

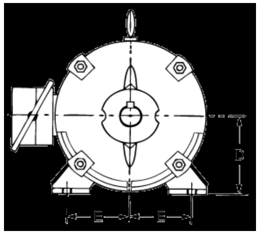
Frame Size Designations



- NEMA MG 1 assigns a frame size based on enclosure, HP and rpm for 60 Hz operation

- IEC does not associate any specific output power and speed to a specific frame size
  - CENELEC harmonization document HD231 does
  - This document covers totally enclosed squirrel cage motors at 50 hz, 56 to 315M frames, up to 132 kW

Frame Size Designations



NEMA			IEC		
Frame	Shaft Height (in)	Shaft Height (mm)	Frame	Shaft Height (in)	Shaft Height (mm)
			63	2.480	63
42	2.625	66.675	71	2.795	71
48	3.0	76.200	80	3.150	80
56 / 140T	3.5	88.900	90	3.543	90
			100	3.937	100
180T	4.5	114.300	112	4.409	112
210T	5.3	133.350	132	5.197	132
250T	6.3	158.750	160	6.299	160
280T	7.0	177.800	180	7.087	180
320T	8.0	203.200	200	7.874	200
360T	9.0	228.600	225	8.858	225
400T	10.0	254.000	250	9.843	250
440T	11.0	279.400	280	11.024	280
5000	12.5	317.500	315	12.402	315
5800	14.5	368.300	355	13.976	355
			400	15.748	400
6800	17.0	431.800	450	17.717	450
			500	19.685	500

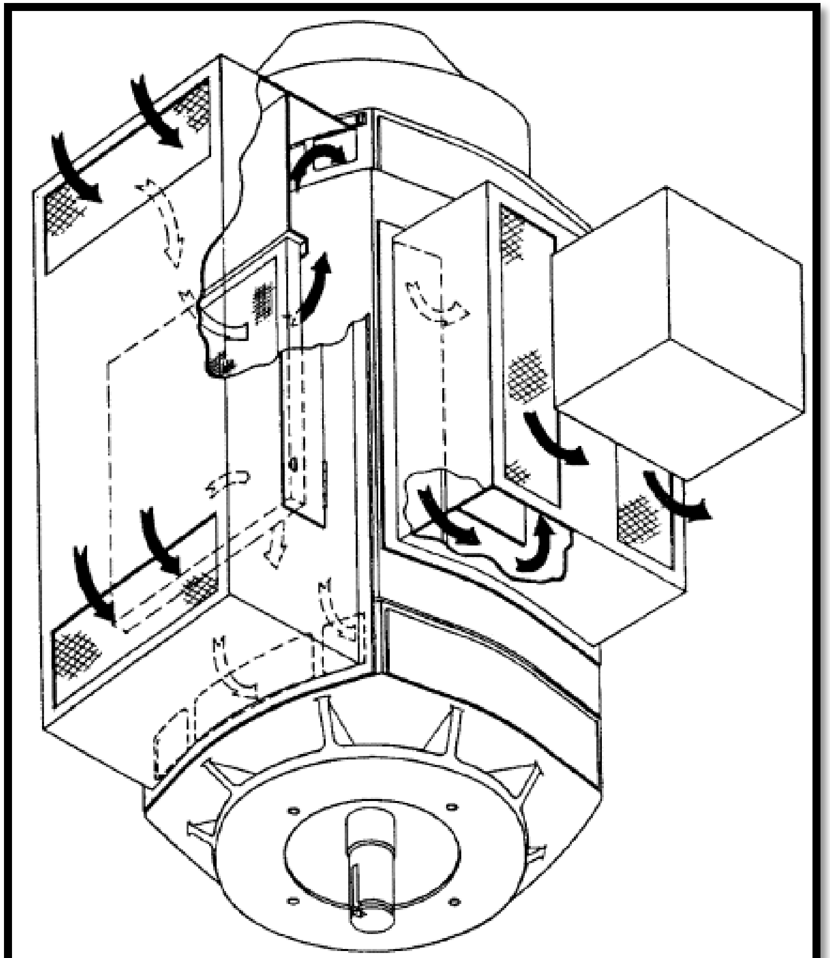
Motor Enclosures

Motor Enclosures

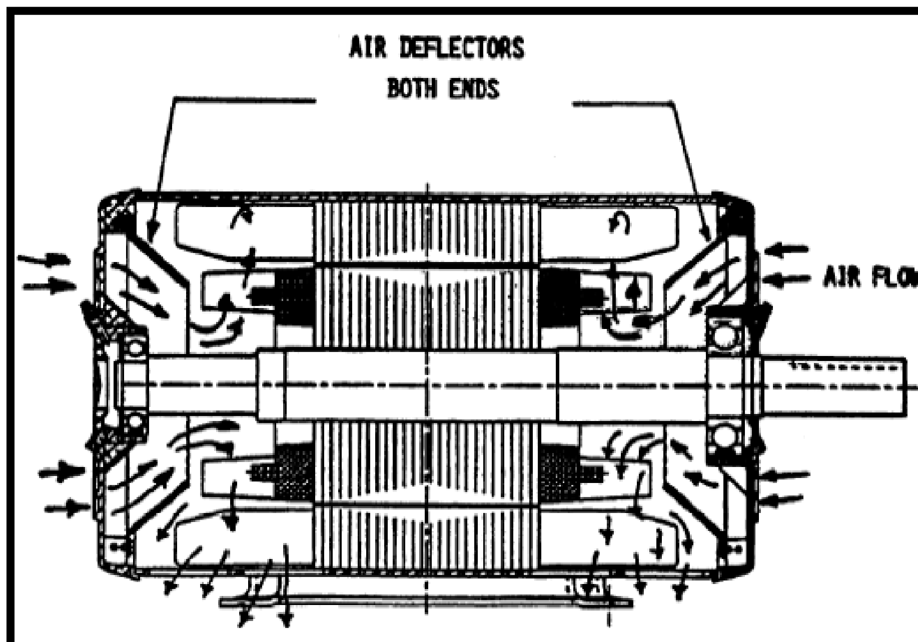
Open
Systems

Enclosed
Systems

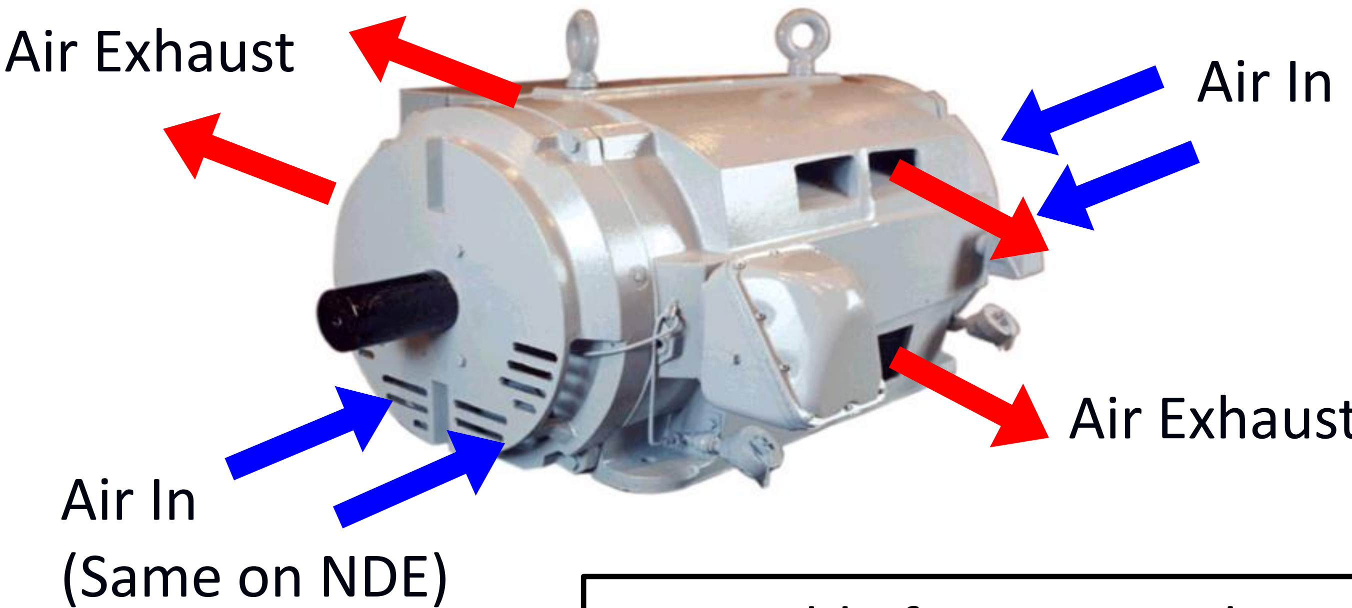
Open Motors



OPEN DRIP PROOF (ODP)
DRIP PROOF GUARDED (DPG)
SPLASH PROOF GUARDED (SPG)
WEATHER PROTECTED I (WP-I)
WEATHER PROTECTED II (WP-II)
OPEN DRIP PROOF FORCED VENTILATED (ODP-FV)
SPLASH PROOF GUARDED FORCED VENT (SPG-FV)
OPEN DRIP PROOF SEPARATE-VENTILATED (ODP-SV)
SPLASH PROOF GUARDED SEPARATE VENTILATD (SPG-SV)

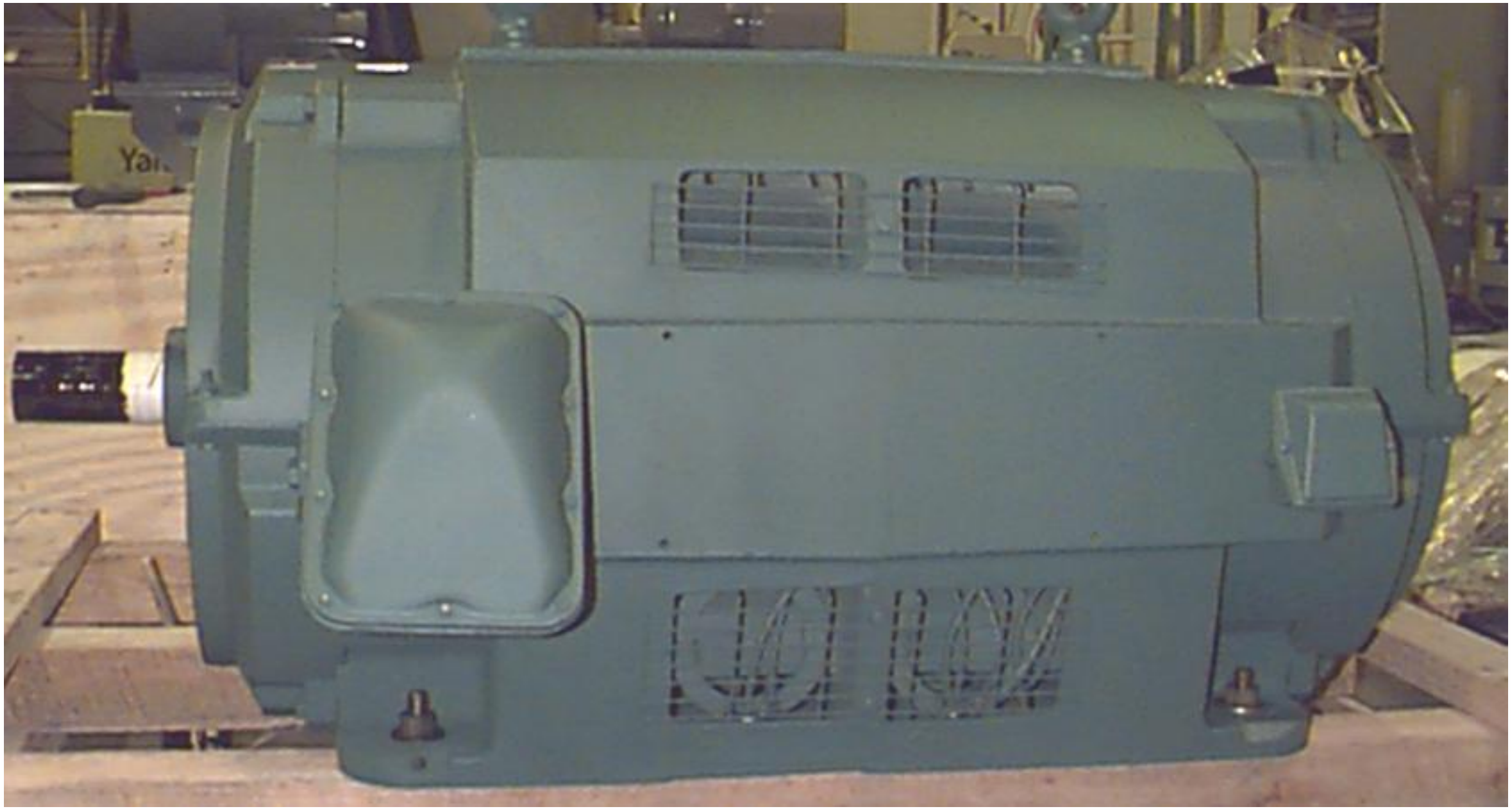


Open Drip Proof – ODP



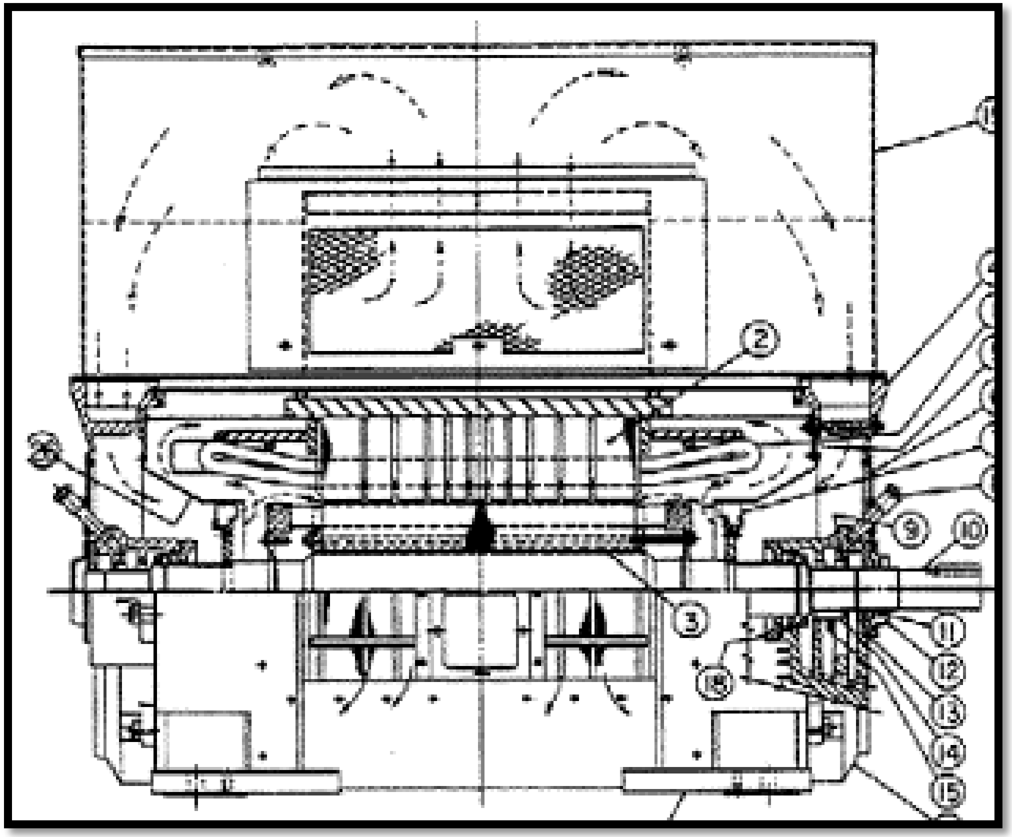
- Suitable for areas with reasonably clean air and non-corrosive environments.
- Protects from water drops falling at up to 15° from the vertical.
- Symmetrical airflow circuit.

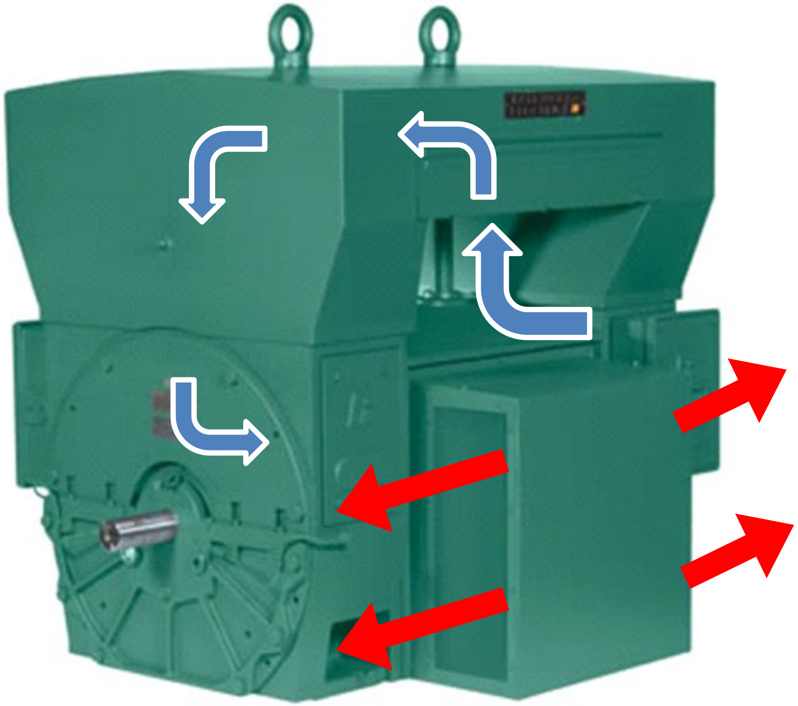
Weather Protected (WP – I) Motor Enclosure



- Ventilation openings constructed to prevent the passage of a ¾” Ø cylindrical rod.
- Mechanical parts and windings painted for protection against atmosphere.

Weather Protected (WP – II) Motor Enclosure

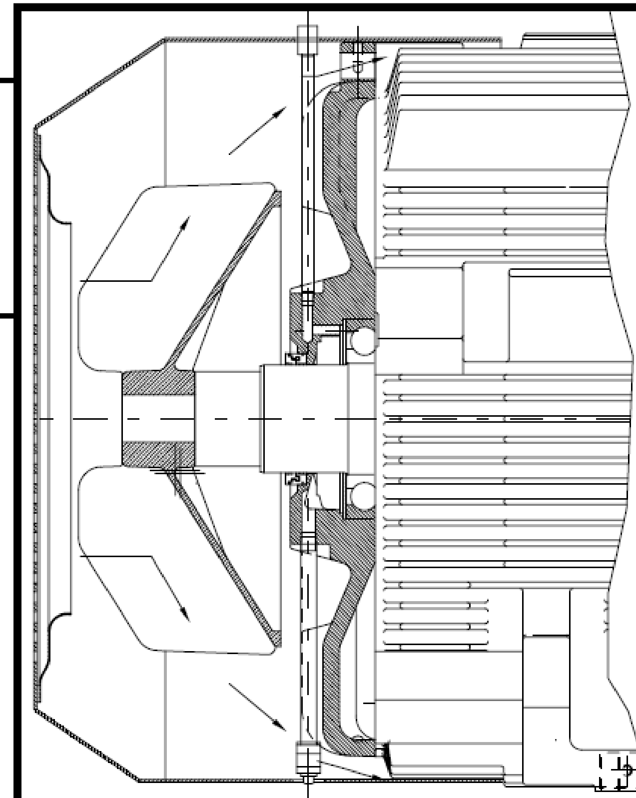


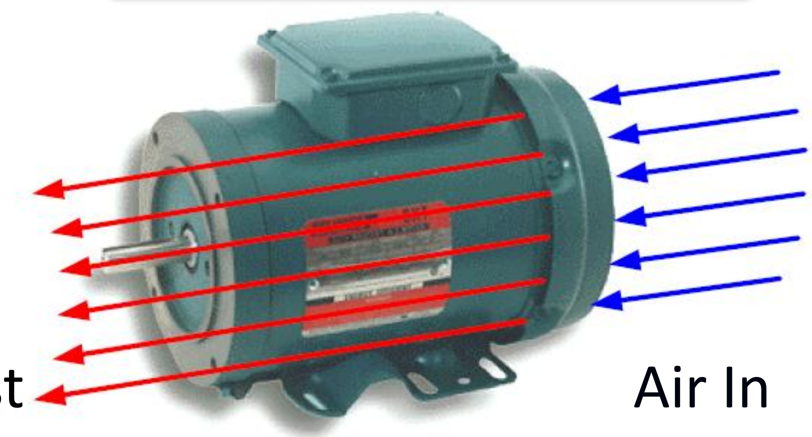


- Airflow path has three 90° directional changes.

Enclosed Examples - TEFC

Shaft mounted fan blows ambient air over the outside of the motor frame.





Enclosed Examples - TENV

- **TOTALLY ENCLOSED NON-VENTILATED (TENV)**
- No external fan
- Cooled by free convection

Explosion Proof Motors

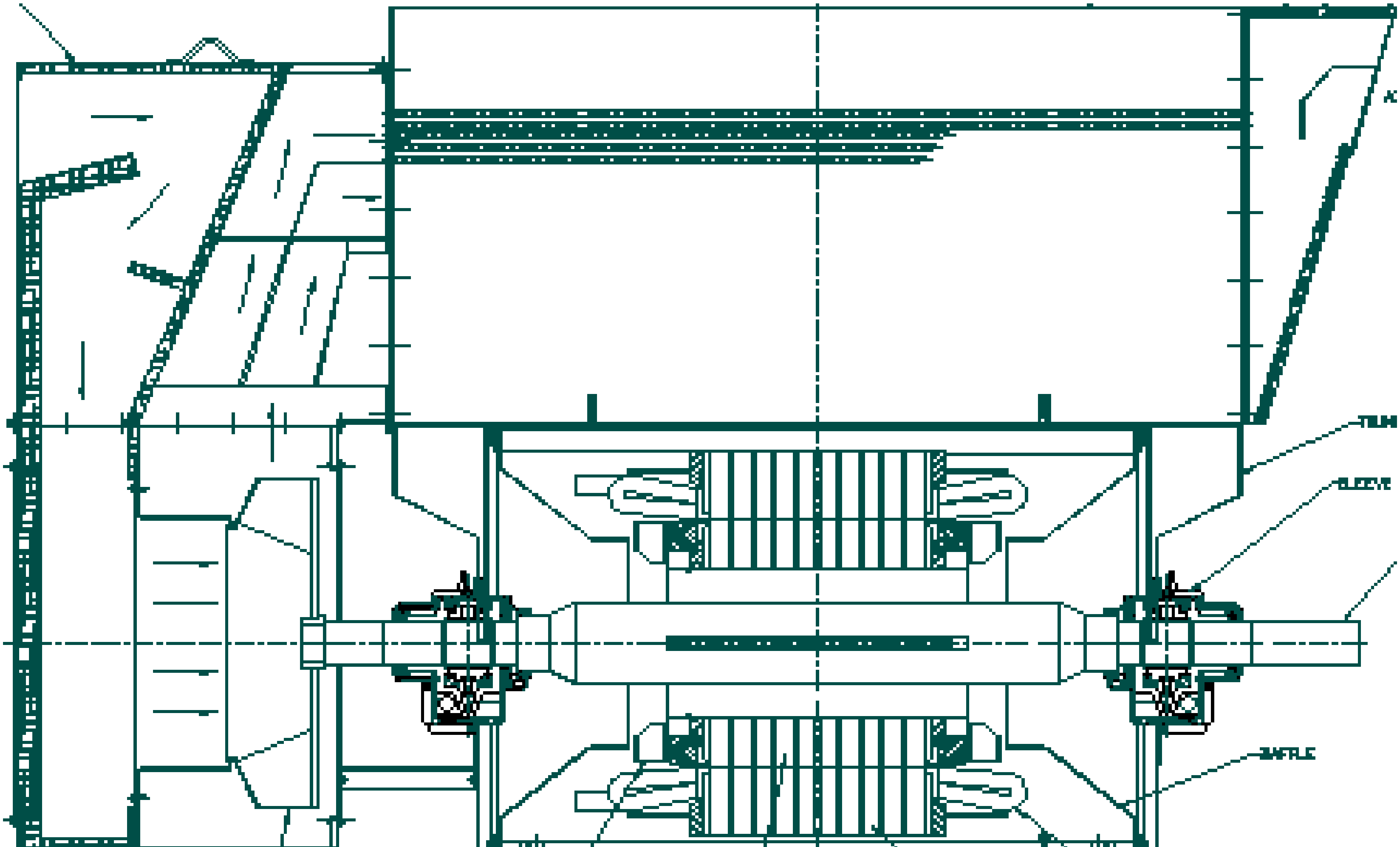
- Designed to contain internal explosions with controlled flamepaths.
- Temperature rise is designed to not exceed site classification limits.

- Internal Thermostats
- Special Conduit Box

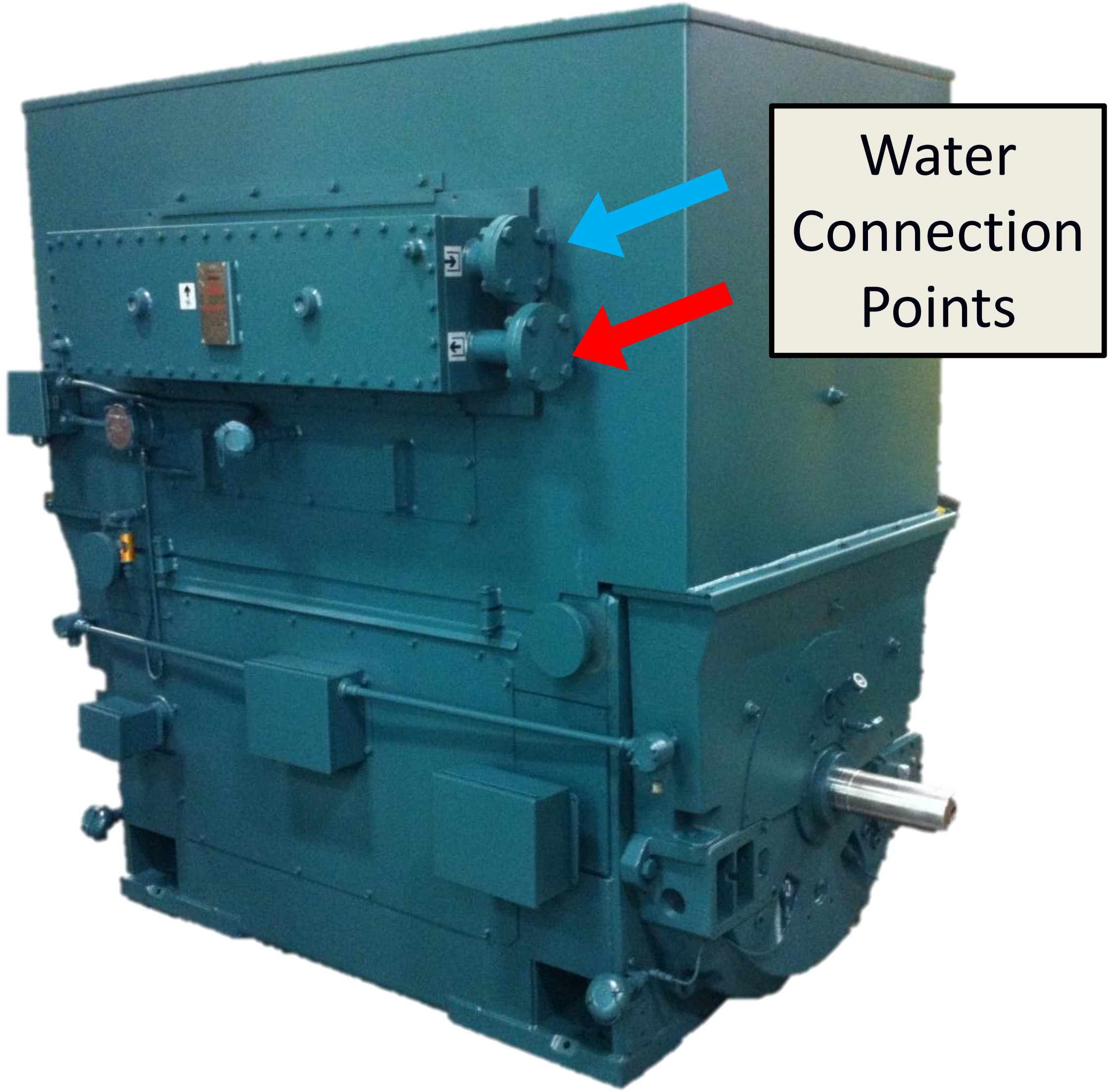
Enclosed Examples - TEAAC

TEAAC = Totally Enclosed Air to Air Cooled

Enclosed Examples - TEAAC

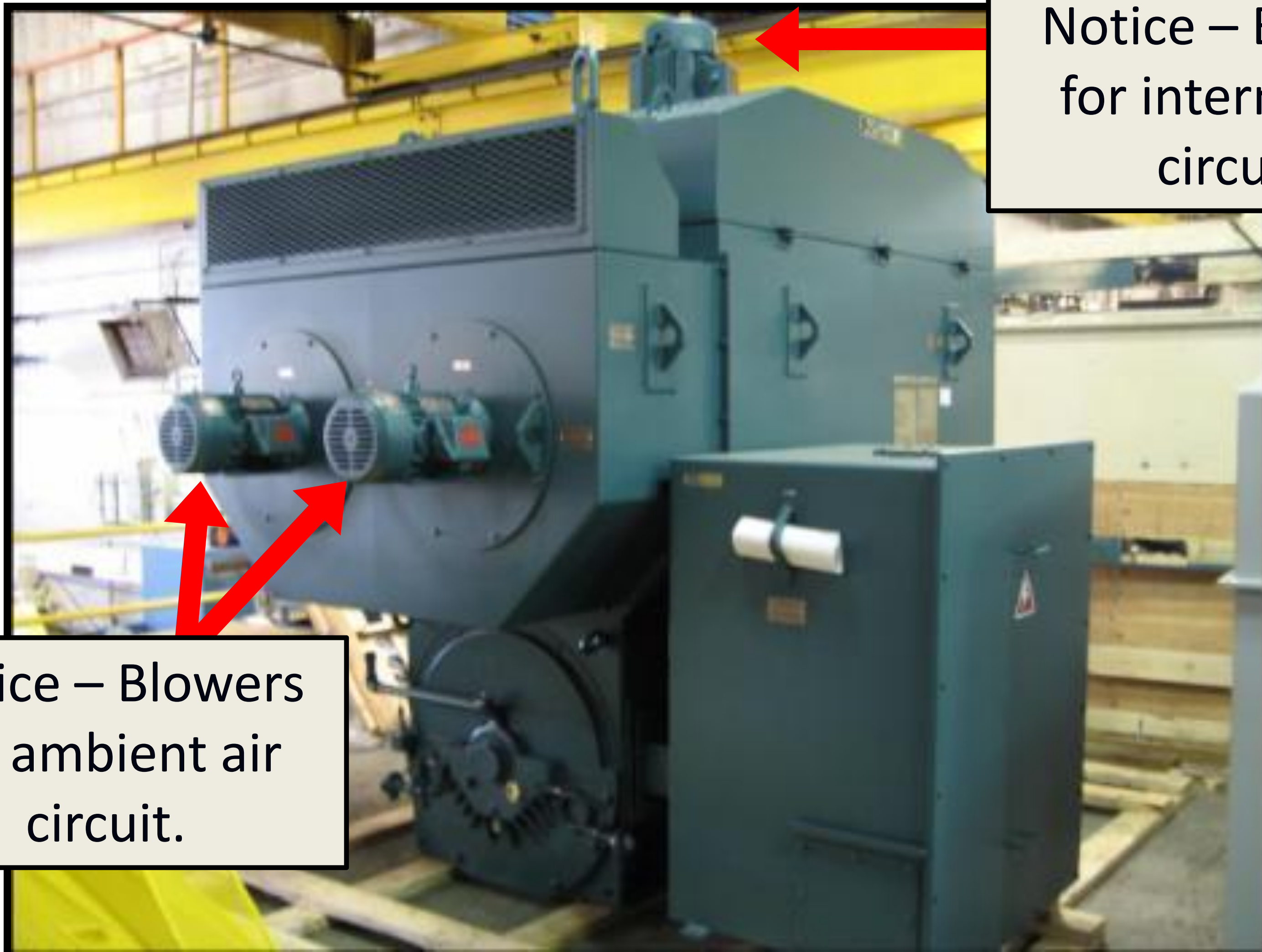


Enclosure Examples - TEWAC



TEWAC = Totally Enclosed Water to Air Cooled

Enclosures: Adjustable Speed



TEAAC – Blower Cooled

Enclosures: Adjustable Speed

TEAO-BC

ODP-FV

Choosing the *Correct* Enclosure

Open Motors

- ODP motors are generally have a lower initial cost.
- Since they force the ambient air through the rotor and stator, they cool more effectively and require less active material.
- The problems with open motors are that moisture and particles present in the motors environment will build up on the rotor and stator, and restrict the air flow through the motor.
- ***ODP motors should be installed in clean, dry, indoor environments. They may also require periodic service that includes cleaning the rotor and stator.***

Choosing the *Correct* Enclosure

Enclosed Motors

- They can be operated indoors or outdoors.
- Since TEFC motors cool by air flow over the surface of the frame, the frame surface should be kept clear of materials that will restrict the air flow or reduce the heat transfer from the frame.
- ***TEFC motors are generally well suited for harsh, dirty and wet environments.***

Submersible & Immersible Motor Designs

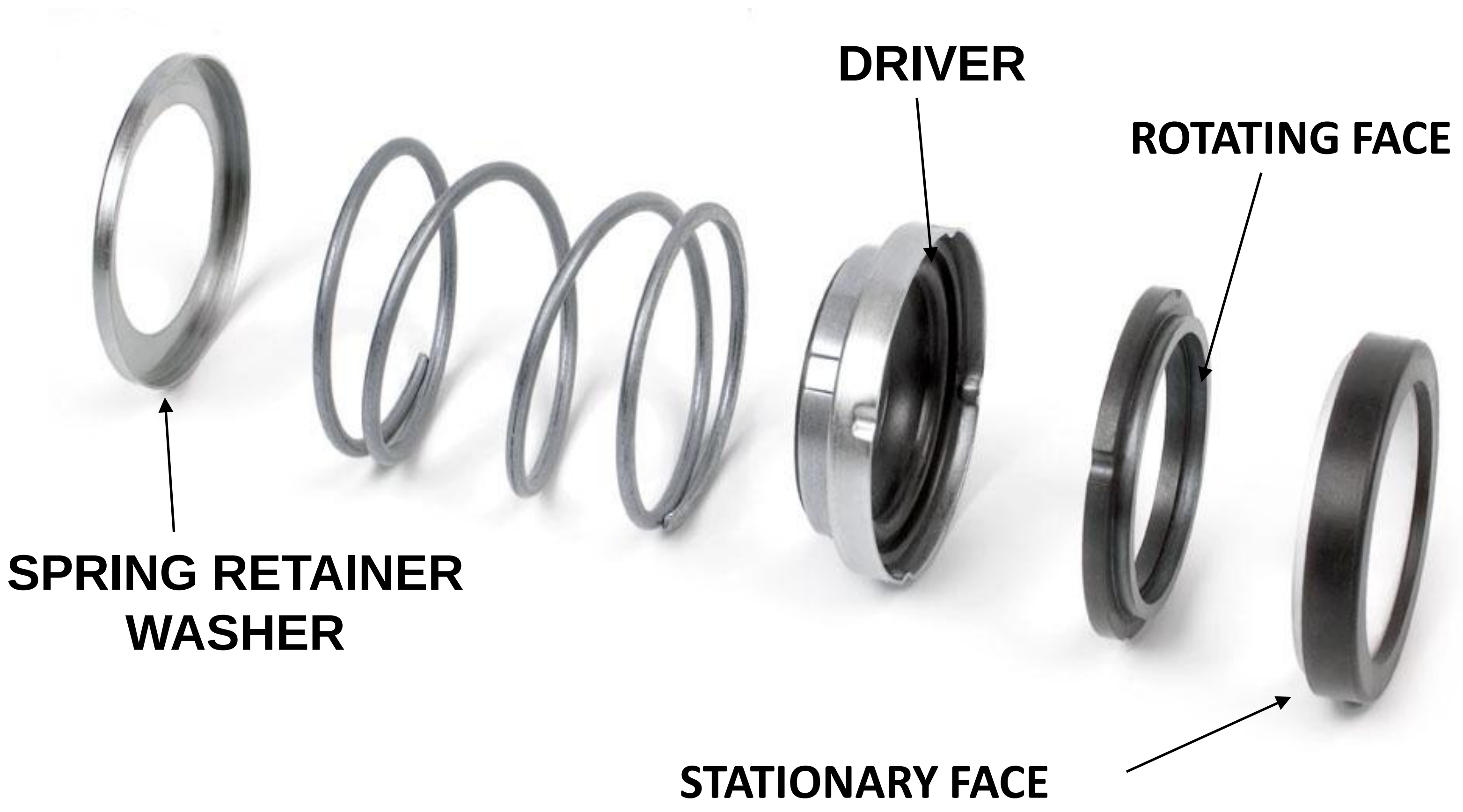
Submersible and Immersible Motors

Gainesville, GA Motor Facility

Submersible Std. Features

- Cast iron construction
- 25 feet of cable
- 416 Stainless Steel shaft
- Tandem mechanical seal (Type 21)
  Inner seal and outer seal
  - » Carbon Ceramic
  - » Tungsten Carbide
  - » Silicon Carbide
  - » Slurry Seal (non U/L)

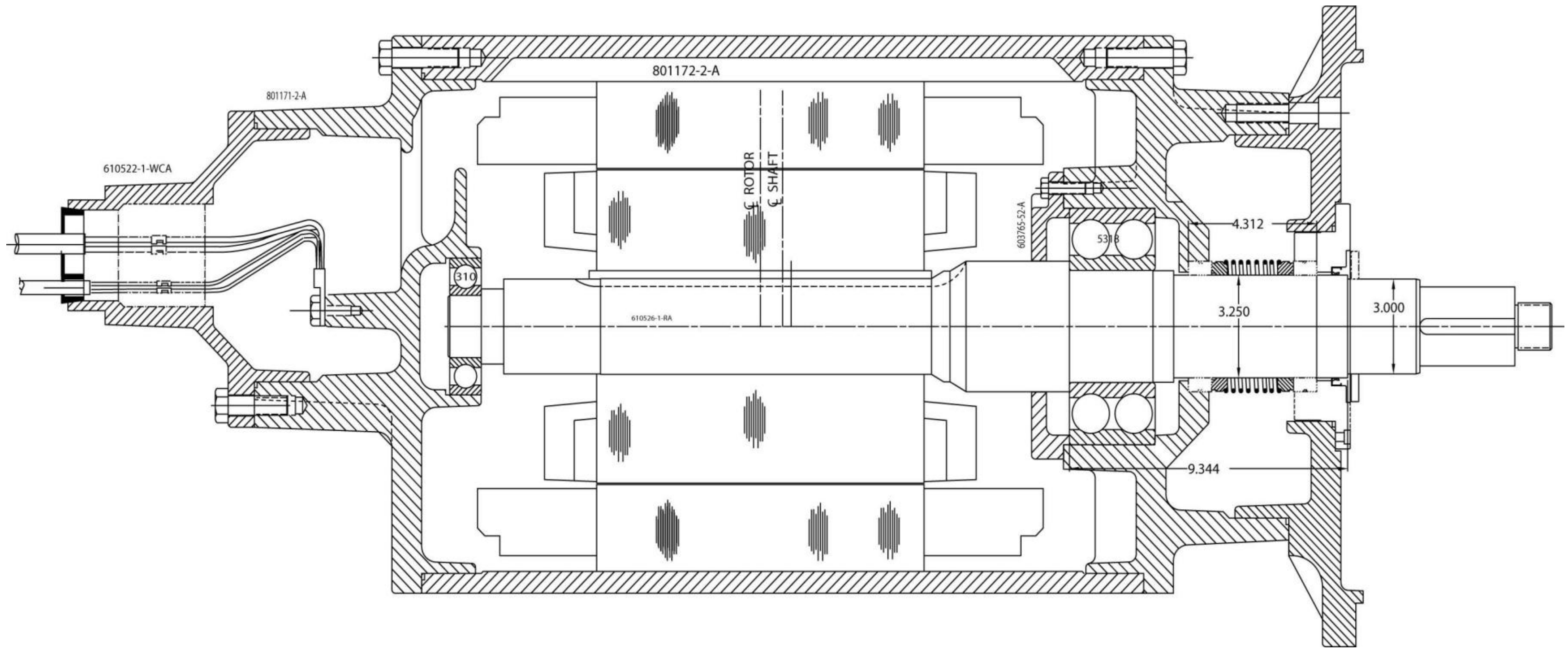
Type 21 Mechanical Seal

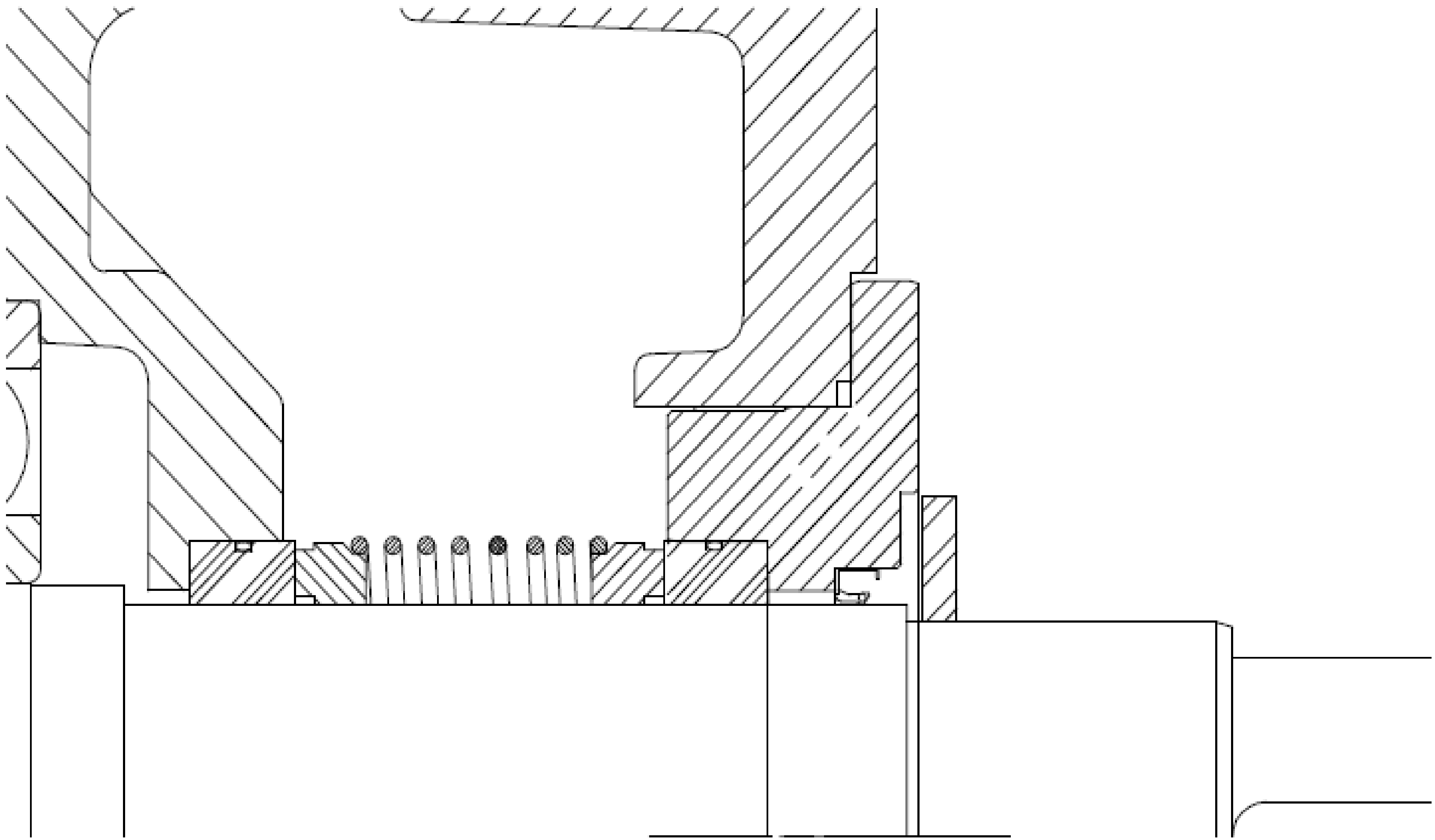


Submersible Seals

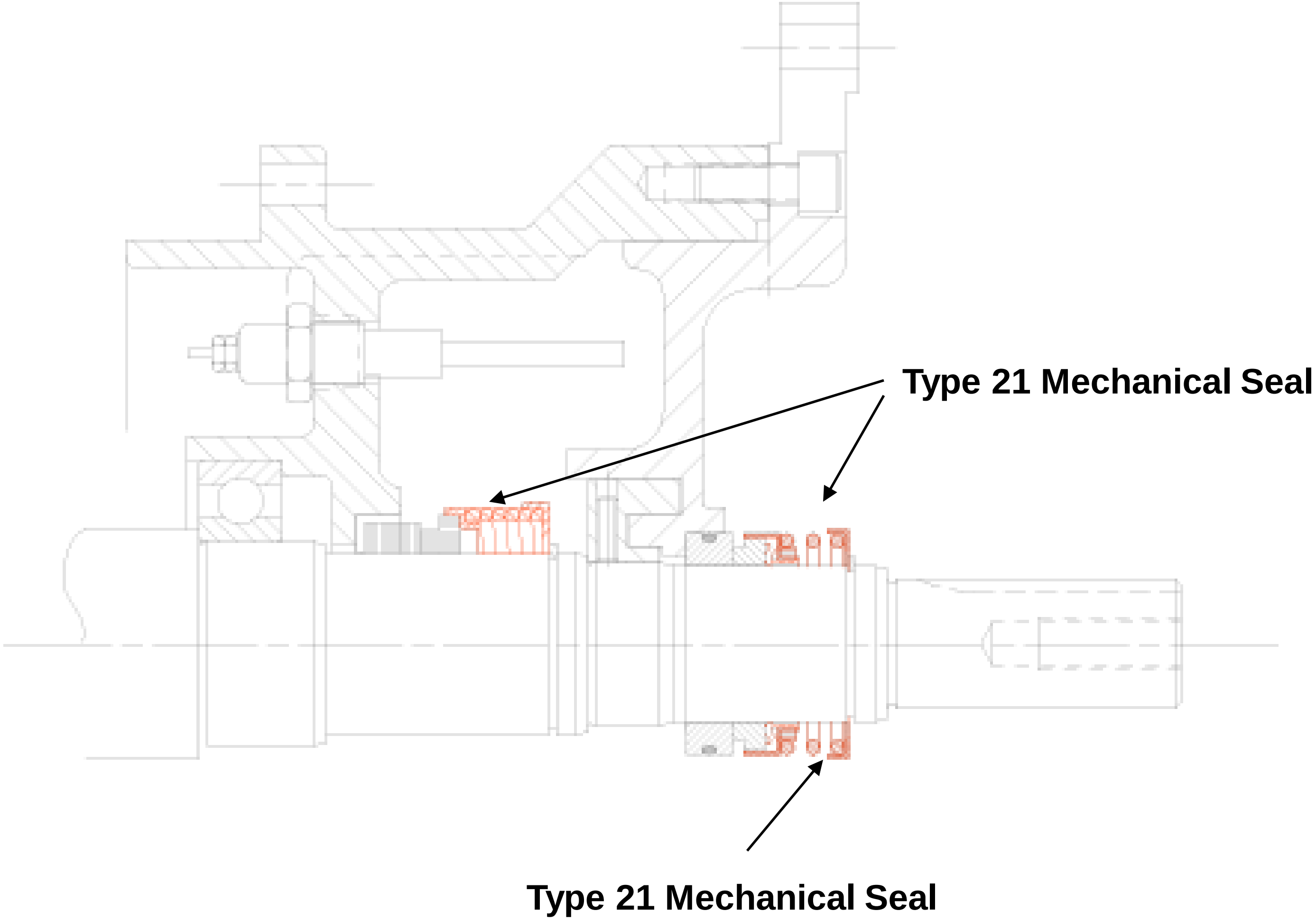
Seal	**Description**	**Application**
Type 21 Carbon Ceramic Faces	Standard seal offering. A general purpose seal of stainless steel construction with carbon ceramic seal faces.	Used in food processing, petrochemical, and, wastewater applications with relatively clean effluent.
Type 21 Tungsten Carbide Faces	Same type of seal except with tungsten carbide faces. Harder seal faces. ***Most popular seal type.***	For more demanding applications, more viscous fluid.
Type 21 Silicon Carbide Faces	Same type of seal except with silicon carbide faces.	For the most demanding, slurry type applications.
Slurry Type Seal	Seal completely contained in the oil chamber. Available in 210 - 440 frame only.	Used in non-explosive proof slurry applications. Can be used continuous in air.
Hydropad Seal	Special seal design with hydropad scallops to run cooler.	Recommended for continuous in air applications.

Slurry Seal Design





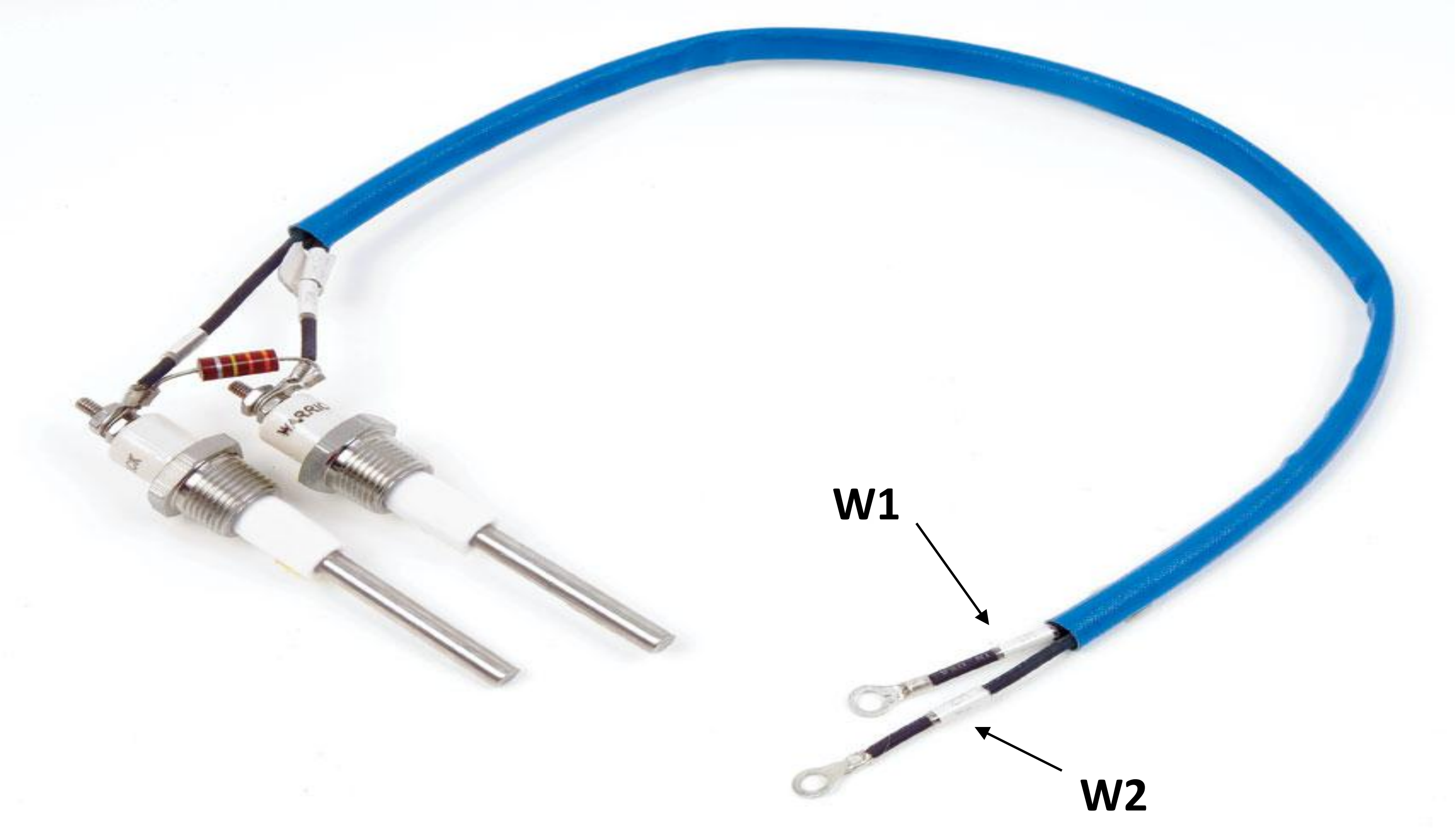
Submersible Seal Design



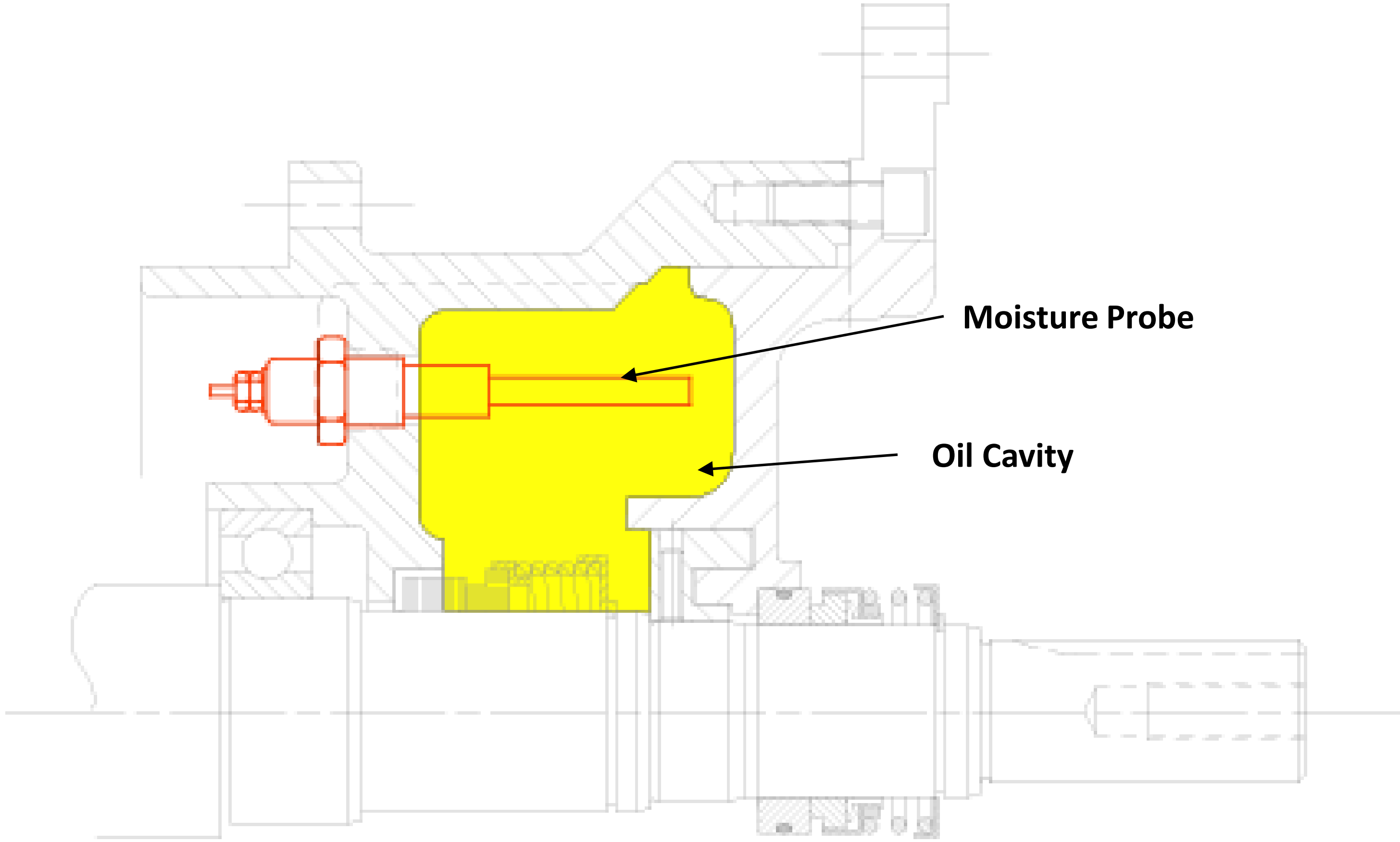
Standard Features

- **Dual probe moisture sensing**
  - Warwick moisture probes
  - Detect moisture in oil chamber
  - www.gemssensors.com
- **Two winding thermostats**
- **5 year prorated warranty**

Warwick Moisture Probes



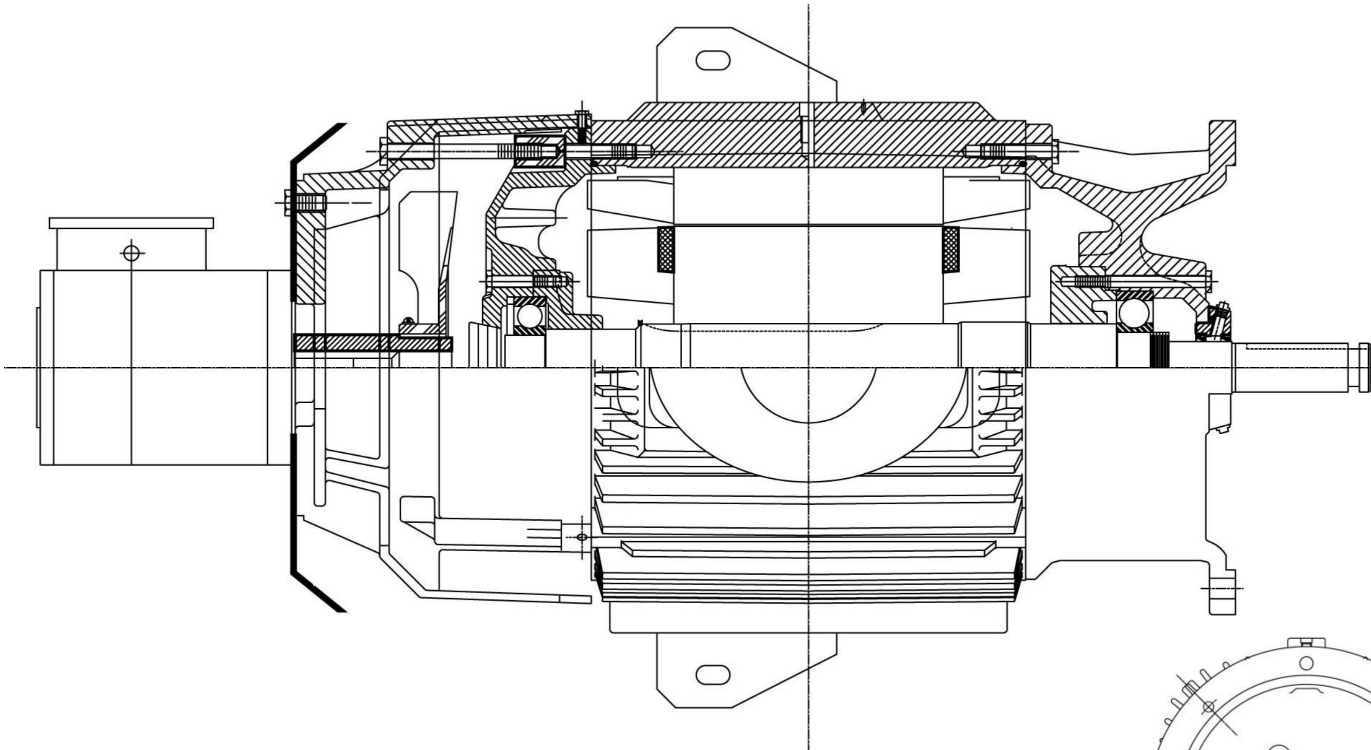
Moisture Probe

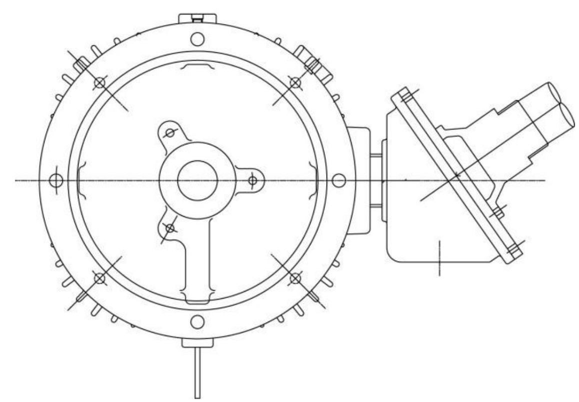


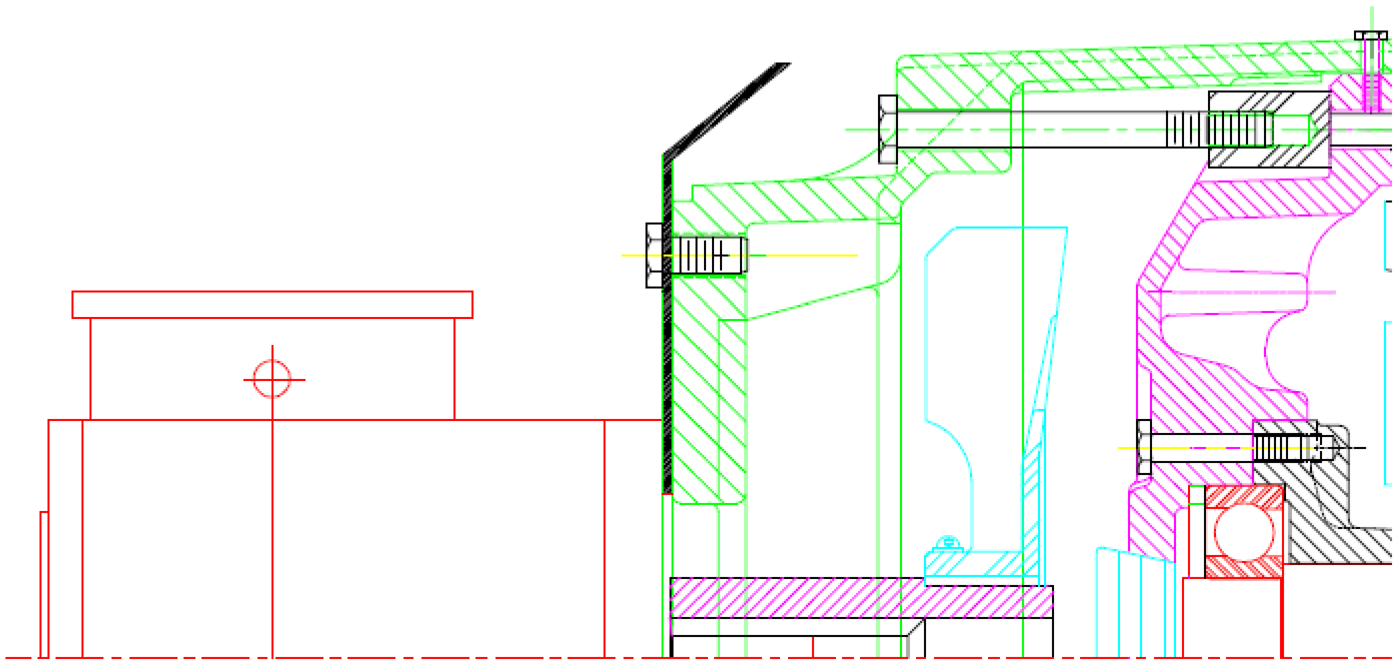
Immersible Motor Product

- Dry Pit applications
  - Motor will run continuous in air.
  - 14 days submerged at a max depth of 30 feet
  - No explosion proof designs available
  - Non stock product
  - Meets IP67

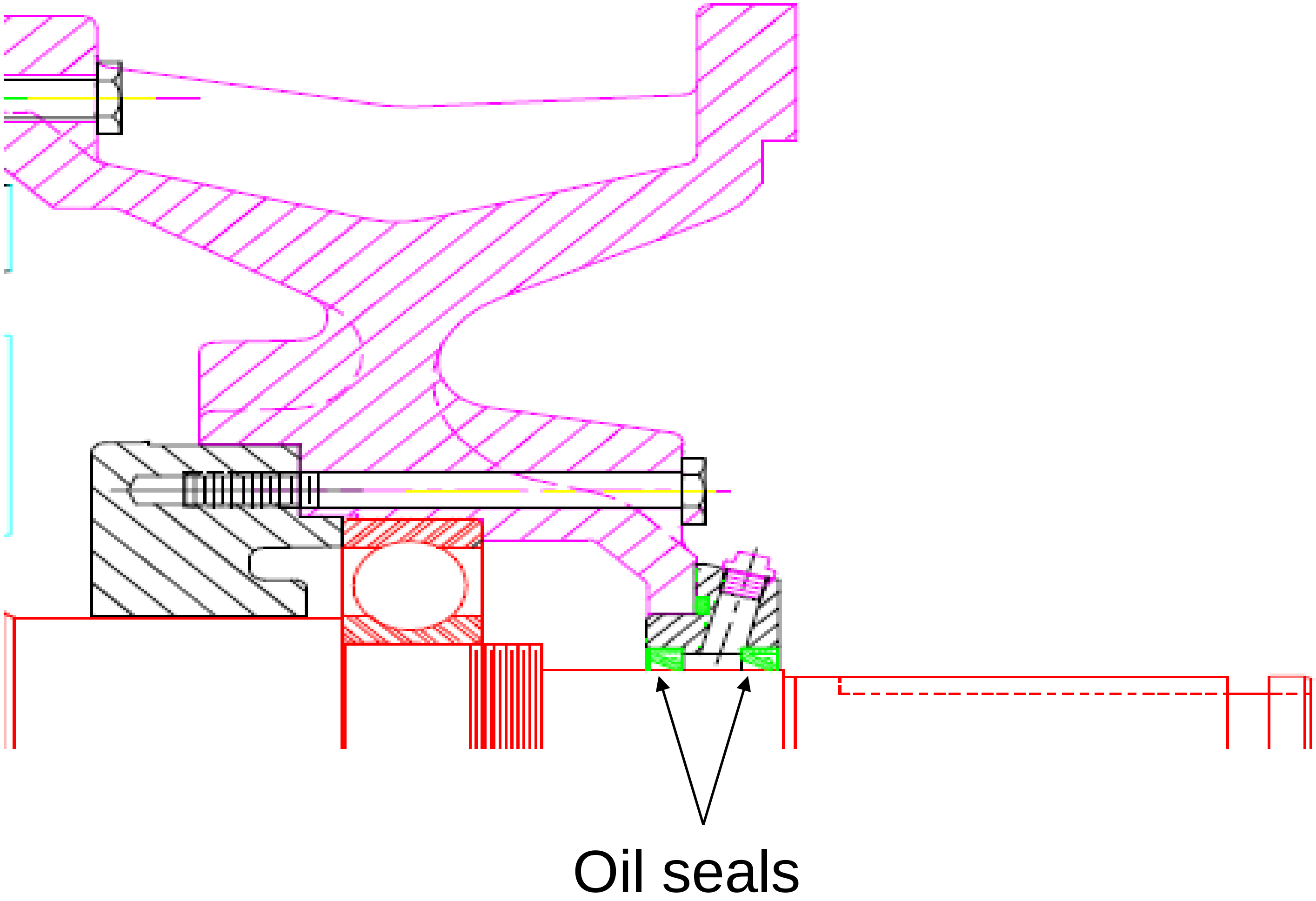
Immersible Design







Immersible Motor Sealing System



Motor Mounting Types

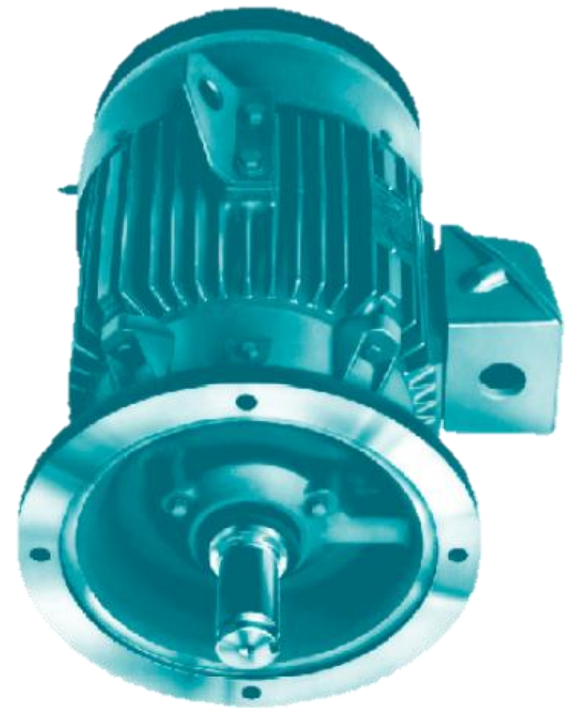
Motor Mounting Types

- Base Mount / Foot Mounted
- Flange Mounted:
  - C- Flange
  - D-Flange
- P-Base
- Pump Mount
- IEC Metric
  - B3 base
  - B5 C-face
  - B14 Flange

Motor Mounting Types

C-Face

D-Flange



P-Base

Examples of flange mounts

Motor Mounting Types - Positioning

Section I
DIMENSIONS, TOLERANCES, AND MOUNTING

MG 1-2011
Part 4, Page 13

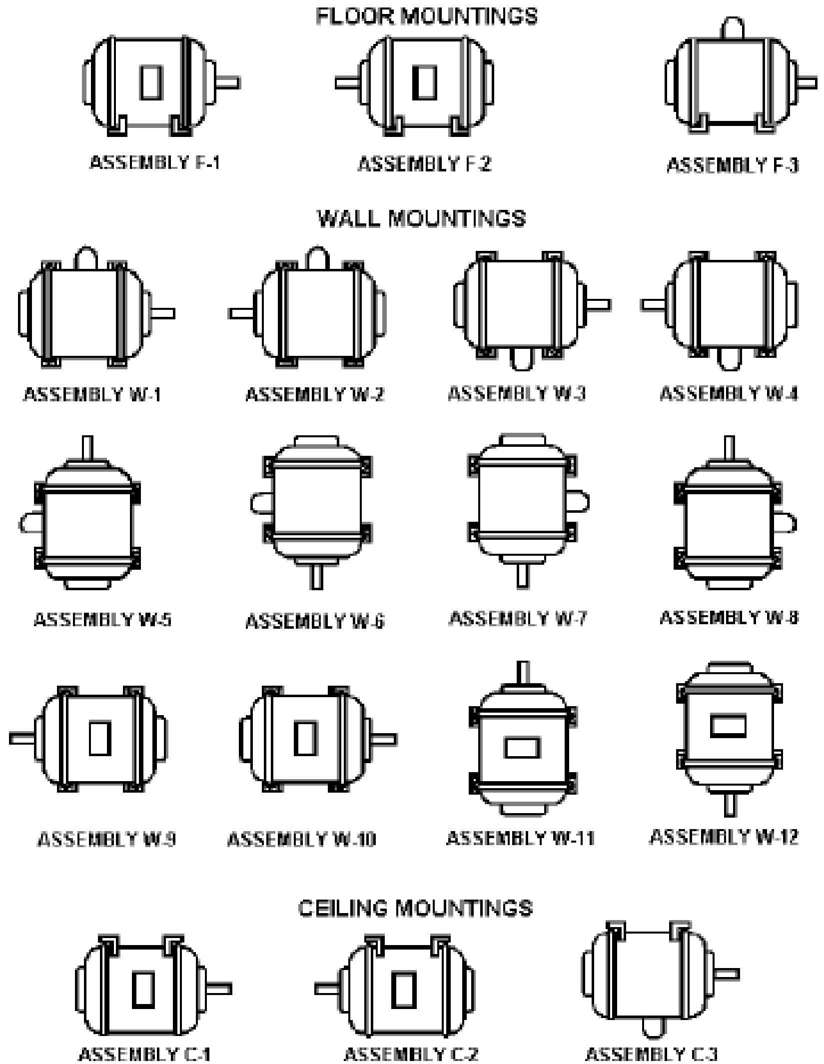
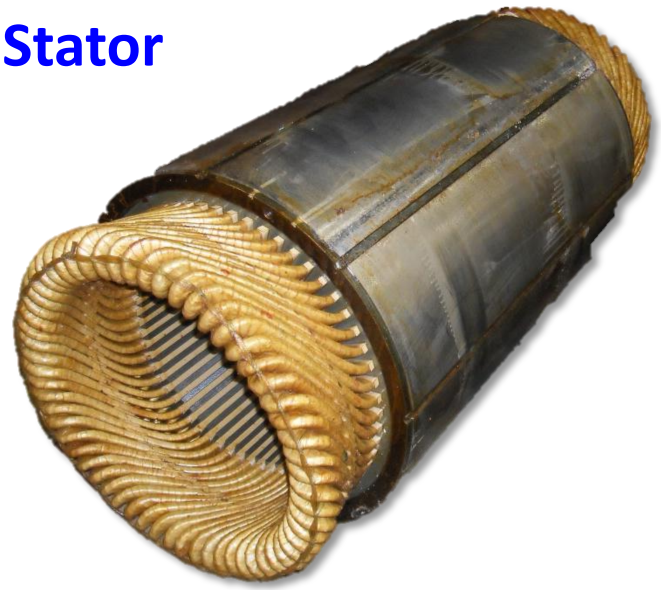


Figure 4-6
MACHINE ASSEMBLY SYMBOLS

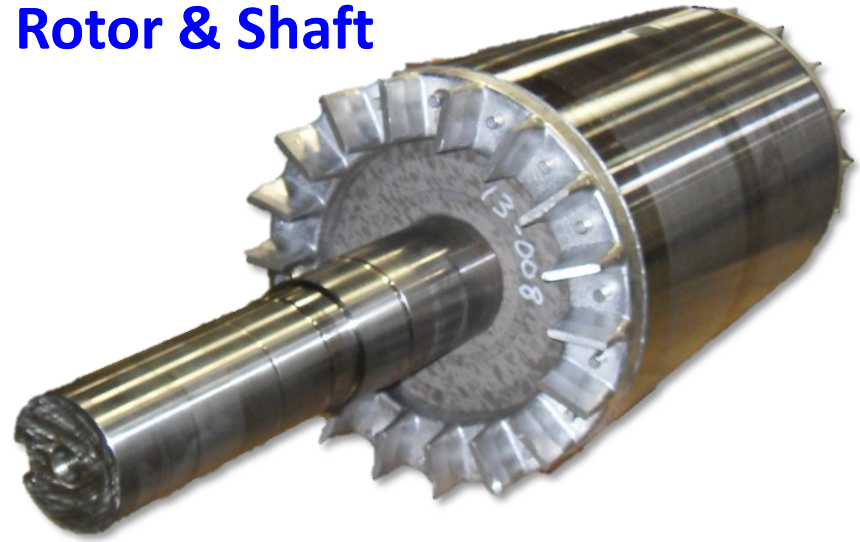
Basic Components

Two Basic Parts of any AC Motor

Stator



Rotor & Shaft



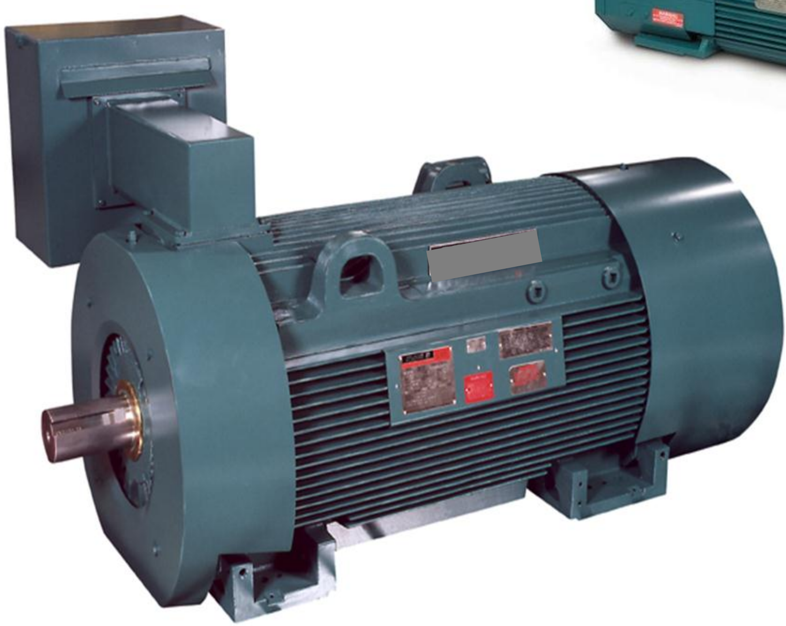
- Stator – Contains the windings within the steel laminations.
- The stator is not mechanically connected to the load

- Rotor & Shaft – A rotating unit mounted on bearings and provides mechanical power transmission
- The rotor and shaft are mechanically connected to the load

Motor Frame

- Typical construction materials:
  - Steel Band: Carbon and Stainless Steel
  - Laminated
  - Cast Iron: Grey and Ductile Iron
  - Fabricated Steel

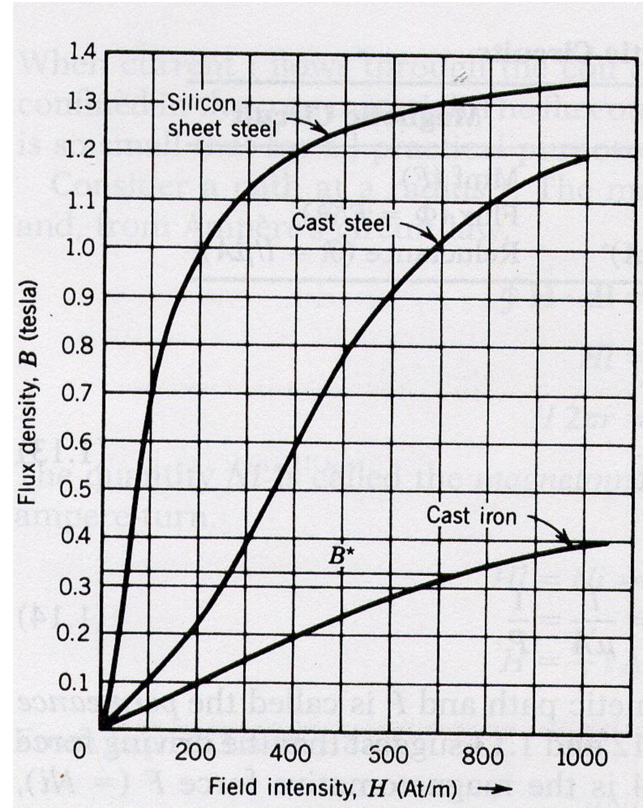





Stators

What is Electrical Steel?

- A special cold rolled steel with special coating on both sides (also called lamination steel)
- It has relatively low loss (in a motor this is called core loss)
- Mixture of ~ 3- 6% silicon
- Very efficient at generating/concentrating magnetic fields per given current flow



Microscopic view

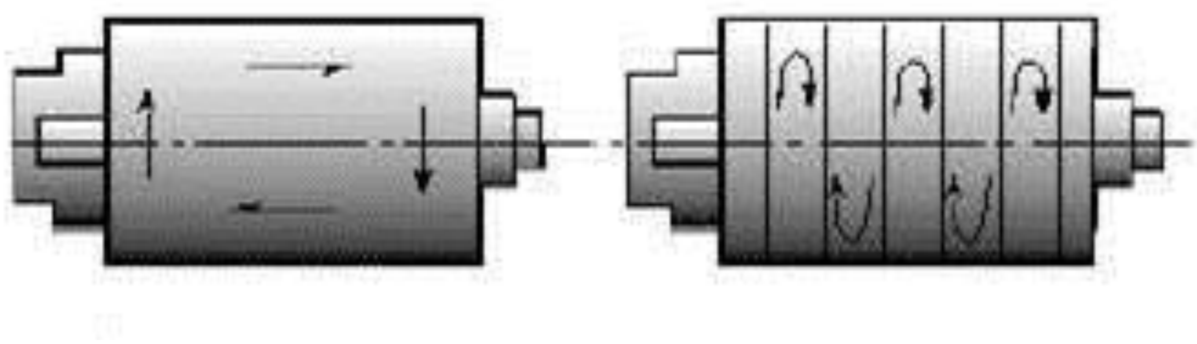
Why use Laminations?

Solid Core

Low resistance

Large eddy currents

Higher core losses

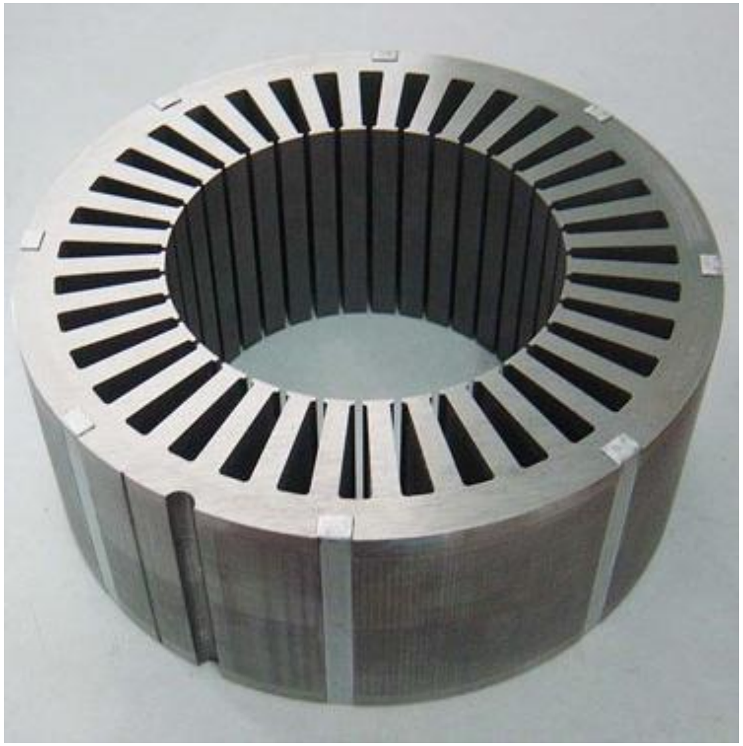


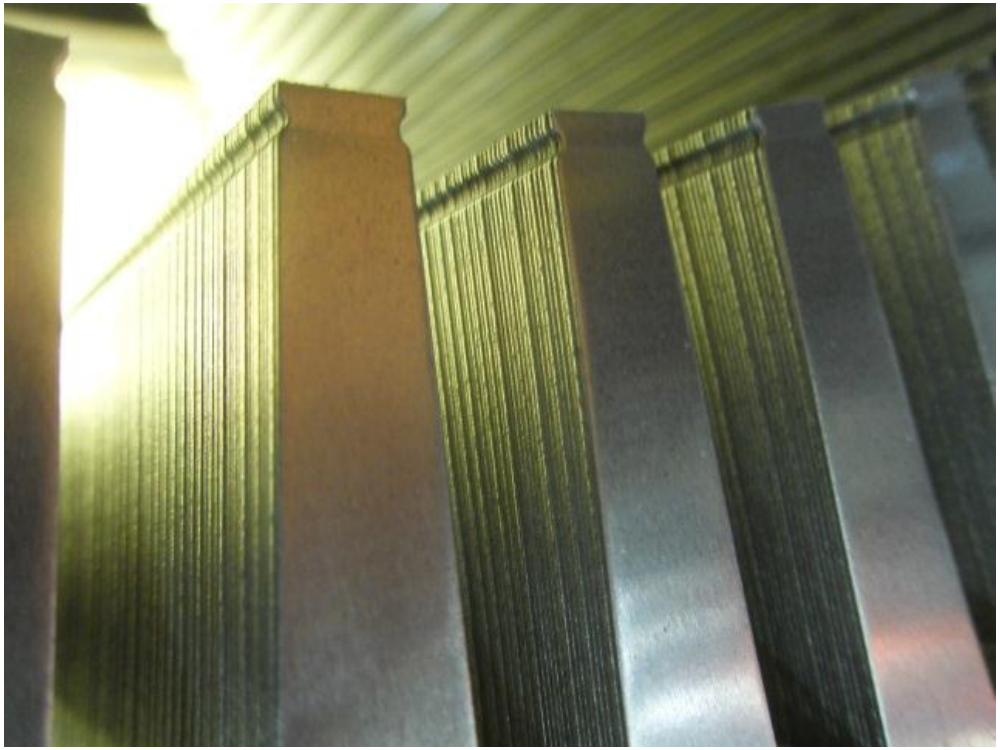
Laminated Core

High resistance

Small eddy currents

Lower core losses



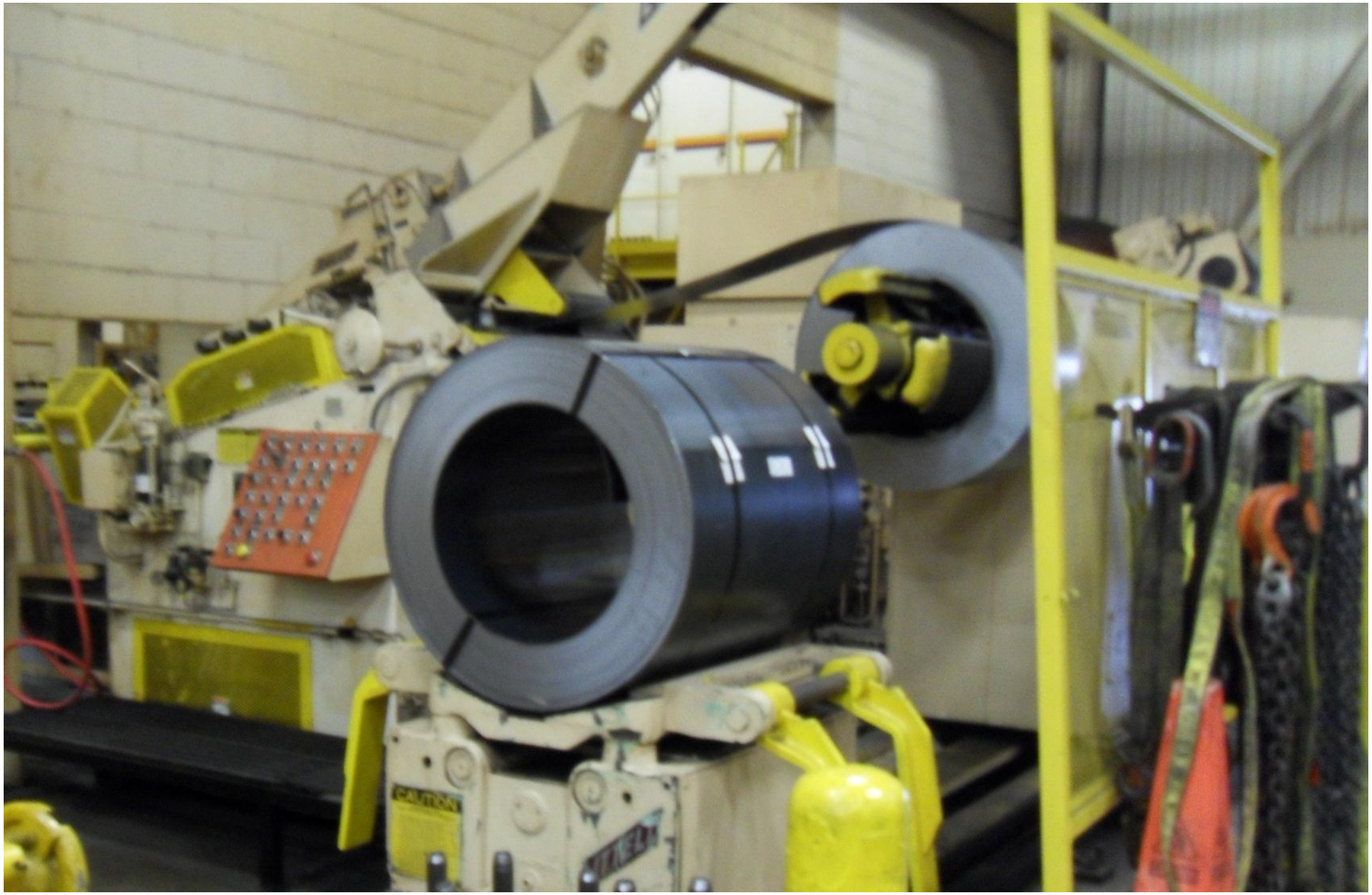


Steel
Core Plates

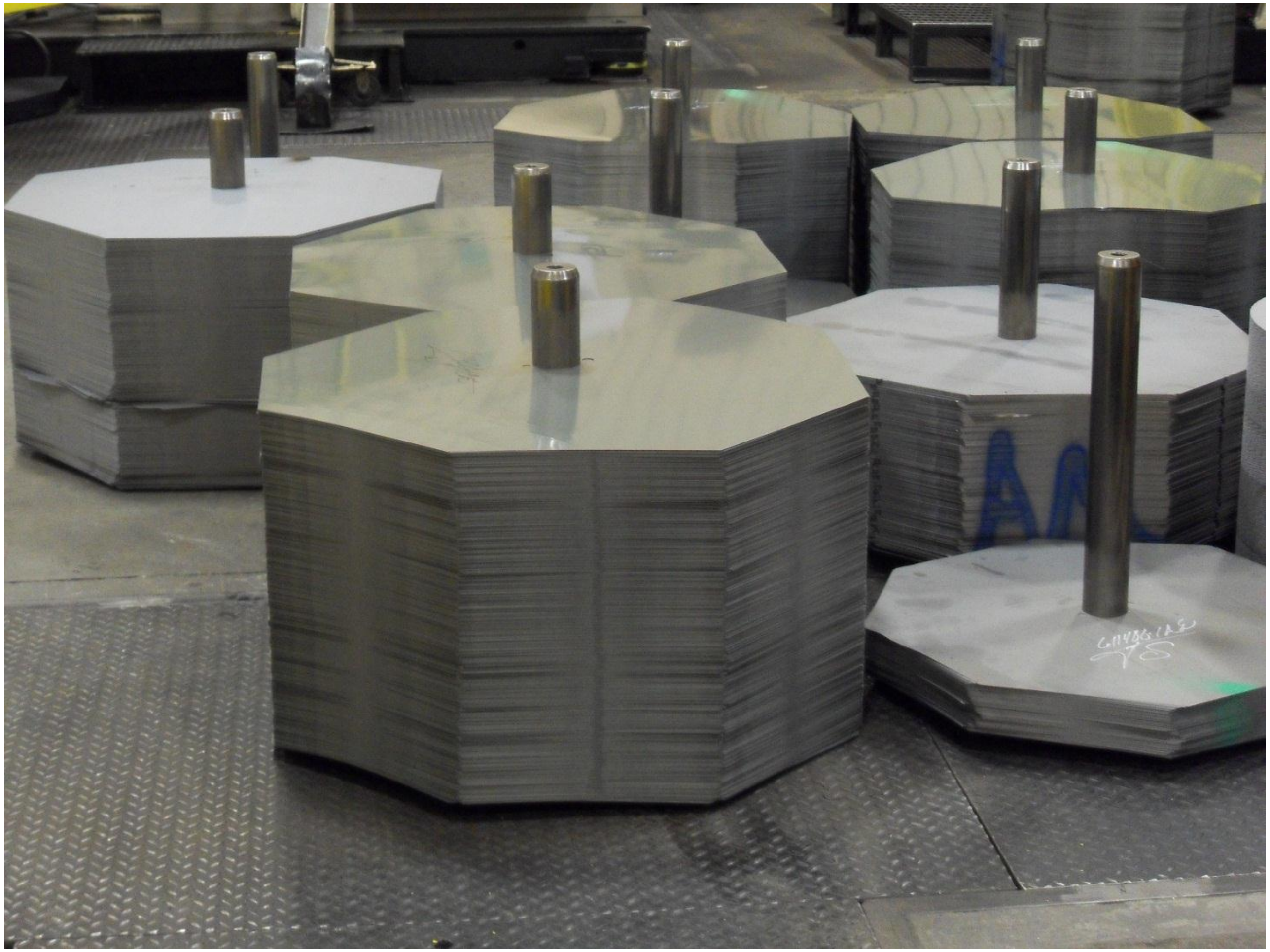
- Core Plate C3
- High Grade Varnish
- Intended for Air-Cooled or Oil Immersed Cores
- Approved for NEMA Class F Service
- Will Not Survive Lamination Annealing Process
- Provides Less Resistance Between Laminations
- Core Plate C5
- Oil and Heat Resistant Inorganic Coating
- Suited for High Temperature Applications
- Withstands Lamination Annealing Temperature, Welding Temperature and Typical Burn-Out Temperature

Coil Steel

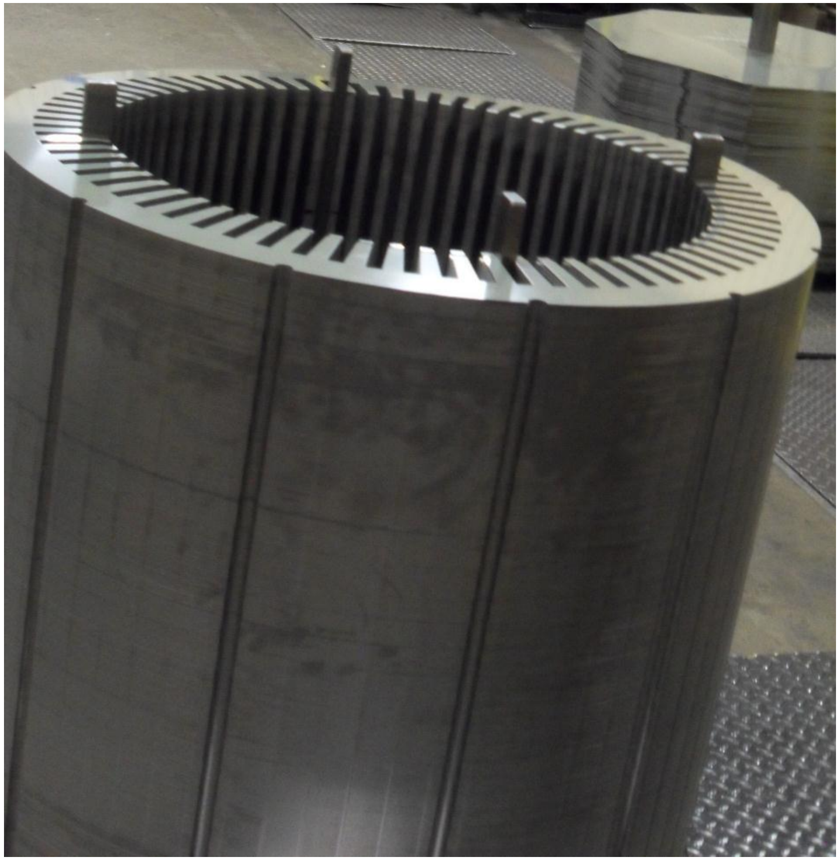
Punch Press



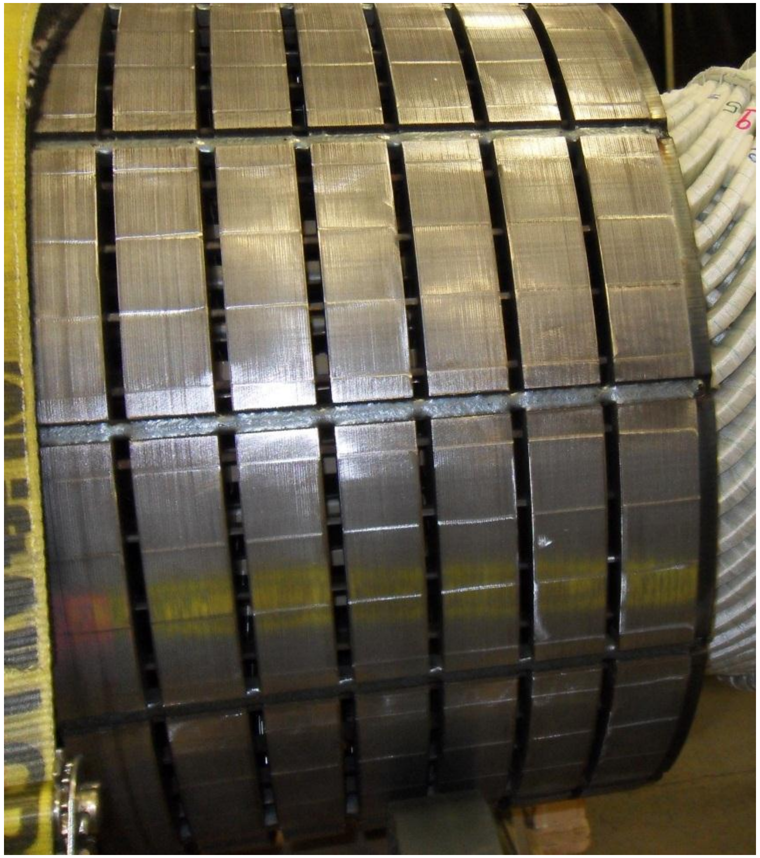
Lamination Blanks



Stator Laminations and Rotor Blanks

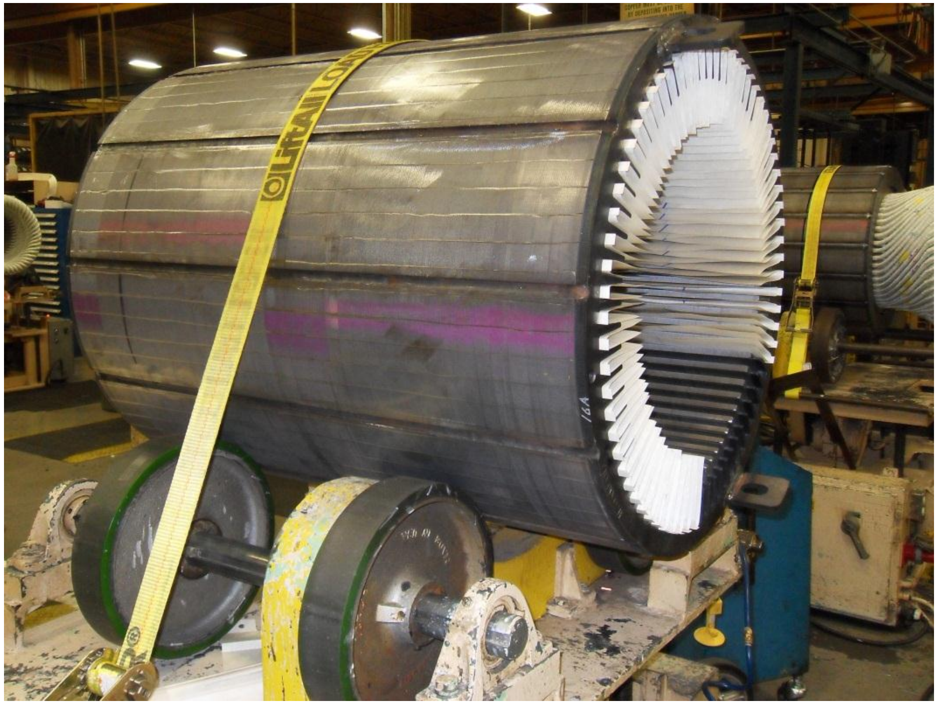


Stator Core



Ducted

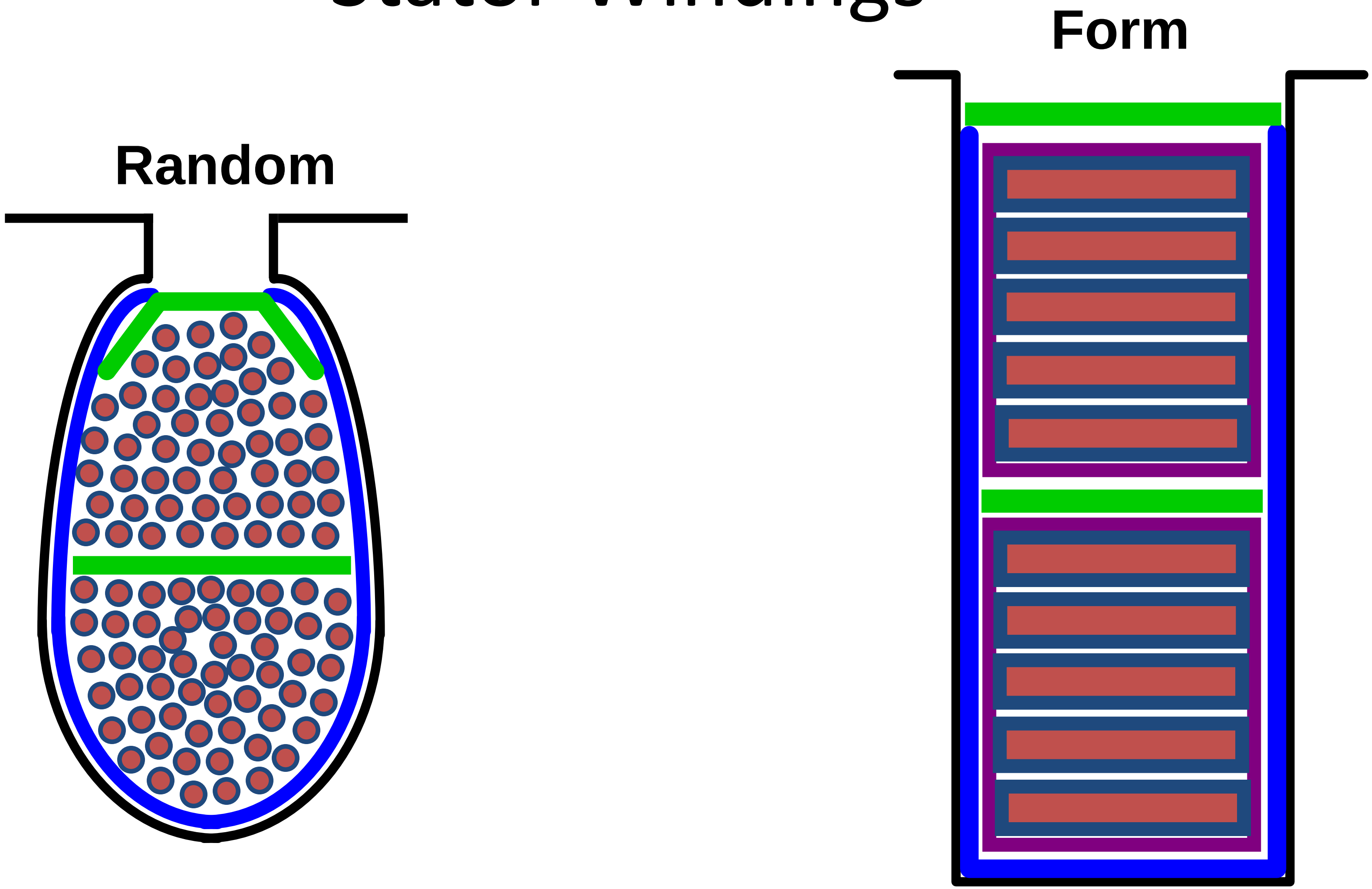
Solid



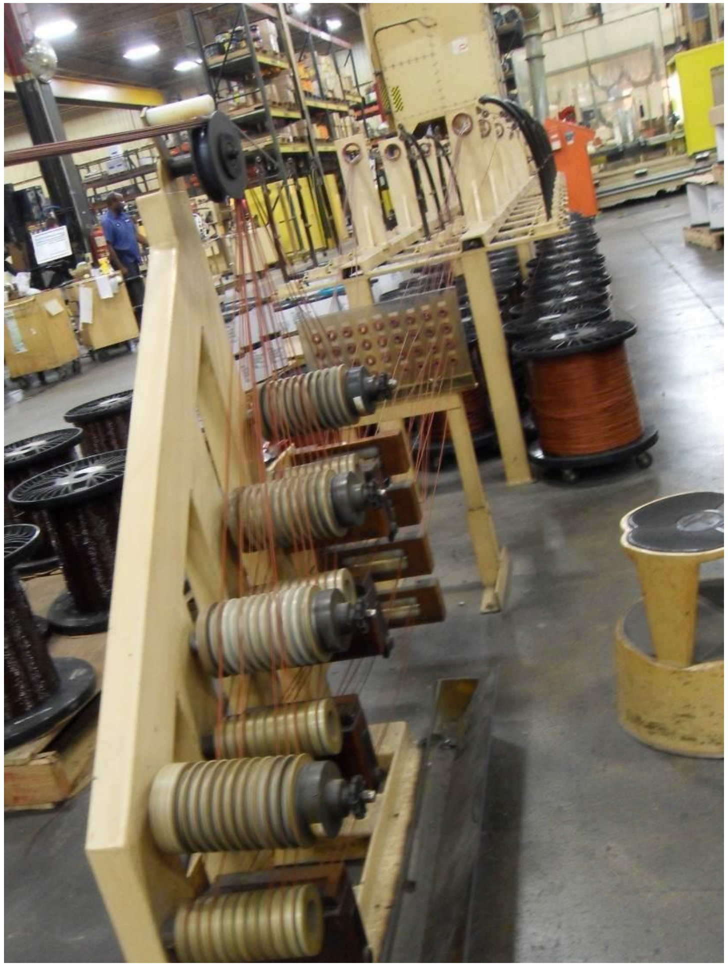
Stator Windings

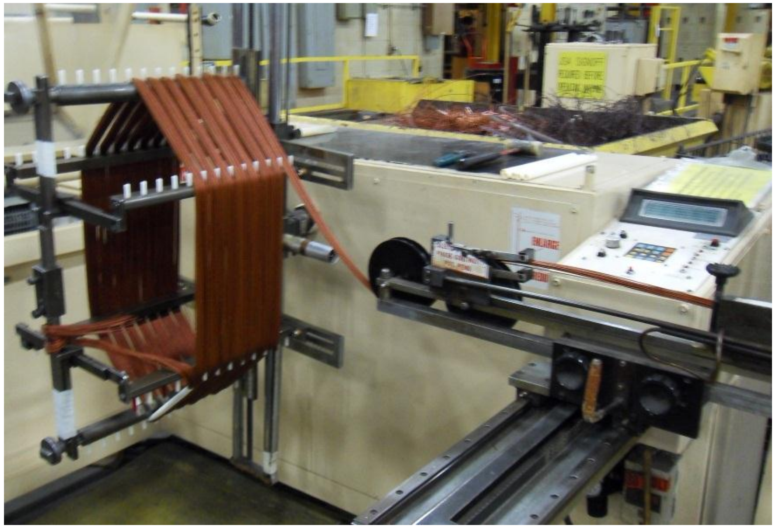
- All coils are manufactured with insulated copper wire.
- Form Wound or Random Wound
  - Number of Turns
  - Size/Shape of Wire
  - Insulation
    - Class F or Class H
    - Enamel or Glass over Enamel

Stator Windings



Stator Windings - Random Wound





Stator Windings
Random Wound

Stator Windings
Form Wound

Stator Windings
Form Wound

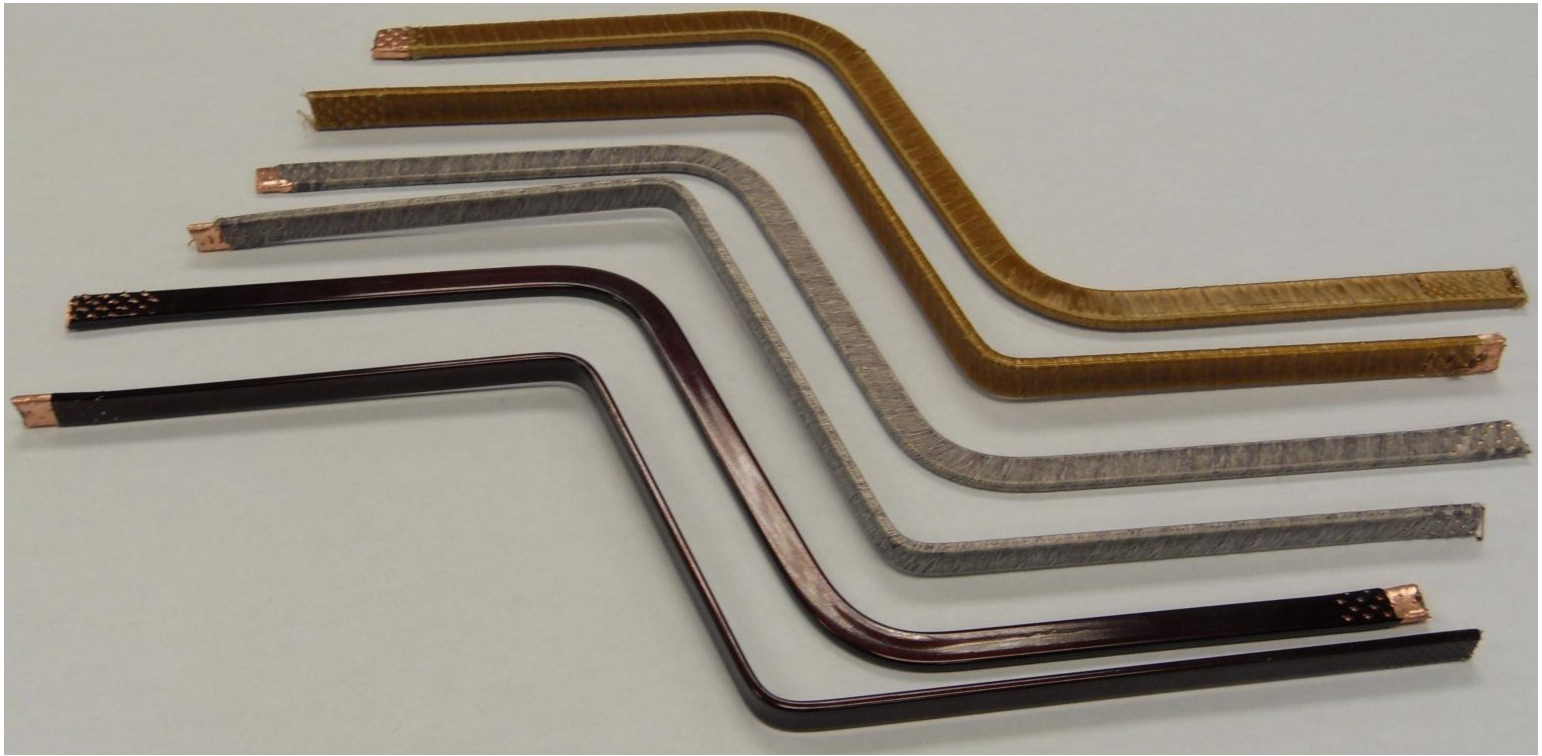
Stator Windings Manufacturing Process

Stator Windings

- **Random Wound (Round Wire)**
  - Wind Wire in Phase Groups
  - Insulate Stator Slot
  - Insert Windings
- **Form Wound (Rectangular Wire)**
  - Wind Wire Into Individual Coils
  - Shape Coils to Fit Stator Core
  - Insulate Coils w/Nomex Tape
  - Insulate Stator Slot
  - Insert Windings
  - Connect Coils in Phase Groups

Stator Windings
Magnetic Wire Types

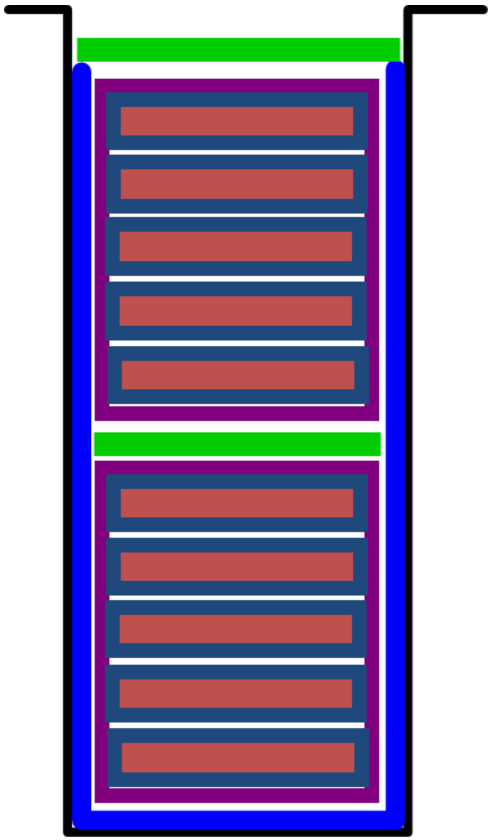
NEMA Class	Description	Insulation Thickness
H	Heavy Film, Single Glass, Epoxy Saturant, Copper Wire	0.013”
F	Heavy Film, Single Glass, Copper Wire	0.013”
F	Dual Film, Copper Wire	0.005”



Form Wound Stator Windings

Ground Wall Insulating Layers by Voltage Class

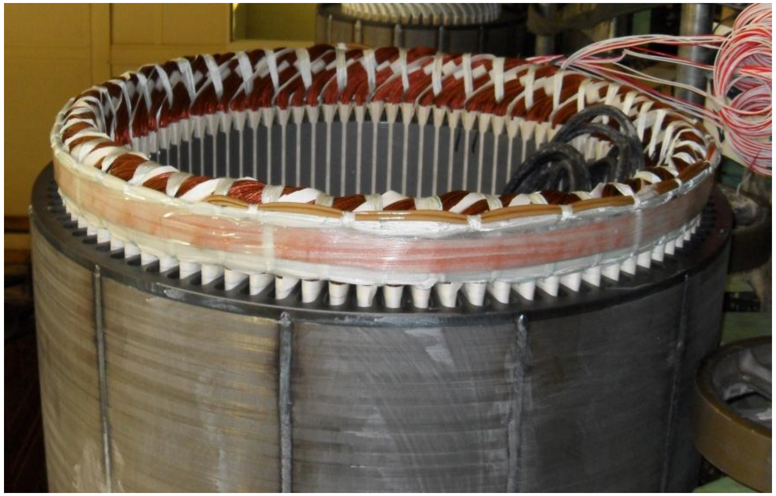
Voltage	0 to 3kV	3.1 to 5kV	5.1 to 7Kv	7.1 to 13.2kV
Layers ½ Lap Nomex Mica Tape	2	3	5	9



Insulation Systems
Random Wound

- Dip & Bake
- Vacuum Impregnate (VI)
- VPI (Vacuum Pressure Impregnation)

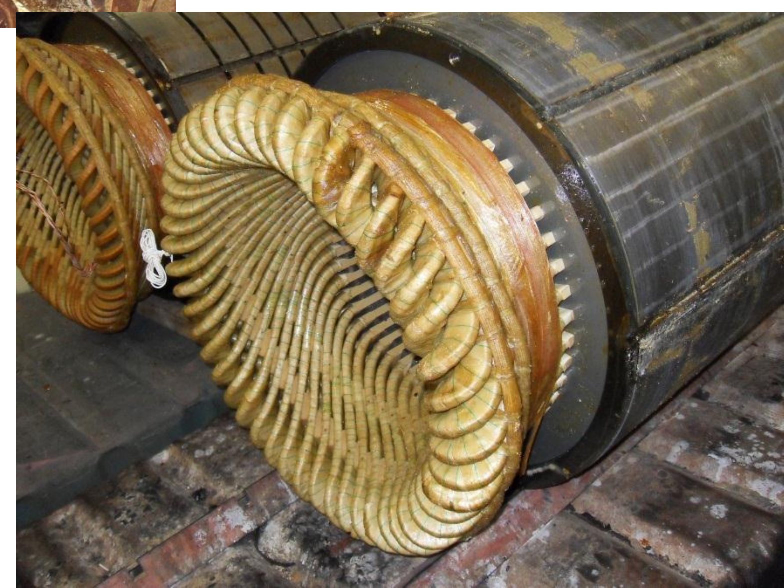
Insulation Systems
Random Wound



Insulation Systems
Form Wound

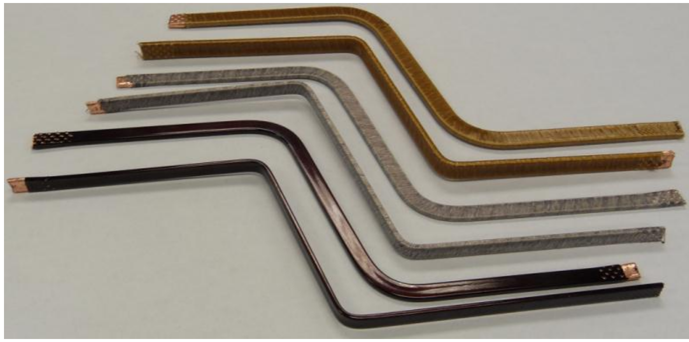
- VPI (Vacuum Pressure Impregnation)
- Sealed VPI
  - Additional sealing components
  - Capable of Passing the Water Immersion Test

Insulation Systems
Form Wound



Sealed Insulation Water Test

Stator Windings Testing



- Magnetic wire test (NEMA MW1000)
- Surge (IEEE 522)
  - Individual Coils
  - Wound Stator Before Connect
  - Wound Stator After Connect
- High potential test (NEMA MG1-20, IEEE 112)
- Added Testing for Enduraseal
  - One Minute Megger Dry @ 500VDC (IEEE 43)
  - Polarization Index Wet 10 min to 1 min Ratio @ 500VDC(IEEE 43)
  - High Potential Test Wet (NEMA MG1-20.18, IEEE 112)
  - One Minute Megger Wet @ 500VDC (IEEE 43)

Rotors

Motor Rotor

- Rotor Highlights and Considerations
  - Material
    - Copper Bar
    - Cast Aluminum
  - Ducted or Solid
  - Bar Shape / Slot Design
  - Balance Tolerance

Motor Rotor – Material Considerations

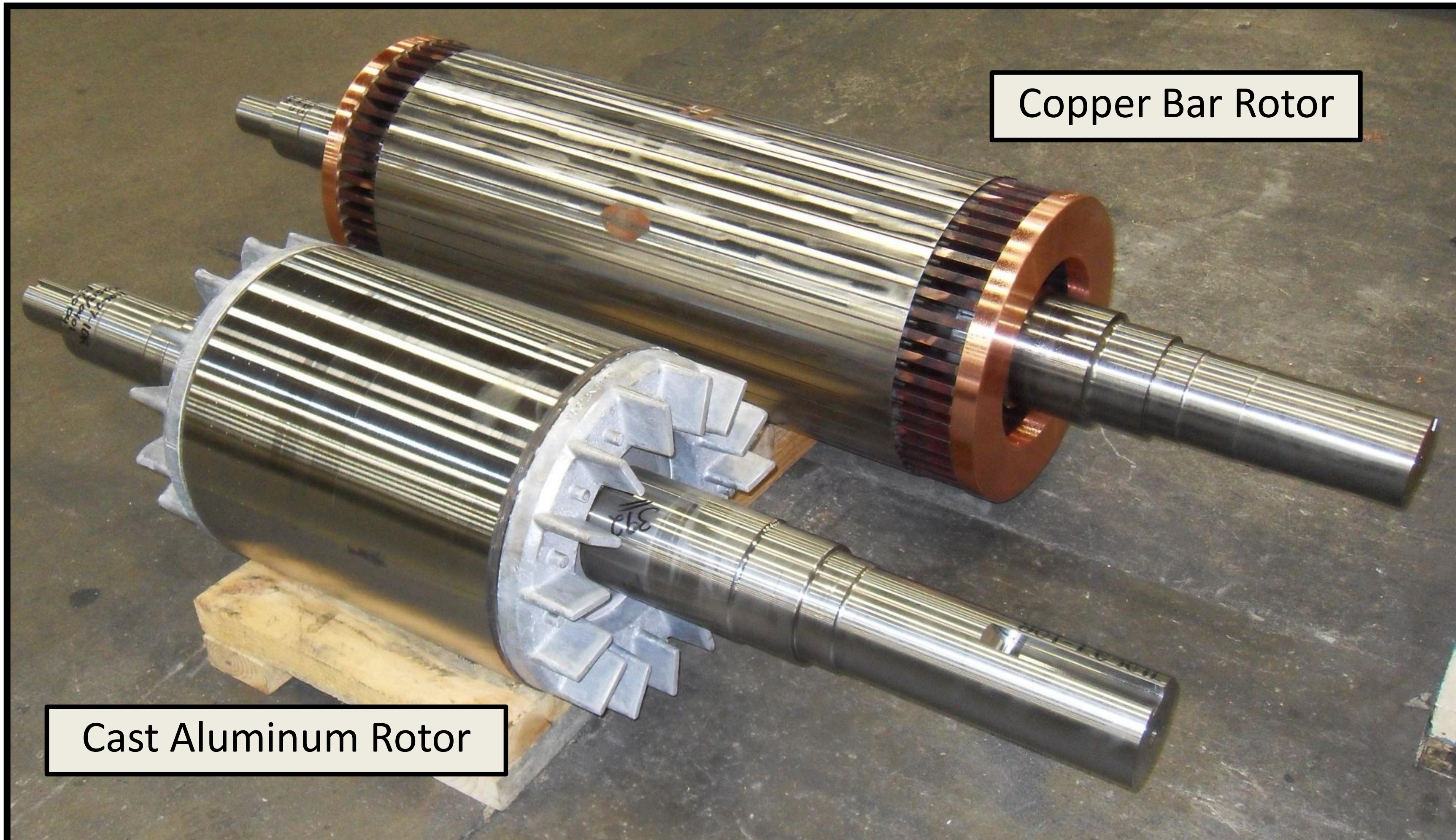
Cast Rotor

- Rotor bars are formed during casting. Therefore, they are in direct contact with laminations
- Less expensive
- Lighter weight
- Internal fans are part of the casting

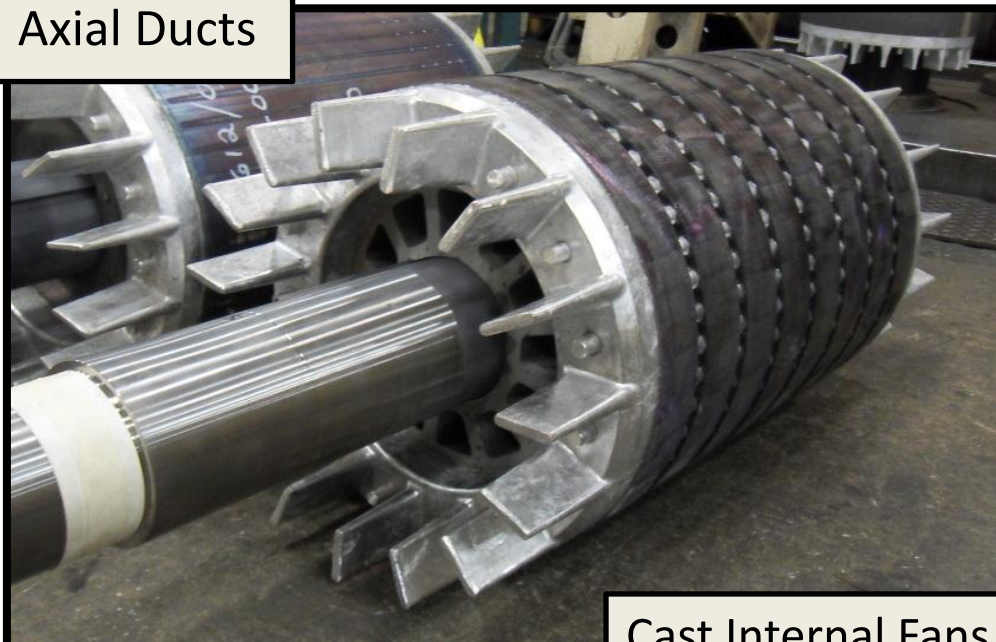
Bar Rotor

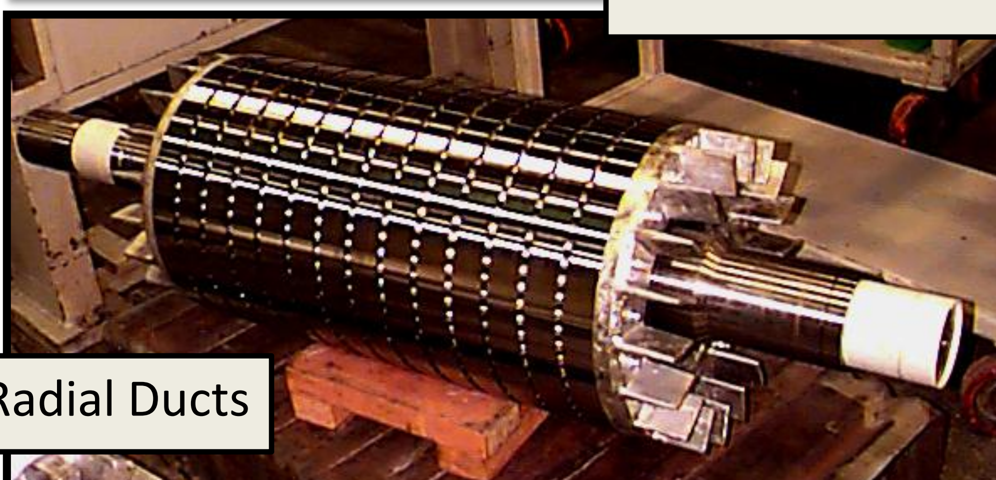
- Rugged Construction
- More Expensive
- Repairable
- Multiple Alloys = Different Speed/Torque Characteristics
- Better for high start applications

Motor Rotor – Solid Rotors



Motor Rotor – Cast Ducted Design

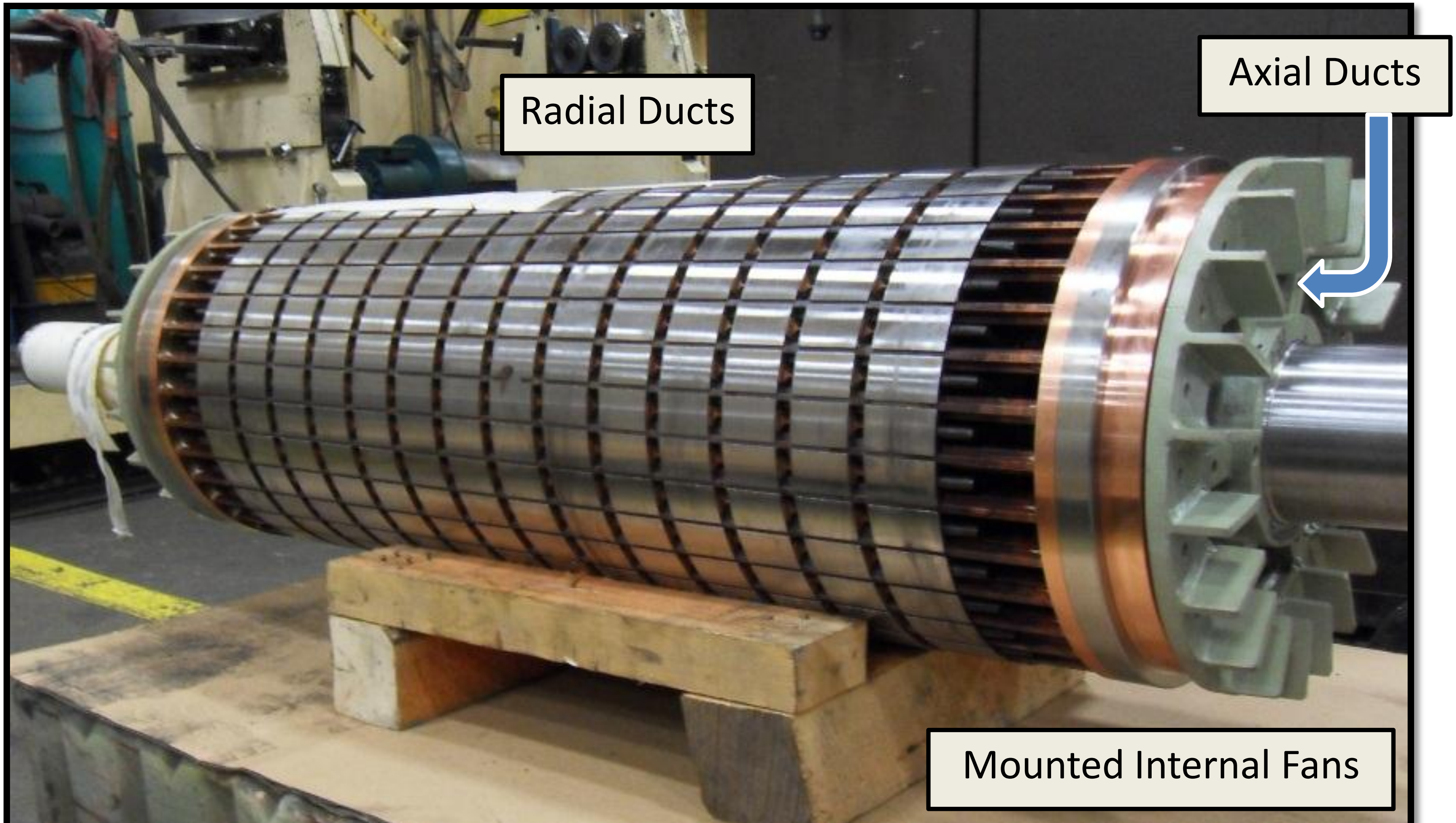




<u>Notice:</u>

- Integral cast fans
- Integral cast end rings
- Integral balance sprues
- Axial passages thru rotor
- Radial paths thru rotor laminations

Motor Rotor – Bar Ducted Design



Cast Rotor Construction

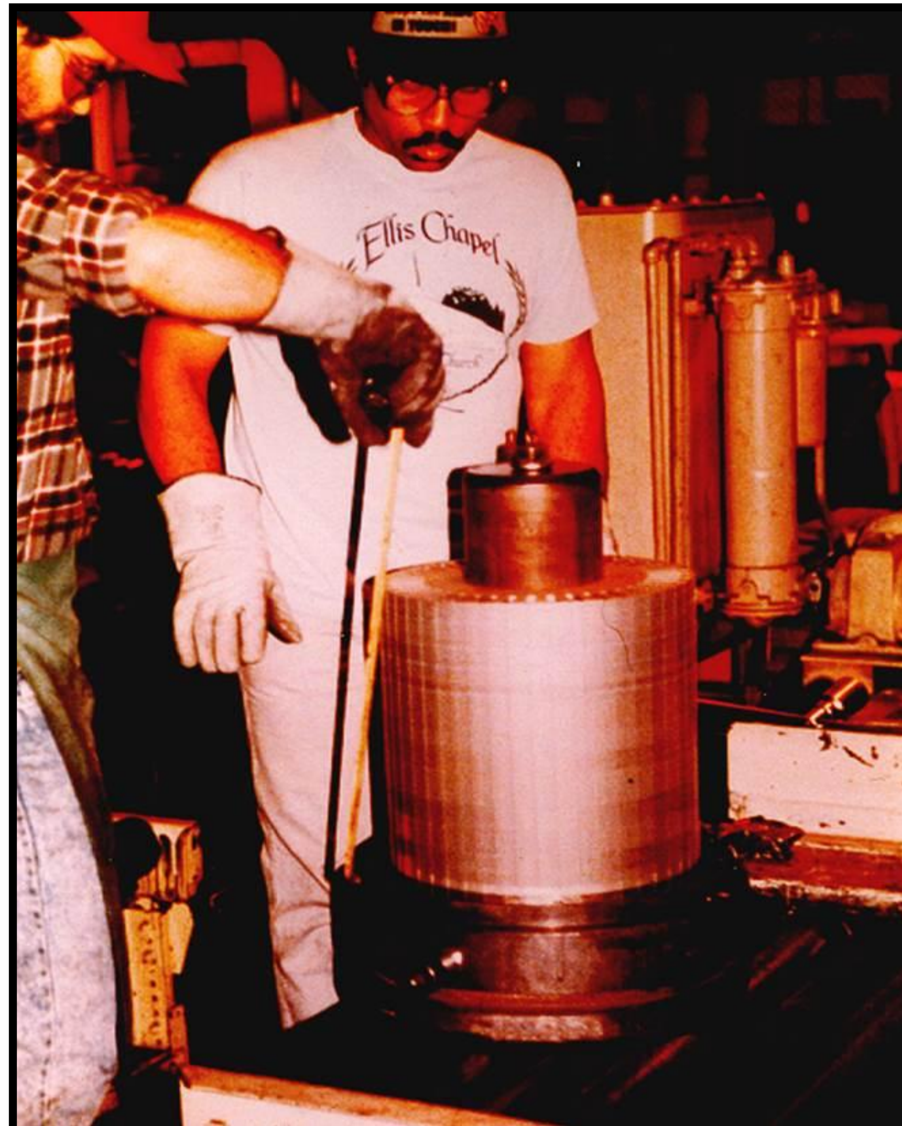
Cast Rotor Construction

- Rotor laminations and molds used to form the end rings and integrally cast fans are placed in a preheated oven.
- Preheating helps ensure quality castings by reducing the stresses and voids that would occur due to temperature variations between the molten aluminum and the tooling.

Cast Rotor Construction

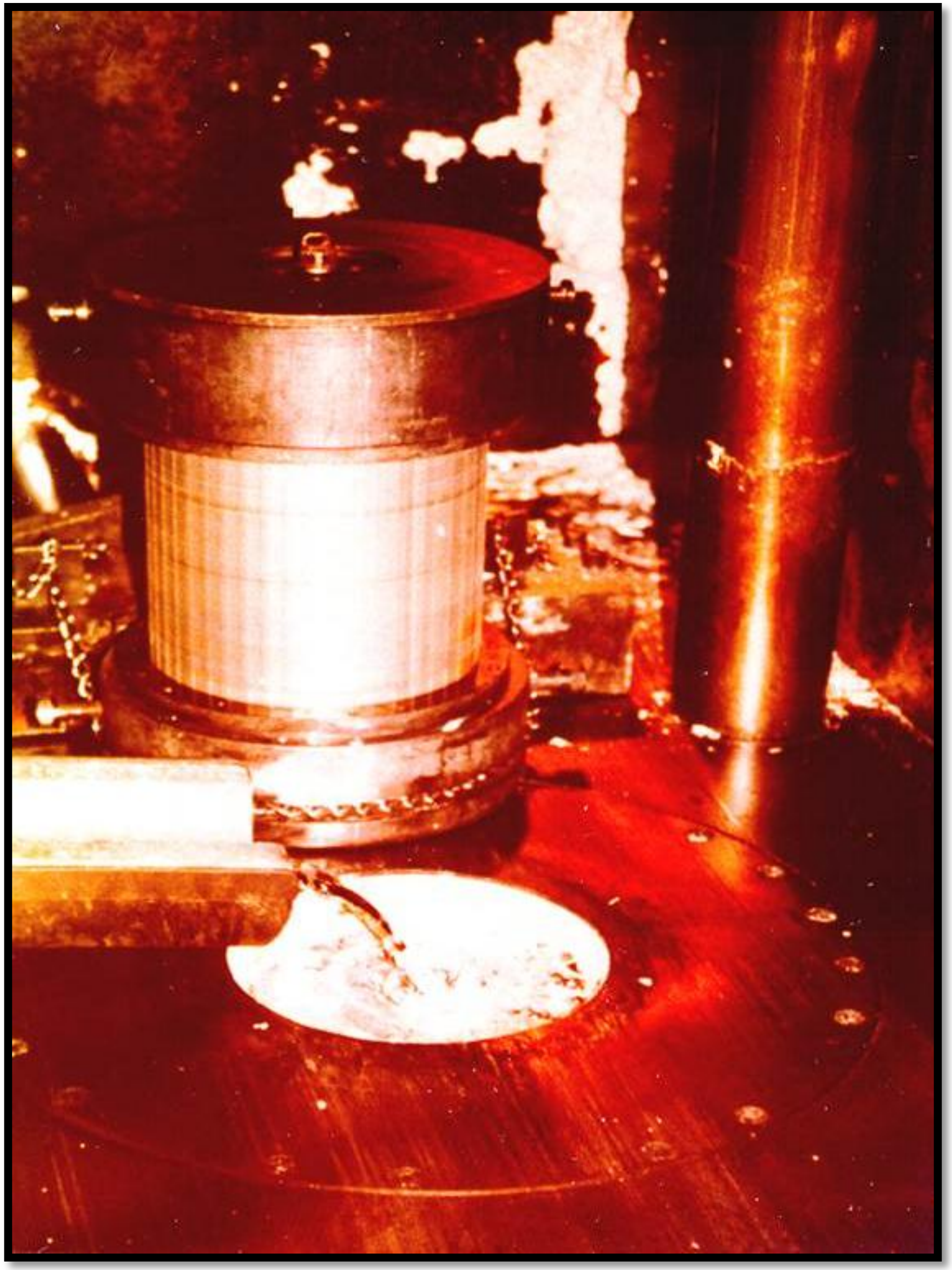
- Laminations and molds are stacked on an arbor to form a tooling assembly

- Laminations are rotated during the punching operation to make sure that any thickness variations in the steel are evenly distributed along the length of the rotor.

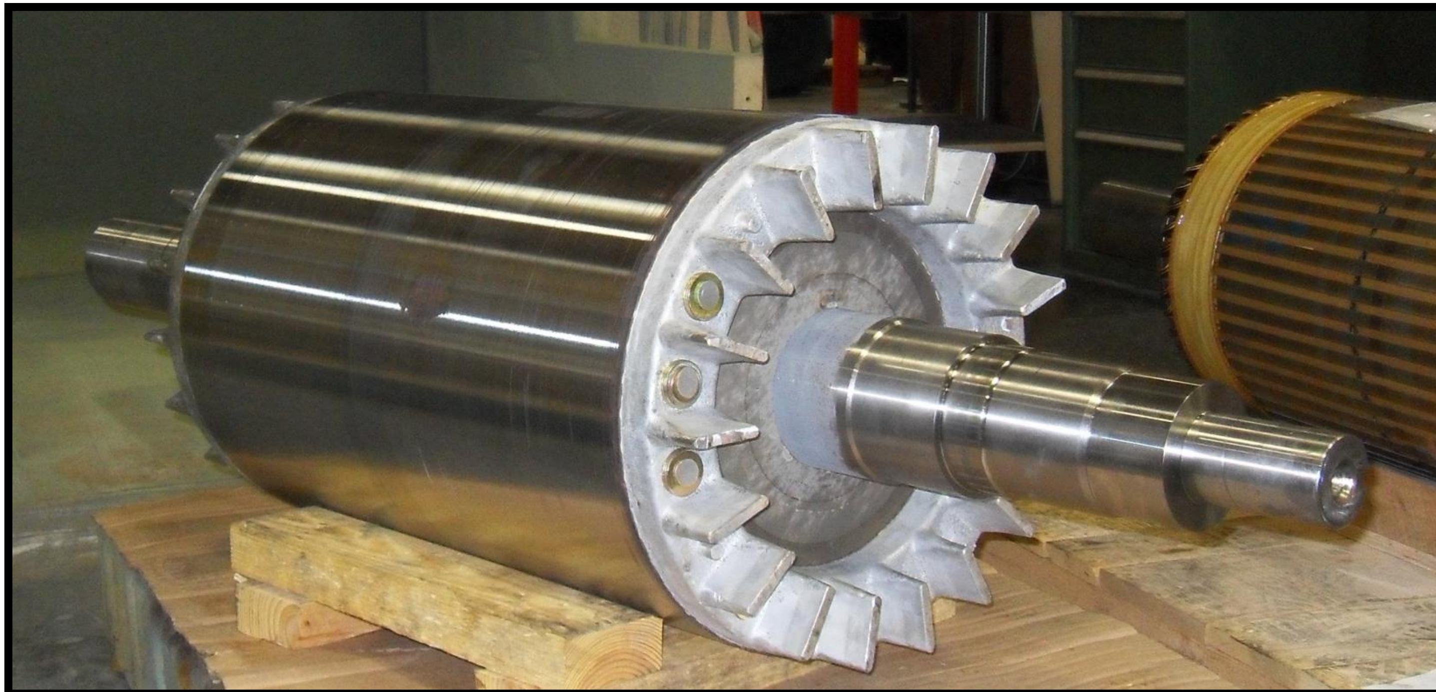


Cast Rotor Construction

- Molten aluminum at over 1200 °F is poured into the shot well in the bottom of the casting machine.
- The tooling assembly is then placed over the well and pressed together.
- The casting machine door is closed and the aluminum is injected into the tooling assembly.
- Vent holes in the mold (near the top) allow for escape of gases.



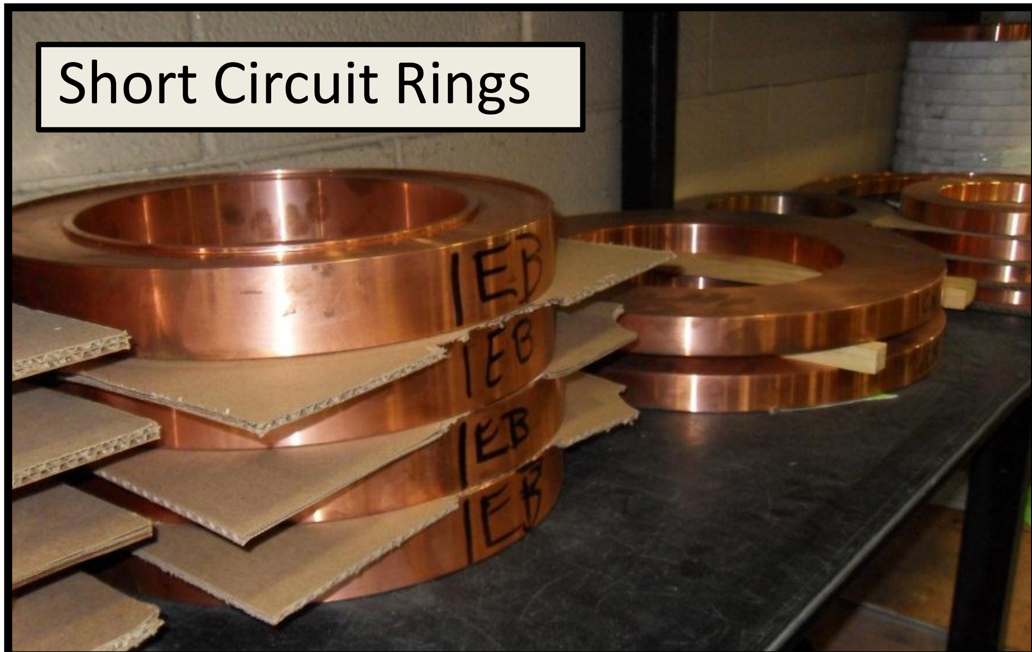
Cast Rotor Construction

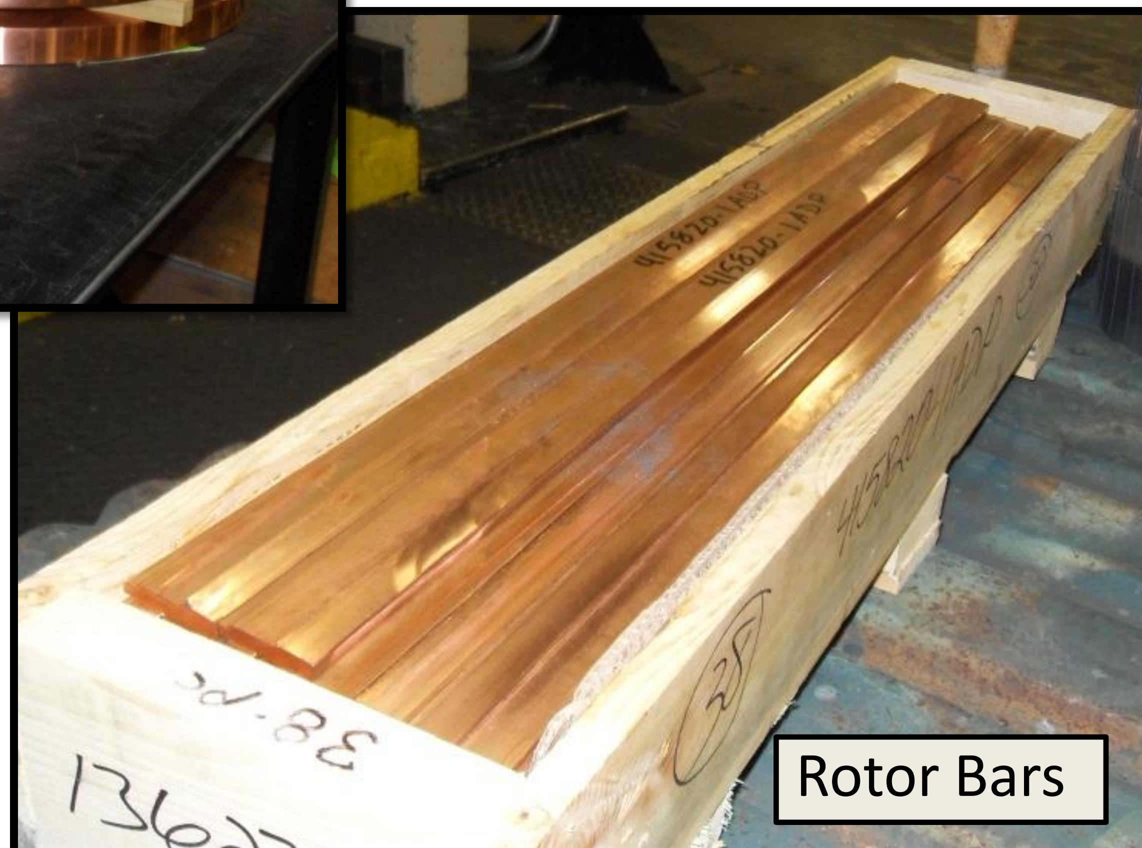


- The tooling assembly is removed from the casting machine and the lower and upper molds are removed.
- At this point the core is now held together by the bars and endrings which are cast into one continuous piece.
- The extra aluminum or flashing is then removed from the rotor by using a file or hand grinder.

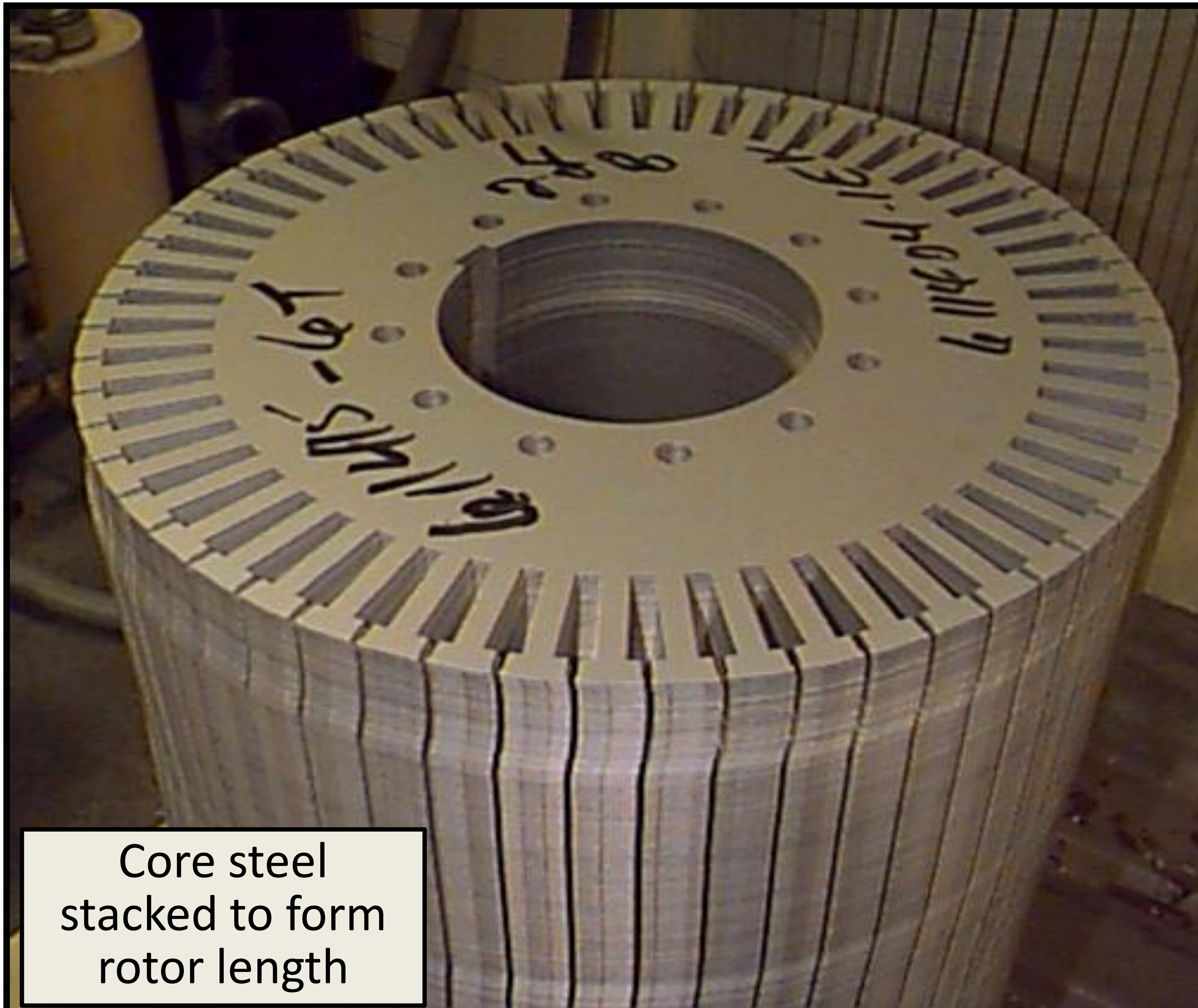
Copper Bar Rotor Construction

Copper Bar Rotor Construction

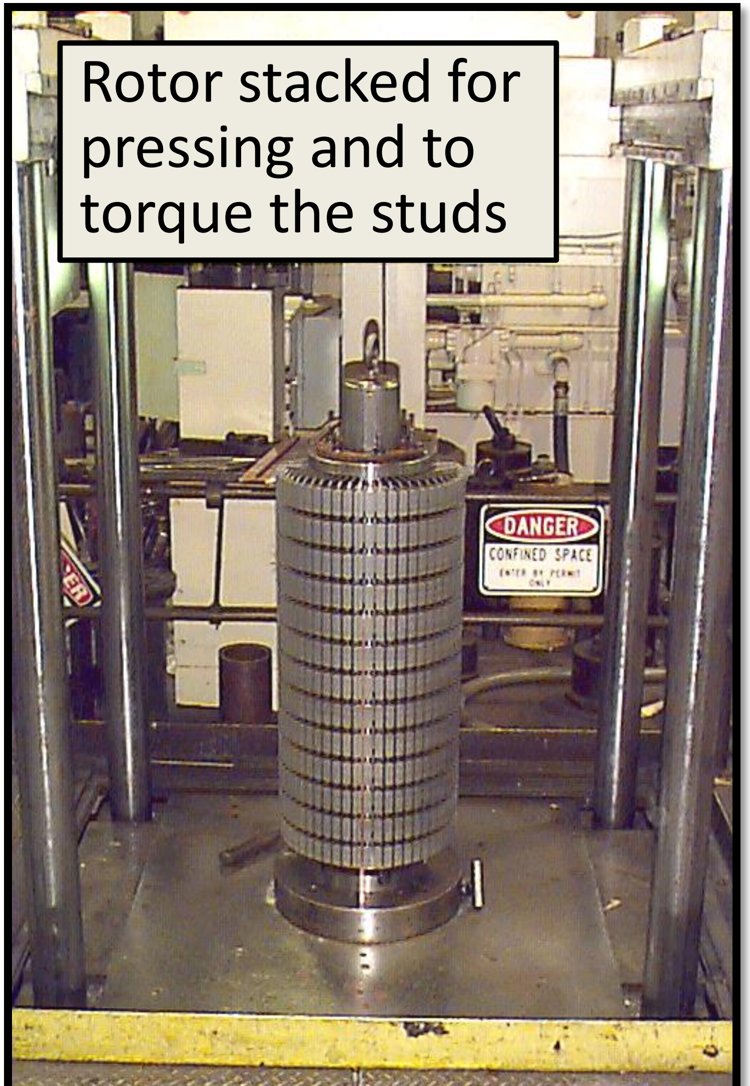




Copper Bar Rotor Construction



Copper Bar Rotor Construction



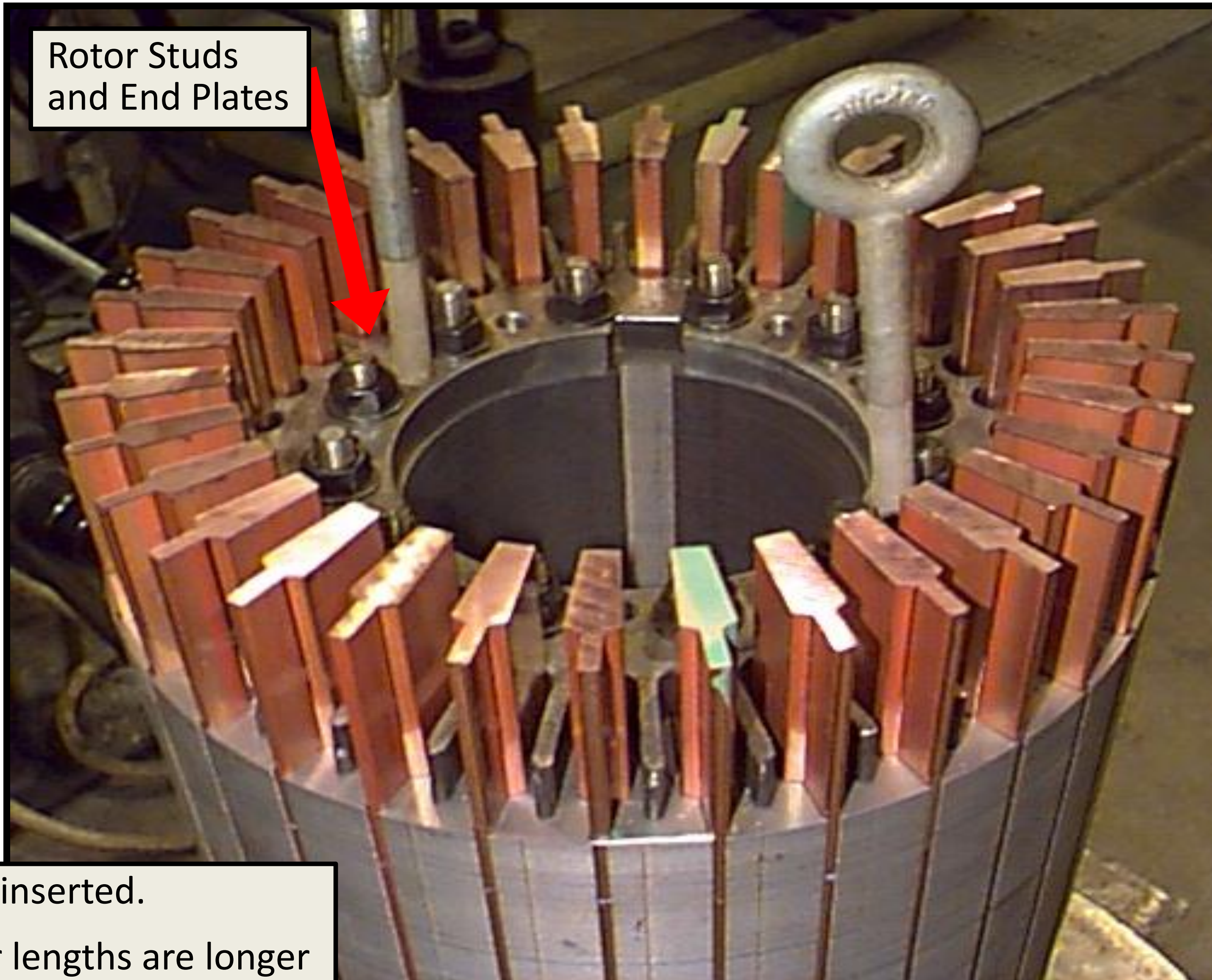
Rotor stacked for pressing and to torque the studs


Rotor Core Assembly

Copper Bar Rotor Construction

Inserting Bars

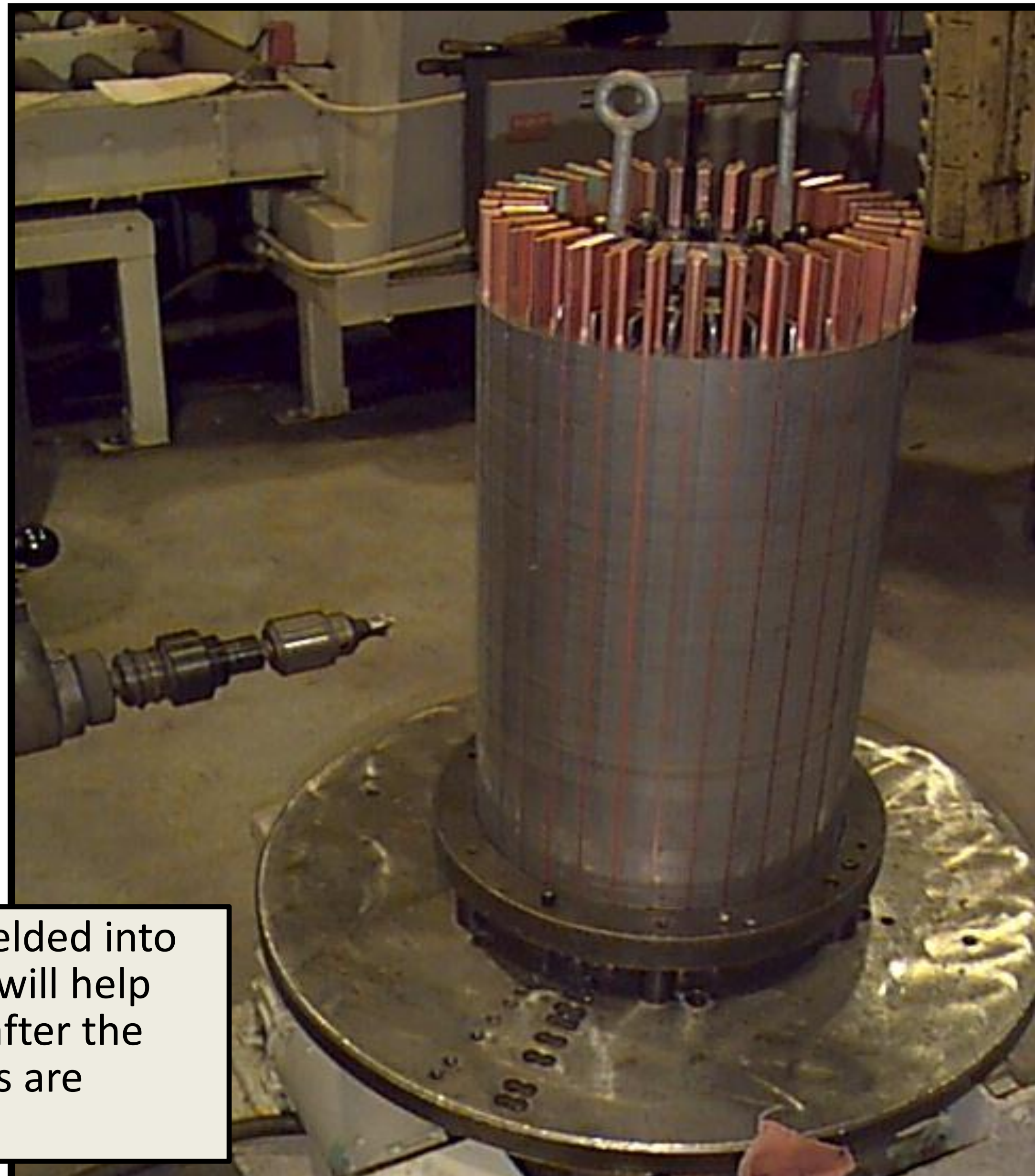
Copper Bar Rotor Construction



Bars are inserted.

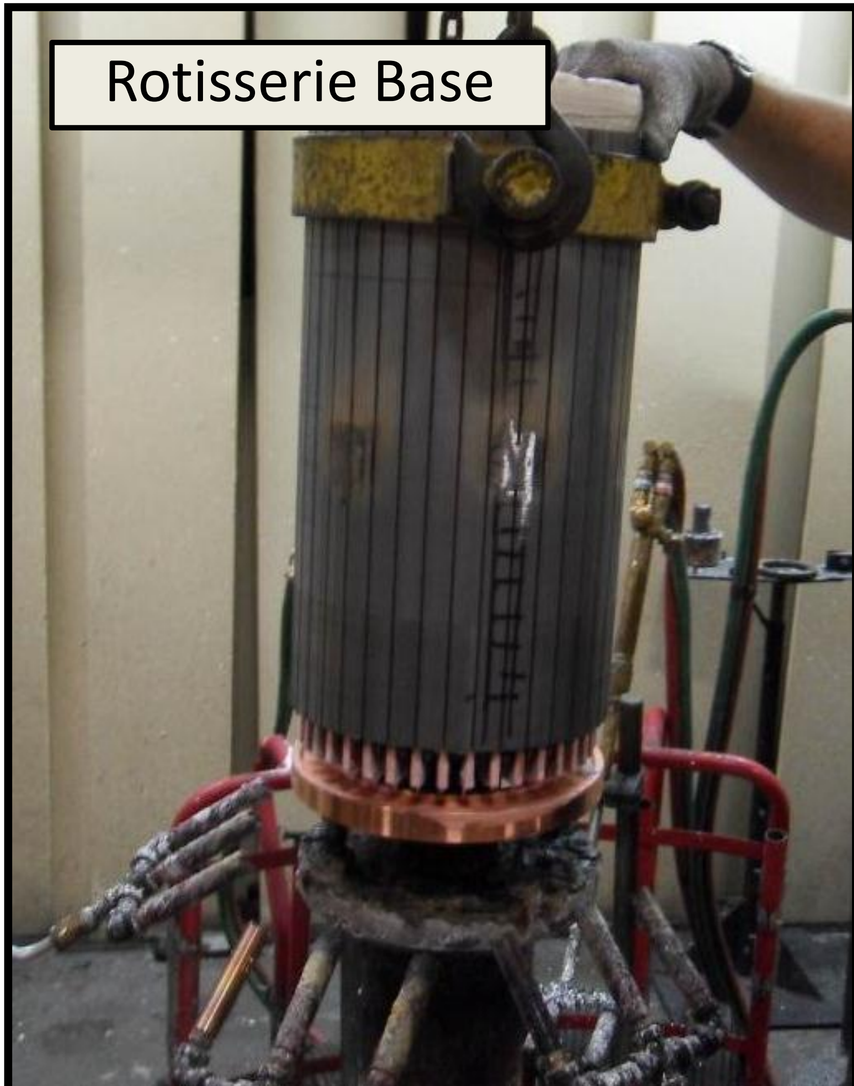
Note bar lengths are longer than the rotor stack

Copper Bar Rotor Construction

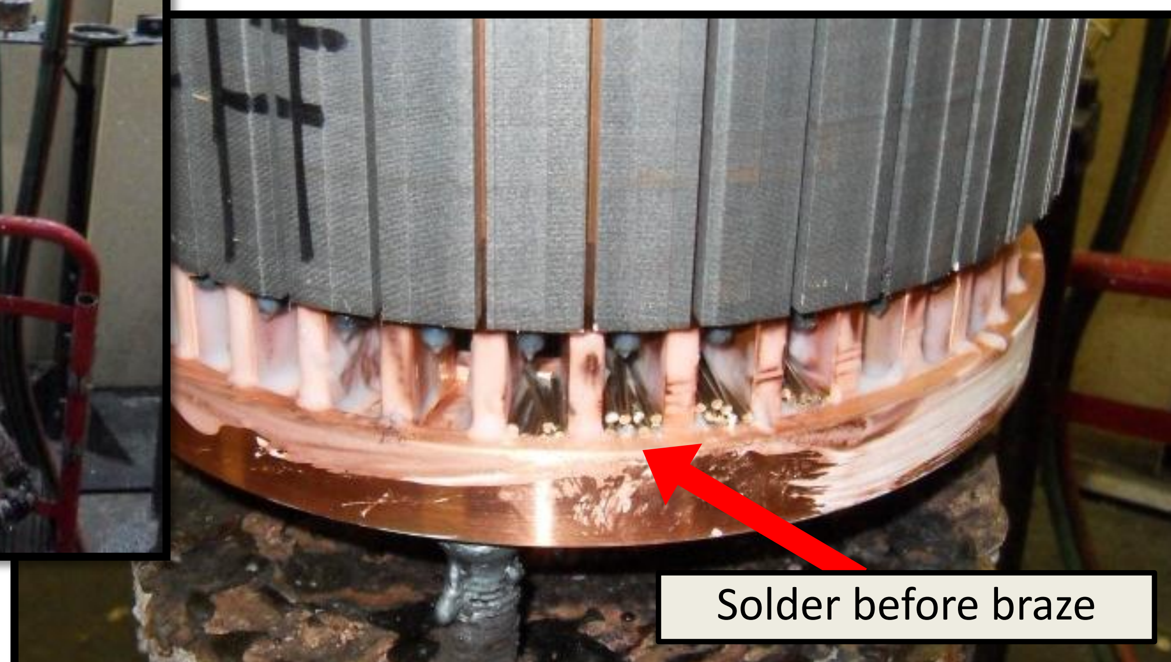


6-8 “Pins” are welded into the rotor. These will help locate the cage after the short circuit rings are brazed on.

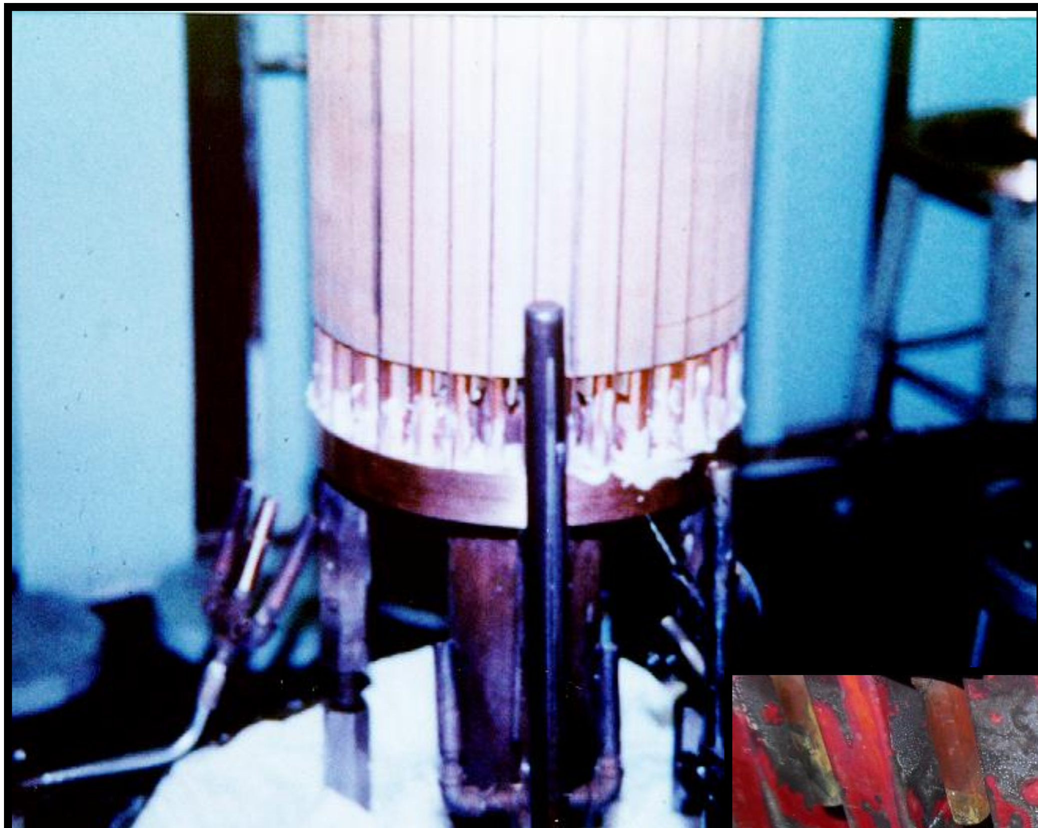
Copper Bar Rotor Construction



- Silver Solder and Flux installed between bars.
- A machine cuts each piece of solder to the same length from a spool of material.
- The same number of solder pieces are placed between each bar.

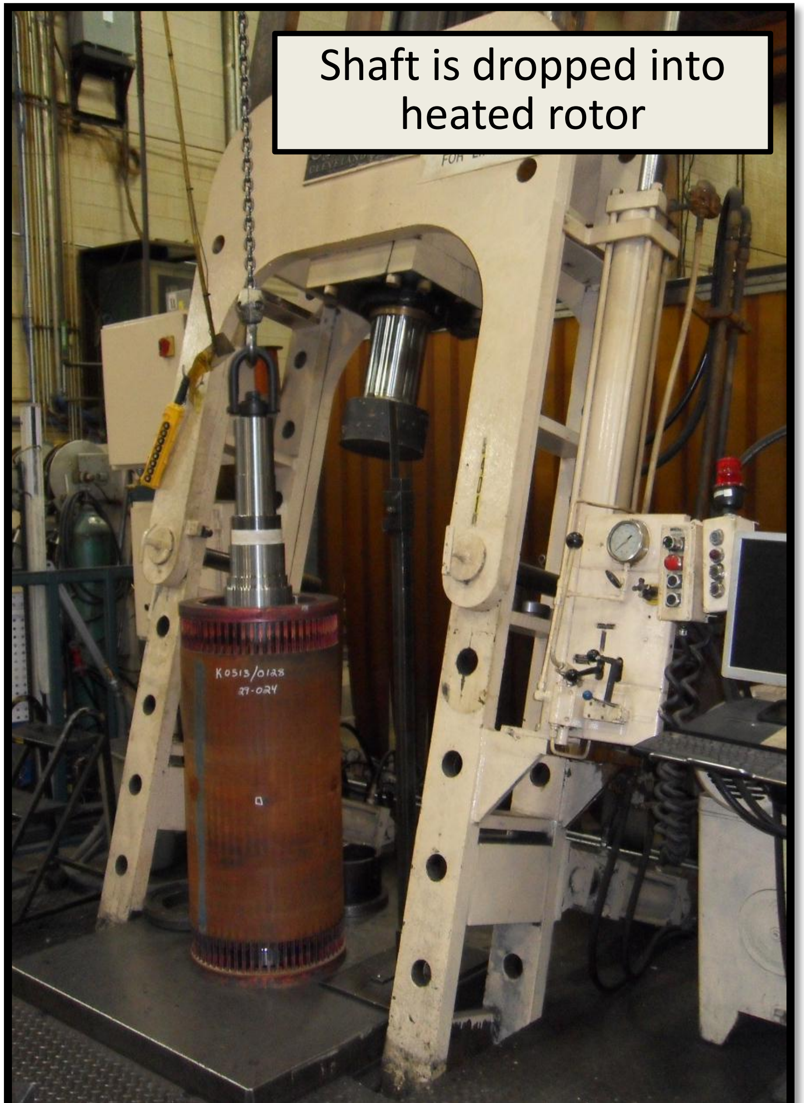


Copper Bar Rotor Construction

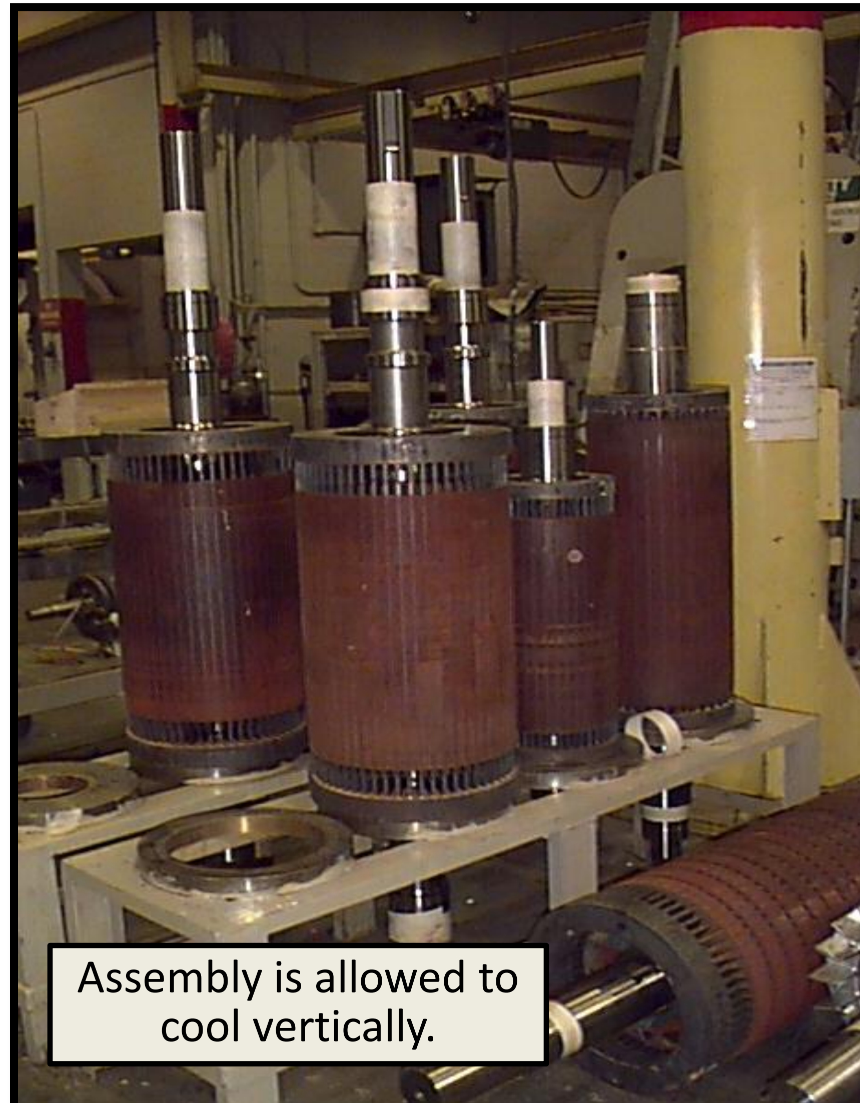


Rotor/Shaft Construction

Rotor/Shaft Construction

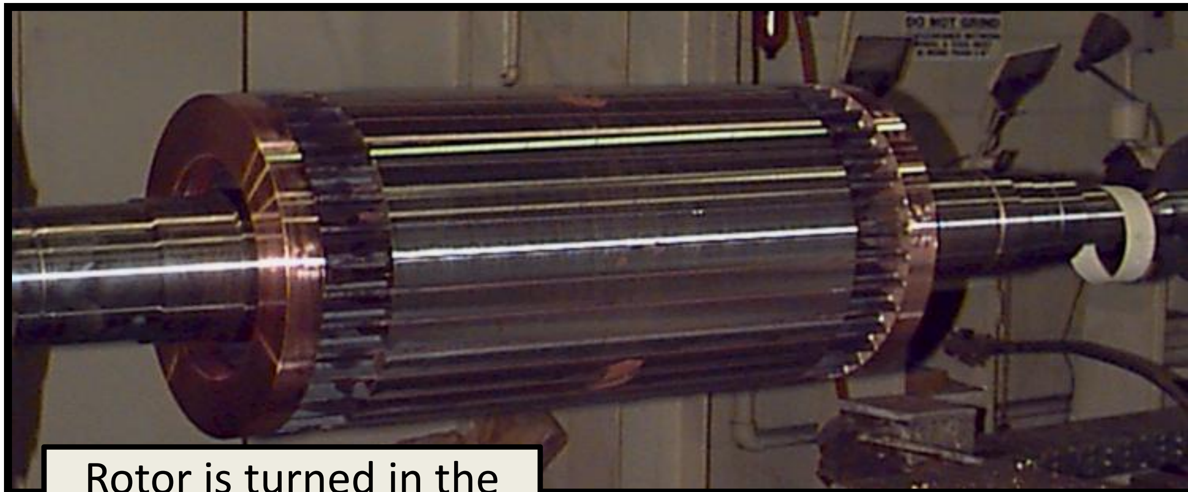


Shaft is dropped into heated rotor

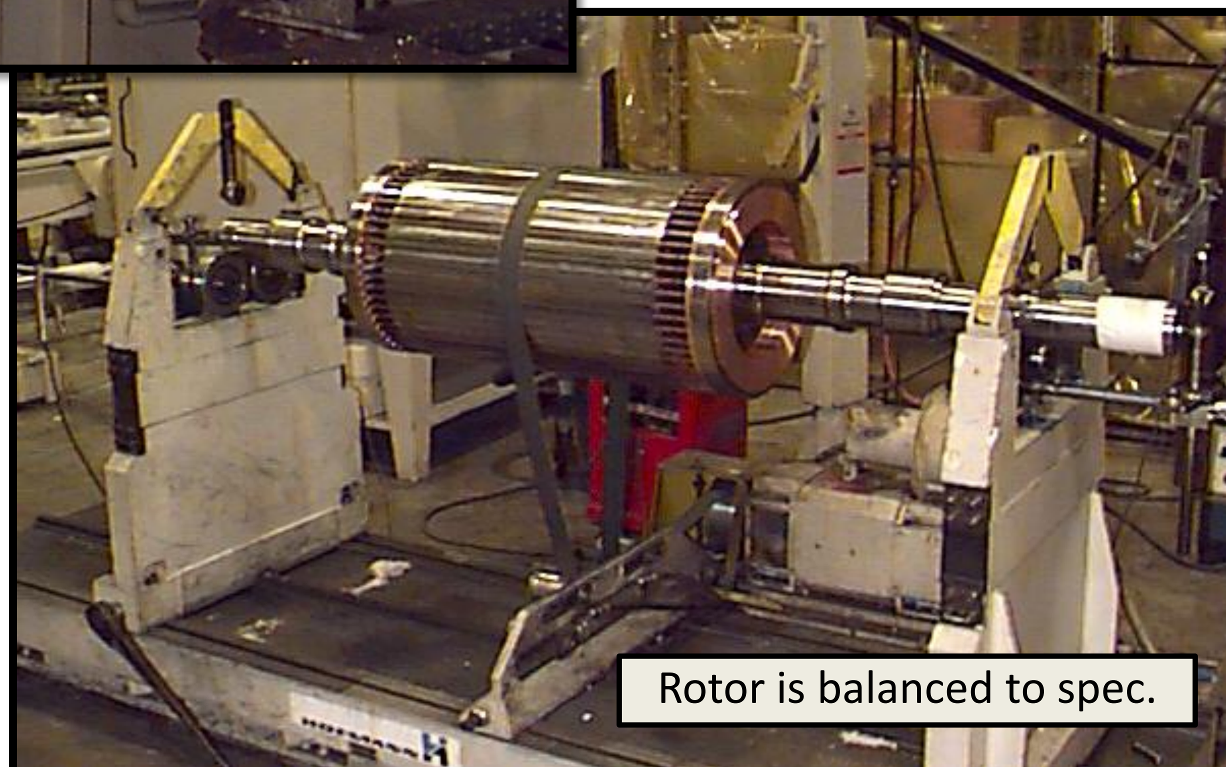


Assembly is allowed to cool vertically.

Rotor/Shaft Construction

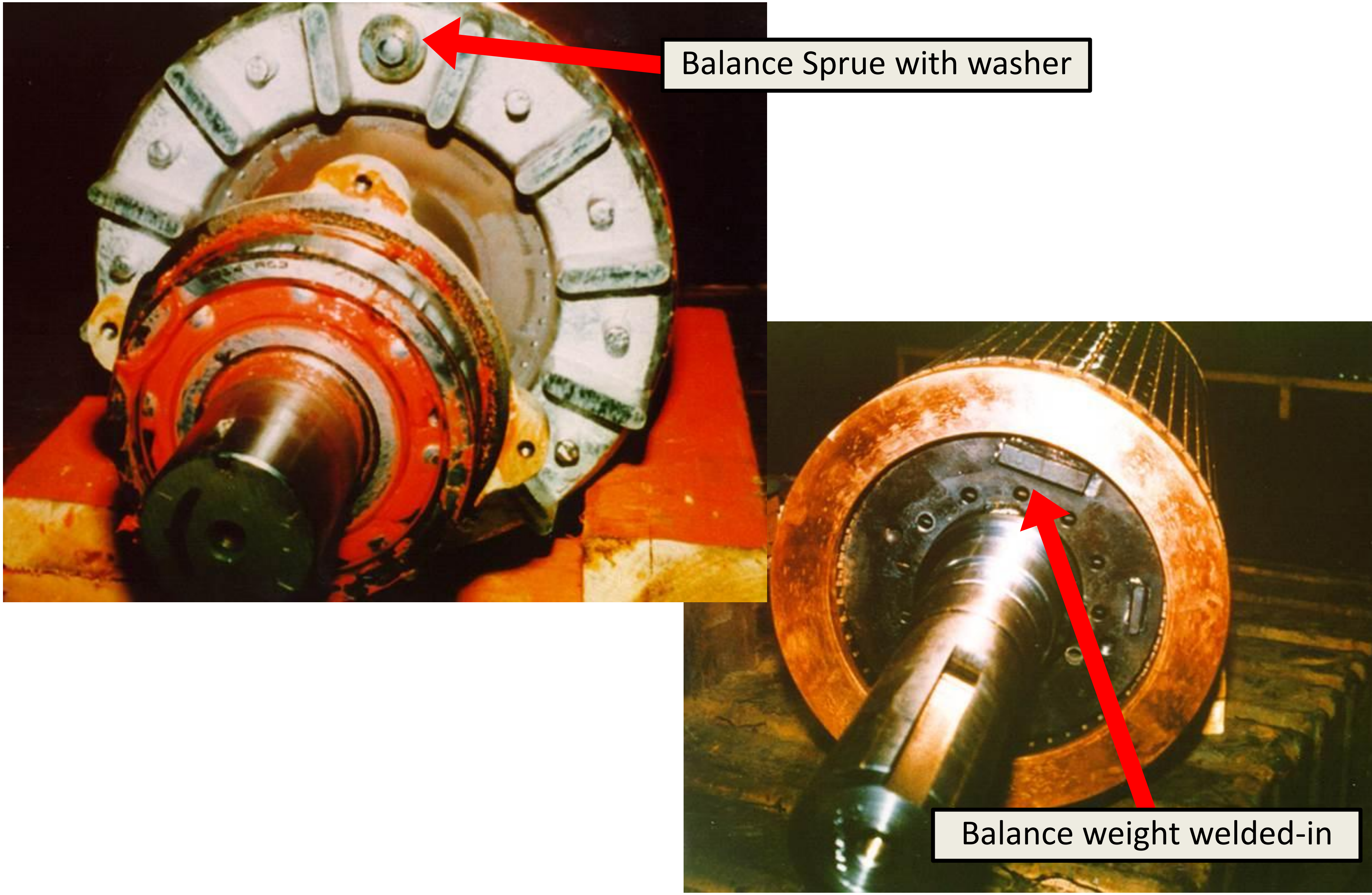


Rotor is turned in the lathe to size.

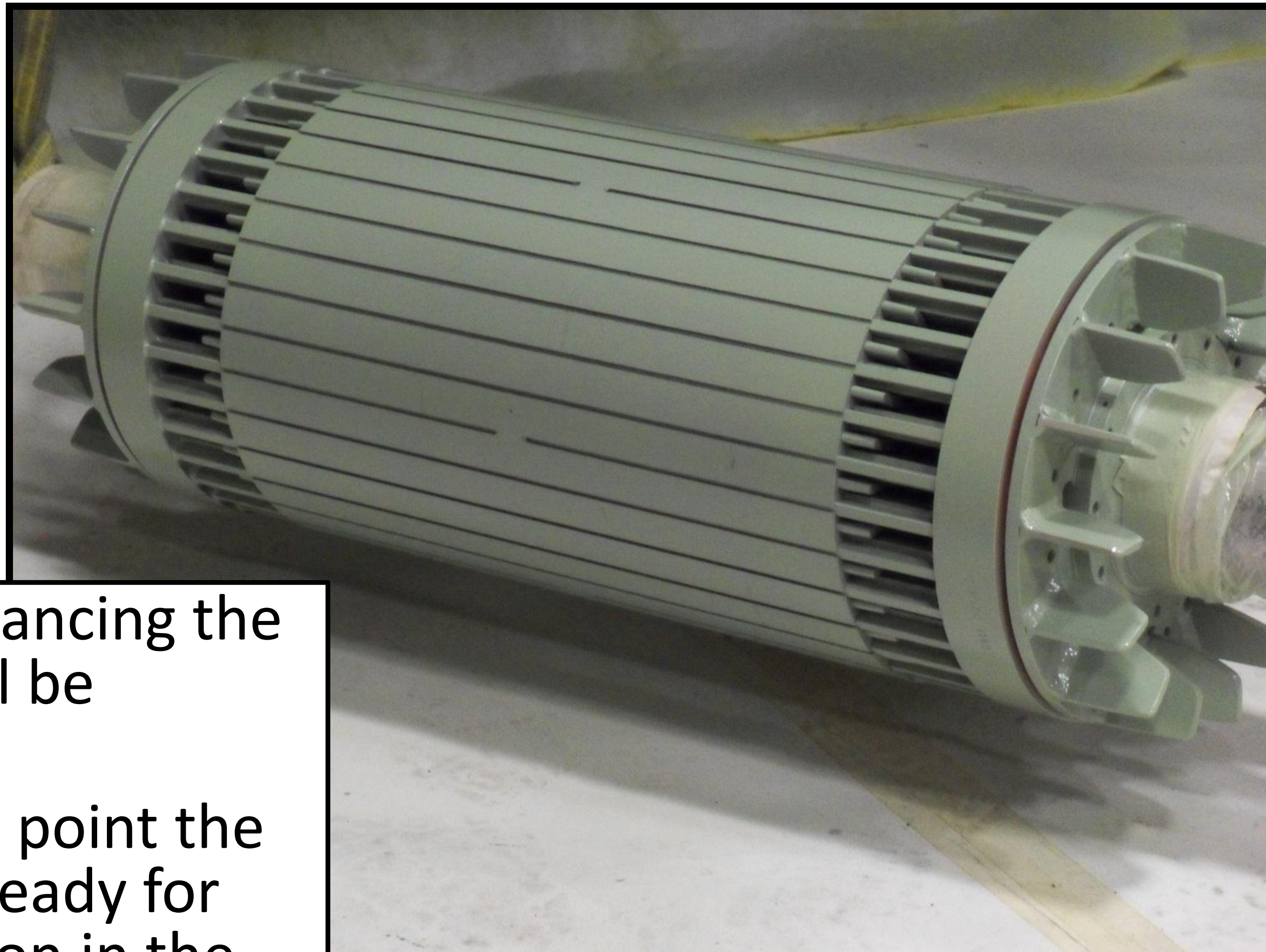


Rotor is balanced to spec.

Rotor/Shaft Balance



Rotor/Shaft Construction



- After balancing the rotor will be painted.
- At which point the rotor is ready for installation in the motor.

Motor End Plates

Motor End Plates

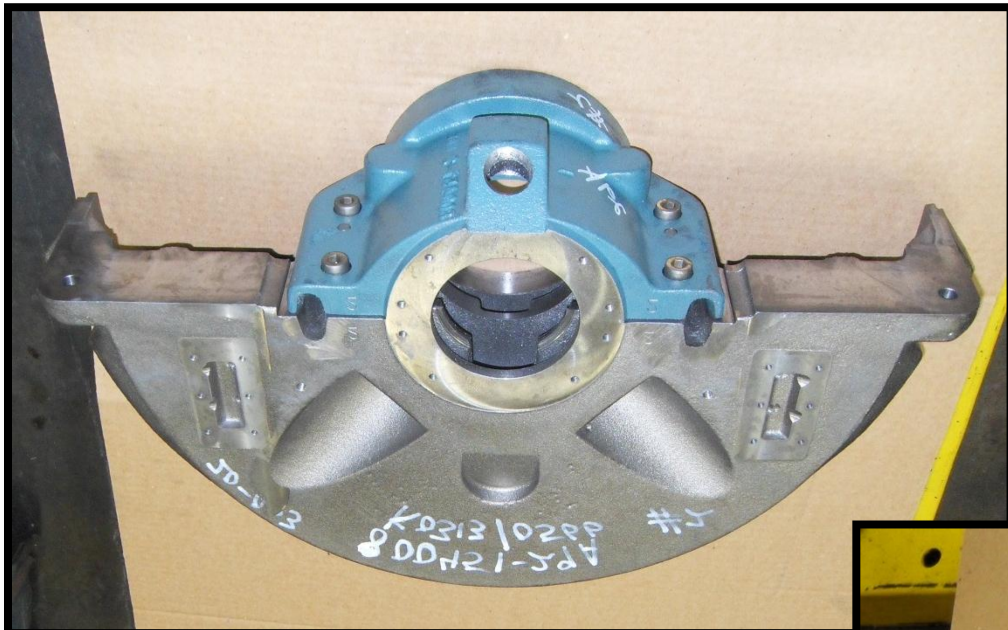
- Typical construction materials:
  - Cast Iron
  - Ductile Iron
  - Fabricated Steel

Also, known as:

- "End bells"
- "Brackets"
- "Cartridges"

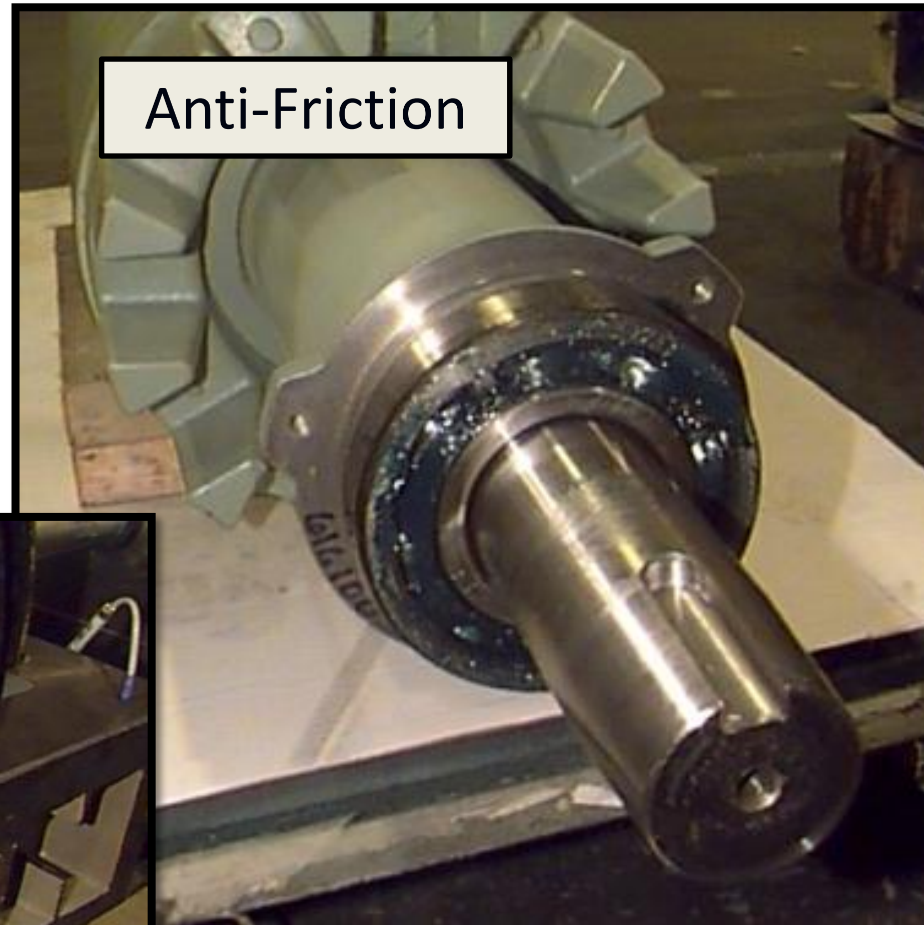
Motor End Plates – A/F

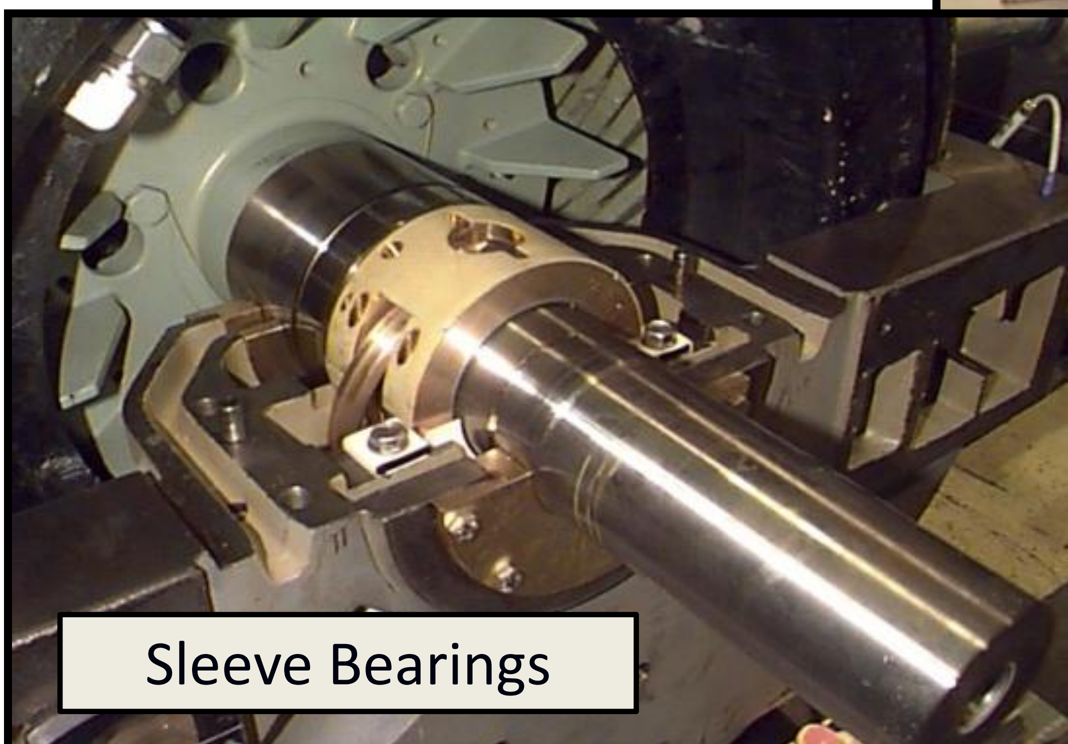
Motor End Plates – Sleeve Brgs.



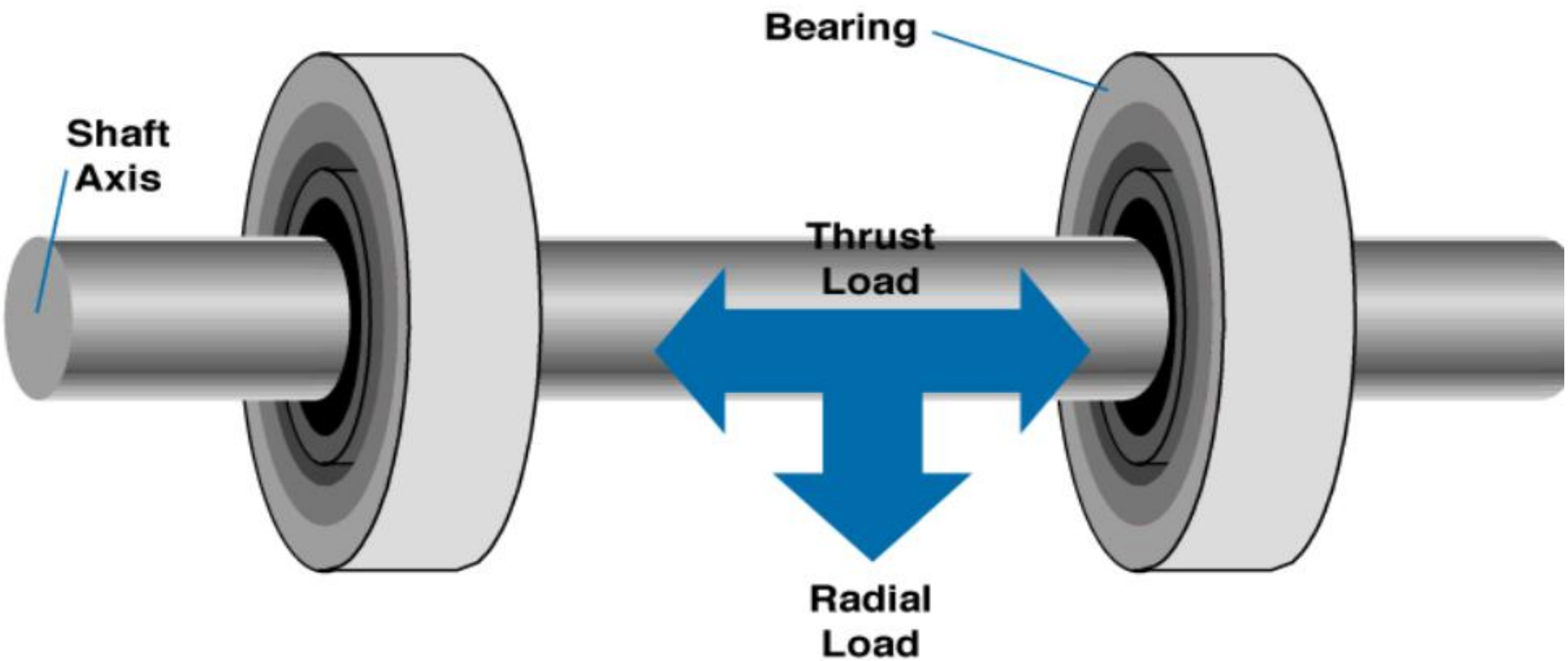
Motor Bearings

Motor Bearings



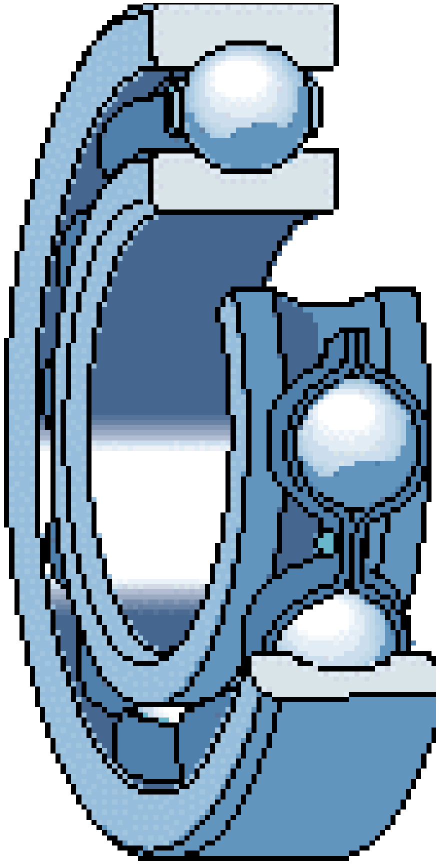


Purpose of Motor Bearings



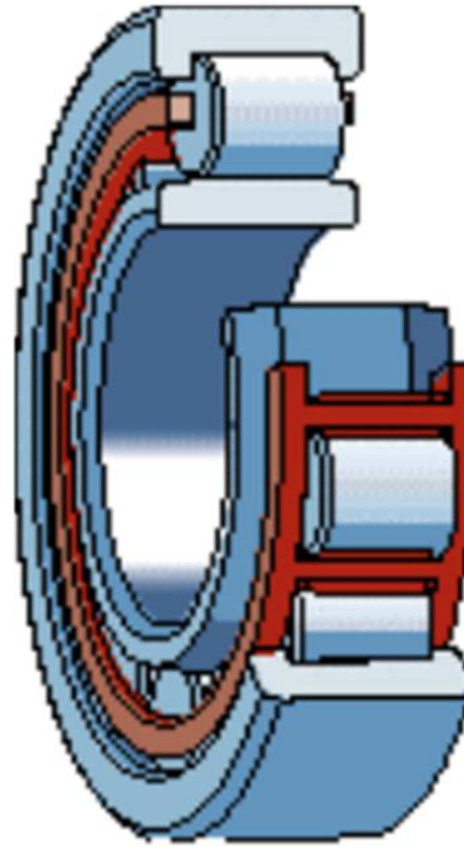
- Support and locate the rotor
- Keep the air-gap small and consistent
- Transfer loads from the shaft to motor frame

Anti-friction Bearings



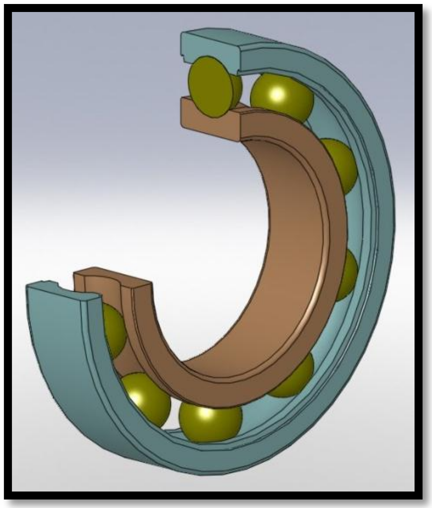
Deep Groove Ball

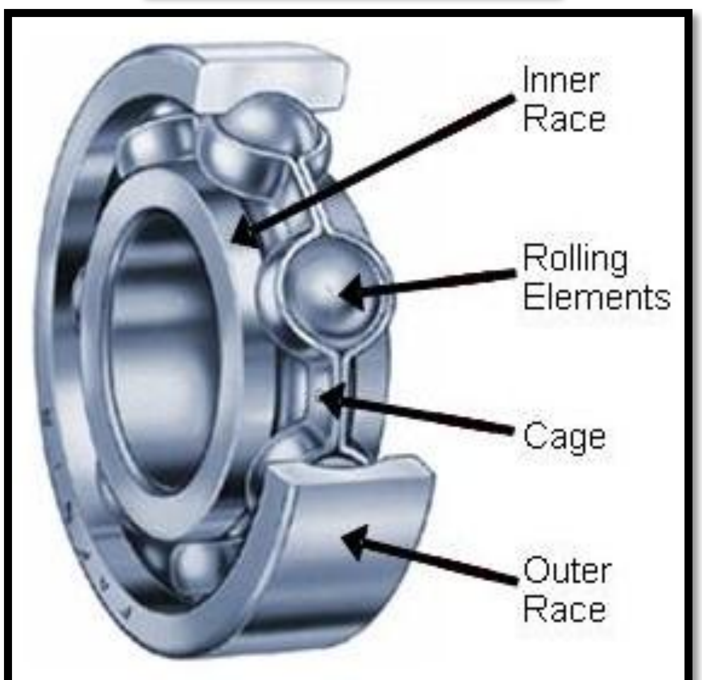
Angular Contact



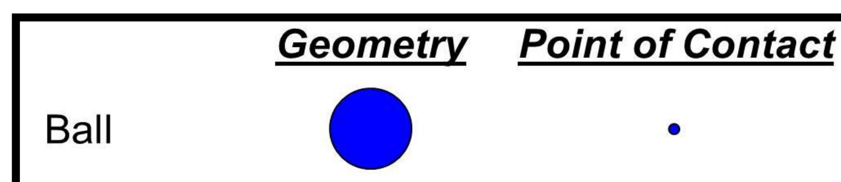
Cylindrical Roller

Deep Groove Ball Bearing

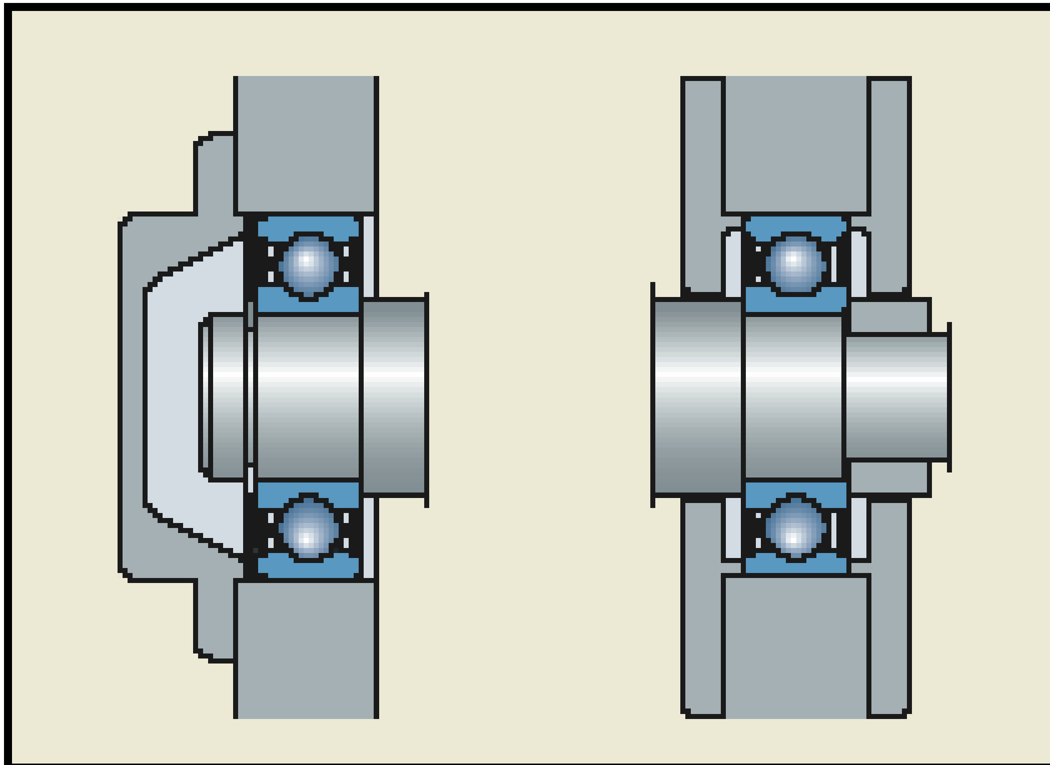




- Common bearing type
- High speed and quiet running capabilities
- Moderate radial and axial loading capability
- Low minimum radial loading required
- Economical



Anti-Friction Bearing Mounting



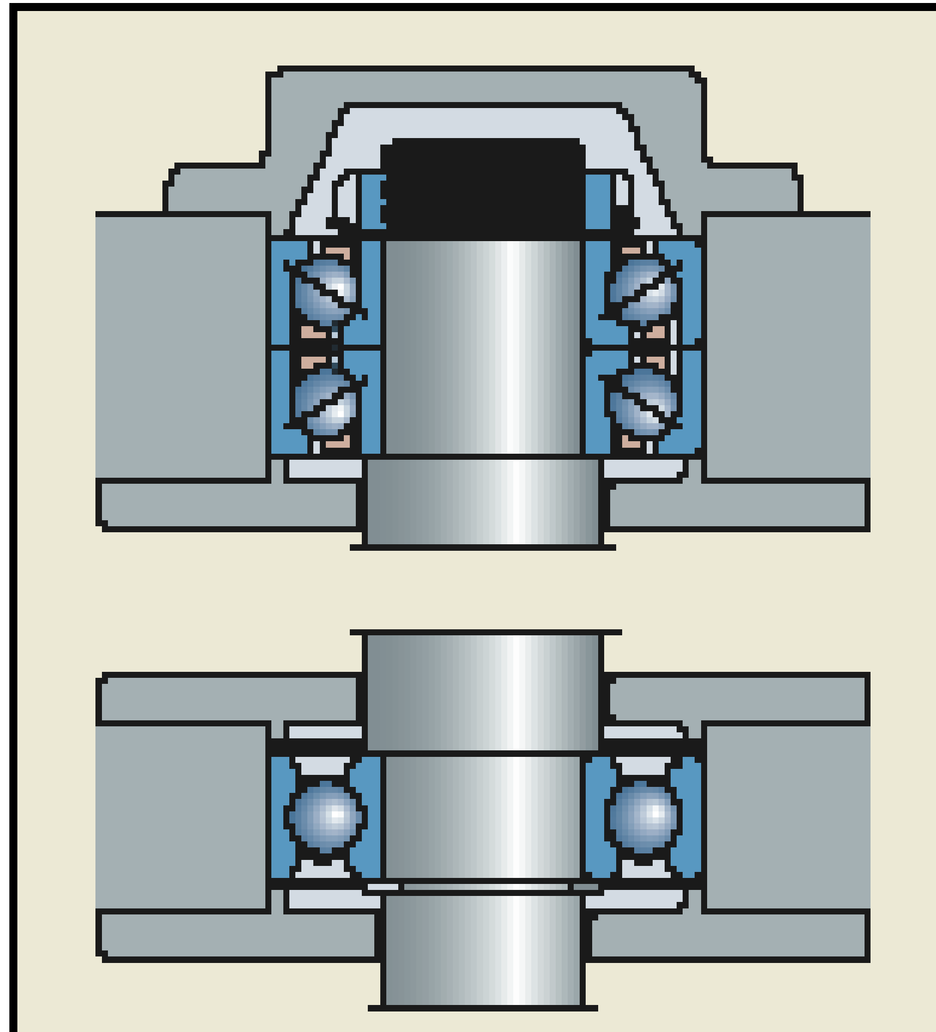
- Two Deep Groove Ball Bearings
- Fixed and Free (Expansion) setups
- Snap Rings or Locknuts with shaft shoulders

Angular Contact Ball Bearings

- High axial load and combined load capability
- Good high speed capability
- Low friction
- Usually used vertical motors
- Low minimum load requirements
- Used in pairs for reversing axial loads

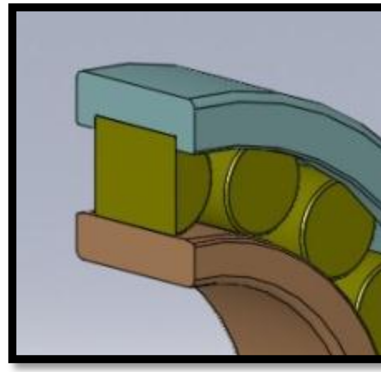
Vertical Motor Brg. Arrangement

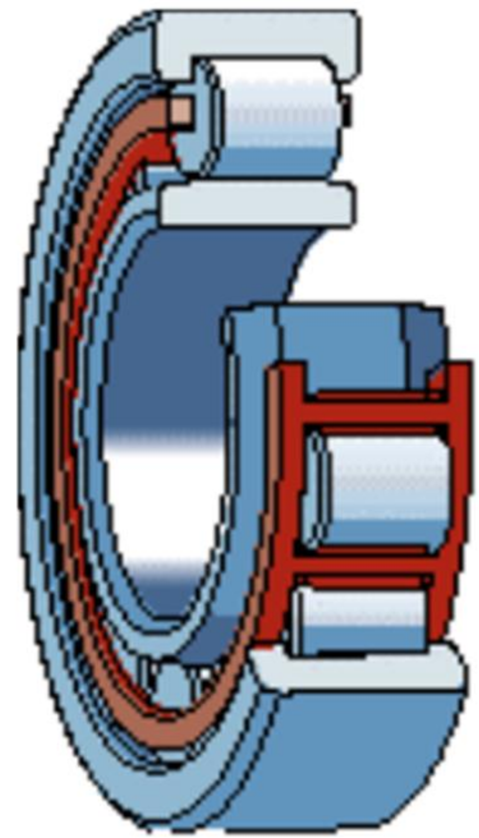
- Paired angular contact thrust bearings on ODE.
- Ball guide bearing on DE.
- Moderate axial loads in both directions with back to back (duplex) arrangement.
- Heavy axial load in one direction with tandem arrangement



Cylindrical Roller Bearing

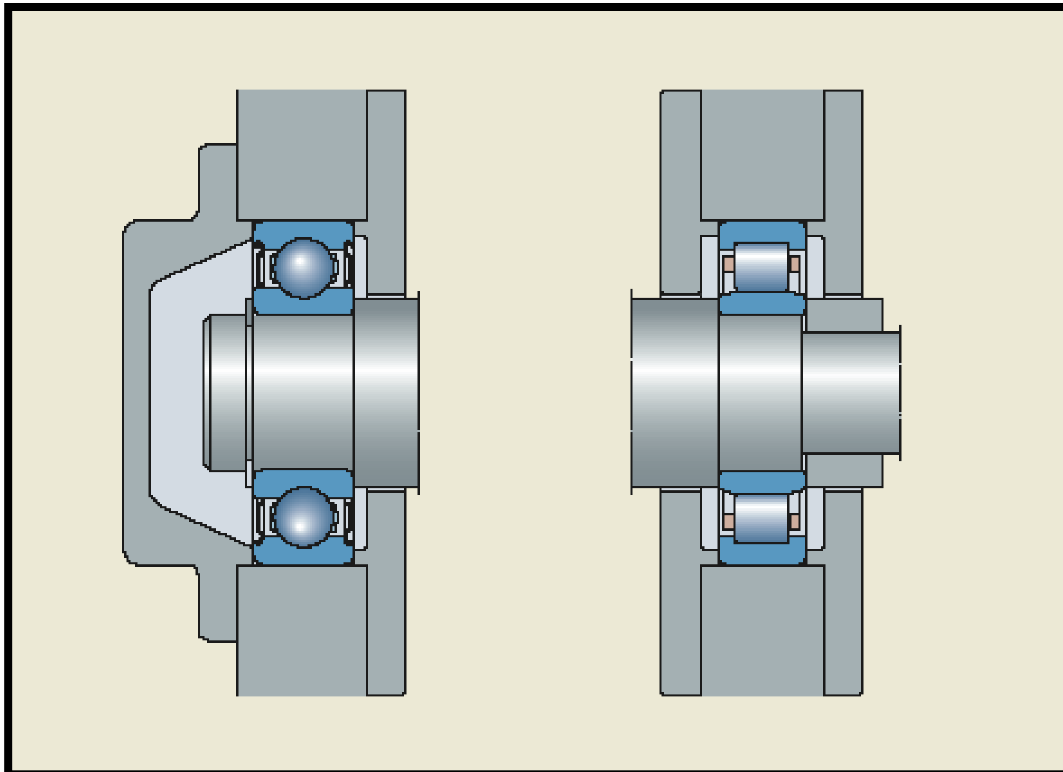
	Geometry	Point of Contact
Cylindrical Roller		





- Axially free bearing design (internally)
- Opposite drive end bearing must be held captive with retainer
- Heavy radial load capability
- Minimum radial load required greater than ball bearings
- Speed limitations could exist

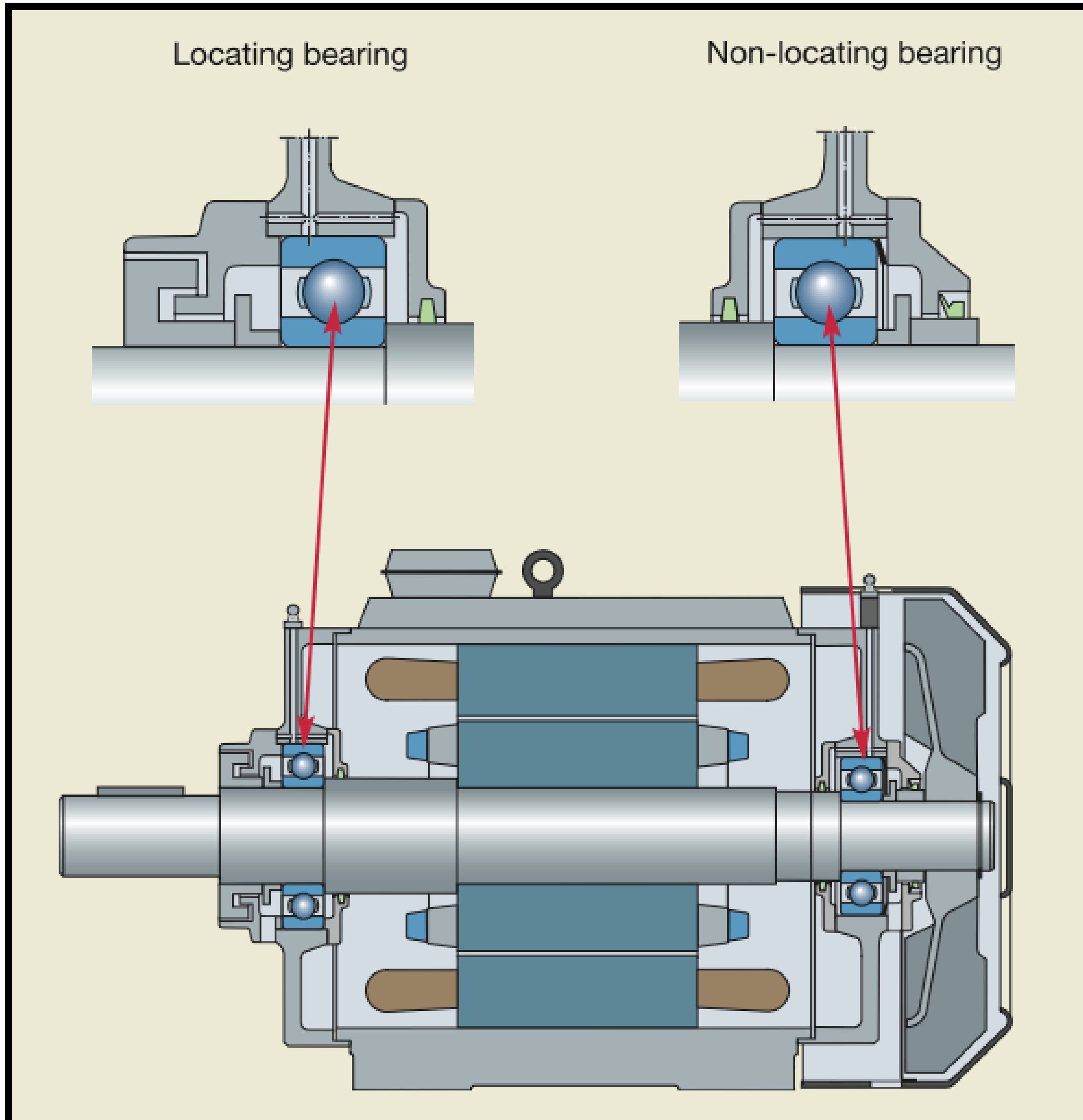
Anti-Friction Bearing Mounting



- Roller bearing on drive end
- Ball bearing on non-drive end
- The locating bearing is the non-drive end

Typical NEMA Motor Bearing Arrangement

- Why?
  - Drive End is fixed (locating)
  - Opposite drive end is allowed to float
  - Allows for shaft expansion when motor is running



Motor Accessories

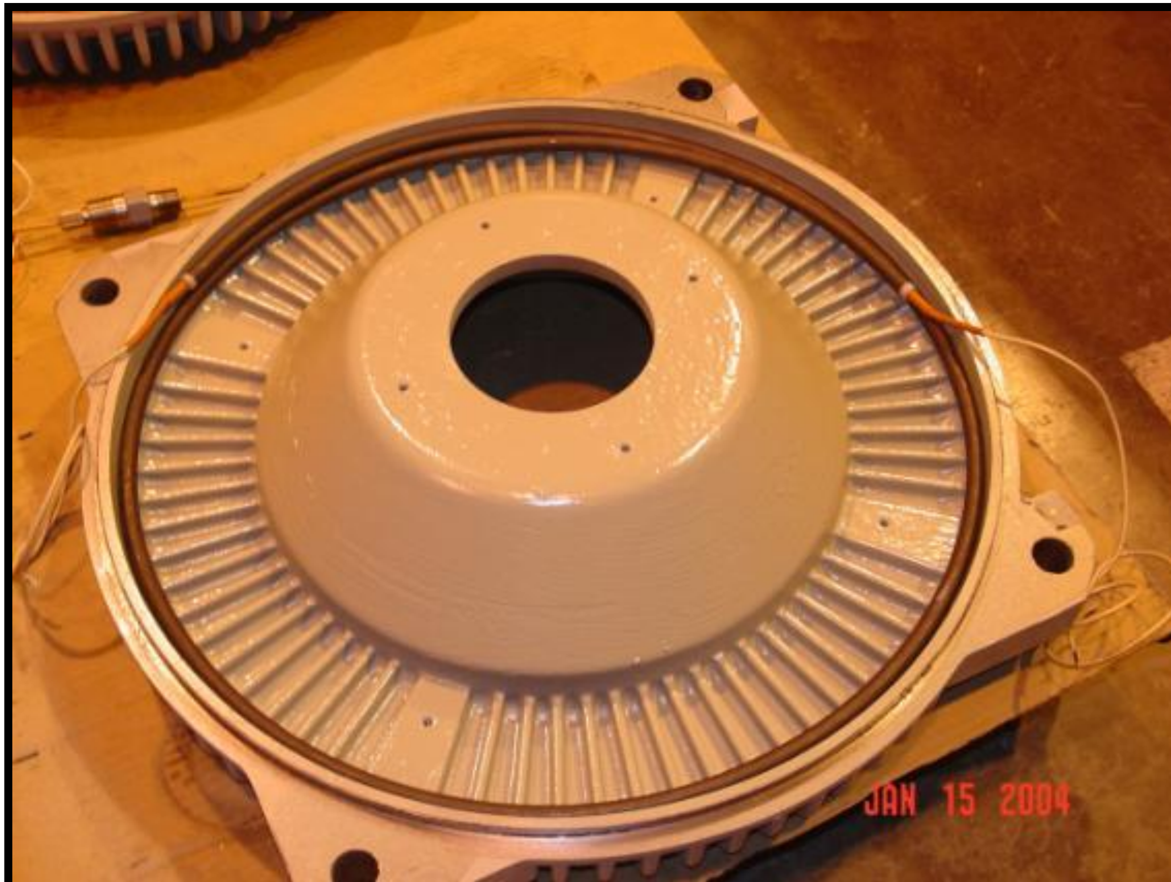
Motor Accessories

- Space Heaters
  - Replaceable
  - Coilhead
- Auxiliary Boxes
- Temperature Detectors
  - Resistance Temperature Detectors (RTD's)
  - Thermocouples (T/C's)
  - Thermistor
  - Thermostat (T/stats's)
- Terminal Box Accessories
  - Standoff / Bus Bar
  - Surge Capacitor
  - Lightning Arrestor
  - Current Transformer
    - Load
    - Differential Protection
  - Power Factor Correction Capacitor
- Filters
- Differential Pressure Monitors
  - Switch
  - Gage
- Leak Detector
  - Switch
- Constant Level Oilers
  - Oil-Rite®
  - Trico
- Vibration Monitors
  - Vibration Probes
  - Velocity Transducer
  - Accelerometer
  - Vibration Switch

Motor Accessories – Space Heaters

- Open Motors - Strip or Ring Type Heaters
  - Mounted inside the motor frame. Heaters may be installed without significant disassembly
- Fan Cooled Motors - Ring or Tube Type Heaters
  - Anti-friction motors utilize “ring” type heaters mounted on the inner cap. Motor must be disassembled to install / replace.
  - Sleeve bearing motors utilize “tube” type heaters mounted inside the motor frame. Motor must be disassembled to install / replace.

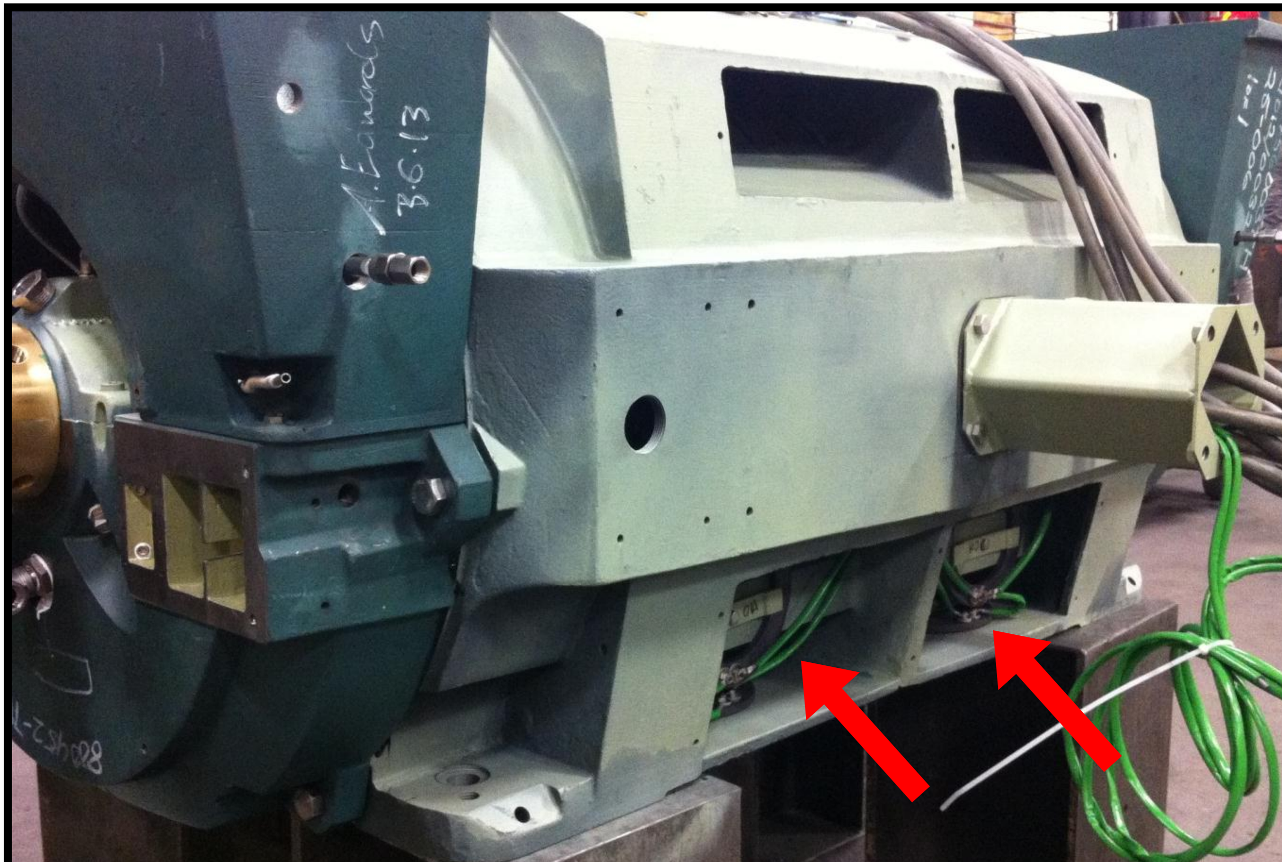
Motor Accessories – Space Heaters

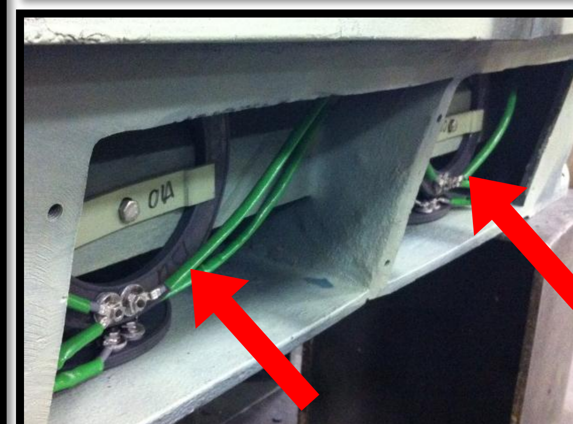


Tube Type Replaceable Space Heater

Please note this is not “installed” into the motor bracket. This picture just shows dimensional qualities of the space heater.

Motor Accessories – Space Heaters

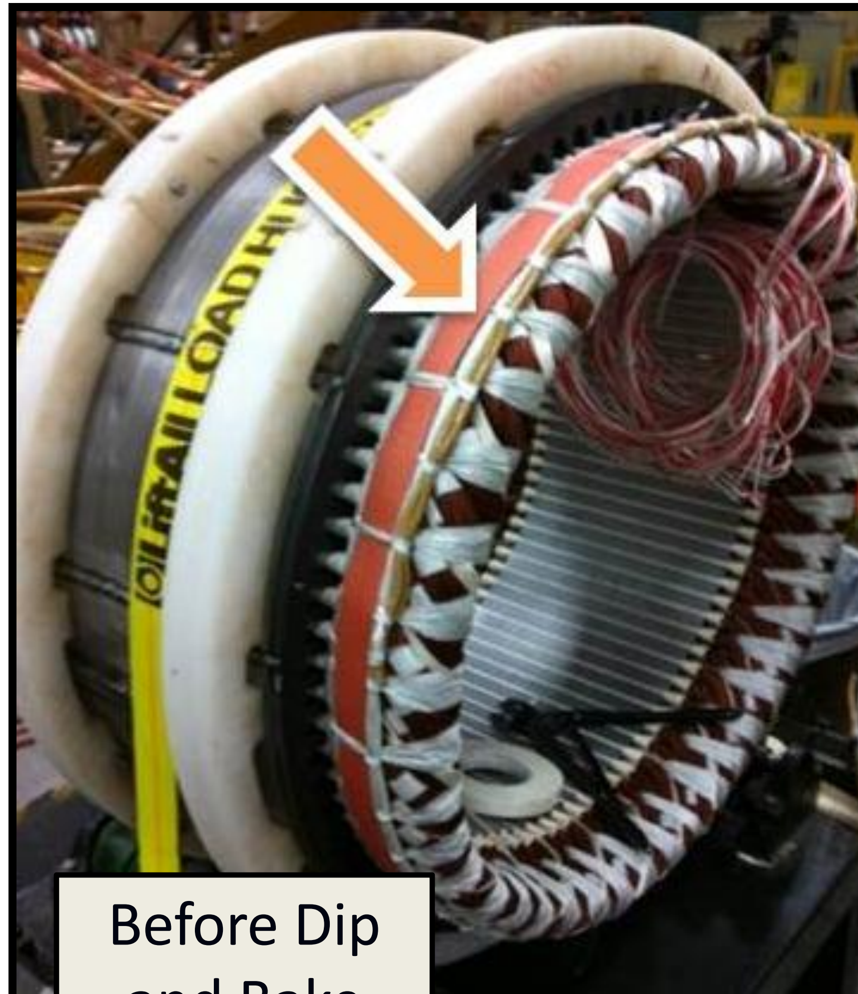




Ring Type Replaceable Heater installed in frame stringers.

Motor Accessories – Space Heaters

After Dip and Bake

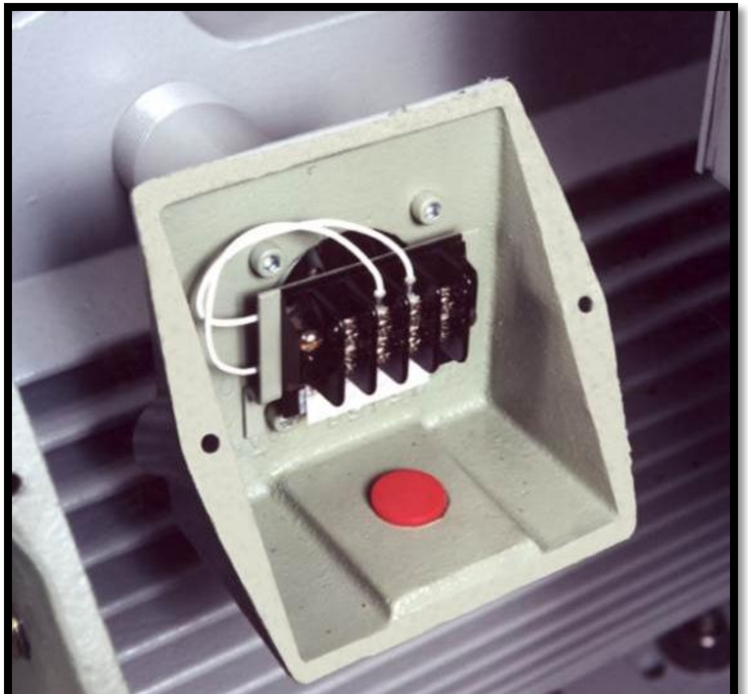


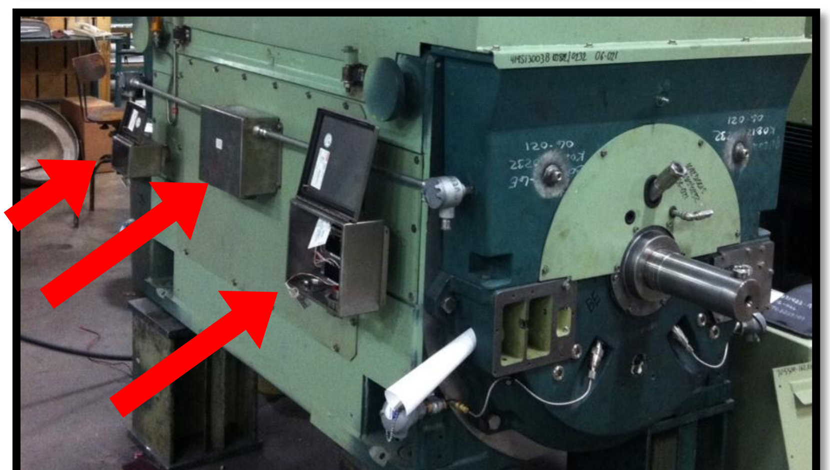
Before Dip and Bake

Coilhead Space Heaters

- Used on both Open and Fan Cooled Motors
  - Install during winding process.
  - Non-replaceable after curing.

Motor Accessories – Auxiliary Boxes





- Mounted to motor frame via pipe nipple

- Boxes available
  - Cast Iron - Standard
    - NEMA 4
    - IP54, 55
  - Fabricated Stainless Steel
    - NEMA 4X
    - IP 54, 55
  - Cast Aluminum
    - IP 54, 55
    - Suitable for Div I

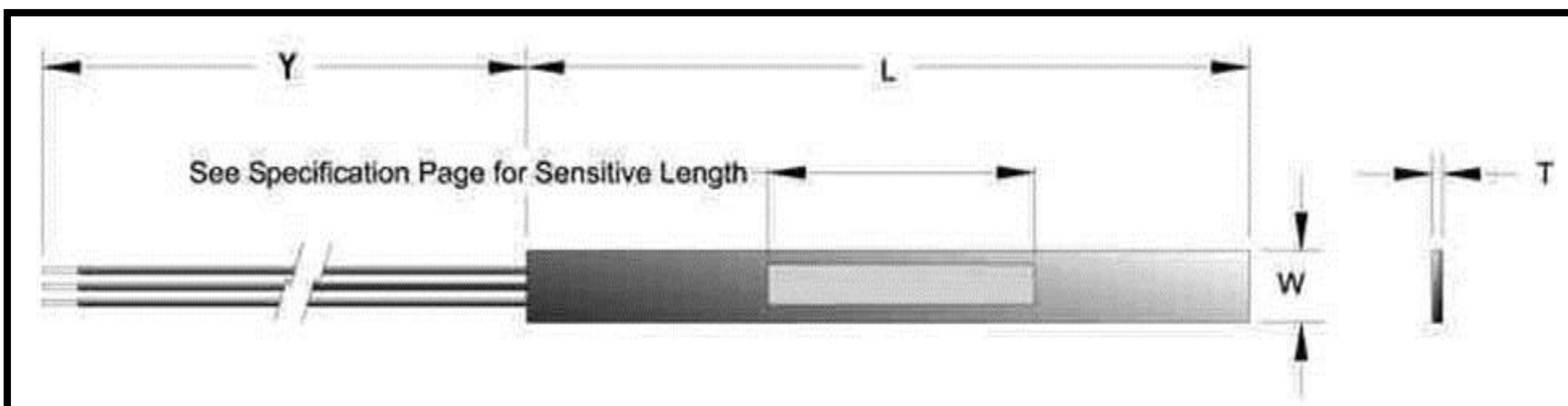
Temperature Devices - Winding

Motor Accessories - ATO - MTO

- Automatic or Manual Thermal Overload
- Acts as breaker for motor current and temp
- Usually sized to specific winding and rating
- Single or three phase
- Often used on HVAC applications
  - May require customer testing
  - Air over requires testing with customer equipment
  - UL/CSA Listed

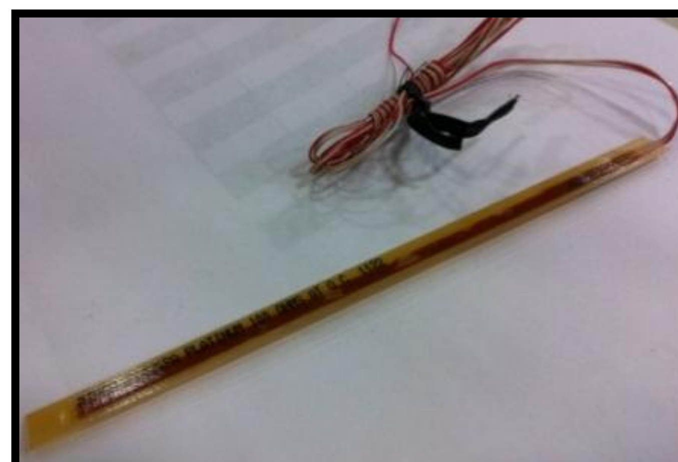
Motor Accessories – RTD's

- Resistance Temperature Detector (RTD) (Temperature Detector)
  - RTD's are thermal sensing devices containing a sensing element that is a non-inductively wound coil molded into a rectangular or round laminate with leads coming from the resistance coil. By knowing the rated change of resistance with temperature, the RTD can be used to continuously measure the internal winding temperature.
  - Types of RTD's
    - 100 ohms at 0º C (Platinum wire) <u>Most Common</u>
    - 120 ohms at 0º C (Nickel wire)
    - 10 ohms at 25º C (Copper wire)

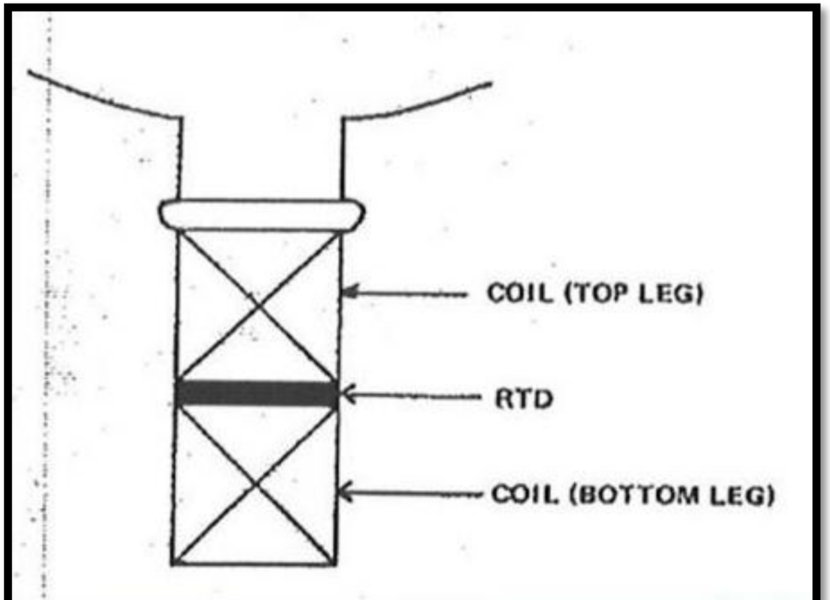


Motor Accessories – RTD’s

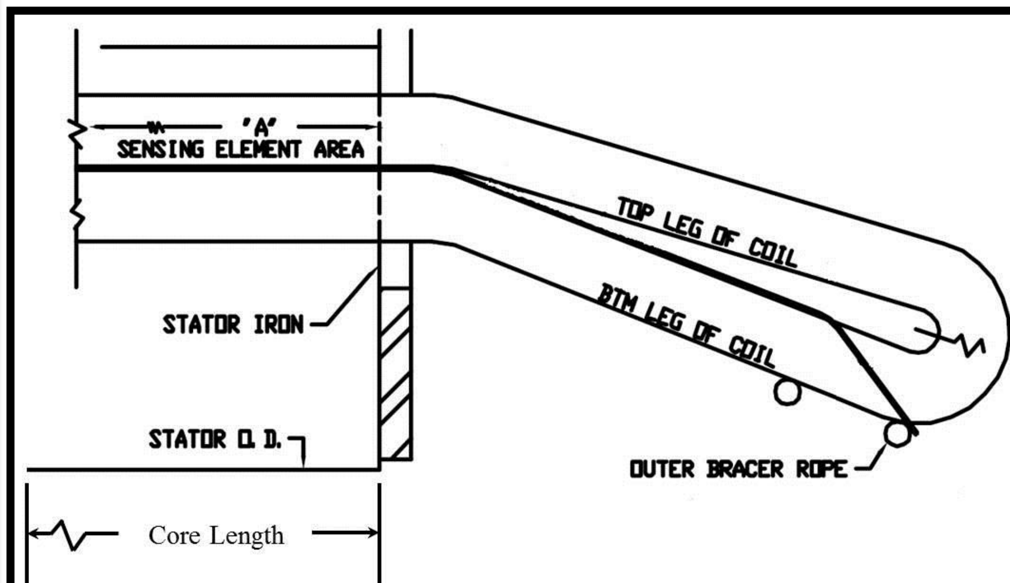
- Applications
  - Bearings - Probe type with tip sensitive area.
  - Windings - Inserted between the bottom and top coils in the slot
- Advantages
  - Capable of transmitting continuous temperature readings
  - Installed in the Hot-Spot region of the stator winding (between 2 coils), or directly contacting bearings.
  - Senses an average temperature
  - 200º C maximum operating temperature
- Disadvantages
  - External control required by customer
  - Fragile construction (New RTD is more flexible and forgiving)



Motor Accessories – RTD’s

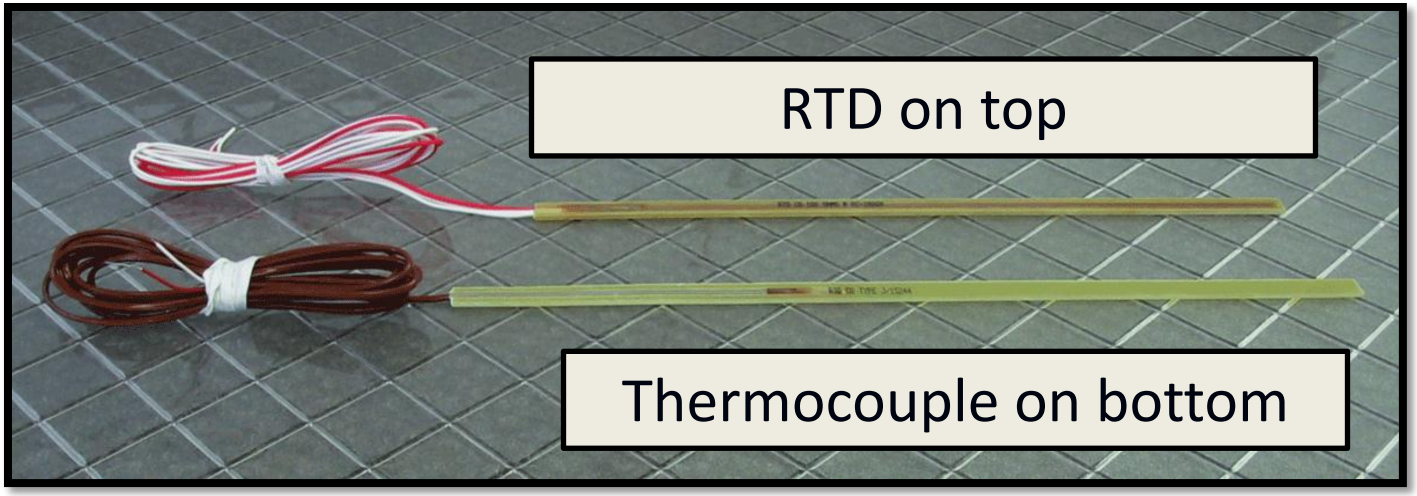


- RTD’s inserted between top and bottom coil per NEMA
- All RTD’s routed to common point on stator
- 1,2,3 per phase options available



Motor Accessories - Thermocouples

- Thermocouple (TC) (Temperature Detector)
  - Thermocouples are used to measure temperature in order to monitor and/or display the temperature reading. The sensing point of the TC is a junction of two (2) dissimilar metals that produces a small voltage (current) proportional to the temperature of the measured area. By knowing the rate of change of voltage with temperature, the TC can be used to continuously measure temperature
  - Types of TC's used at RSN
    - Iron-constantan (Type J) Most Common
    - Copper-constantan (Type T)
    - Chromel-constantan (Type E)
    - Chromel-alumel (Type K)



Motor Accessories - Thermistors

- Thermistor (PTC) (Temperature Switch on/off)
  - Thermistors are positive temperature coefficient devices that operate with a solid state relay. At normal temperatures, the resistance is relatively low. The resistance remains relatively constant up to a pre-determined temperature, depending on thermistor design. A rise in temperature above this pre-set limit causes the resistance to greatly increase very abruptly, thus tripping the relay.
  - Some common setpoints.
    - 155º C -class F insulation
    - 185º C -class H insulation

Motor Accessories - Thermistors

- Applications
  - Bearings - Probe type with tip sensitive area.
  - Windings - Inserted between the bottom and top coils in the slot. (Not recommended for Form Wound Stators. Slot configuration does not have allowable space, therefore thermistor must be taped to coil end away from the hot-spot of the stator.
- Advantages
  - Rapid thermal response
  - Inexpensive thermal protection
  - 600 volt rated
- Disadvantages
  - External control required
  - Can not provide continuous temperature readings (on/off switch)

Motor Accessories - Thermostats

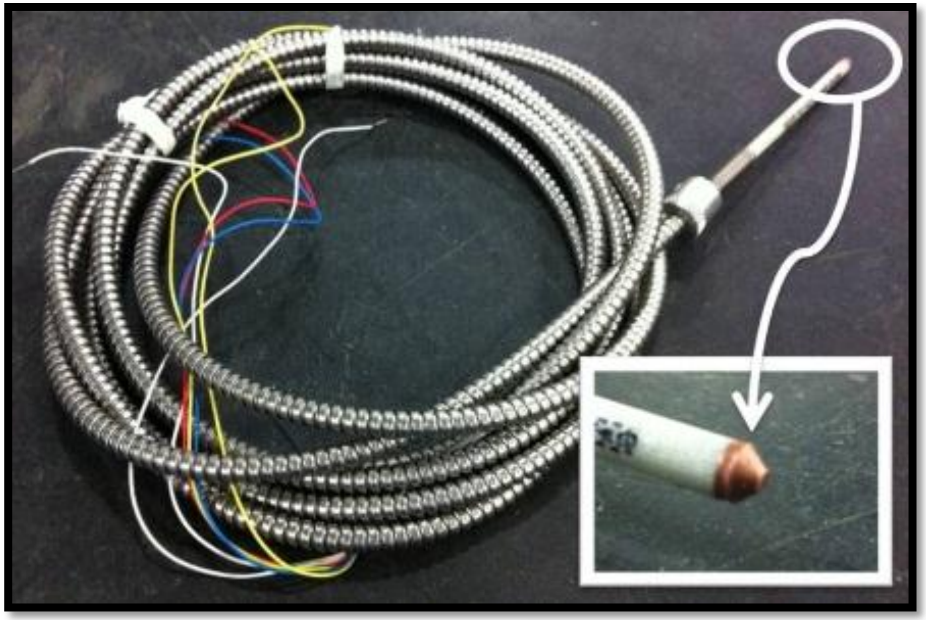
- Thermostat (Temperature Switch on/off)
  - Thermostats are bi-metallic snap switches. They use bi-metallic discs to operate a set of contacts. When heated the internal stresses of the bi-metal causes the disc to reverse its curvature with a snap action at a fixed non-adjustable temperature and open the electrical contacts. A decrease in the temperature below reset temperature of the disc relieves the internal stresses in the disc which returns the disc to its normal curvature and closes the contacts.

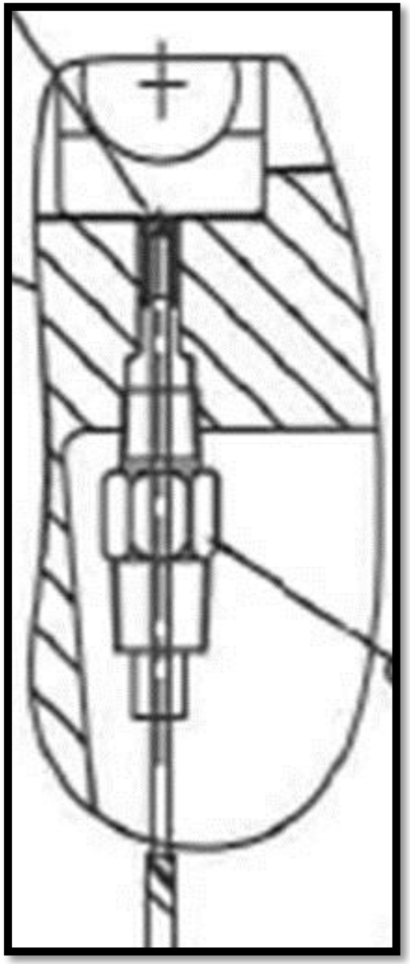
Motor Accessories - Thermostats

- Applications
  - Windings - Installed on the stator winding head. (The thermostats used are hermetically sealed and therefore can be used in hazardous areas.) Required on all DIV 1 motors
  - Setpoints 160ºC, 140ºC
- Advantages
  - Simple to install
  - Low cost
  - Can be wired to the customers holding coil circuit
  - 600 volt rated
- Disadvantages
  - Slow thermal response
  - Can not provide continuous temperature readings (on/off switch)
  - Not located in hot-spot areas of stator

Temperature Devices - Bearings

Motor Accessories – Bearing Probes





Motor Accessories – Bearing Probes

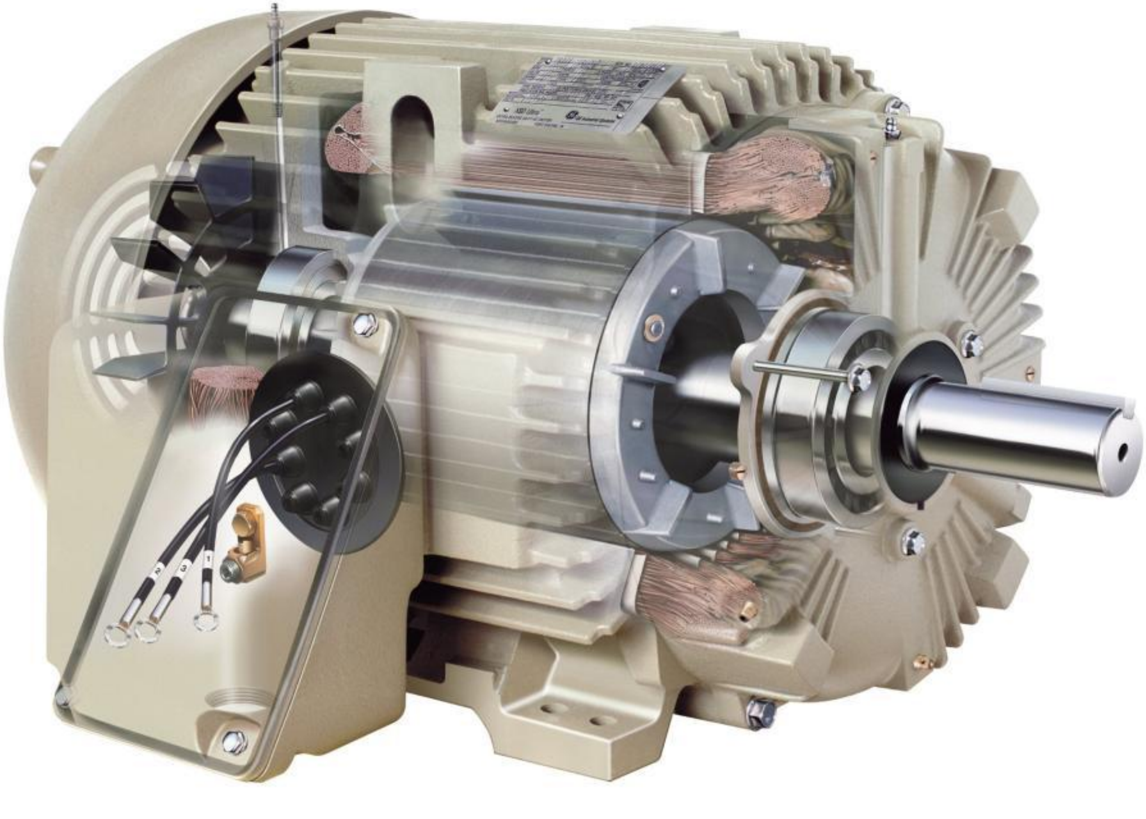
- Bayonet style probe installed into bracket using bayonet adapter.
- RTD leads routed to condulet.

Motor Accessories – Condulet Heads

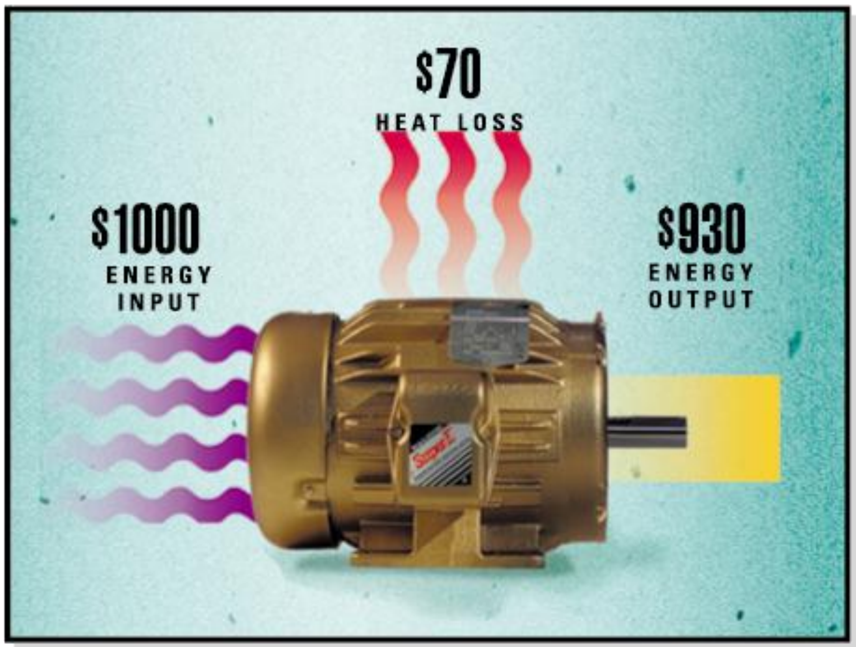
- One condulet per bearing is standard
- Bearing RTD’s may be routed to winding RTD box via flex conduit

Questions?

Making Motors More Efficient



Motor Electricity Usage



- All of the electricity that enters a motor is either lost as heat or converted into mechanical energy (torque).
- The heat produced by losses must be removed.

Motor Efficiency

- Motor efficiency is a measure of the effectiveness with which a motor converts electrical power to mechanical power.

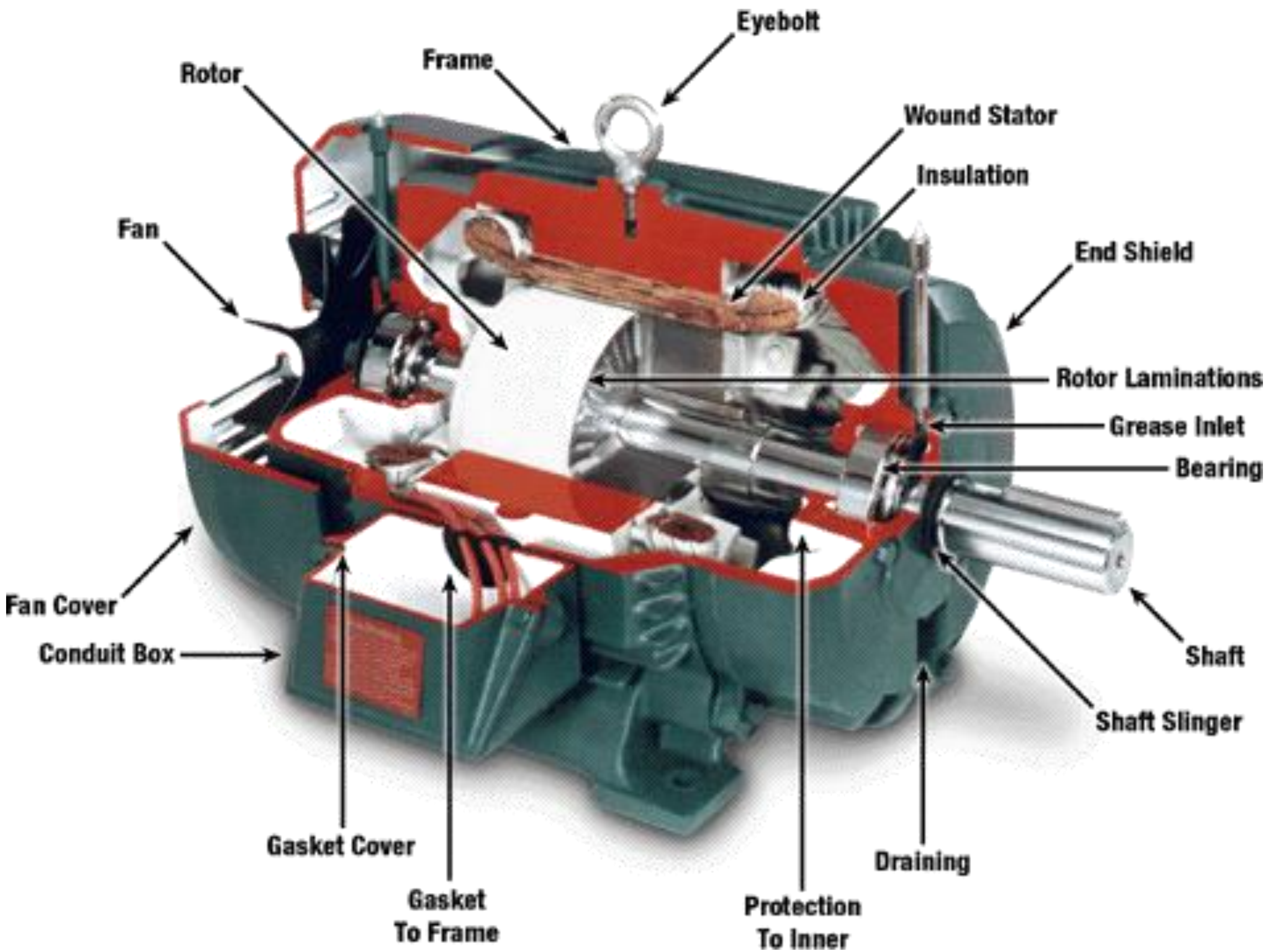
- The only power actually consumed by the motor is electrical power, or watts, lost during the conversion process, which takes the form of heat dissipated by the motor frame.

- It is defined as the ratio of power output to power input or, in terms of electrical power, watts output to watts input. (1 HP = 746 WATTS)

- Motor Efficiency = $\dfrac{\text{HP x 746}}{\text{(HP x 746) + Watts Loss}}$

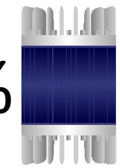
- **Efficiency =** $\dfrac{\textbf{Output}}{\textbf{Input}} = \dfrac{\textbf{Output}}{\textbf{Output + Losses}}$

AC Motor Components



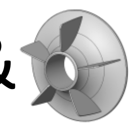
Induction Motor Power Losses

- Primary I^2R (Stator Winding) 40%



- Secondary I^2R (Rotor bars) 25%

- Core Losses (Iron) 15%

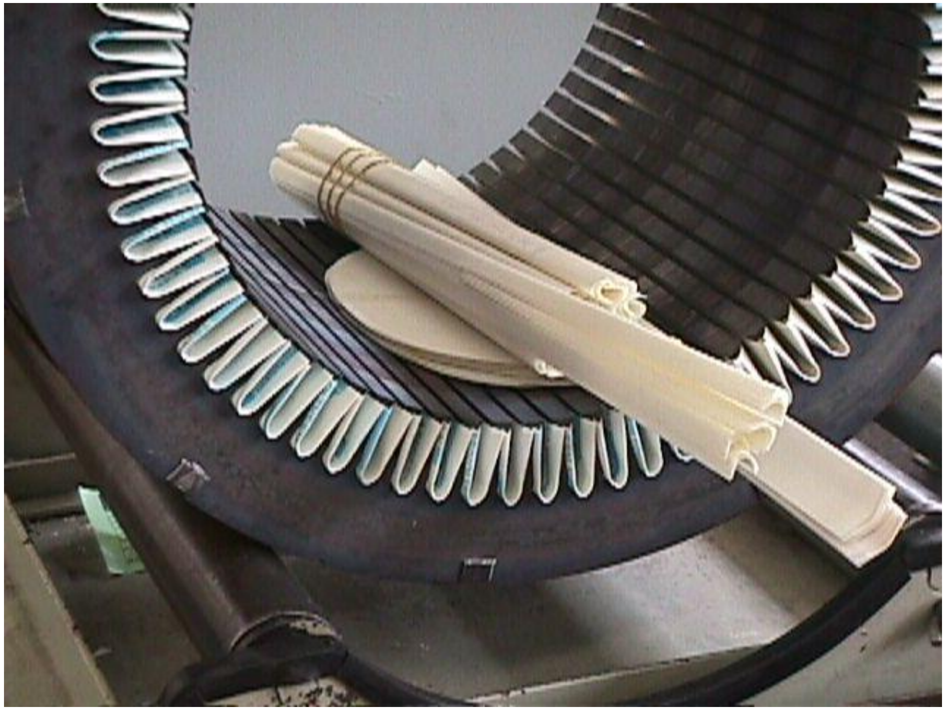


- Friction & Windage (Fan & bearings) 9%

- Stray Load Loss 11%

Next

Stator with Slot Insulation



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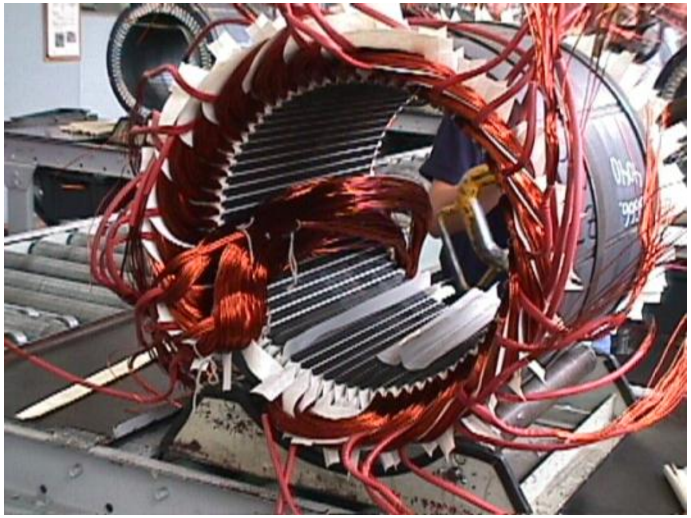
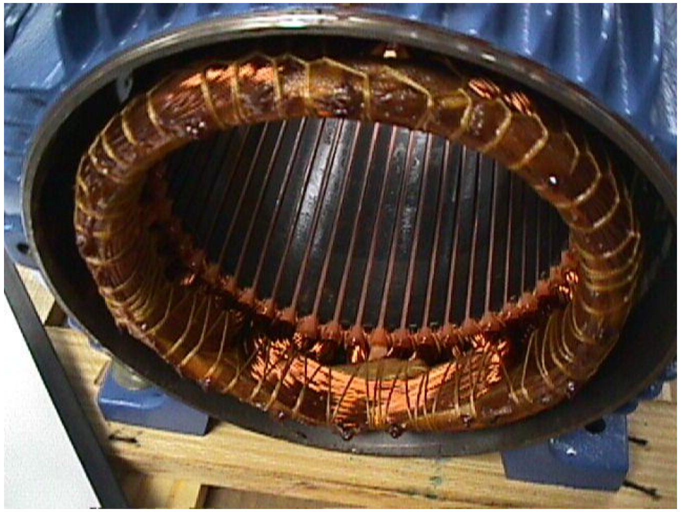
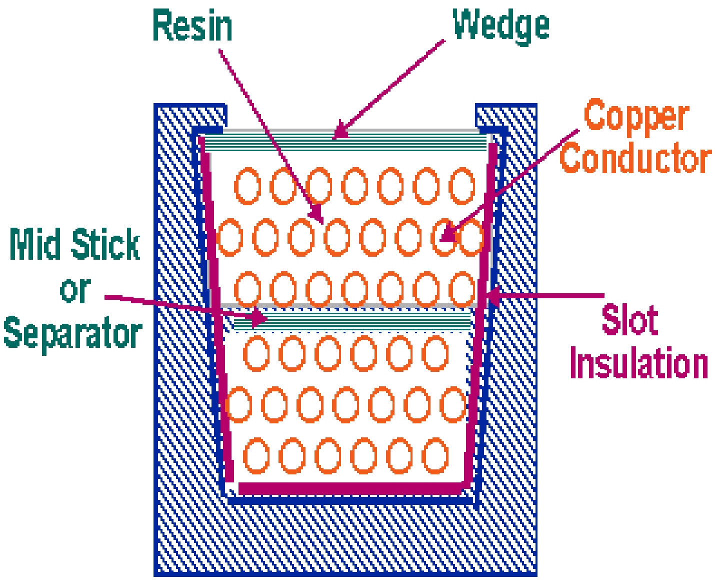
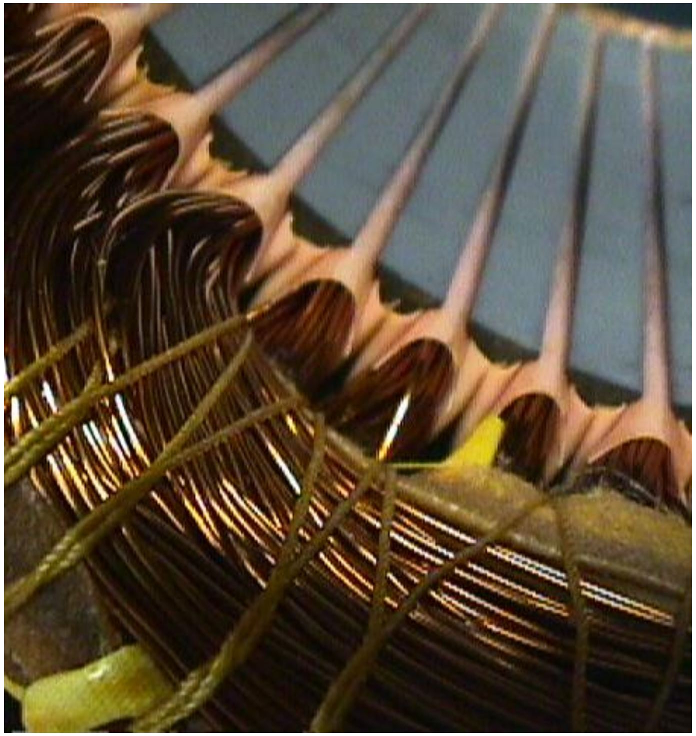
Winding



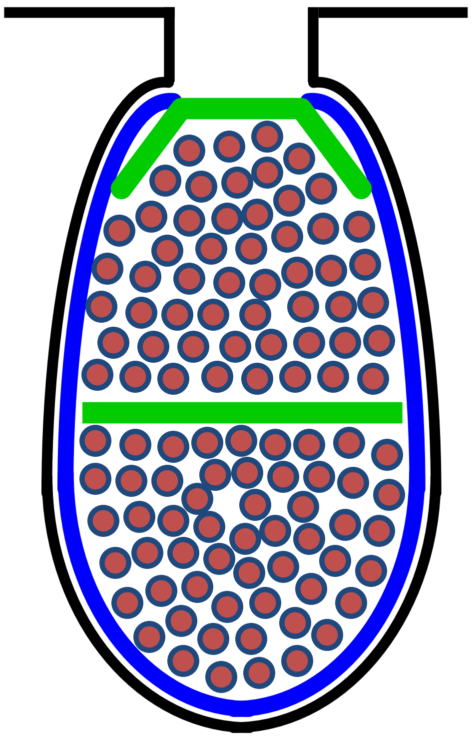


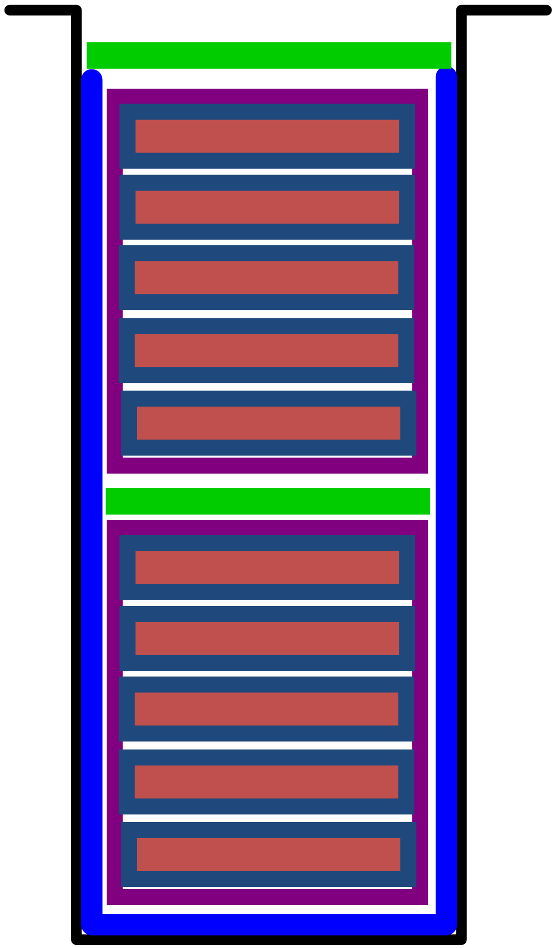
Slot fill


Resin
Wedge
Copper Conductor
Mid Stick or Separator
Slot Insulation



Stator Windings





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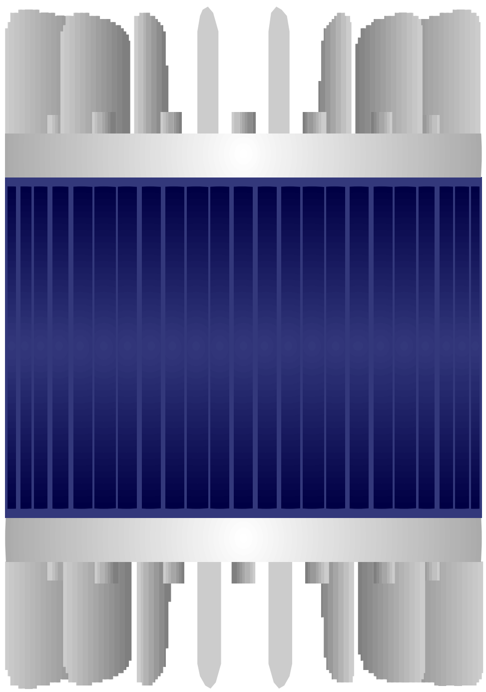
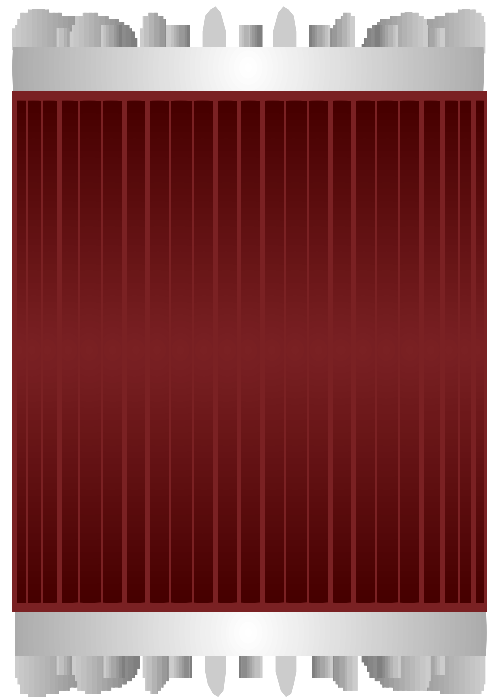
Rotor General Comparison



Standard

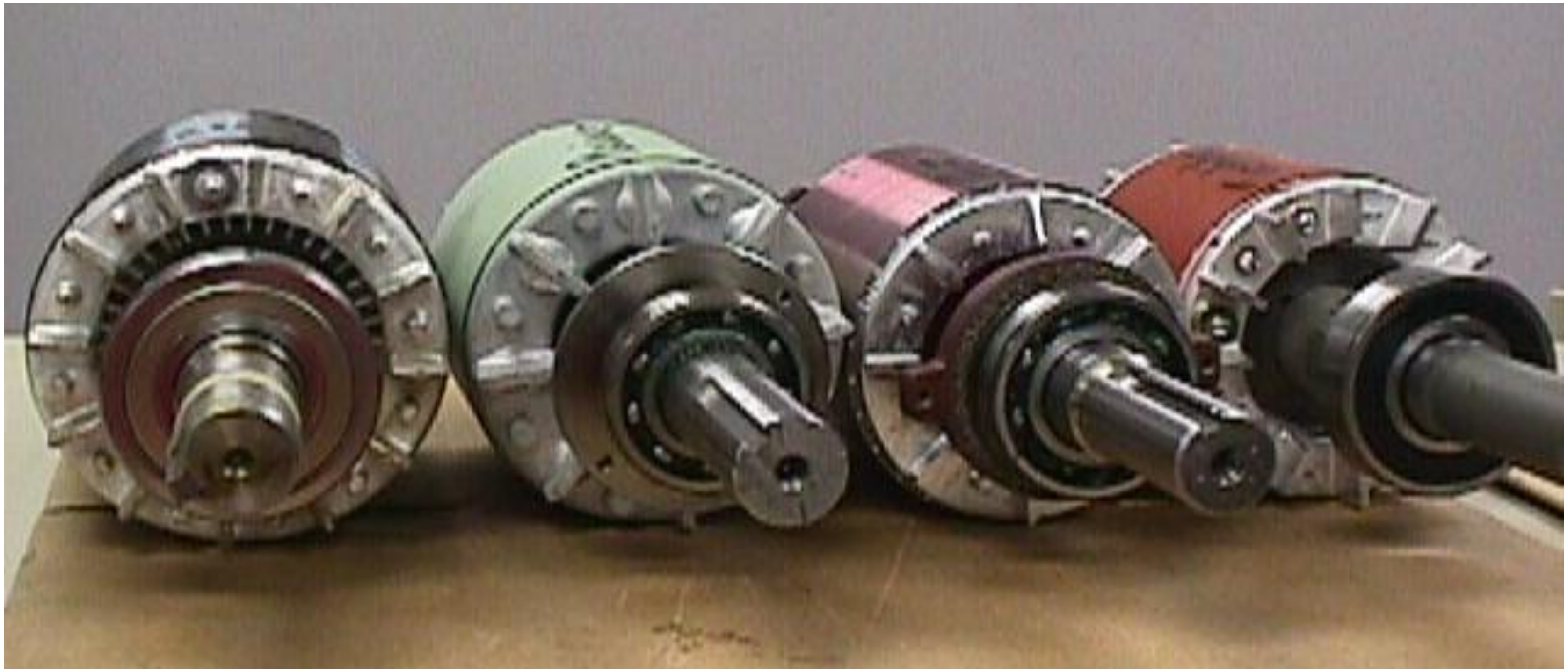


Premium

~50% more material

Design Choices

10HP Rotor comparing various manufacturers. Diameters require distinct tooling.



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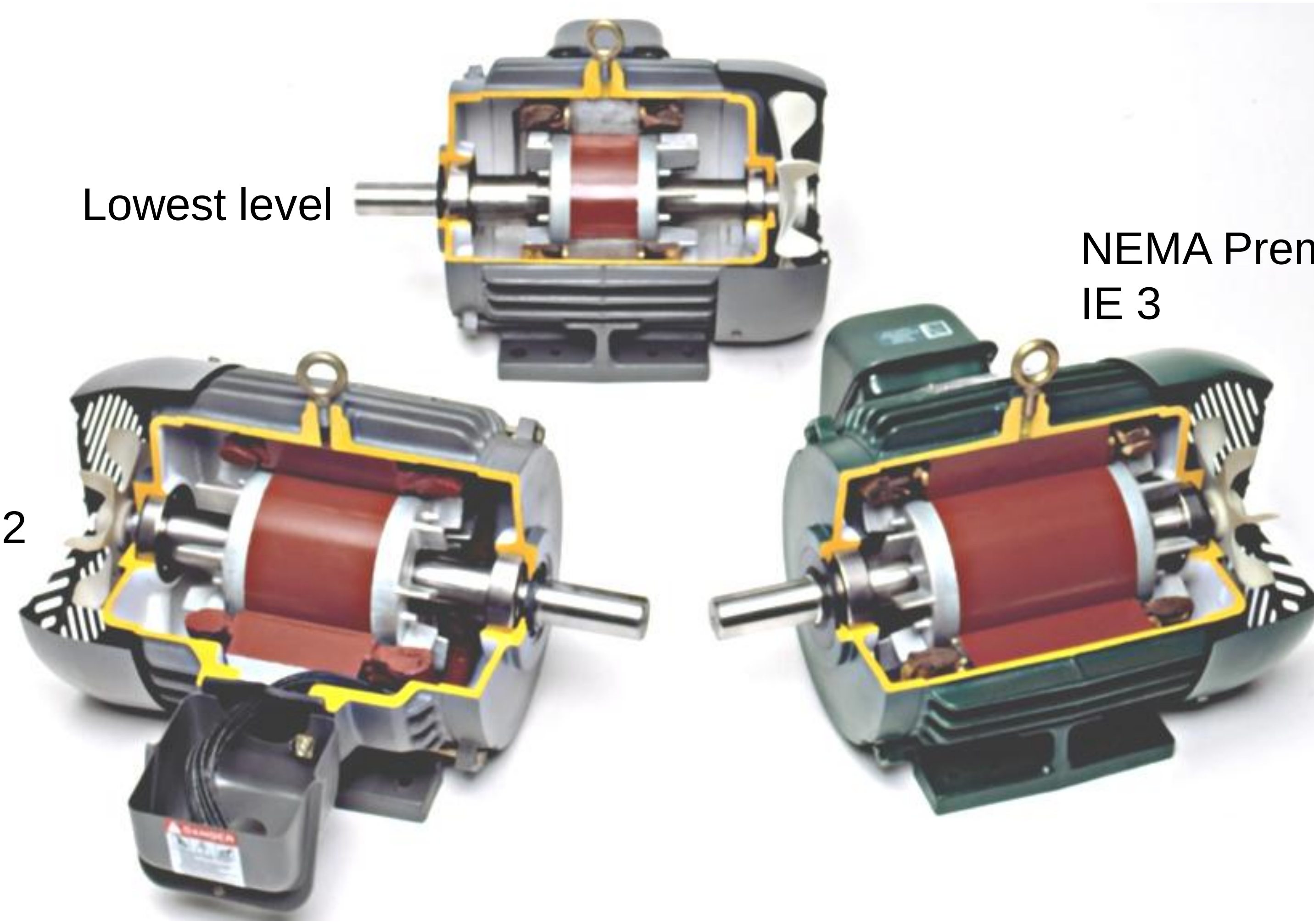
Progression of Active Material Requirements

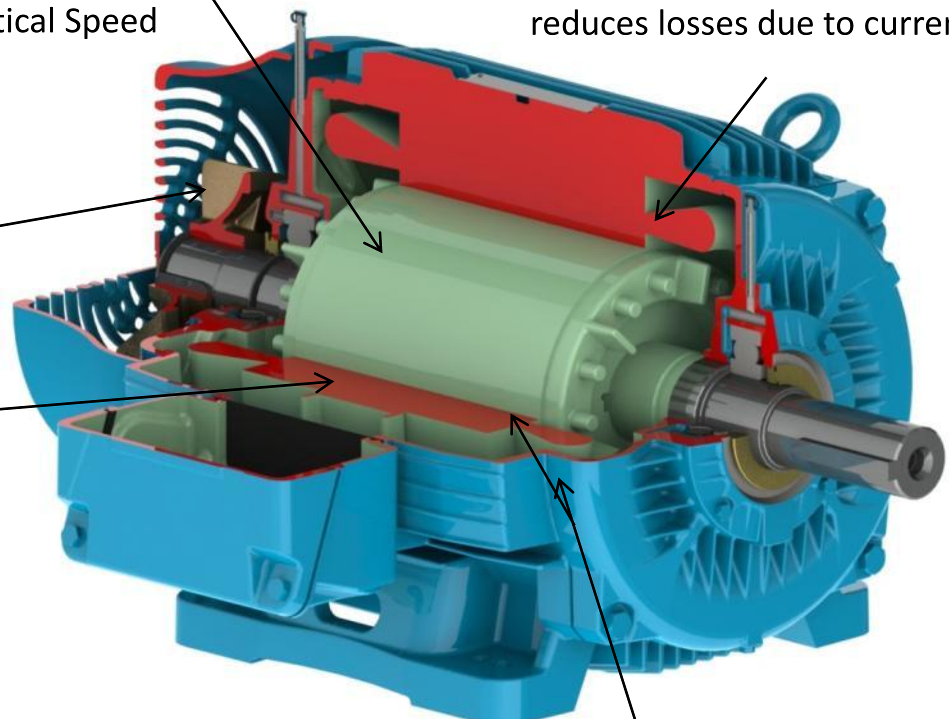


The Making of a NEMA Premium® Motor

•Use of larger redesigned rotor conductor bars increases size of cross section, lowering conductor resistance (R) and losses due to current flow (I) while maintaining critical Speed and Torque characteristics

•Special Stator slot designs allows use of more copper and larger conductors increase cross sectional area of stator windings
This lower resistance (R) of the windings and reduces losses due to current flow (I)

•Low loss fan and cooling system design reduces losses due to air movement



•Use Premium grade silicon steel laminations - thinner to reduce eddy current losses in core steel
•Core plated laminations to insure quality core and allow rewinds back to full efficiency
•longer core stacks to reduce magnetic flux density reducing current demand and increase efficiency

•Bracket fits machined with reference to id of stator core to maximize stator to rotor concentricity and minimizing stray load losses

•The highest quality materials and manufacturing techniques are used to assure optimum design
•This combined with strict quality control procedures minimizes stray load losses

Premium Efficient Motor Design

Components of Improvement and Trade-offs

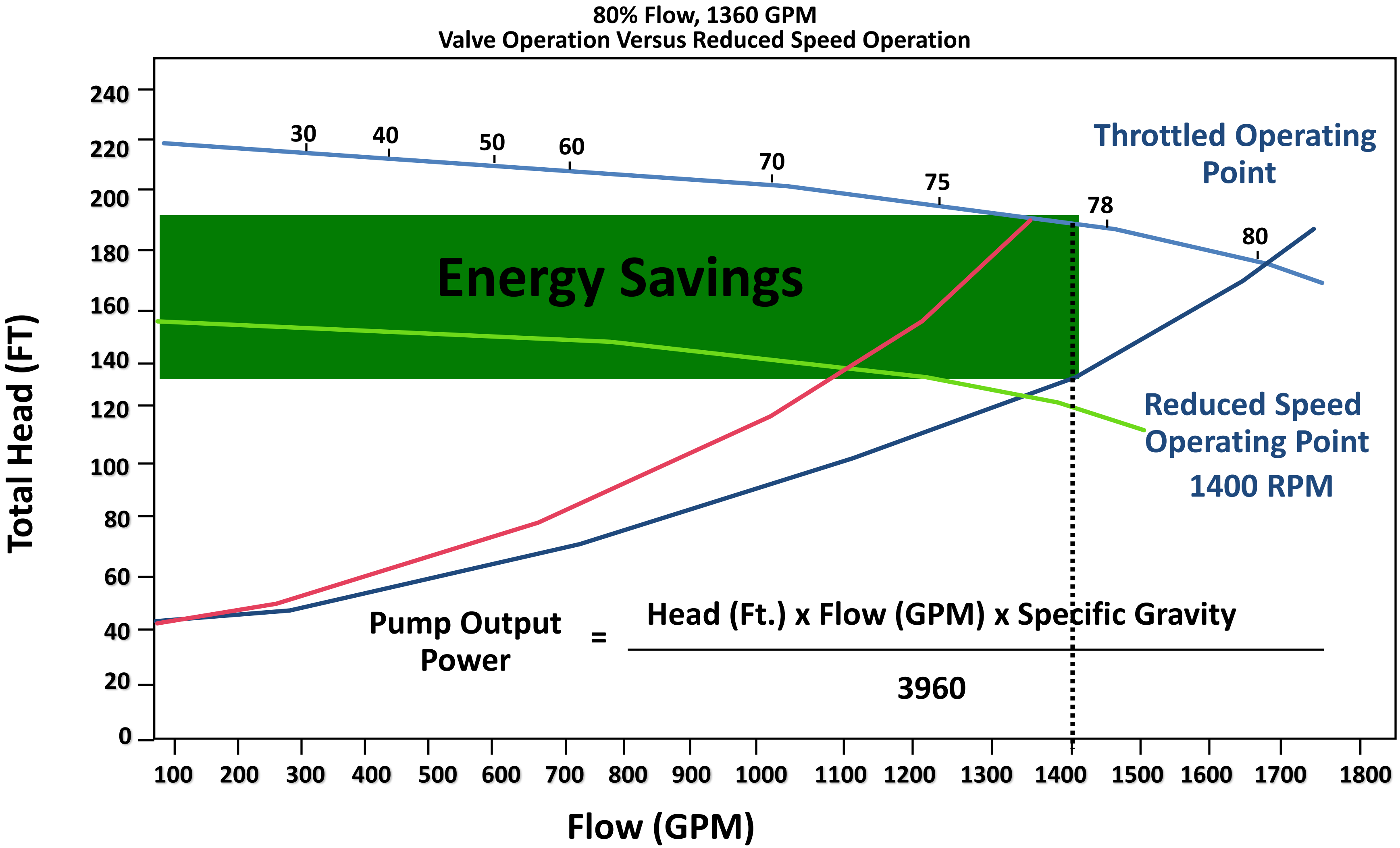
- Lower Resistance to current flow
  - Winding (More Copper Reduce resistance)
    - Higher Inrush currents affect starter/protection
  - Rotor (Slot design reduce running resistance)
    - Higher starting Current
    - Less slip – drive loads faster – Draw more load on Some applications
- Stator Core
  - Improved Electrical Steel
    - Longer core required – Size limits
  - Thinner Laminations
    - More tooling maintenance
  - Inorganic coating
- Fan Design (Low Loss)
- Stray Load losses
  - Manufacturing Processes - Quality Assured
- Optimized Material Utilization – Experience in Design

Everything discussed is at a steady state constant load

Application Considerations

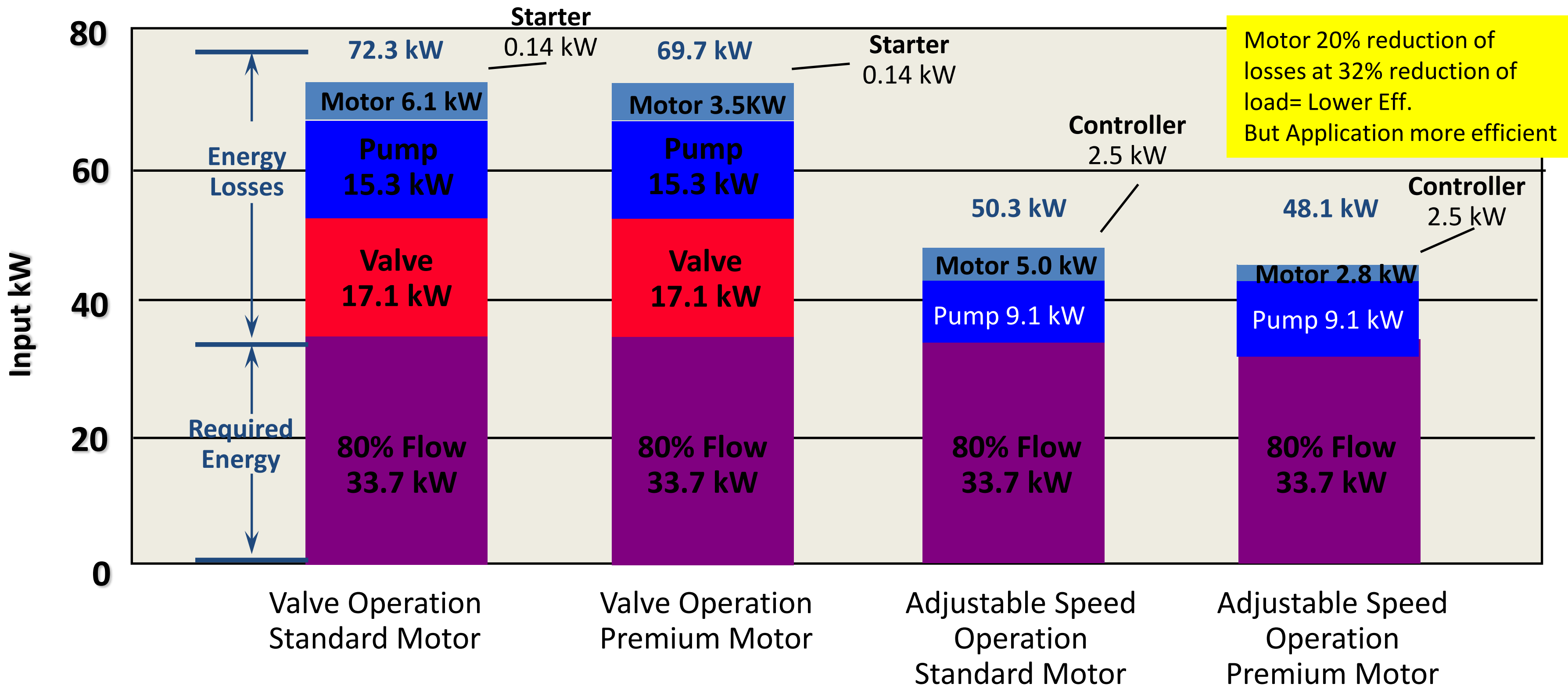
- Design D – High slip makes motor less Eff steady state but <u>system</u> more efficient and more reliable
  - Cyclic or high starting duty loads –
  - Crane and Hoist
  - Oil well Pump jacks
  - Stamping press
- Centrifugal loads- (Pumps and fans)
  - These applications can increase HP required by as much as X^3 of the load. The lower slip of more efficient motors can draw more load and offset efficiency savings on existing applications
- Altitude, Ambient, Voltage Variance
  - Anything impacting the operating temperature of the motor will impact efficiency
- VFD Operation – Can adjust to meet load requirements
  - Adds additional losses at steady state condition
  - Allows adjustments to match system requirements and potentially operate the system at a significantly higher efficiency

Typical 100 HP Pump Application



VFD Savings Potential

Typical 100 HP Pump Application
80% Flow with 25% Lift 6000Hrs/Yr @$.05/kwh



System Efficiency	**46.6%**	**48.4%**	**67.0%**	**70.4%**
Operating Cost	**$21,690**	**$20,910**	**$15,090**	**$14,430**
System Prem Cost	**$0**	**$700**	**$8,000**	**$8,700**


Now on to the next subject

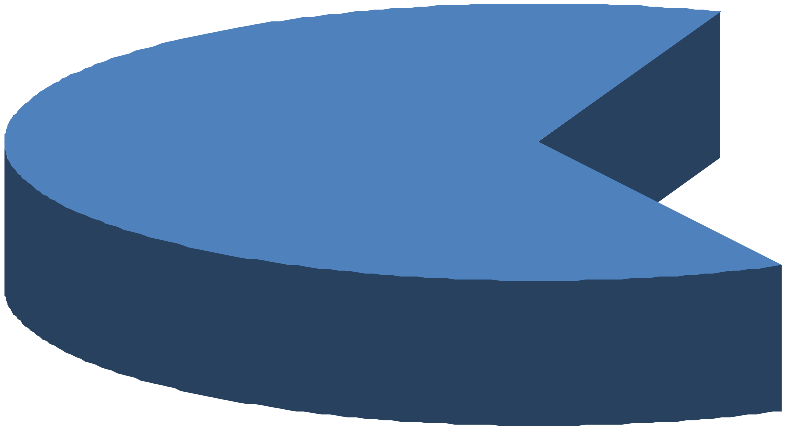
R Boteler

REGULATORY AND CONCLUSION

Regulatory History and Conclusions

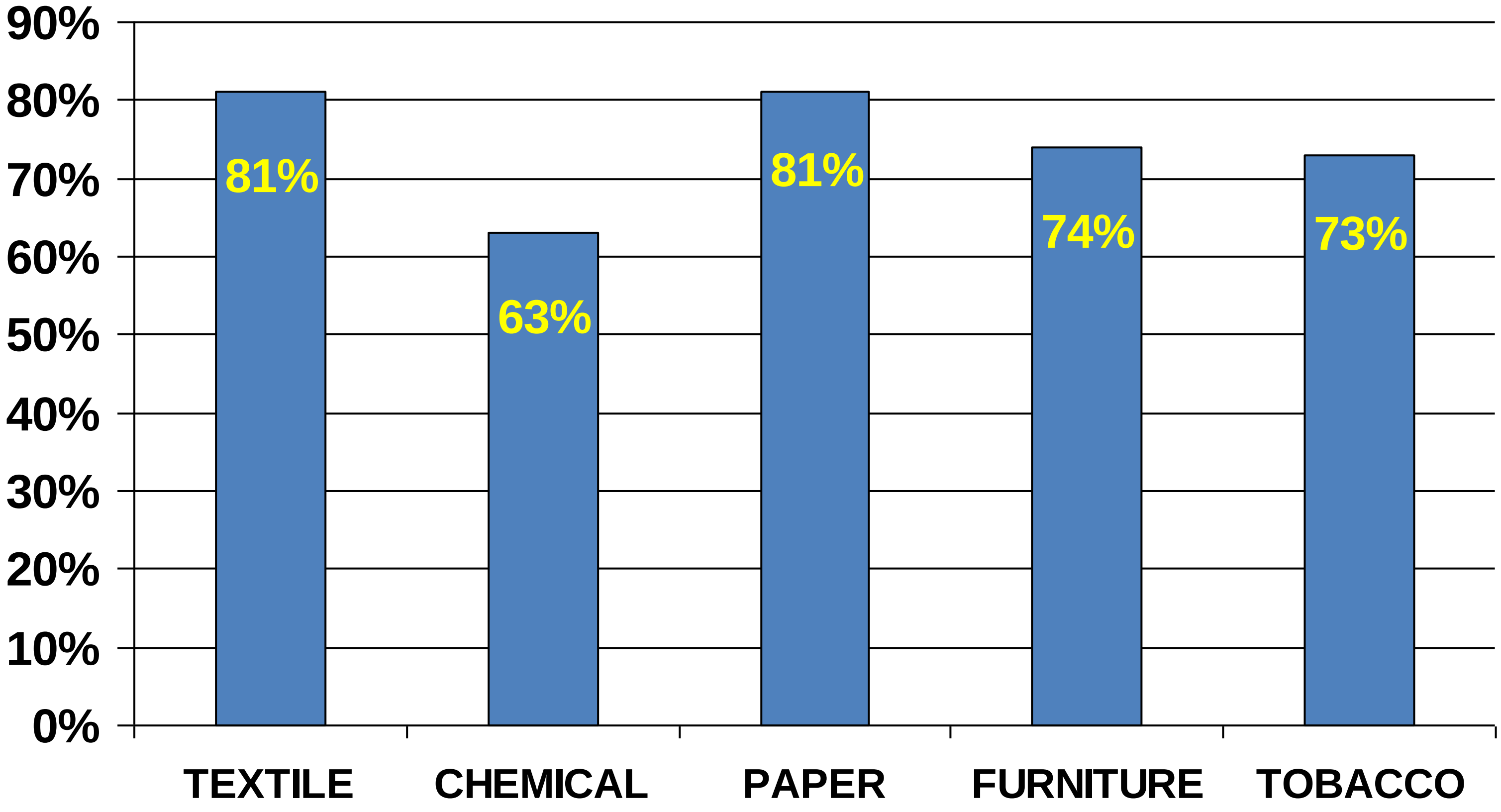
- Motor market
- Levels of efficiency
- Motors as a component of a system
- Carbon study
- Life cycle and other DOE activities
- Historic timeline
- Global standards

Motor Electricity Usage



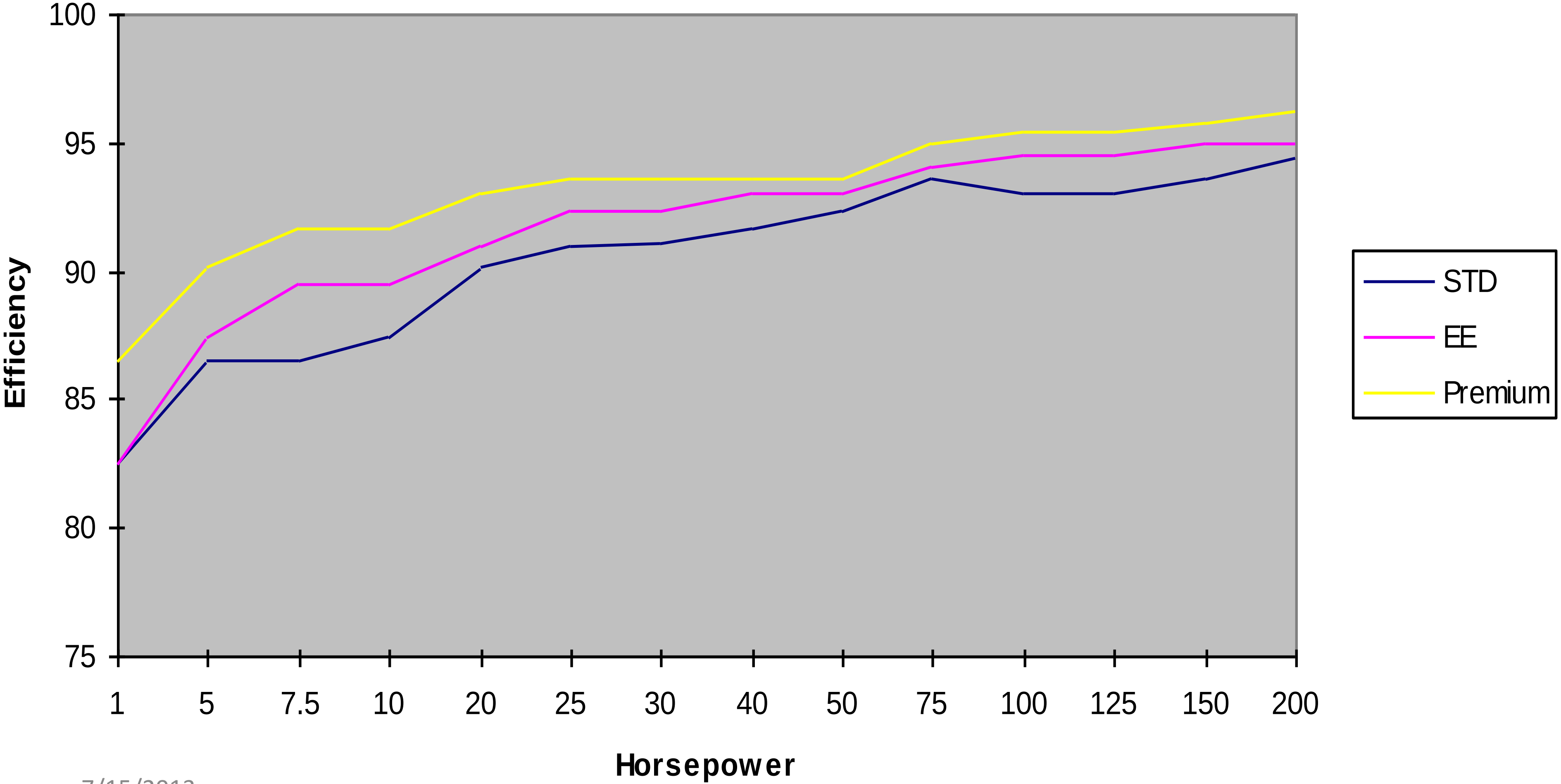
- Electric motors consume 63% of electricity used by industry (1998 DOE) or about 25% of all electricity sold in the U.S.

Certain Industries Have Higher Motor Energy Consumption

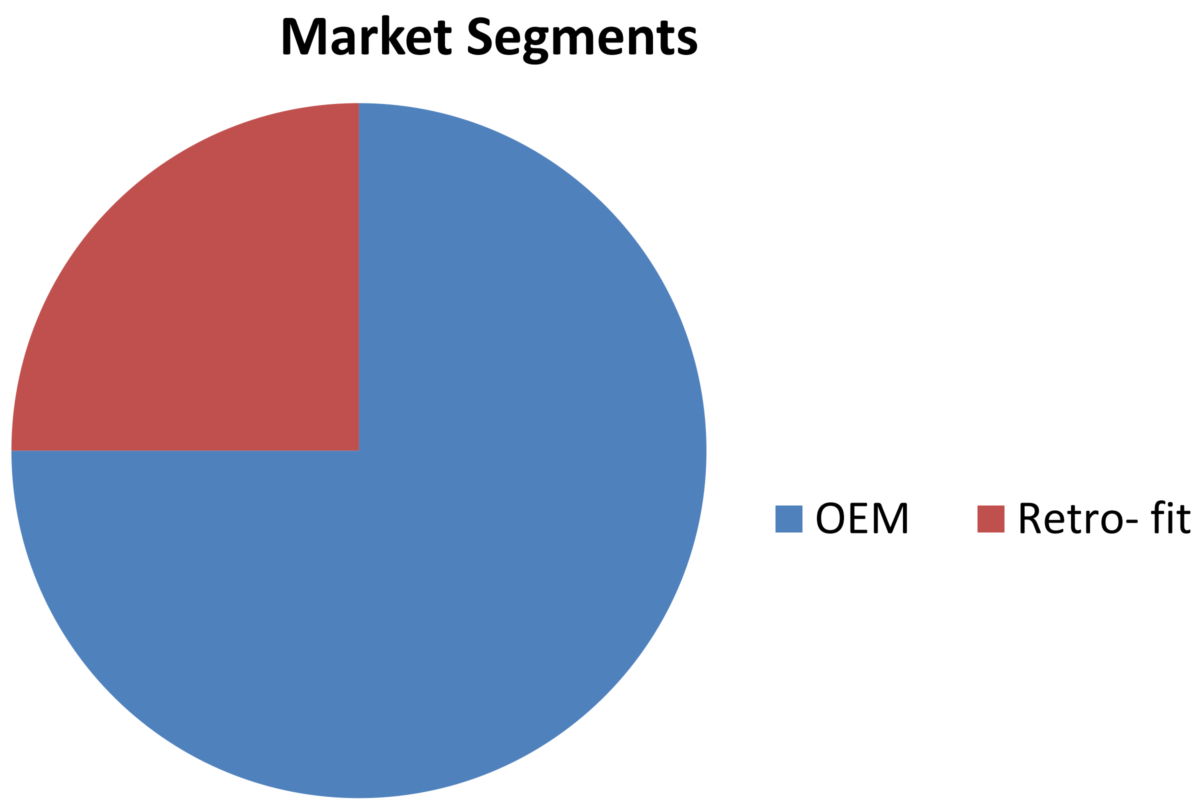


Energy Policy Act of 1992

Three Levels of Motor Efficiency



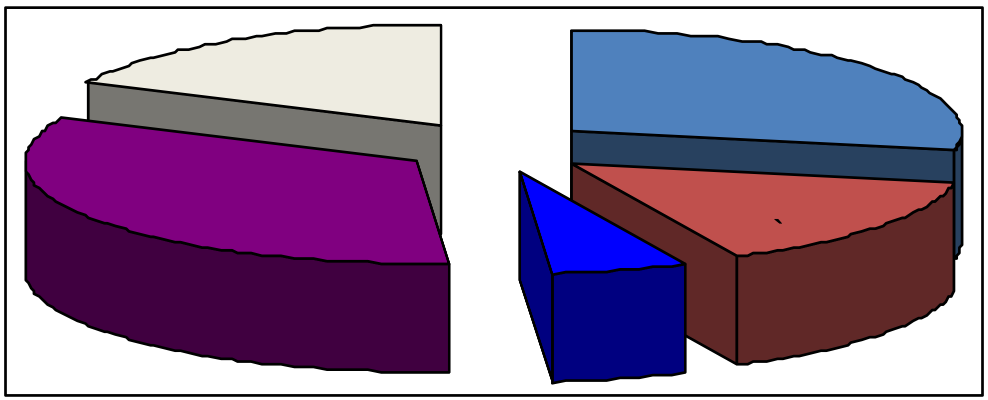
Why do we need motor efficiency regulation?



Current US Motor Market

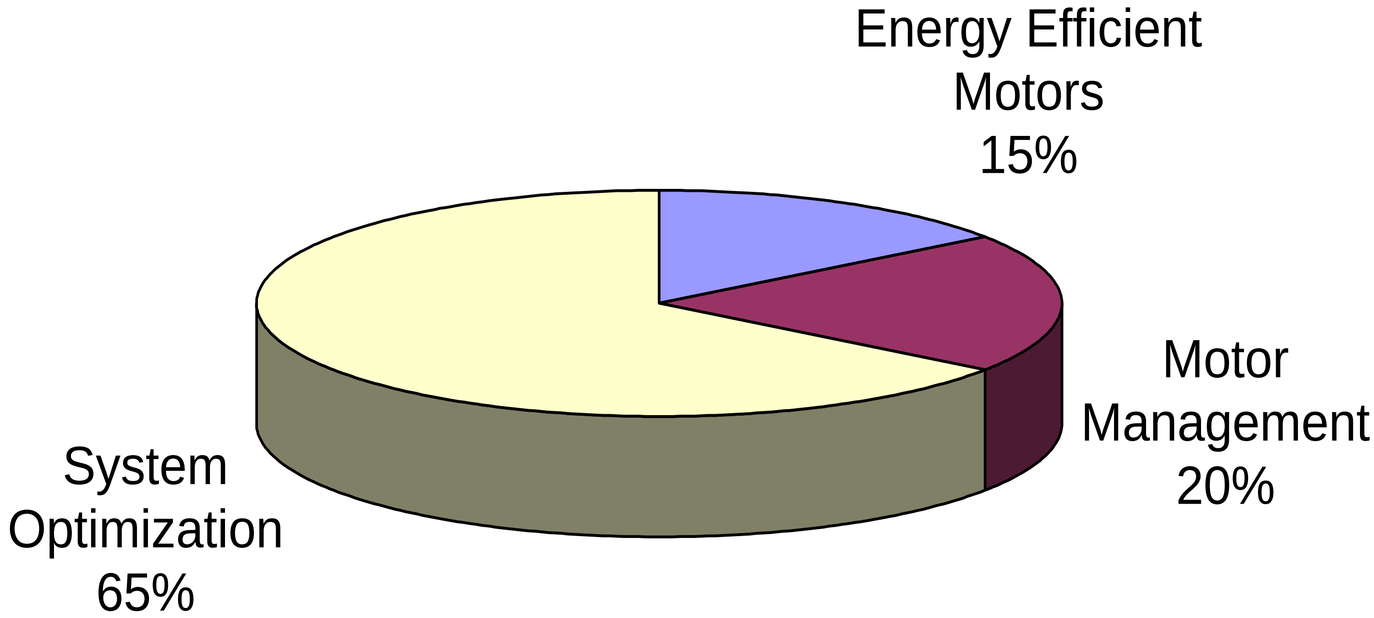
Equipment classes in millions of units per year

Total 5.6 million units USA per year



Type one and two 1.5 million units are covered by regulation today

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"

Recent MIT report supports NEMA

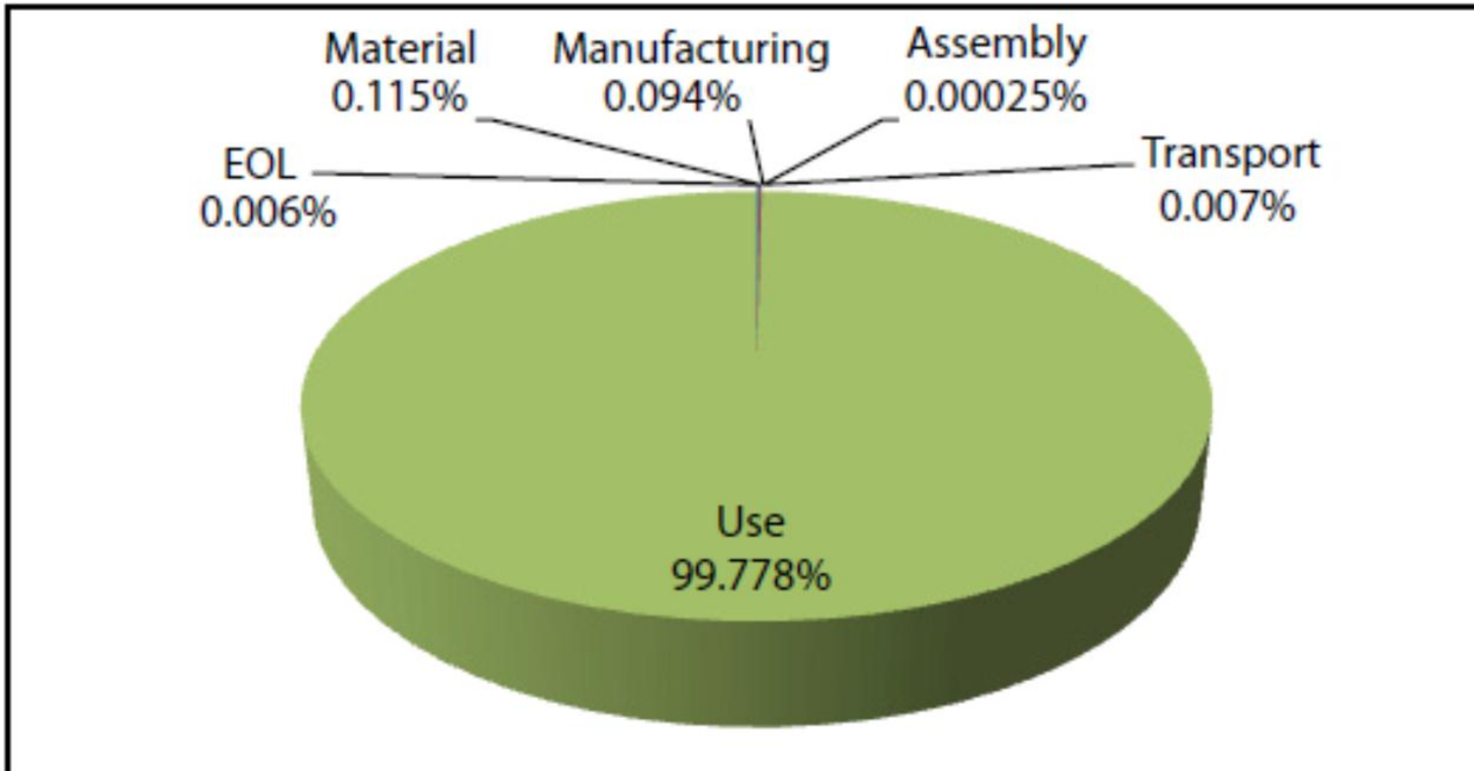
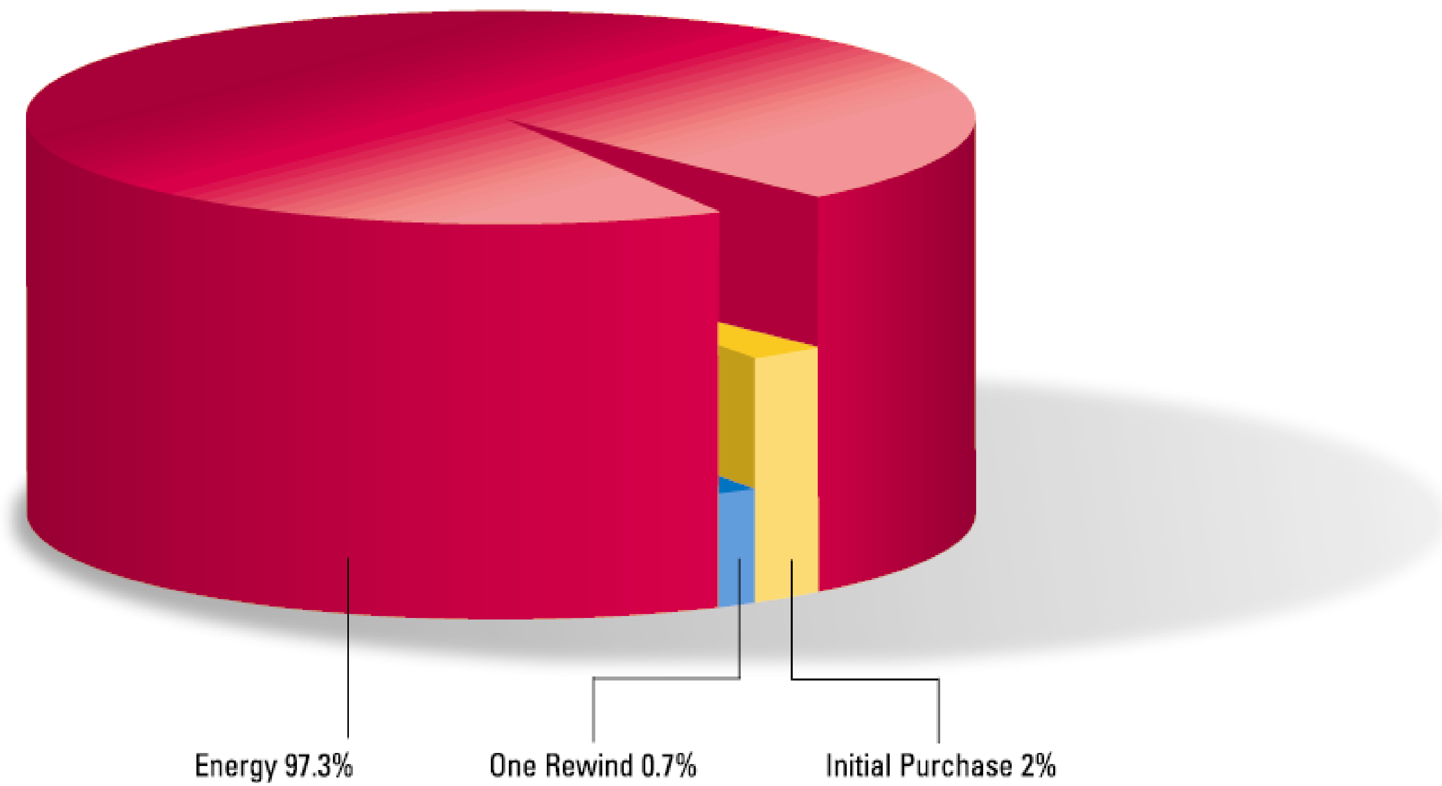


FIGURE 20. Overall life impact (GWP Impact, mean value) for a 25 HP NEMA premium motor

Life Cycle Cost of a Motor



DOE Activities

- Best practices
  - Washington State
    - NEMA motor section participation
  - Superior energy performance
  - Market Assessment
- Tools
  - Motor Master
  - Life Cycle Cost Analysis

Retrofit Options

Replace with a used motor or repair existing motor

fit c

– UL and code requirements
– Starter and system compatibility

Check of the internet reveals hundreds of surplus suppliers

CFR 10 part 431

- Phase one original Epact92
  - Establish base case motor efficiency levels NEMA [12-11]
  - Define cover products [general purpose]
  - Review and accept test standard[s] IEEE112B/CSA390
  - Establish lab accreditation procedures [NIST]
  - Define labeling requirements
  - Agree to timeline and implementation

CFR 10 part 431

- Phase two EISA [energy independence and security act 2009]
  - Raised general purpose motor [type one] efficiency levels to NEMA [12-12]
  - Added seven new motor categories [type two] at NEMA [12-11] efficiency levels

CFR 01 part 431

- Phase three rule proposed
  - Expand scope of covered motor equipment classes adding 4.1 million units per year
- Phase four colaboration
  - Holistic motor driven system approach using DOE test standards to provide deemed savings metrics needed for market transformation initiatives

Efficiency Elements	1992	1997	2001	2005	2007	2008	2010
Covered product	Defined	Implement	Unchanged	Unchanged FEMP	Unchanged FEMP	Unchanged FEMP	Type one and two
Efficiency levels	Defined	Implement	NEMA Premium	NEMA Premium	NEMA Premium	NEMA Premium	NEMA Prem/Epact
Test Method	Defined	Implement	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged
Lab required	Defined	Implement	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged
Compliance enforce	Defined	Implement	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged
Timing	Defined	Implement	Voluntary	Voluntary	EISA	Voluntary	Dec.2010
Revisions	Defined			FEMP Added	Discussion Begins		?

Evolution of Motor Efficiency USA

Global Motor Efficiency Standards

Efficiency Levels	Efficiency Classes	Testing Standard	Performance Standard
3-phase induction motors	**IEC 60034-30-1**	**IEC 60034-2-1**	**Mandatory MEPS ******
	Global classes IE-Code 2008; rev. 2013 *	**incl. stray load losses 2007; rev. 2013 ****	**National Policy Goal**
Super Premium Efficiency	**IE4**	**Preferred Method**	
Premium Efficiency NEMA Premium	**IE3** IE3 Premium Efficiency		**Canada** **Mexico** **USA** Switzerland 2015 EU*** 2015 / 2017
High Efficiency Epact 92	**IE2**	**Summation of losses with load test:** **P_{LL} determined from residual loss**	**Australia** **Brazil** **China** **Europe** **South Korea** **New Zealand** **Switzerland**
Standard Efficiency	**IE1**		**Costa Rica** **Israel** **Taiwan**

bold means in effect

30 November 2012, CUB
A+B International

*) Sizes 0.12 kW - 1000 kW,
50 and 60 Hz, line operated

**) for 3-phase machines,
rated output power < 1 MW

****) Minimum Energy Performance Standard

***) European Union (2015: below 7.5 kW), 2017,
IE3 or IE2 + Variable Speed Drive

MEPS = Minimum Energy Performance Standards

One Basic Model's electrical design is applied to multiple mechanical configurations delivers - NEMA Premium® efficiency

Examples of Motor Applications

Textile Machine

Waste water
aerator

HVAC Chiller

Municipal water
Supply
Reed critical
Frequency

Examples of Motor Applications

Bottle Filler

Mining
Equipment

Packaging
machine

High speed
Blower waste
Water treatment

Application Examples

Fresh Water plant

Printing Press

Pasteurizer

Paper machine

Conclusions

- Two decades of cooperative development of motor standards have delivered significant energy savings to the USA
- Motors are complex devices that drive millions of devices enabling our lifestyles
- Efficiency is only one of many attributes a motor must have to deliver useful work
- Opportunities exist to save energy using more high performance electric motors

Conclusions

- Motor manufacturers are able to customize motors to meet specific application requirements while maintaining premium efficiency performance
- A holistic approach that includes the motor driven system offers even greater saving potential for America
- Maintaining a high degree of product utility and interchangeability is critical to achieving the greatest motor system's energy savings