Technology Day

Use Motor Technology for Variable Speed

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Chemical, Oil and Gas Industry

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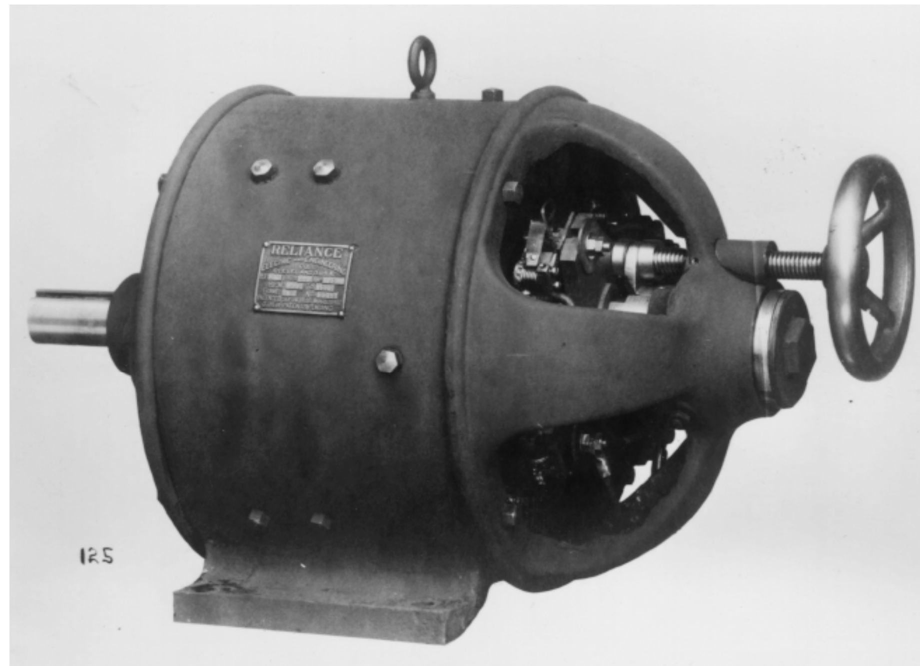
Motor Technologies
in
Variable Speed Applications

Topics for Discussion

- Motor Configurations
- Types of Variable Speed Motors
- Typical Applications
- Additional Features

The Type AS Motor in 1905

- **“Type AS” (adjustable speed) Motor developed in 1905**
- **First customer was Lodge & Shipley**
  - Machine Tool Application
  - Graphite rods for street lights
- **Motor and speed control in a single package**



Speed, frequency, and poles

$$N1 = 120 \times f / P$$

N1 = rotational speed of stator magnetic field in RPM (synchronous speed)

f = frequency of the stator current in Hz

P = number of motor magnetic poles

AC MOTOR SYNCHRONOUS (NO LOAD) SPEEDS AT 50 AND 60 Hz INPUT FREQUENCIES

	FREQUENCY (Hz)	
	50	60
POLES	SYNCHRONOUS RPM	
2	3000	3600
4	1500	1800
6	1000	1200
8	750	900
10	600	720
12	500	600
14	429	514

Poles	Speed	Frequency
6	1800	90
6	1200	60
6	900	45
6	720	36
6	600	30
6	514	25.7
6	300	15

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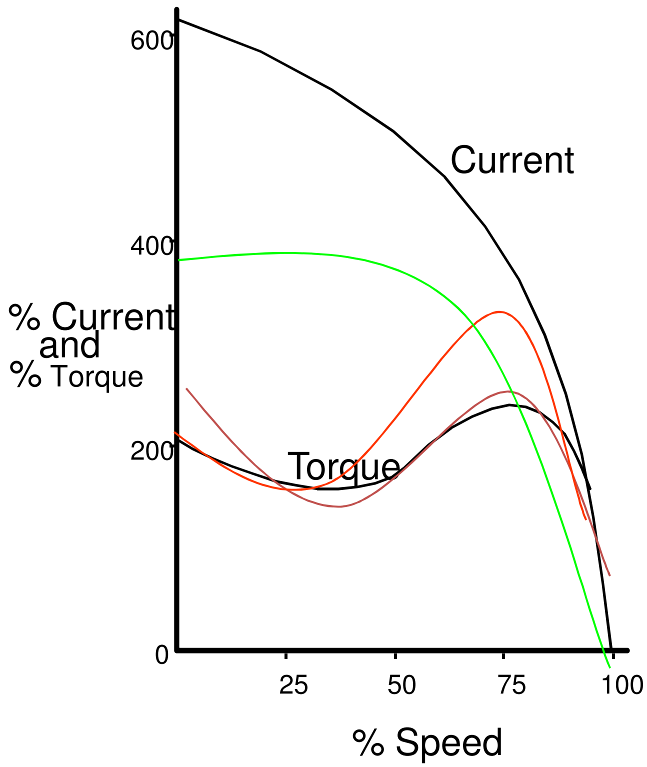
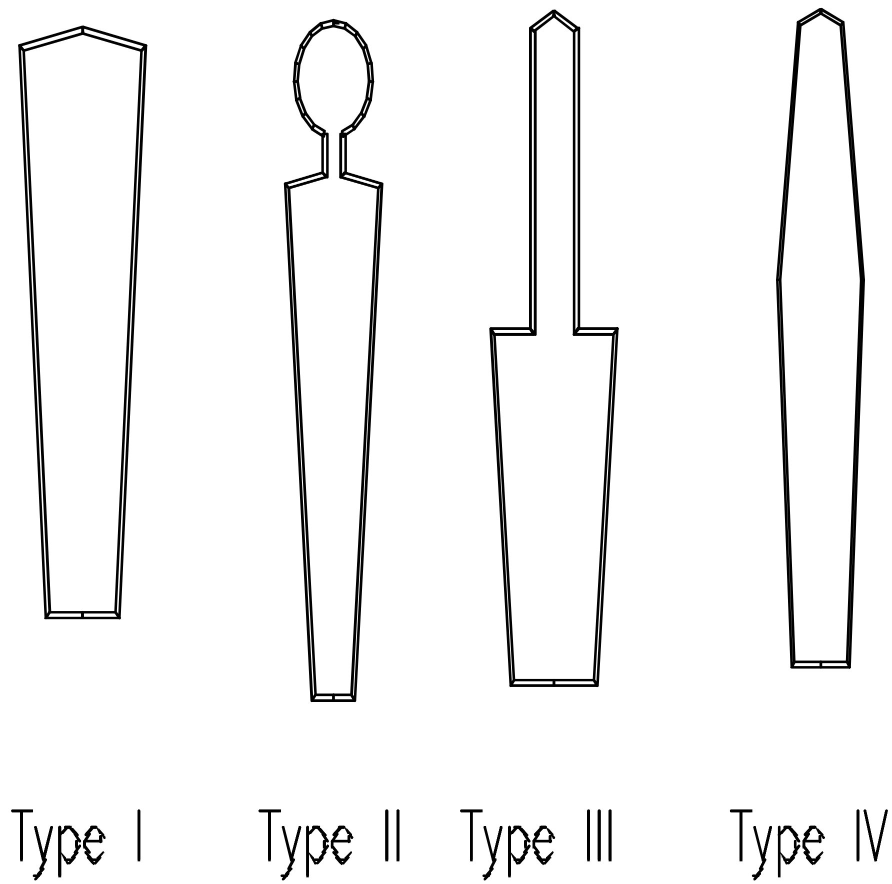
Typical Current & Torque Relationship for Squirrel Cage Induction Motor



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	na	**High**	Hoists

Rotor Slot Types



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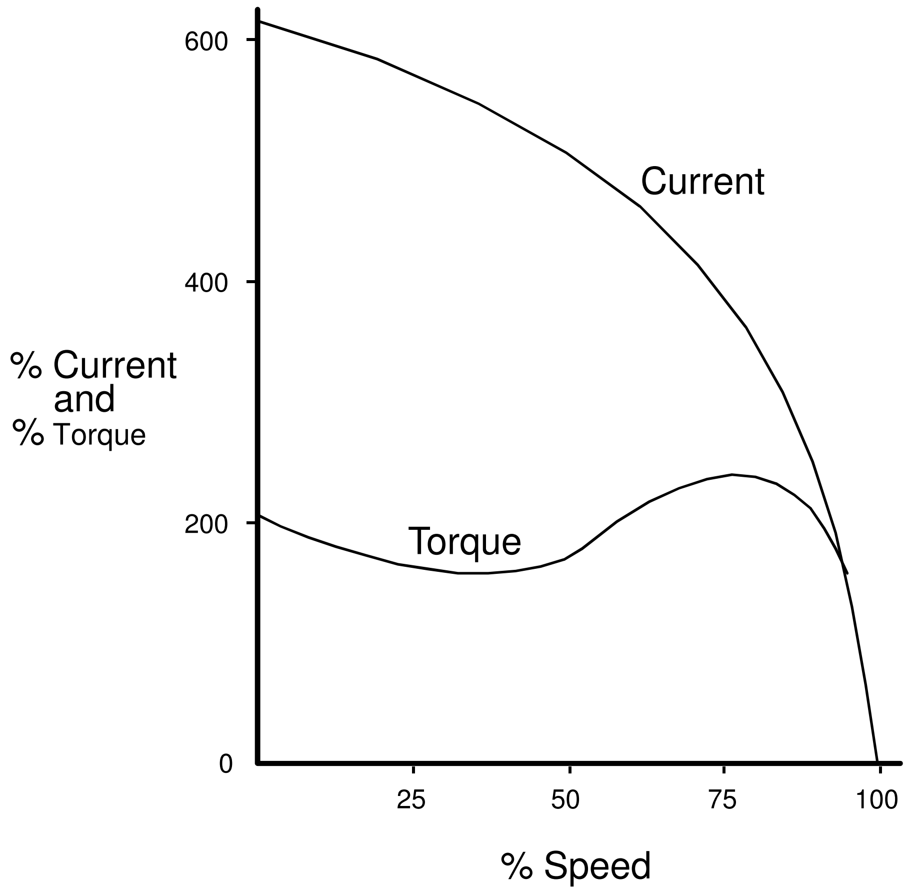
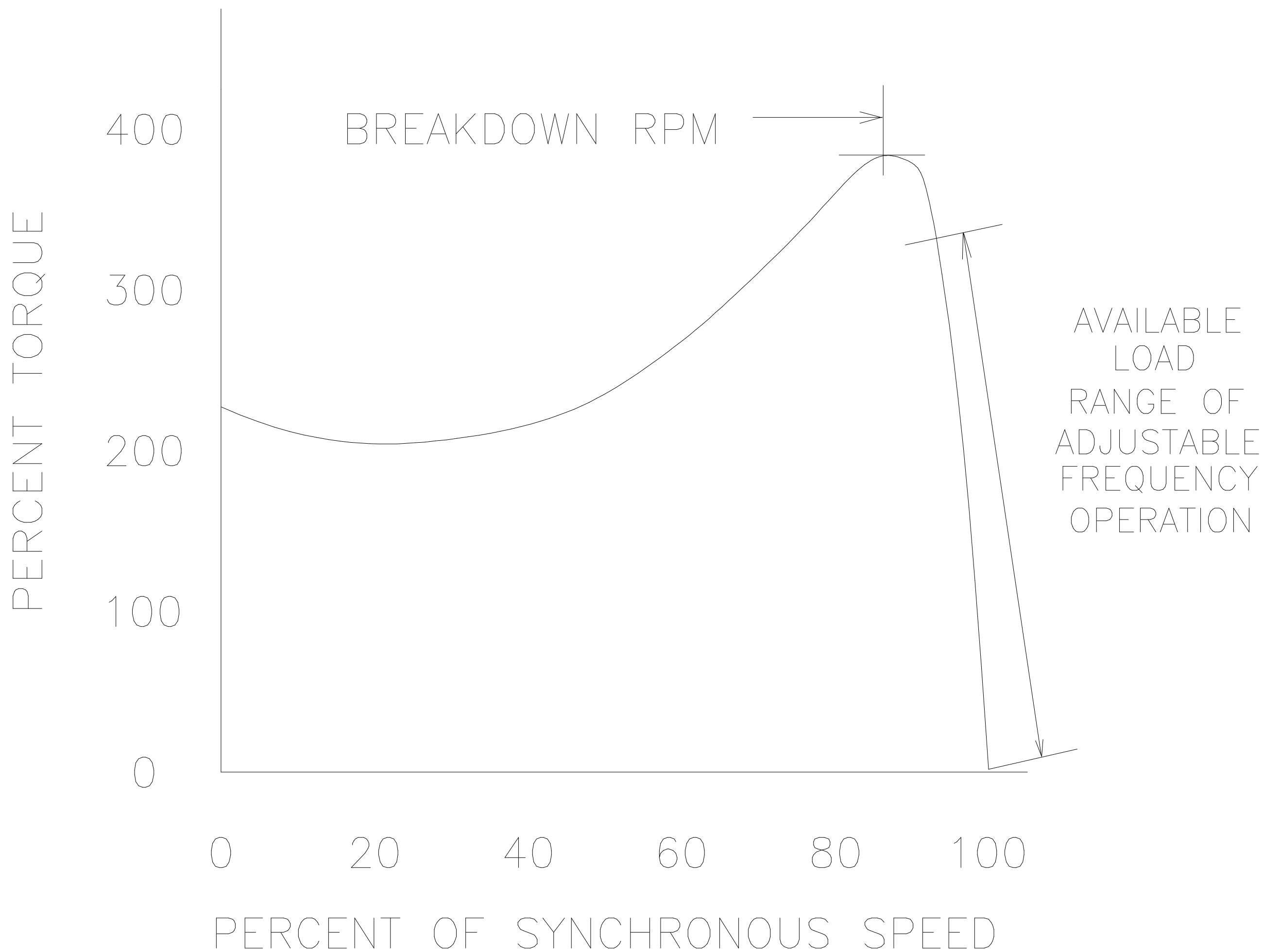


AC Induction Motor

Speed Torque Curve



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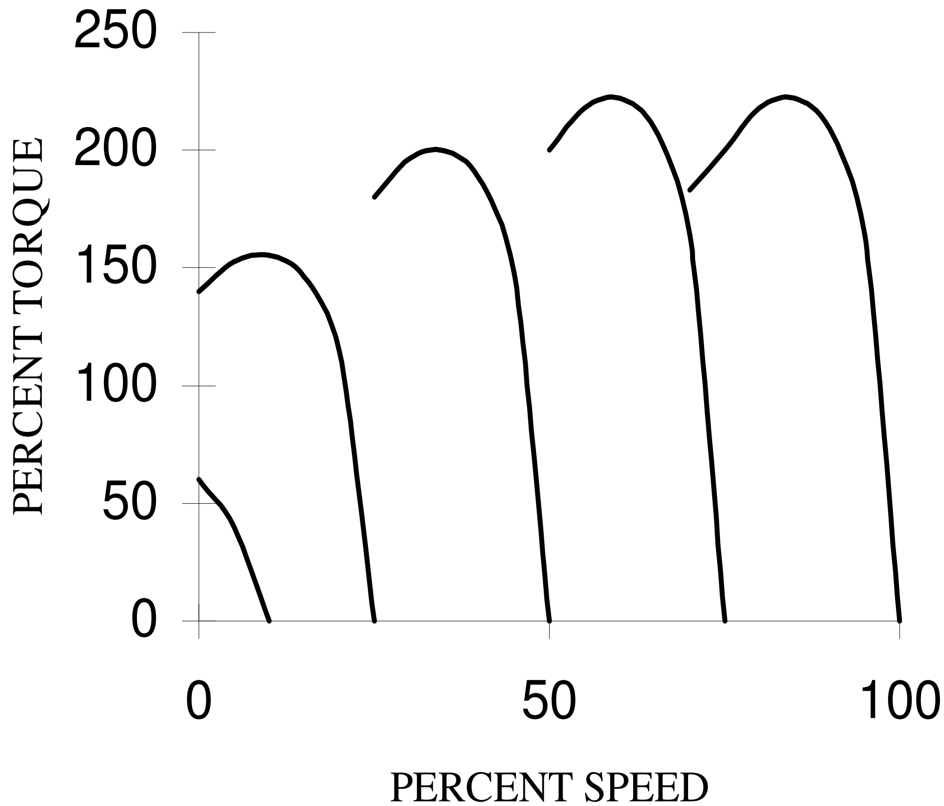
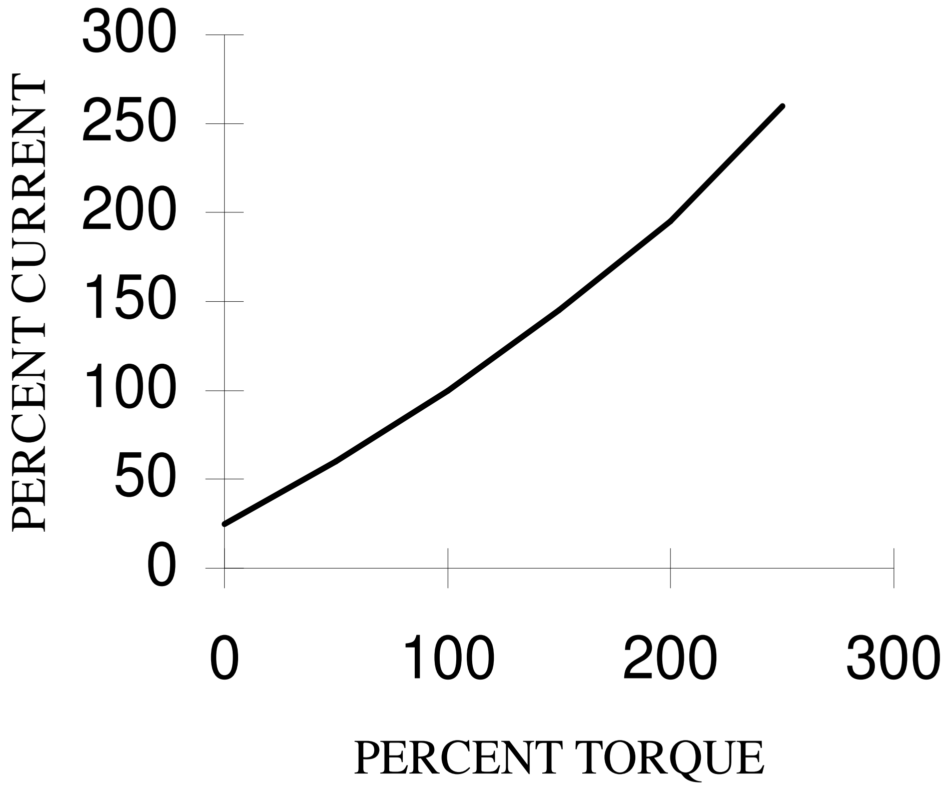
Speed - Torque with Constant Terminal V/Hz



AC Induction Motor
Steady State Operation



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Variable Speed Terms

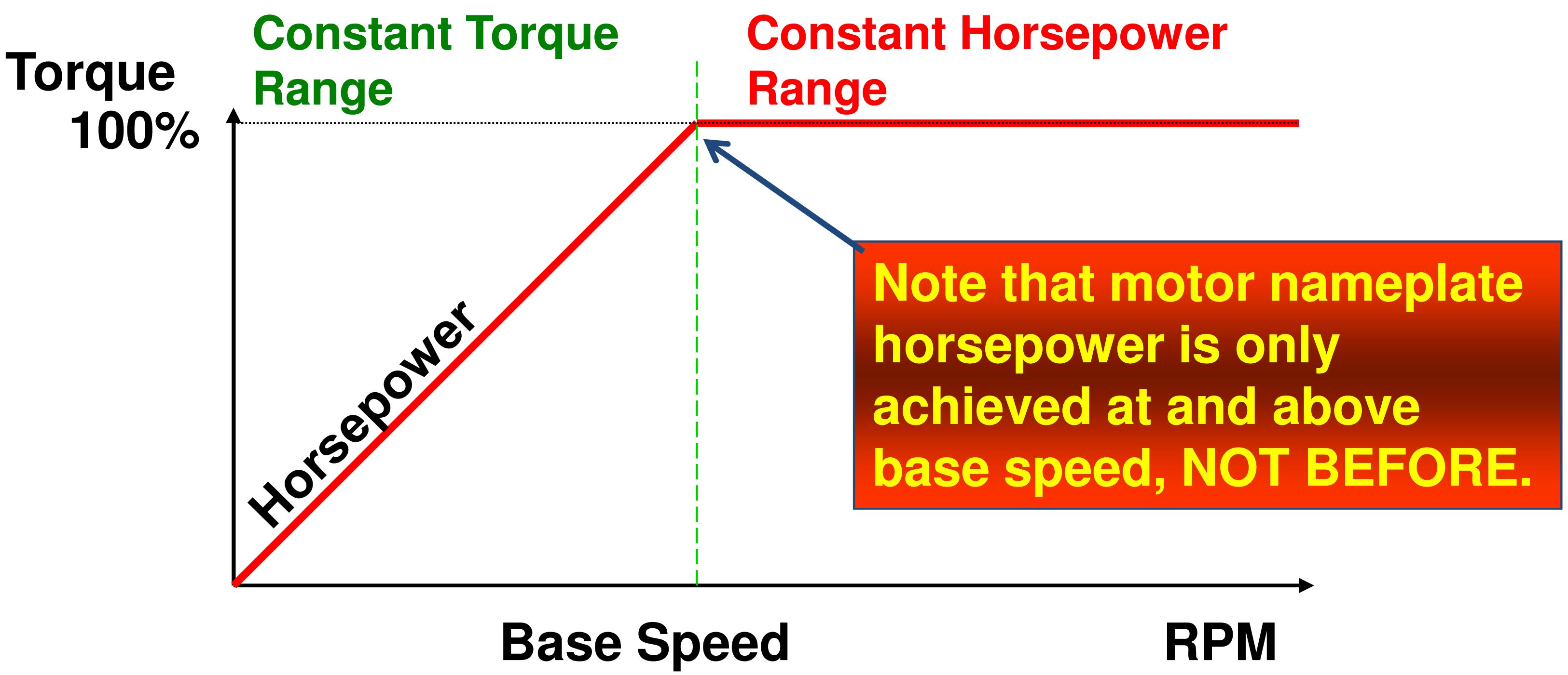
- Base speed – the speed point at which the motor changes from constant torque to constant power operation. This is normally the point at which the motor transitions from constant volts per hertz to constant volts.
- Minimum Speed – the minimum speed the motor can constantly operate.
- Maximum Speed – the maximum speed the motor can constantly operate.
- Maximum Safe Speed – the maximum speed the motor can safely operate.

Variable Speed Terms

- Variable torque application – load torque varies as the square of the speed and cube of the horsepower. Usually below base speed where the motor flux is constant.
- Constant torque range – the speed range that the rated continuous torque is constant. Usually this is the operation range below base speed where the motor flux is constant.
- Constant power range – the speed range that the rated continuous power is held constant. Usually a limited speed range above base speed.

Motor nameplate Horsepower is achieved at Base RPM:

$$HP = Torque * Speed / 5252$$



Motor Insulation Classifications

Insulation Class	Temperature Classification (C.)	Motor Temperature Rise (C.)
A	105	55
B	130	80
F	155	105
H	180	130

AC Motor Construction

3 Phase Winding Circuit w/Connections T1, T2 & T3

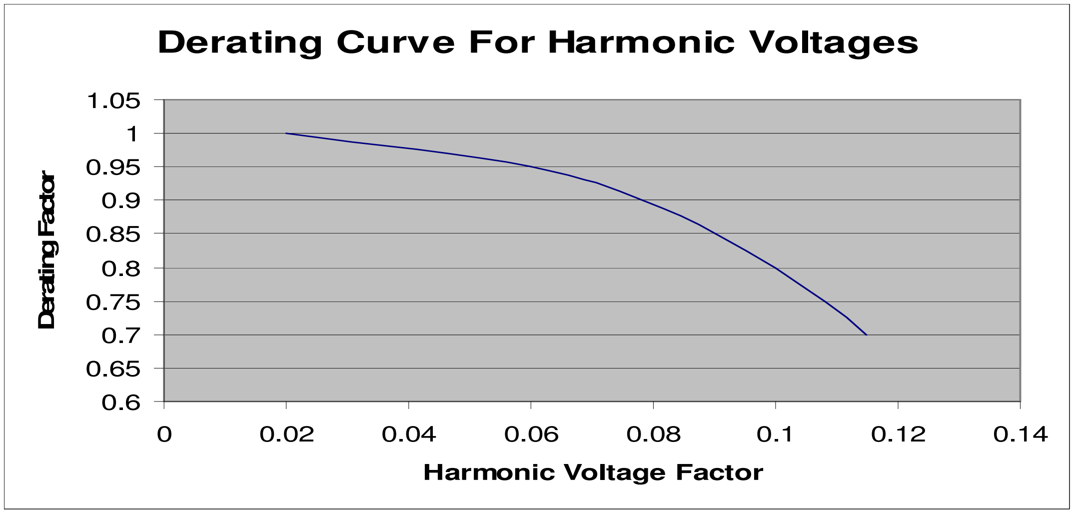
Apply Fixed Speed Motors on AFD Power

- **Issues:**
  - Motor Design Type
  - Temperature Rise at Base Speed
  - Temperature Rise throughout speed range
  - Insulation system
  - Cable length

NEMA Design Type

- NEMA Design A or B motor are preferred for AFD operation.
- Avoid NEMA Type C and D motors, if possible.
- High frequency harmonics may cause excessive bar heating for design C and D.

Thermal Impact at Base Speed

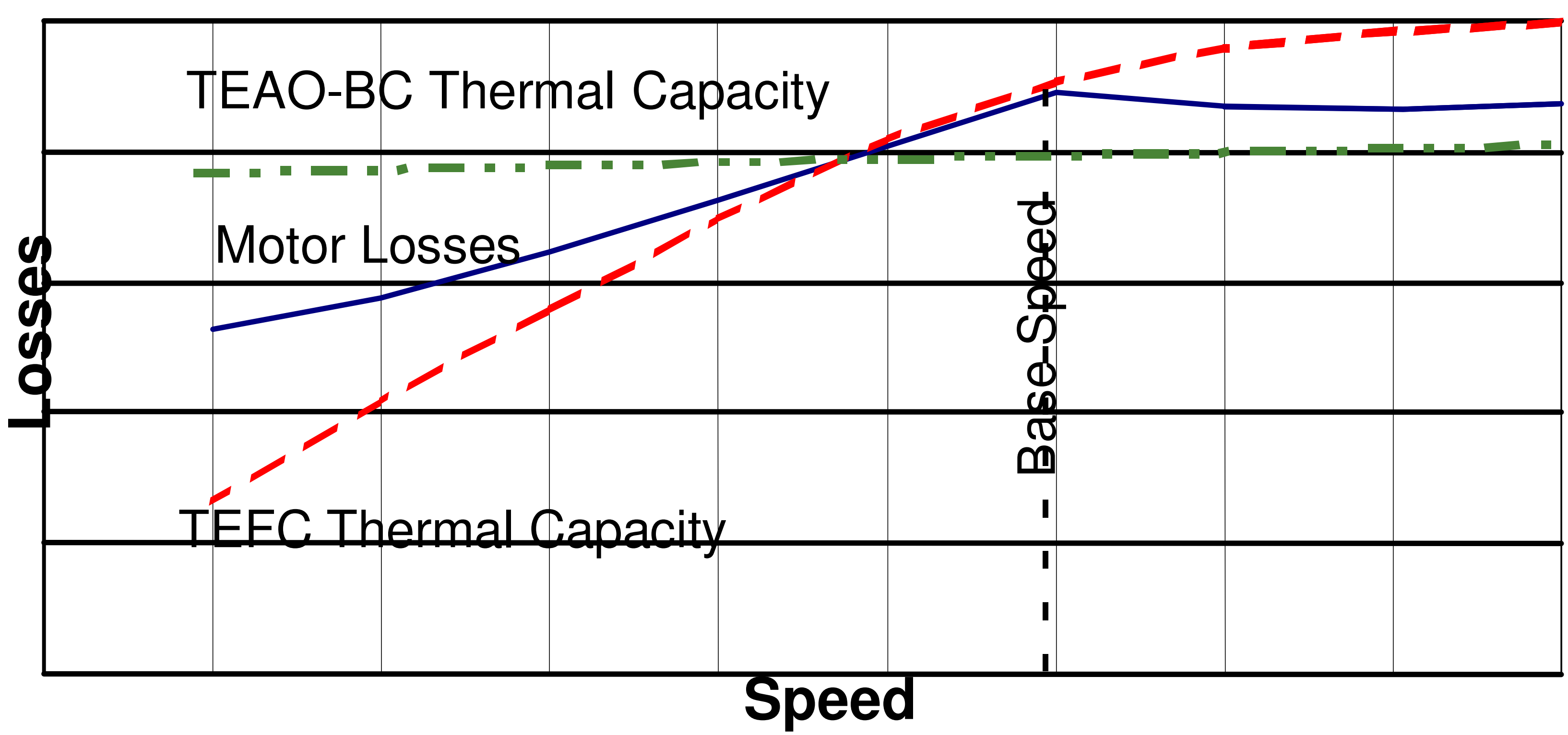


- NEMA Part 30 defines derating factor for motor.
- Good rule of thumb, temperature at base speed will increase one insulation class.
- Example, Class B (80°C) rise on sine wave, Class F (105 °C) on inverter.

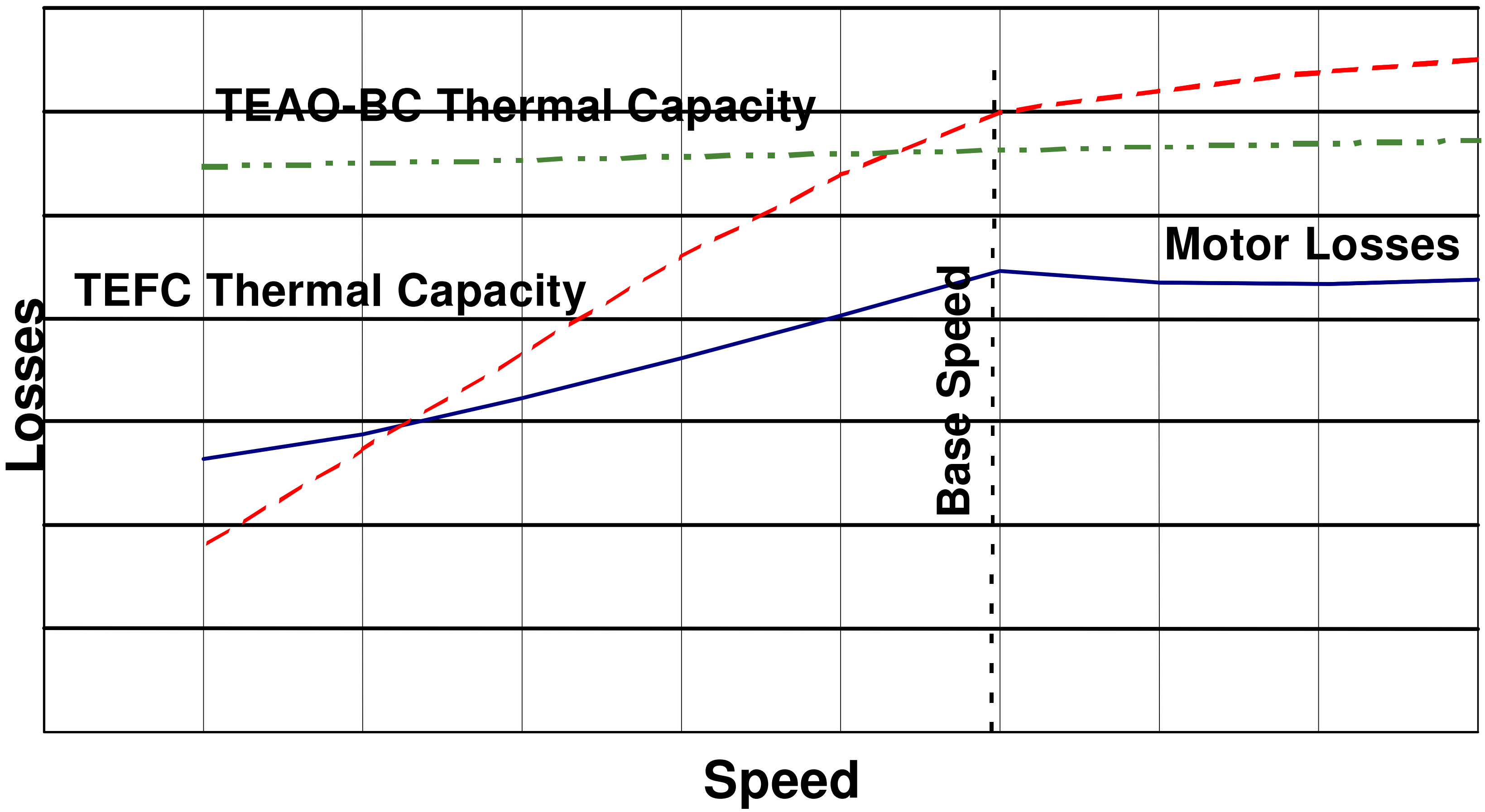
Motor Heating

- Motor losses in a constant torque application decrease with speed.
- Motor thermal capacity also decreases with speed when shaft mounted fans are used.
- The motor thermal capacity decreases more rapidly than the motor losses.
- The thermal capacity of the motor over the speed range must be considered.
- Variable torque loads are not thermally limited.

Constant Torque Range

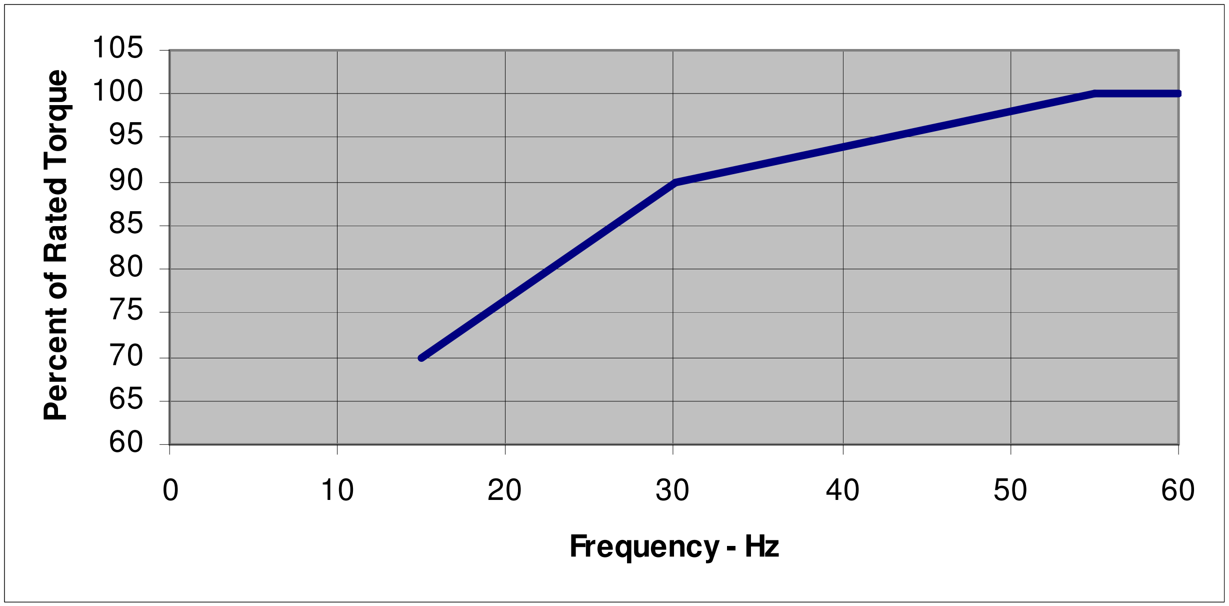


Constant Torque Range



Motor Derate vs Speed

- NEMA Part 30 defines derate for standard motors.
- Curve below is for TEFC per NEMA.
- Derate varies with speed.



Induction motors have five basic loss components:

- Stator I^2R
- Rotor I^2R
- Core losses (hysteresis and eddy current losses in the laminations)
- Friction & windage
- Stray load losses

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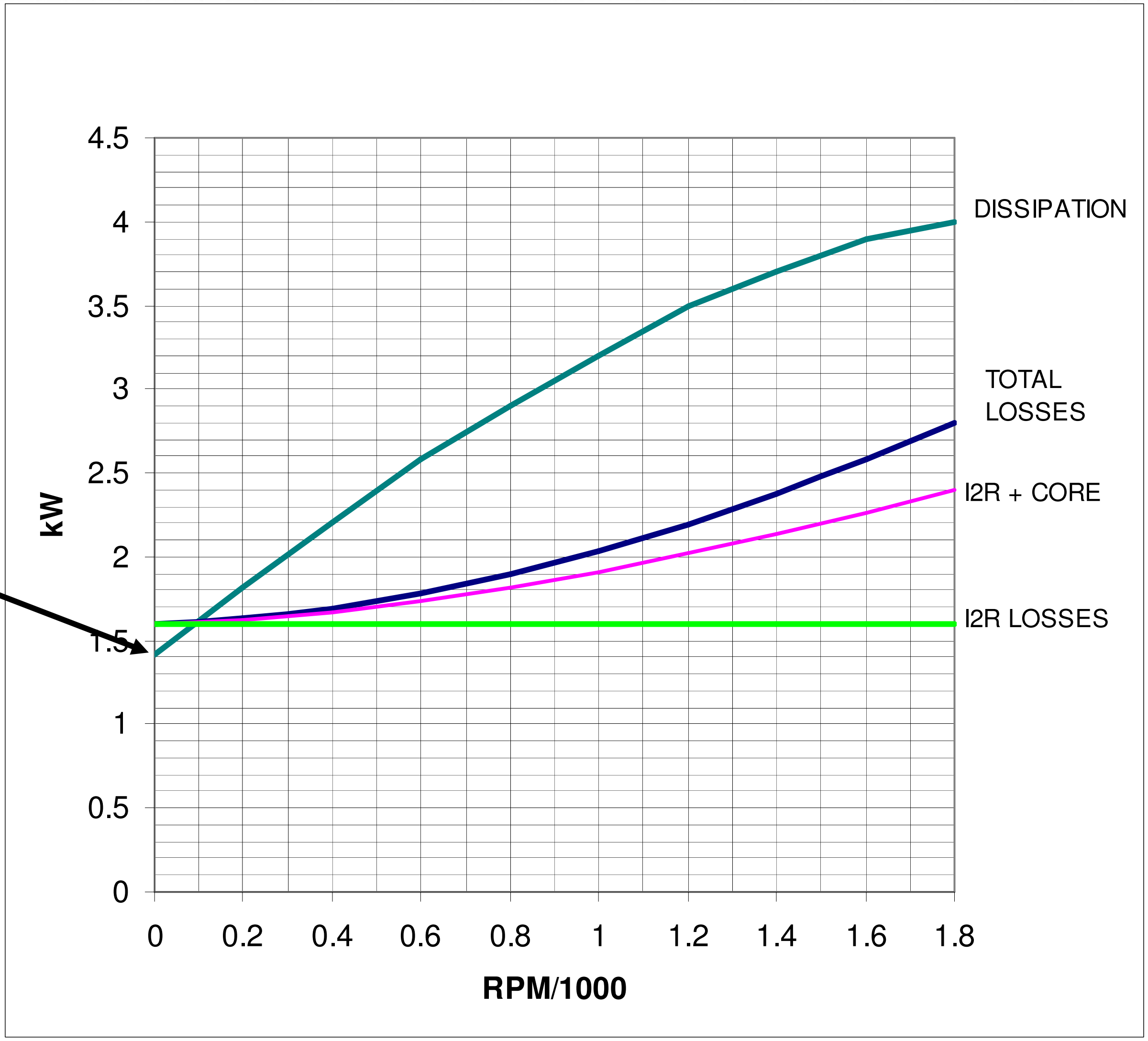
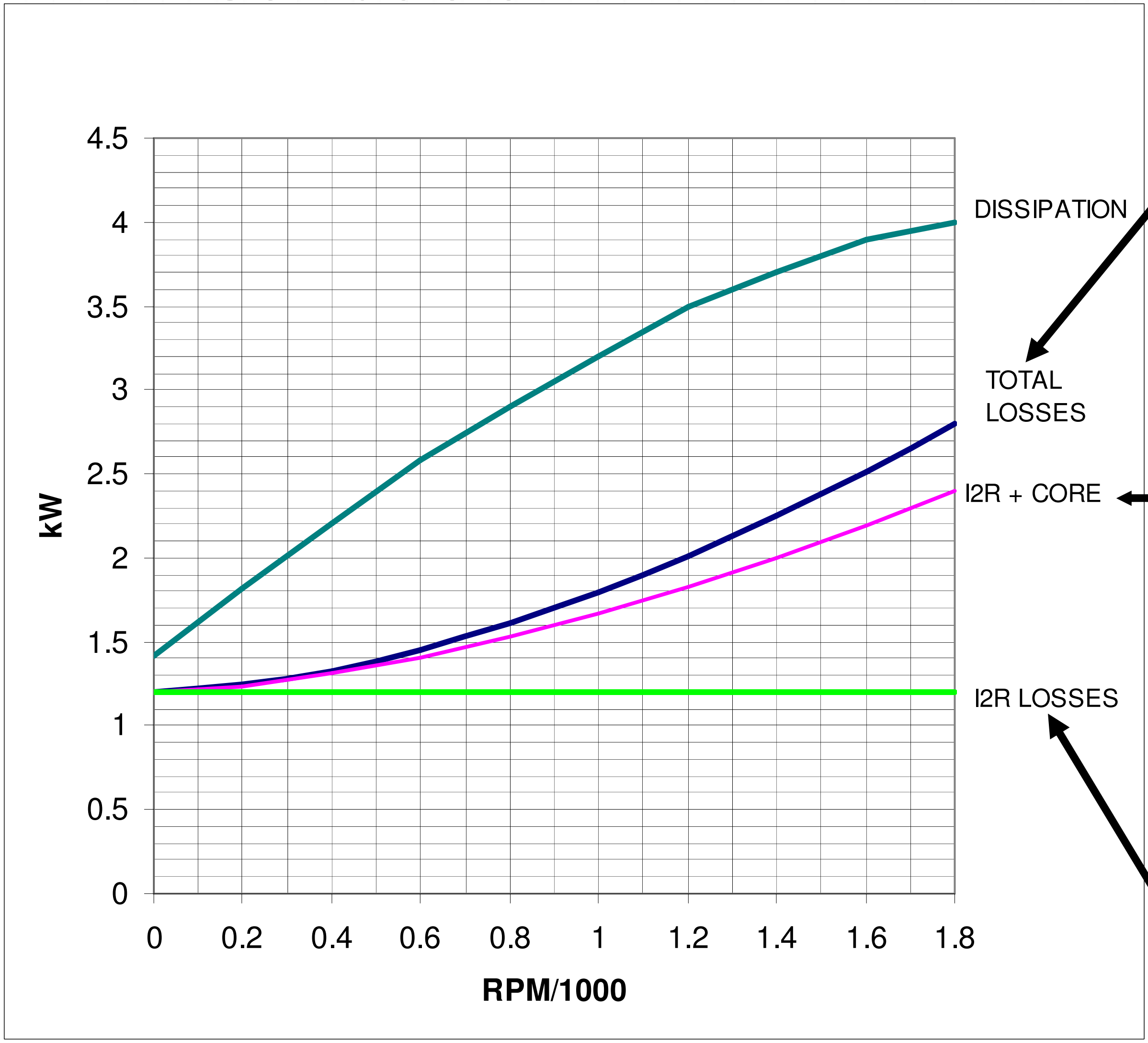
NEMA Design B Typical Loss Distribution

At low speeds the I^2R losses exceed frame's heat dissipation capability



TEFC Inverter Duty Typical Loss Distribution



Total Losses are the same at base speed

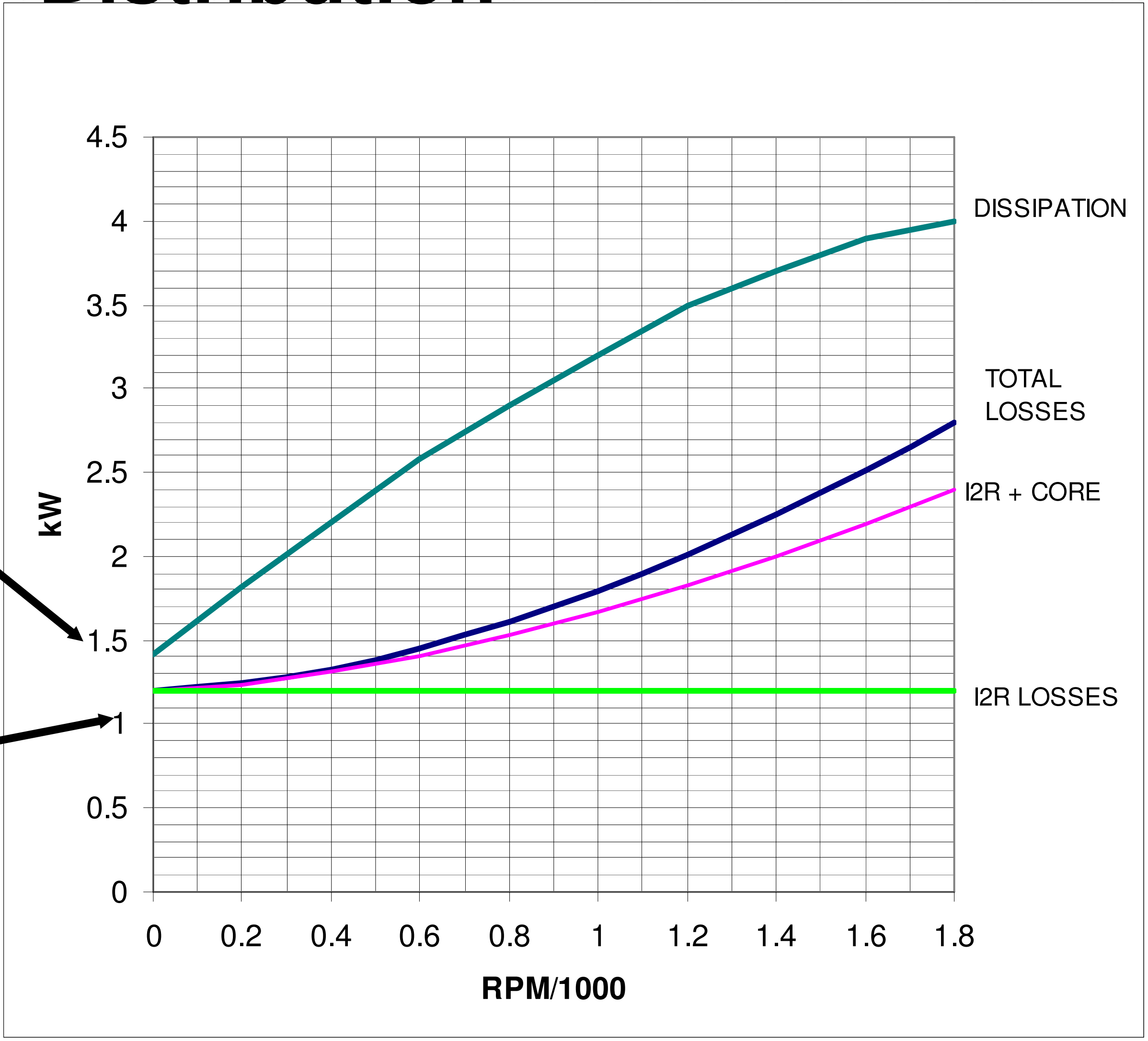
Lower I^2R losses plus higher cores losses add up to the same loss at base speed

I^2R losses are lower and constant for constant load

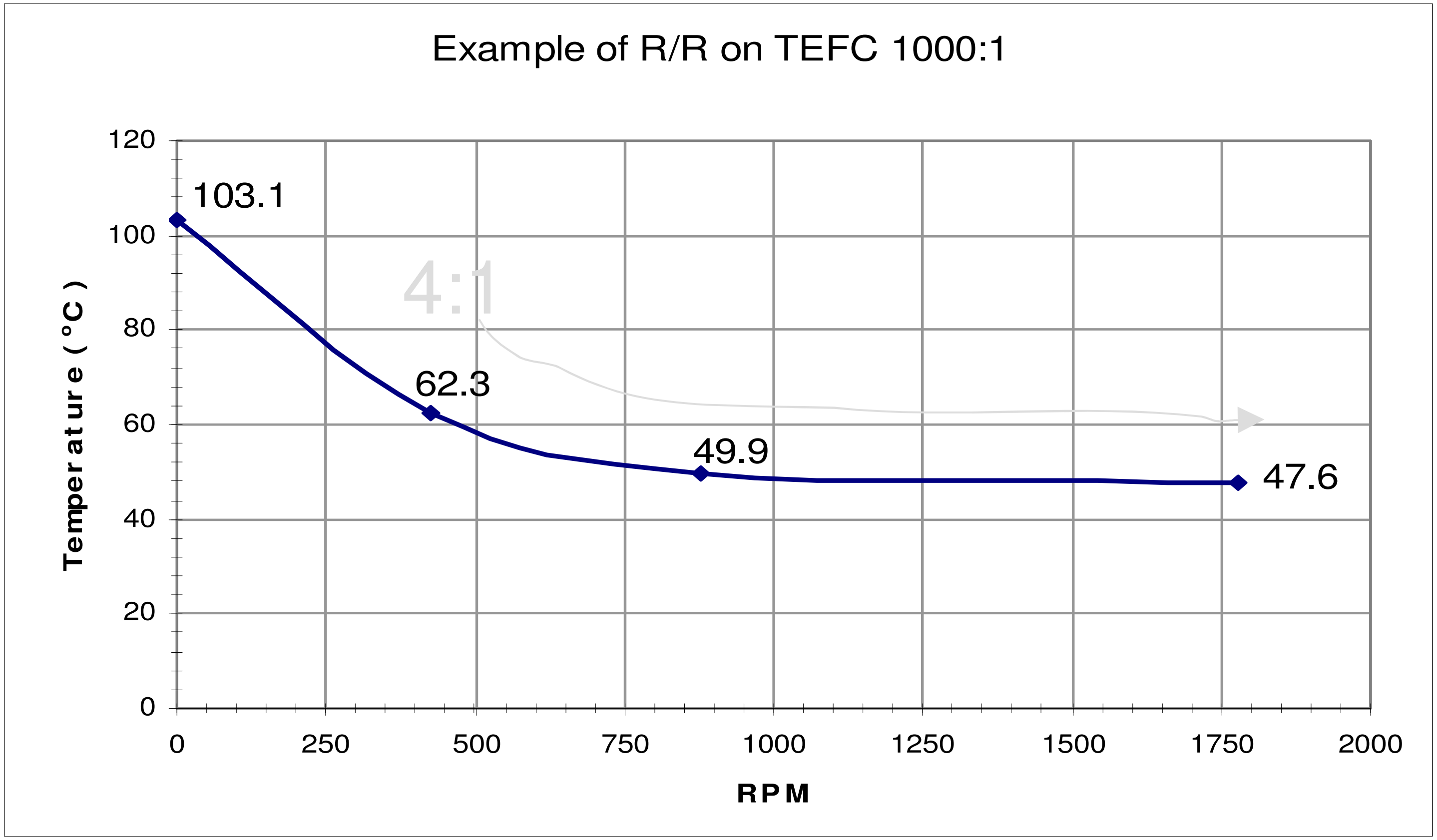
TEFC Inverter Duty Typical Loss Distribution

I^2R losses are below the dissipation capability of the motor at rest

At zero speed, total losses = I^2R losses



Typical Cooling Curve of 1000:1 CT motor



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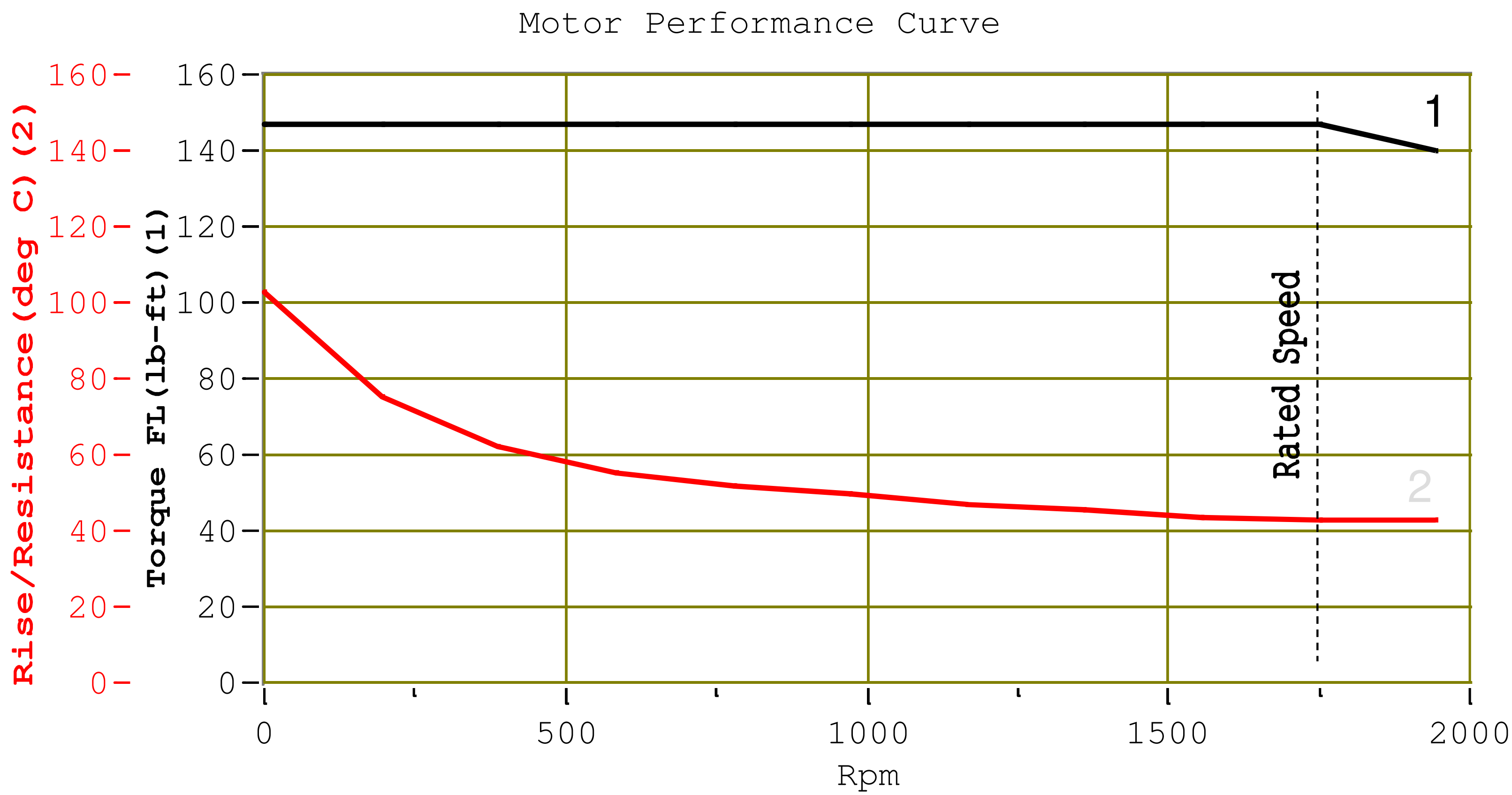
Torque & R/R vs Speed



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Insulation System

- **Fast switching inverters can create high peak voltages and dV/dt at the motor terminals**
- **Corona inception in the motor winding will eventually lead to insulation system failure**
  - Phase to phase from high Vpeak
  - Turn to turn from high dV/dt
- **Corona resistant wire does not eliminate corona damage**
- **Vpeak and dV/dt at the motor depends on more than lead length.**

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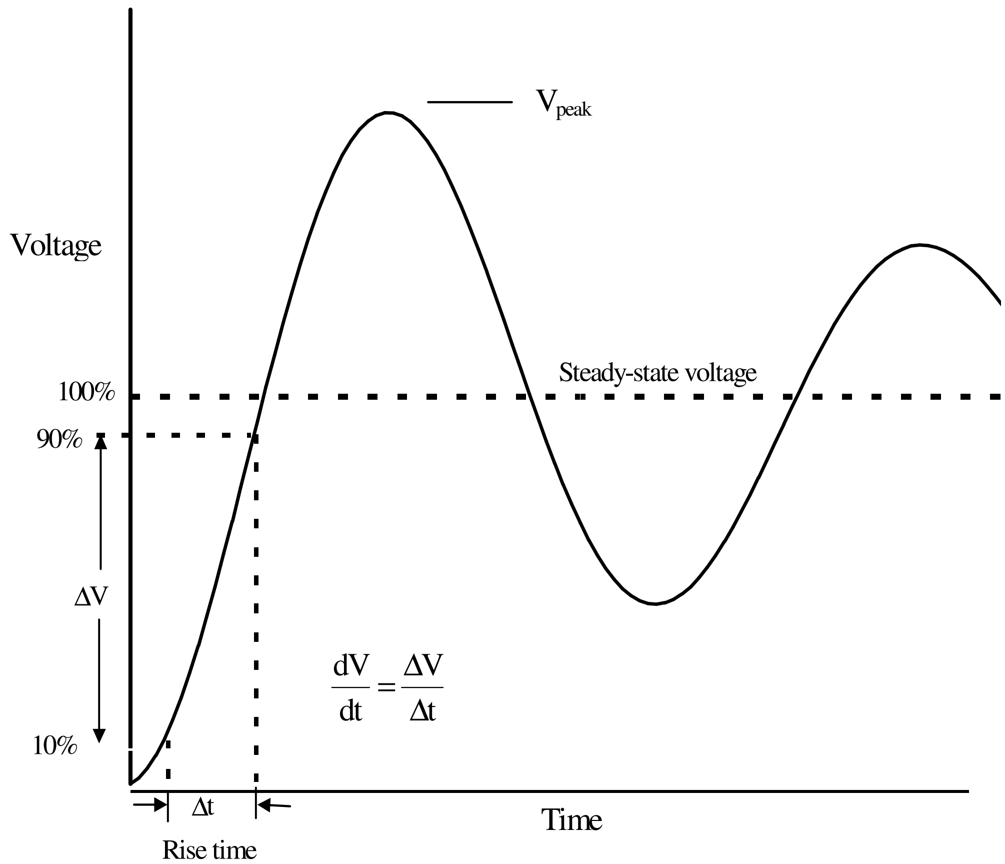
NEMA dv/dt (risetime) definition



Insulation System

Corona elimination is the only way to provide long inverter duty motor life

Do this by reducing the voltage <u>gradient in air</u>

- In the motor
  - Control coil - coil spacing / insulation
  - Improved varnish systems to keep air away from regions of high voltage gradient
- In the installation
  - Limit peak Voltage (shorter leads or install a Terminator)
  - Reduce dV/dt (line filters)

Insulation System

Long life motor insulation requirements:

- **Eliminate corona with a system that has high corona inception voltage levels (CIV)**
  - Proper phase paper placement and varnish coverage for phase to phase.
  - Varnish penetration and coverage for turn to turn (dv/dt)
- **460 V motors capable of:**
  - Max Vpeak of 1600 Volts (NEMA 1426 Volts).
  - Max dV/dt of 10,000 V/µsec.
- **575 V motors capable of:**
  - Max Vpeak of 1850 Volts. (NEMA 1783 Volts)
  - Max dV/dt of 10,000 V/µsec.

Constant Speed Motors on ASD's

- Use only Design A and B motors
- ASD will increase motor temperature rise.
- Cooling over the motors speed range should be considered.
- Insulation system *must* be Inverter Capable.
- Cable length from drive to motor should be considered (Lengths over 200 ft should be reviewed.)
- Purchase VS motor when possible.

Laminated Frame Background

- **Concept first introduced on D-C in 1967**
  -Today, third generation of square laminated frames on RPM DC
- **RPM AC needed to meet high performance variable speed market needs**
- **Developed in 1988**
- **Not limited by NEMA cast iron frame “constraints"**
  - Available as standard or highly modified to meet application
    - Compact & lightweight
    - Special base speeds, high speeds, custom flanges, brakes and feedback devices

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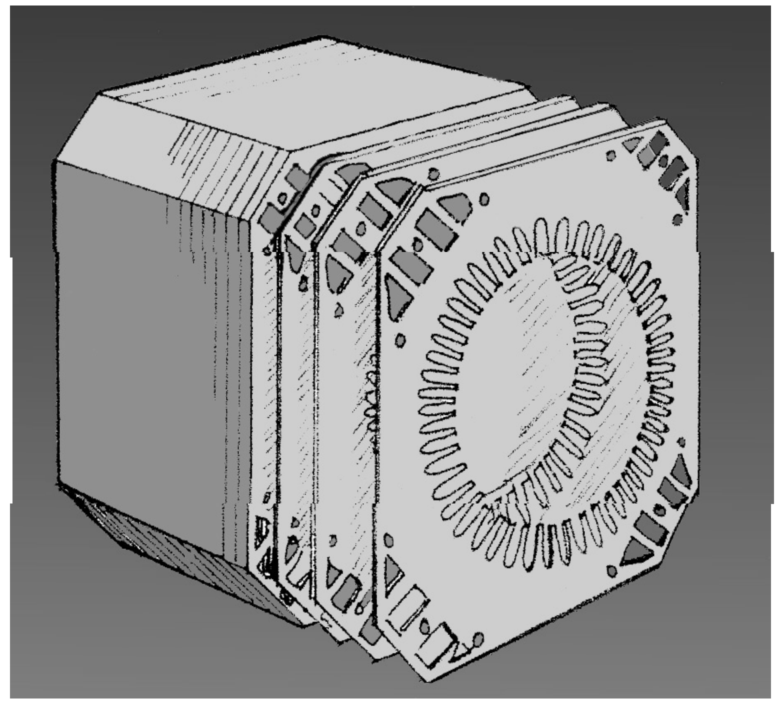
Laminated Frame Construction

- Clamp laminations in a high pressure press
- Permanently riveted with eight through-studs to cast iron end rings
- Frame is now a rigid single structure
- Strength and rigidity of cast iron



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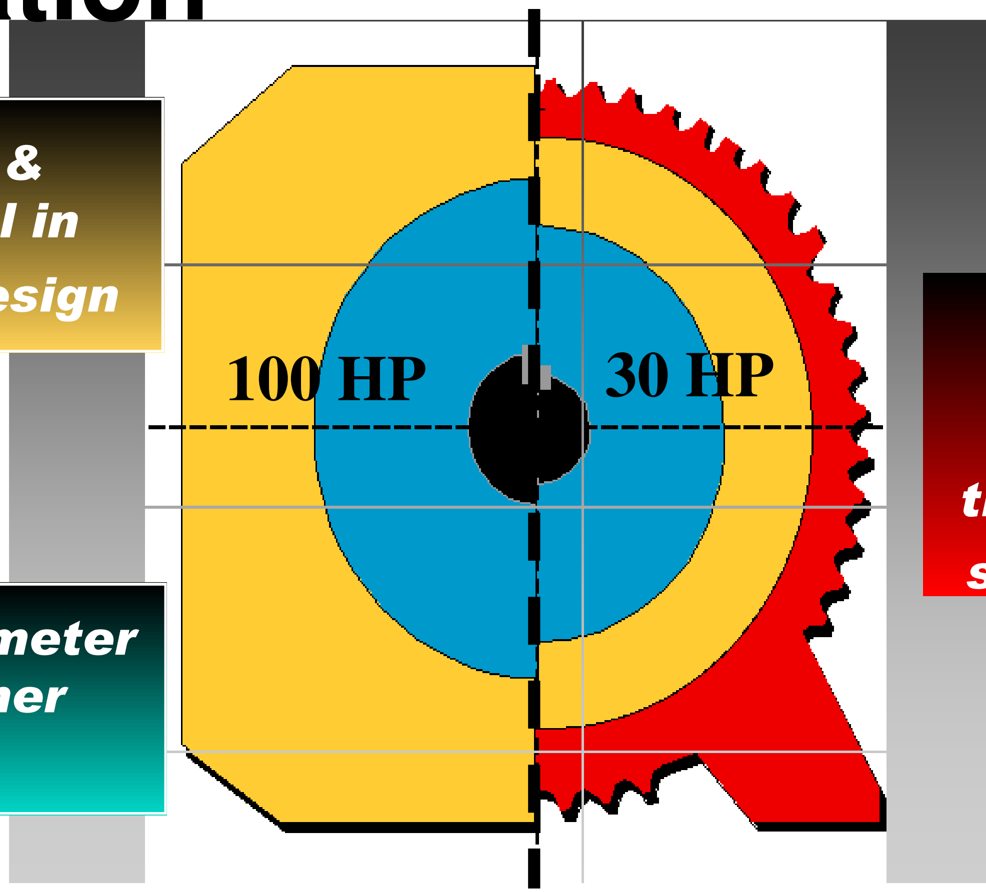
RPM AC Features- Higher power density for better space utilization

More copper & magnetic steel in square frame design

Larger rotor diameter produces higher torque



Inactive Cast Iron Frame - Reduced Heat transfer between stator and frame

SAME NEMA SHAFT HEIGHT

Frame Size Comparison

HP @1750 RPM	Standard TEFC	RPM A-C TEBC	RPM A-C DPFV
5	180	180	-
10	215	180	-
20	250	180	180
30	280	250	180
75	360	320	250
125	440	360	280
150	440	360	280
250	440	400	320
400	440	440	360
500	500	440	400
1000	580	-	440

RPM A-C

vs

Standard NEMA TEFC

1000 Hp in 440 frame

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RPM AC vs. Nema AC Motors

	RPM A-C			GEN. PURPOSE
HP	TEAO-BC	DPFV		TEFC
25	1.99	1.69		3.5
50	6.60	3.12		7.5
100	17.3	6.60		24.0
200	64	17.3		67

Inertia in lb-ft^2

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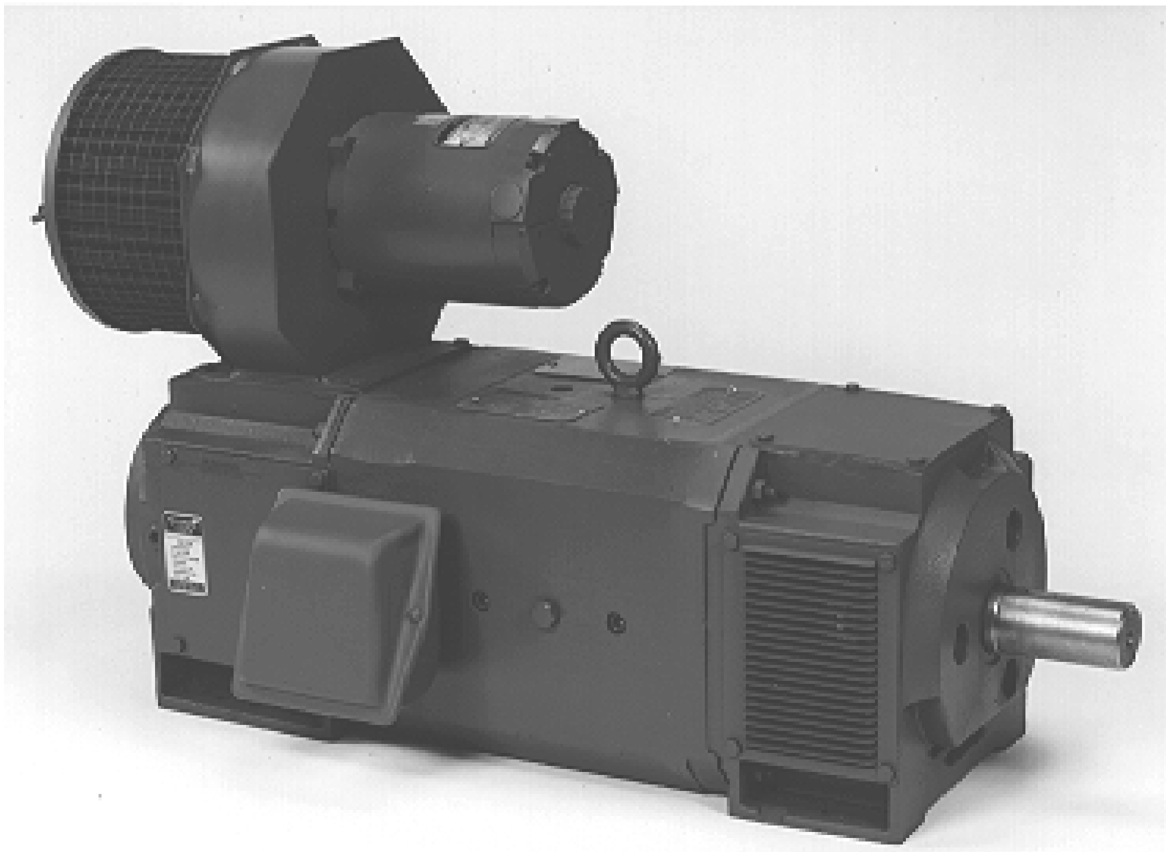
RPM AC vs NEMA AC Motors

- **Acceleration Torque Comparison**
  - Assume 100 Hp, 1750 base speed & acceleration time of 1 second
    - Full load torque = 300 ft-lb
  - Accel. Torque = (WK^2 x RPM) /(308 x time)
  - NEMA Frame - 136.4 lb-ft = **45.5% of Motor Torque**
  - RPM A-C Frame - 37.5 lb-ft = **12.5 % of Motor Torque**

- **More torque is available to accelerate the load - maybe downsize the continuous HP and Controller rating if they are "oversized" for accel duty cycle**

Motor Configurations



Motor Configurations

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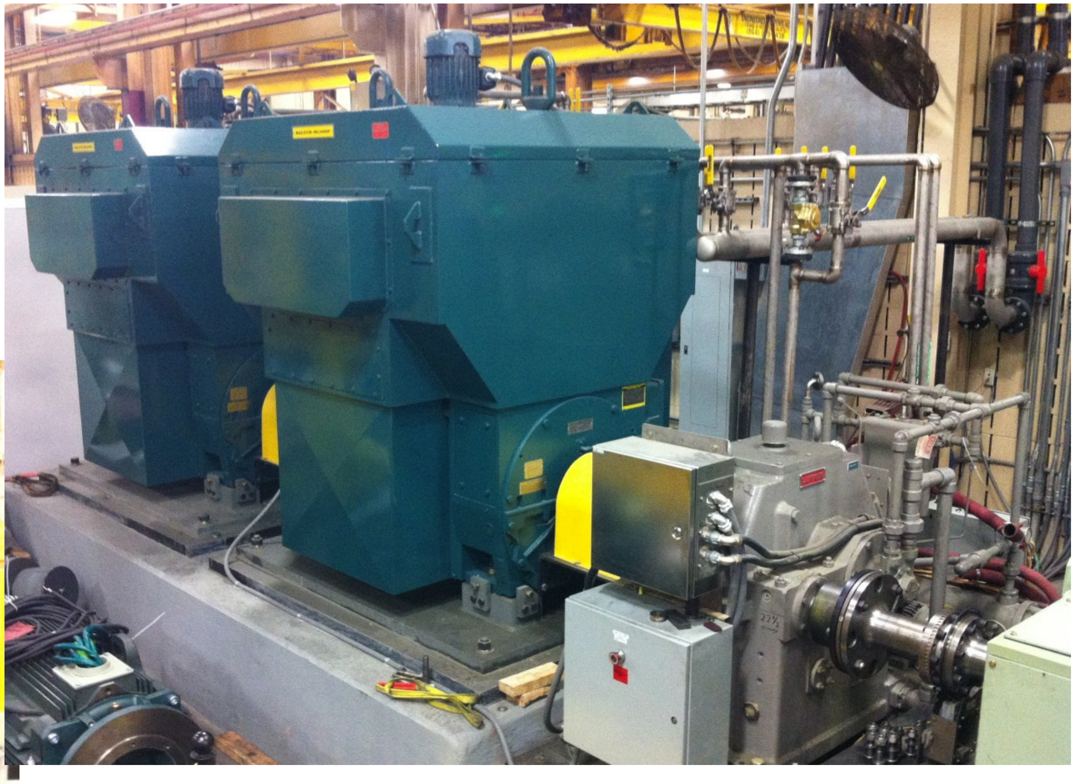

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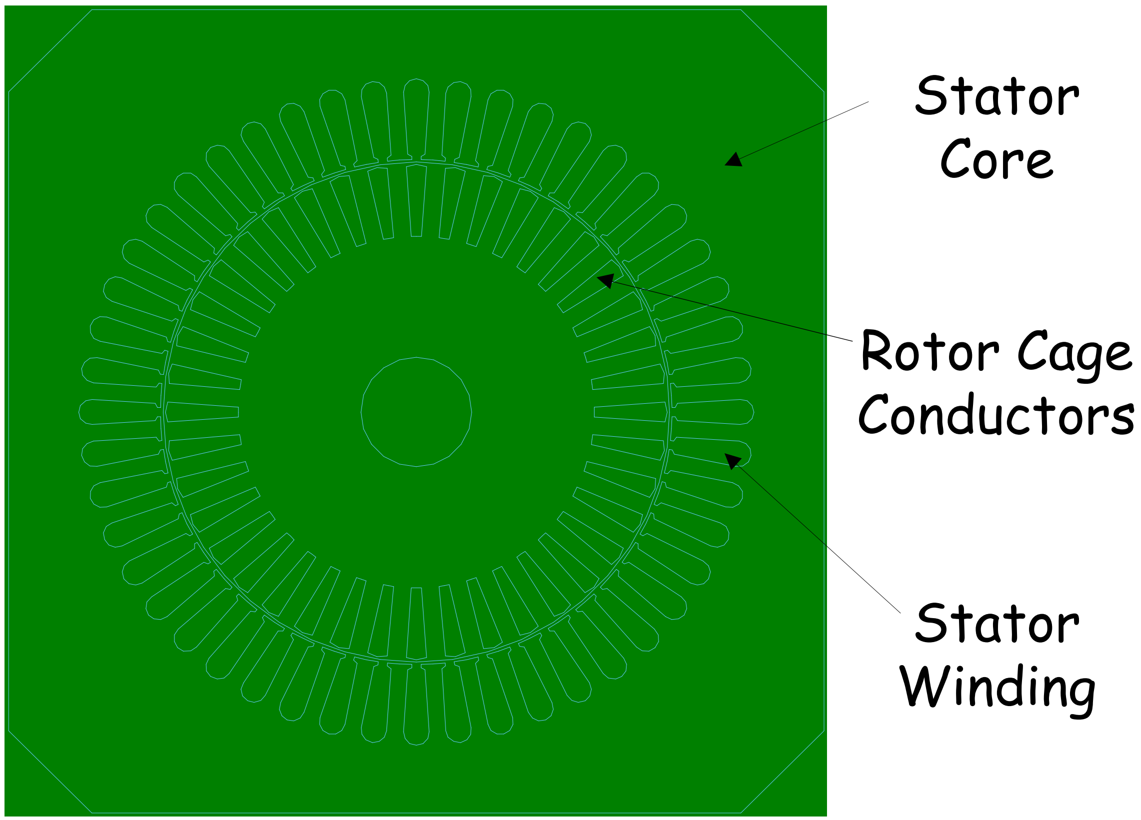
Motor Technologies: Induction AC Motors

- Typical Induction Motor cross section
- Speed varied by controlling Stator Voltage and Frequency
- Slip is required to produce torque so the operation is intrinsically "asynchronous"



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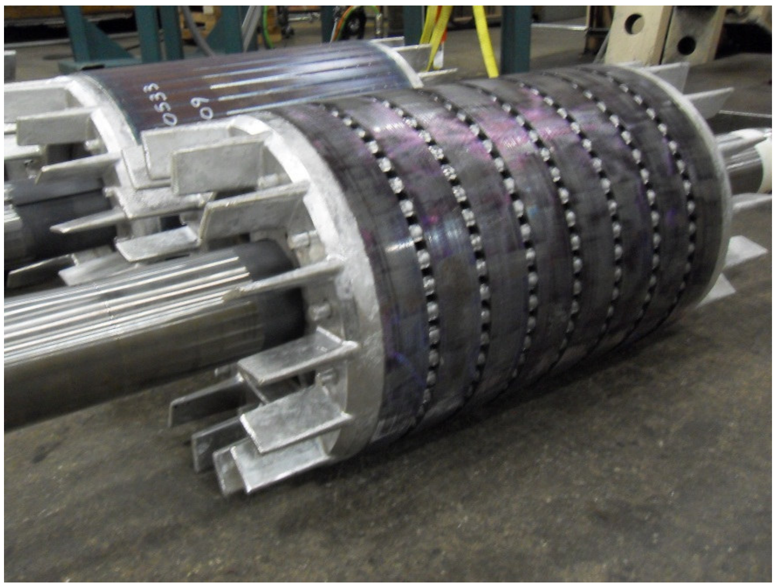
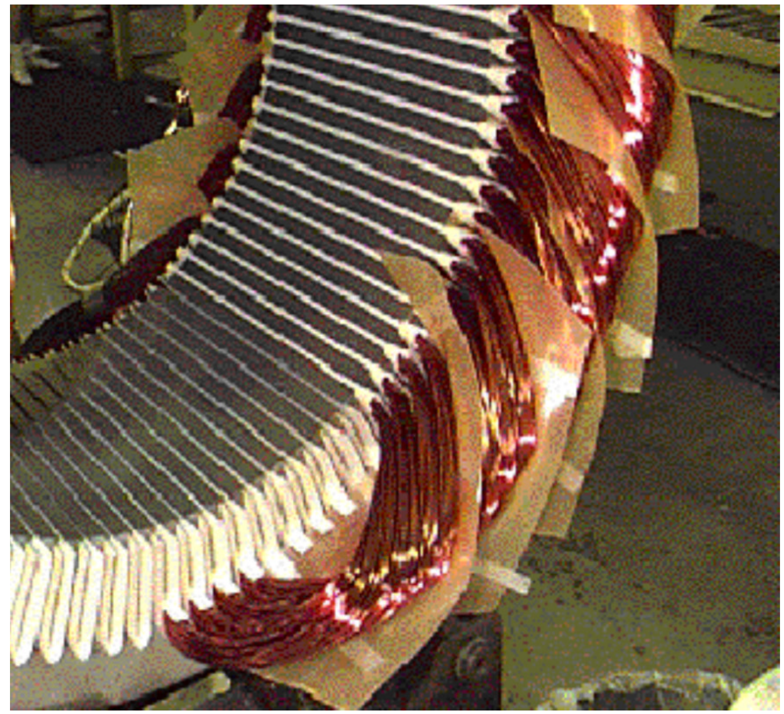
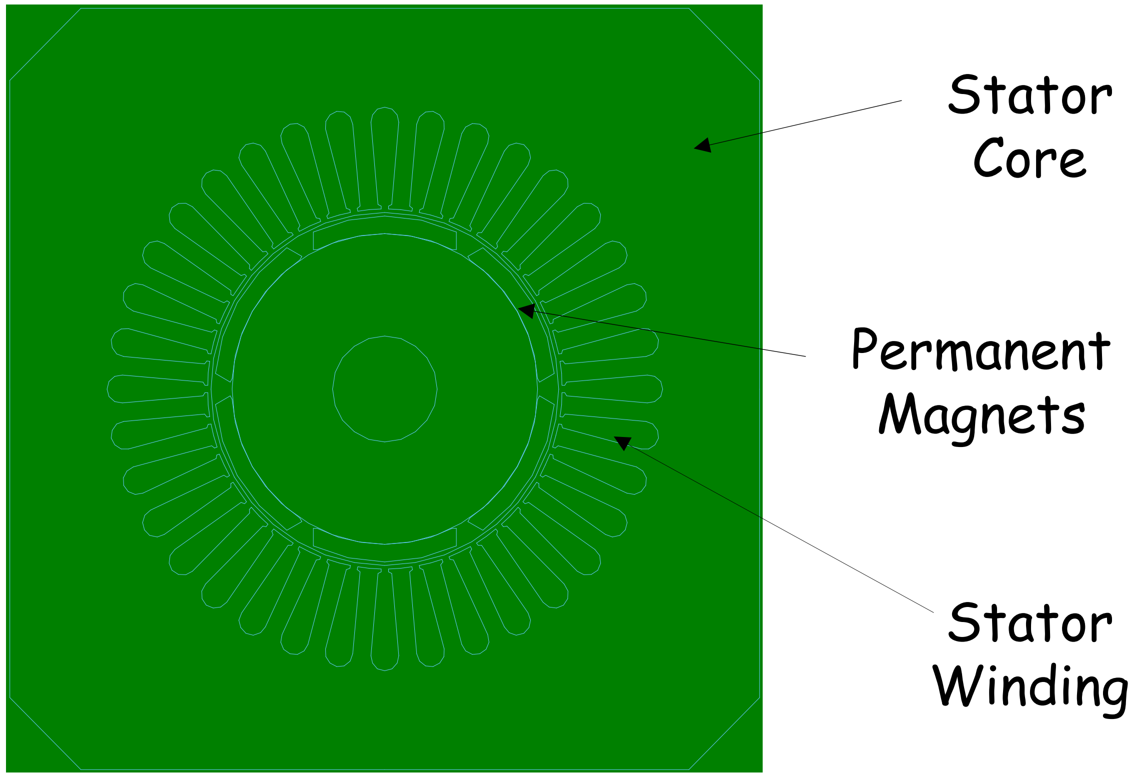
Motor Technologies: Induction AC Motors





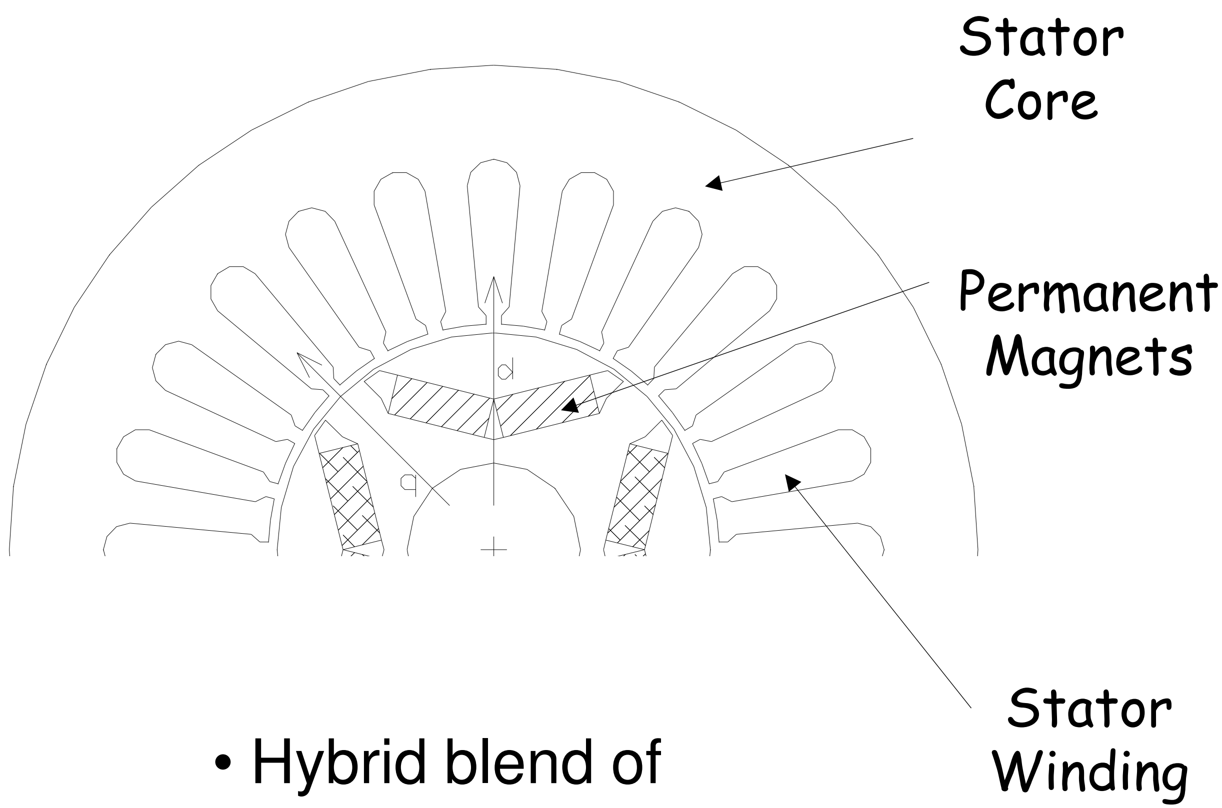
Motor Technologies: Permanent Magnet (PM) AC Motors (Non-Salient)

- **Typical Surface Magnet PM AC Motor cross section**
- **Speed varied by controlling Stator Voltage and Frequency**
- **Often called Brushless DC Motors**
- **Operation has "synchronism" between the applied frequency and the rotational speed**



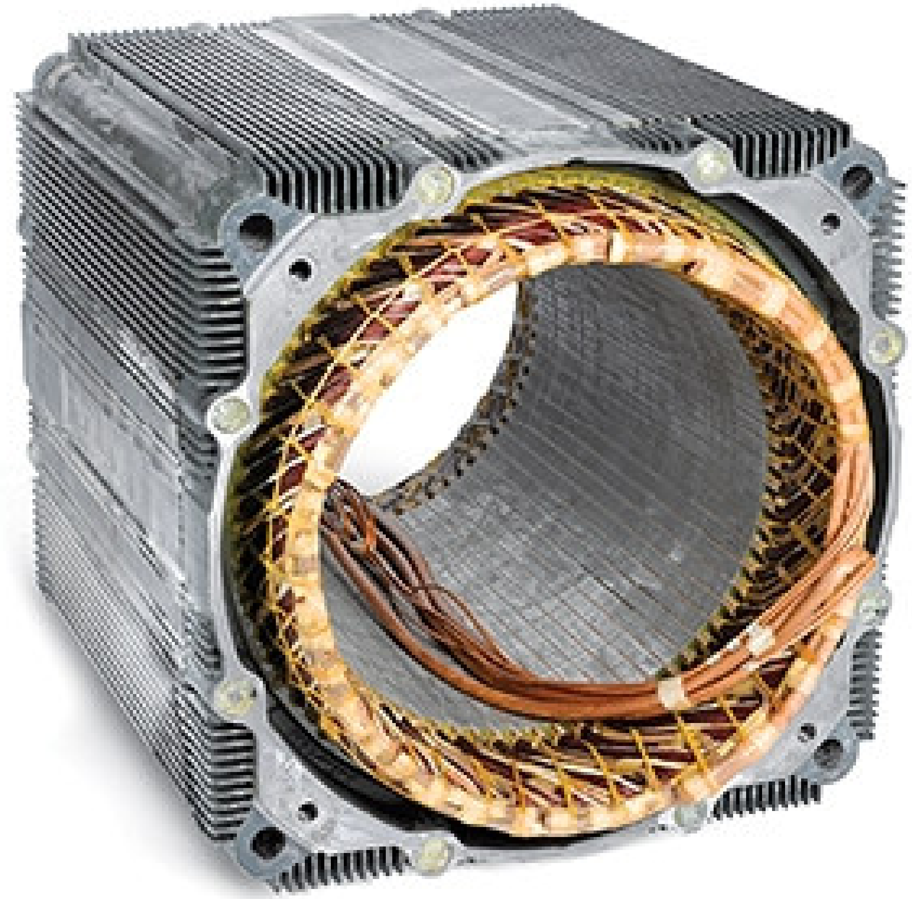
Motor Technologies: Permanent Magnet (PM) AC Motors – Salient Pole

- **Typical Interior Magnet PM AC Motor cross section**
- **Speed varied by controlling Stator Voltage and Frequency**
- **Operation has "synchronism" between the applied frequency and the rotational speed**



• Hybrid blend of magnet and reluctance torque

Permanent Magnet (PM)



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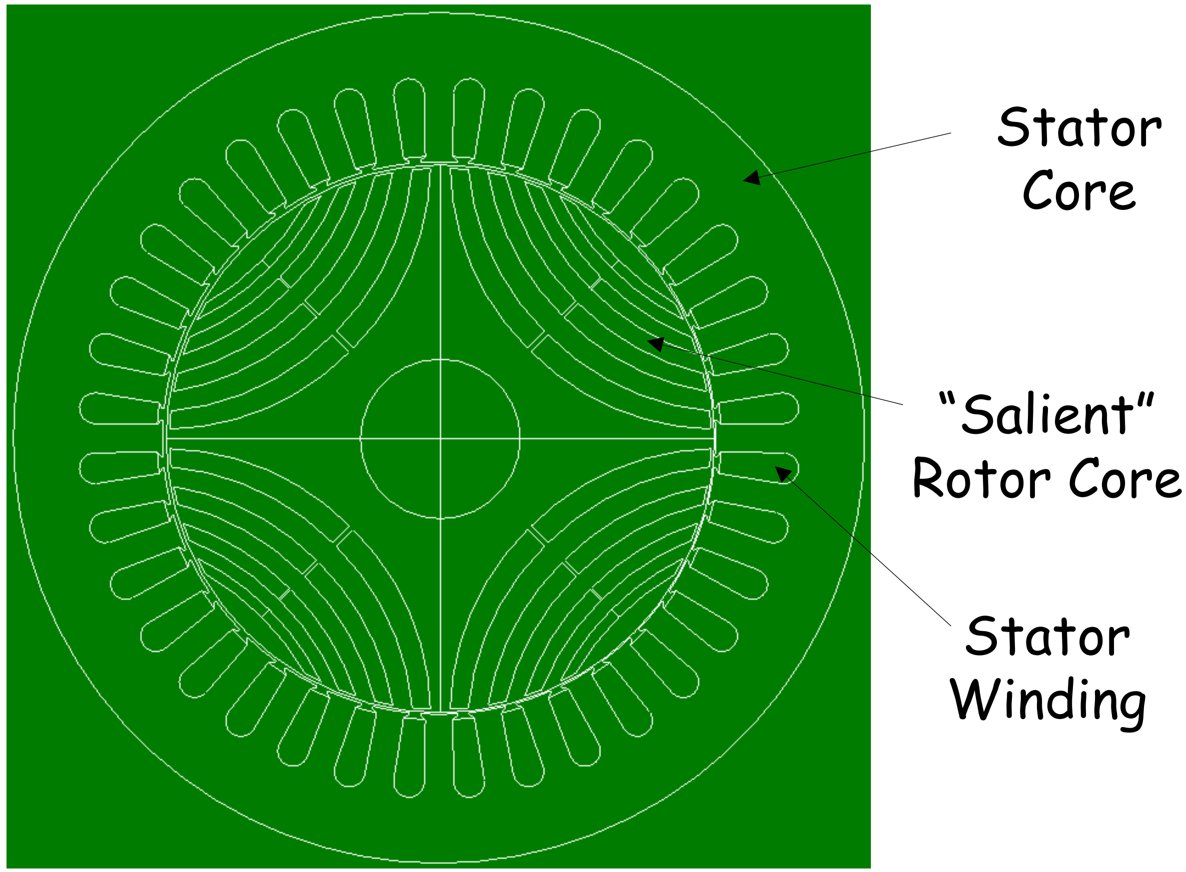
Motor Technologies: Synchronous Reluctance Motors

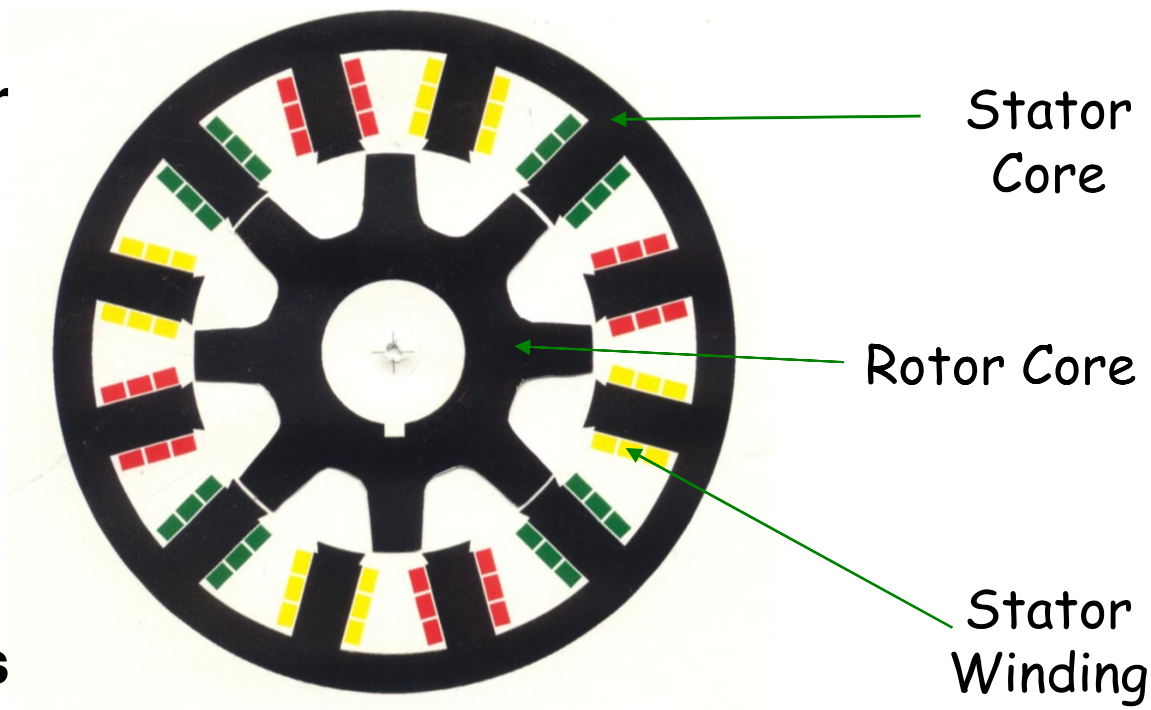
- **Typical Synchronous Reluctance Motor cross section**
- **Speed varied by controlling Stator Voltage and Frequency**
- **Zero slip, synchronous operation without magnets**
- **Configuration as depicted here has no starting cage, so is run only on inverter power**



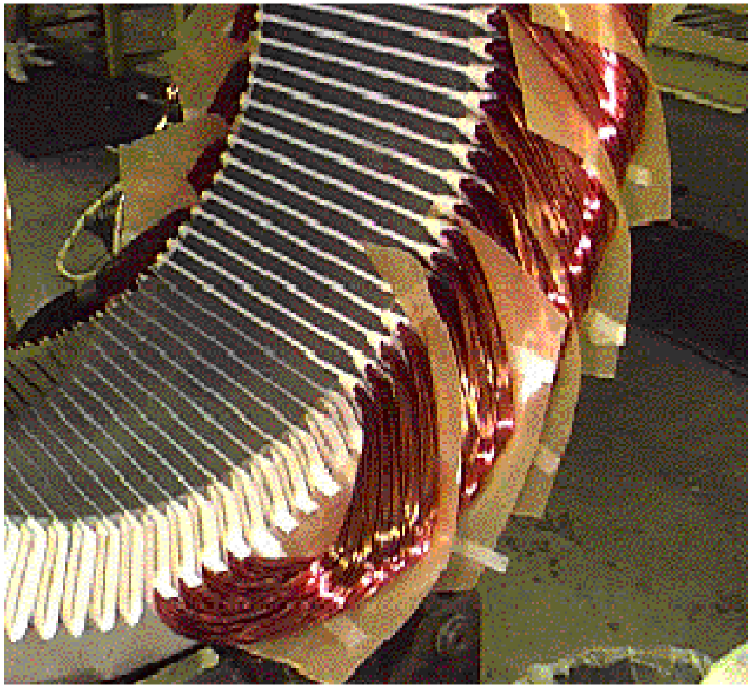
Synchronous Reluctance

Motor Technologies: Switched Reluctance Motors

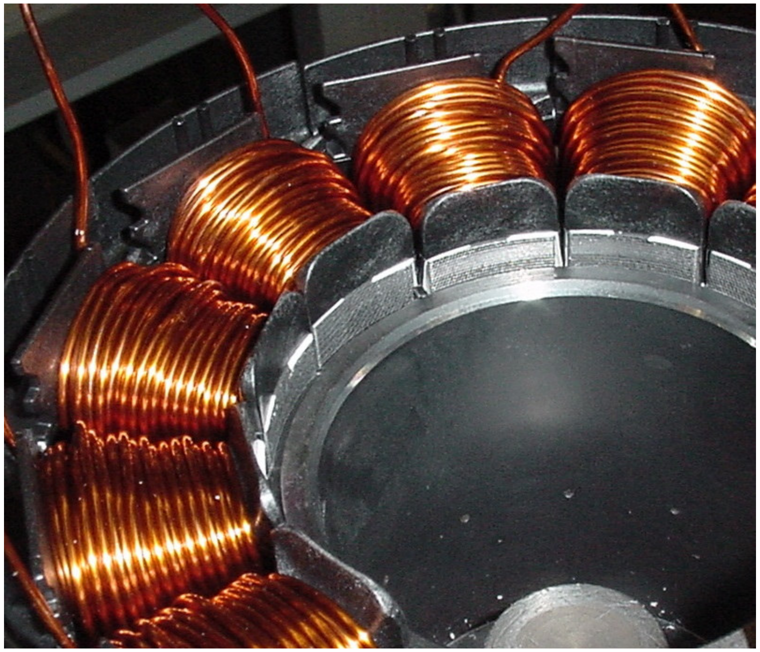
- Typical Switched Reluctance Motor cross section
- Speed varied by controlling current and frequency (current pulses)
- Currents are electronically commutated to be in proper slots with respect to the rotor position



Motor Winding Geometries



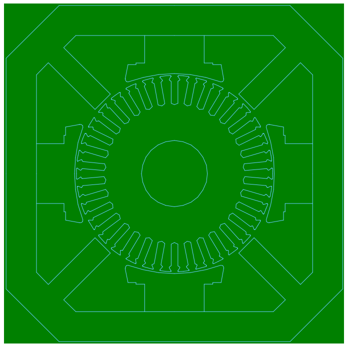
- Traditional Winding



- Concentrated Stator Windings
- Single Coil per Stator "Tooth"

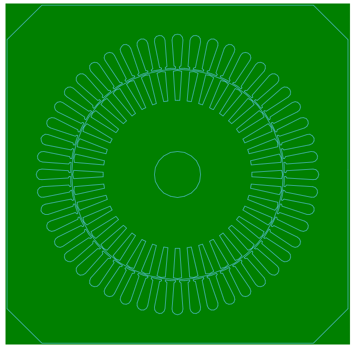
VS Motor Technologies: Advantages

DC



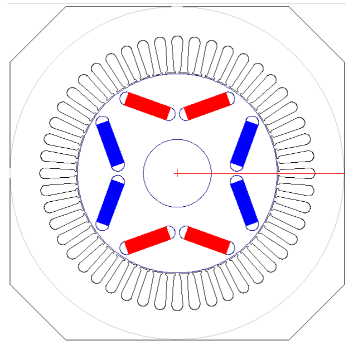
- Wide constant power speed range
- Simple, accurate torque control
- Regeneration

Induction



- Higher speeds
- Simple construction
- Higher torque/inertia ratio
- Higher torque density
- Low cost
- No permanent excitation
- Common drive topology

Interior PM



- Line start capable
- Wide constant power speed range
- Higher torque density
- Very low rotor losses
- Common drive topology

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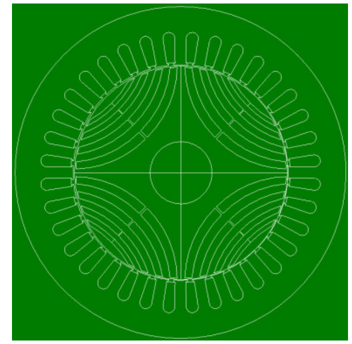

- Common stator construction
- Virtually no rotor losses
- Low cost
- No permanent excitation
- Common drive topology

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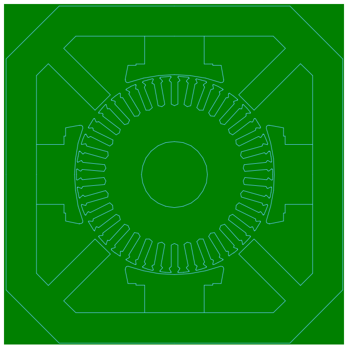
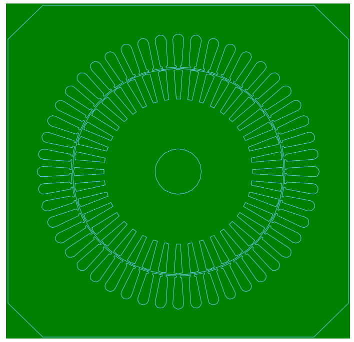
Motor Technologies: Disadvantages

DC



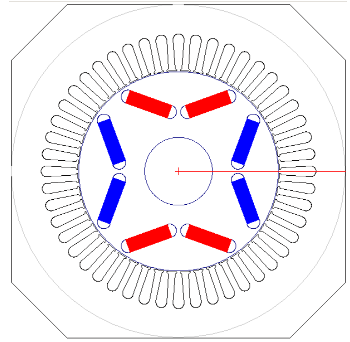
- Lower maximum speed
- Motor cost
- Rotor losses (cooling)
- Low power density

Induction



- Rotor losses (cooling)
- Less constant power speed range
- Low power density

Interior PM



- Complex rotor
- Magnet costs
- Constant rotor excitation
- Permanent magnet temperature effects
- More complex control

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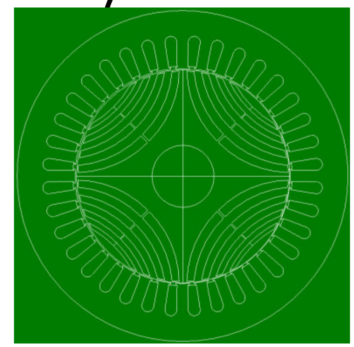
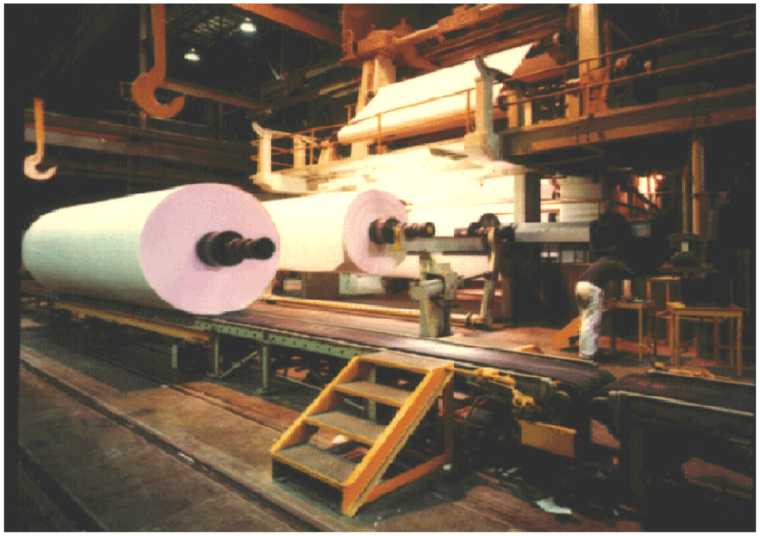


- Complex rotor
- Lower power factor

Typical Applications

- Wide constant power speed range with a low base speed (winders)
- Simple control including regeneration
- Low voltage traction
- Cranes (Hoist, trolley, swing, boom, gantry)
- Test stands



Typical Applications – AC Induction

- Parallel motors with load-sharing or shock loads
- Simple loads such as fans, pumps, compressors (general purpose)

Typical Applications – AC Induction

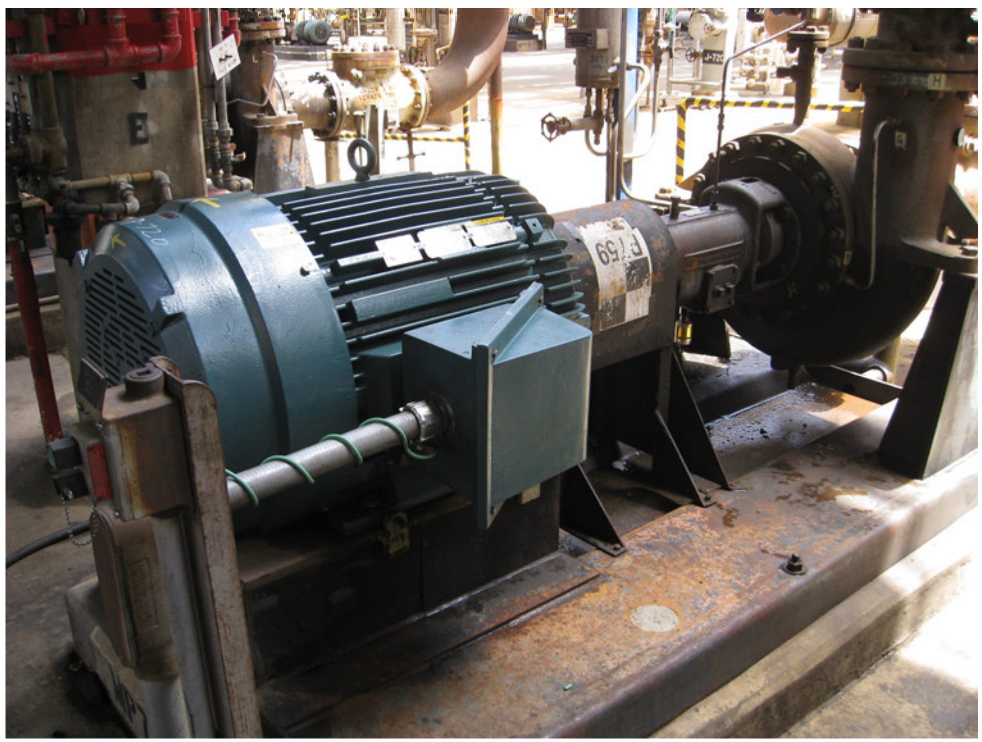
- Parallel motors with load-sharing or shock loads
- Simple loads such as fans, pumps, compressors (general purpose)
- ... And every once in a while a not-so-simple one ...

Typical Applications – Salient pole (interior) PM

- Ultra high efficiency
- Ultra high power density (traction, drilling)
- EV traction (wide constant power speed range with high efficiency throughout)

Typical Applications – Synchronous Reluctance

- High power density
- Very high efficiency
- Fans, pumps, compressors (general purpose)

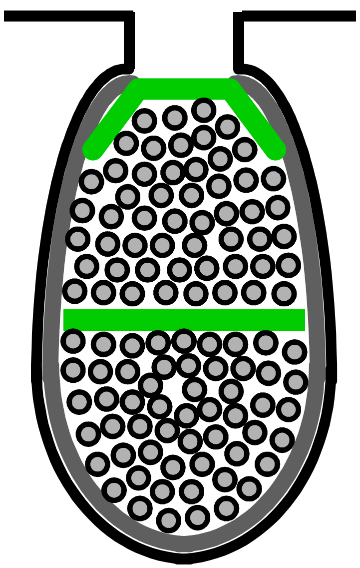


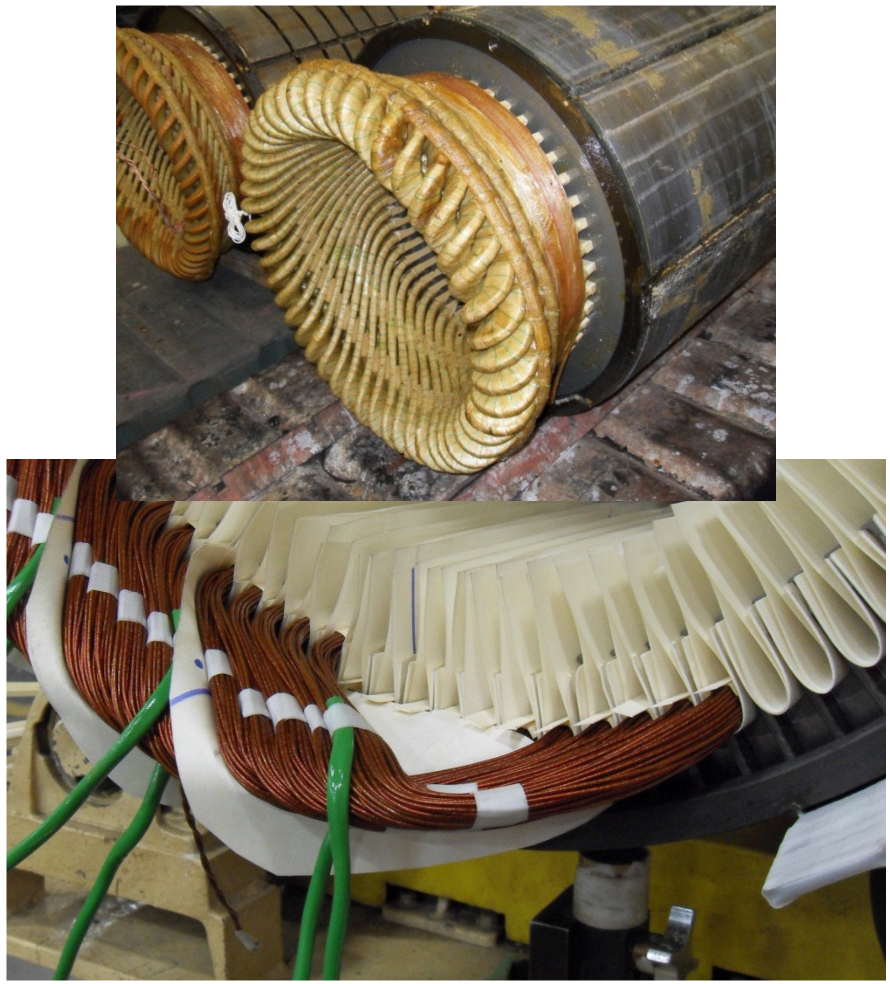
Motor Construction for variable speed

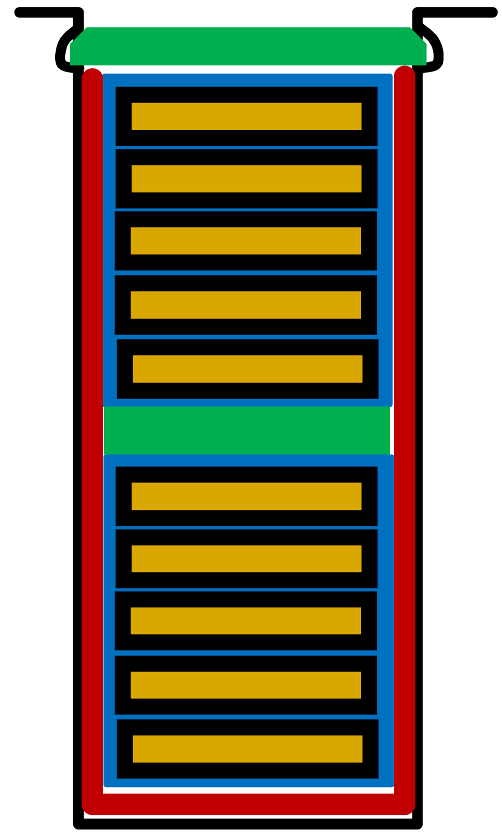
- Stator Insulation
- Insulated Bearings
- NEMA Part 30 vs Part 31

Inverter Duty Motors

- Stator Insulation







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Inverter Duty Motors

- **Bearing currents with sine wave power**

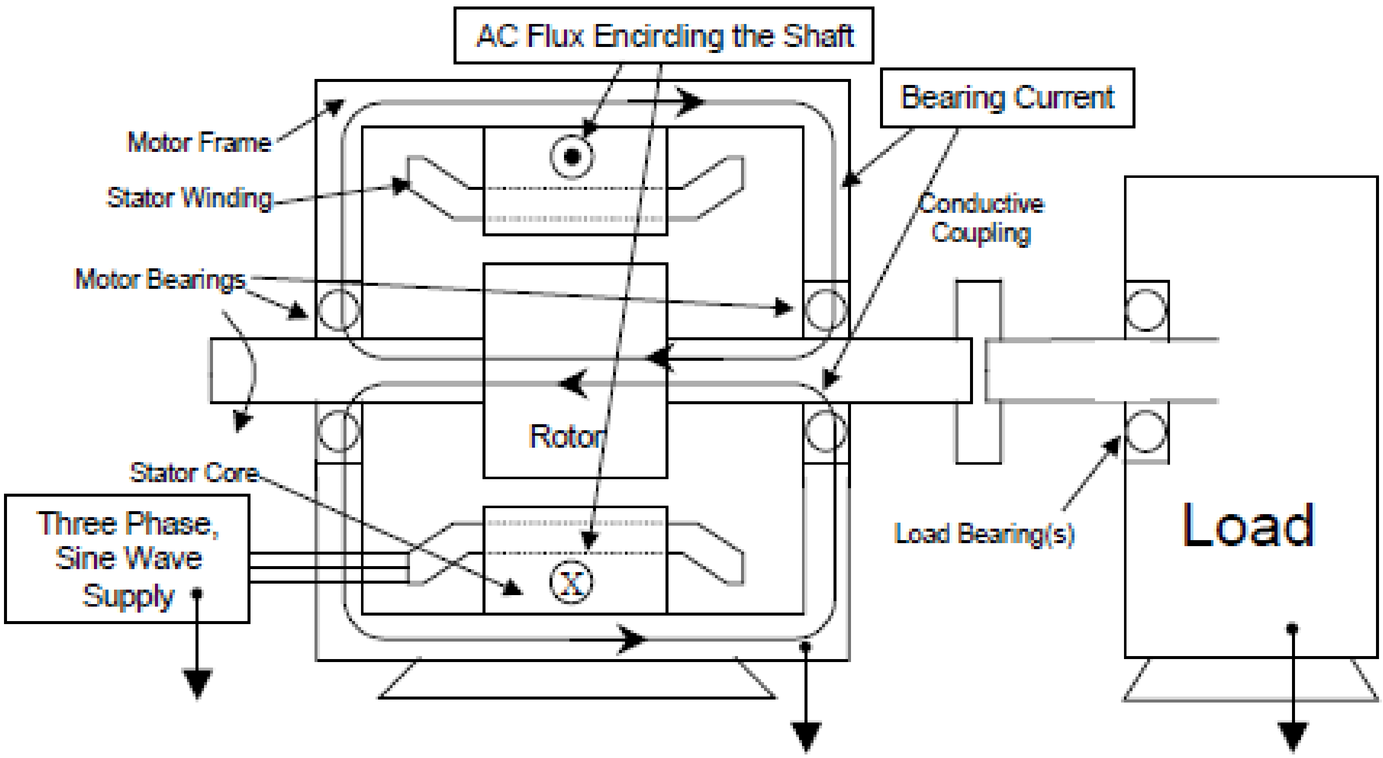


Fig 1 - Internally sourced motor bearing current paths due to alternating flux encircling the shaft.

Inverter Driven Induction Motor Bearing Current Solutions

Inverter Duty Motors

- **Bearing currents with ASD power**

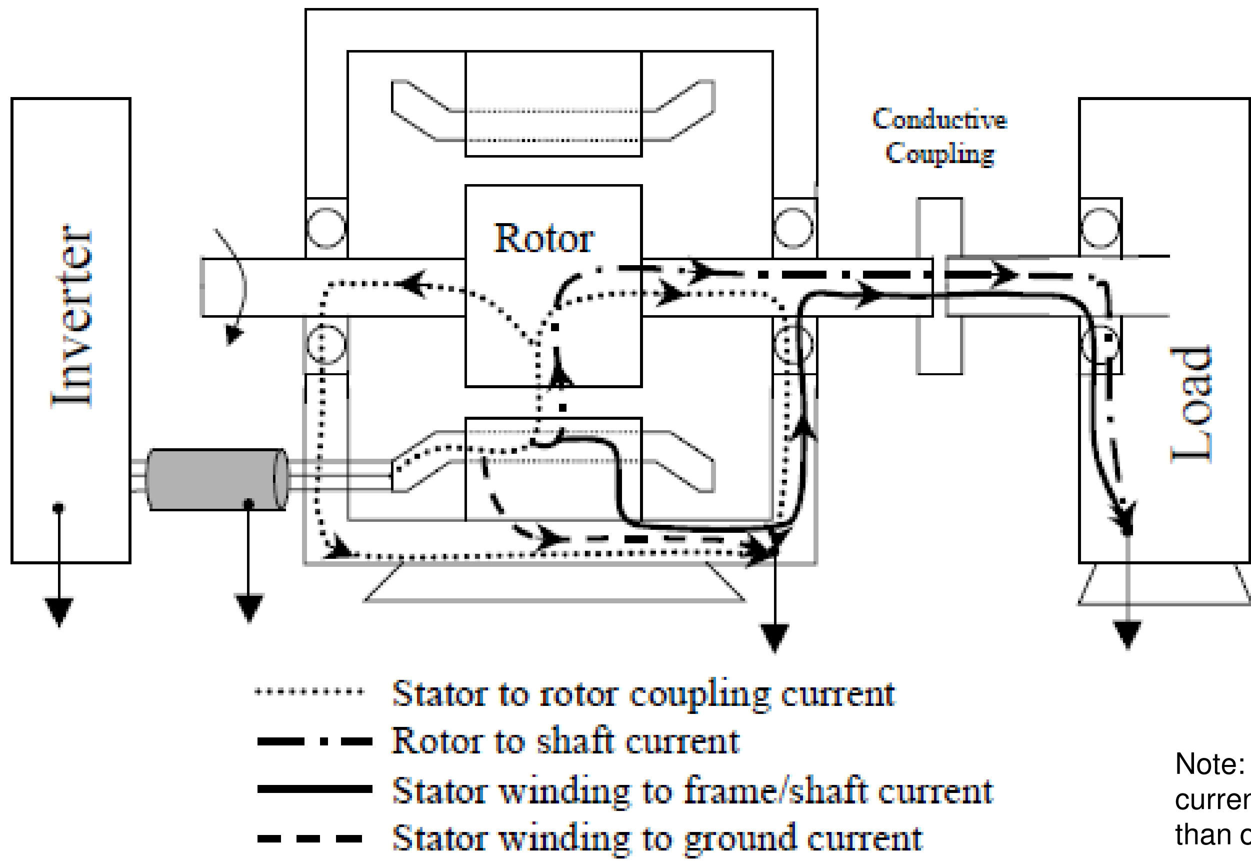


Fig. 2 - Capacitively coupled current paths in an inverter driven induction motor system

Note: Stator winding to frame/shaft current is 10 to 60 times higher than other components

Inverter Duty Motors

- **Solutions**

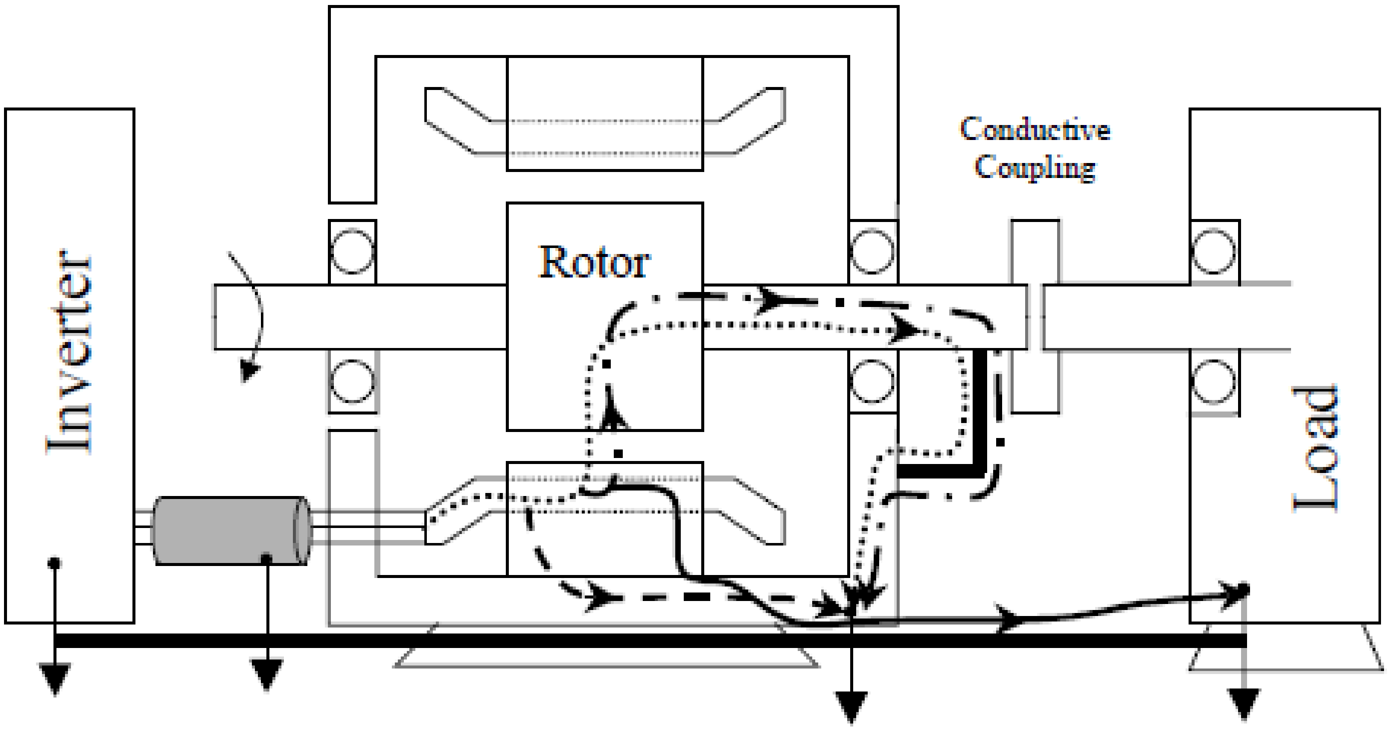
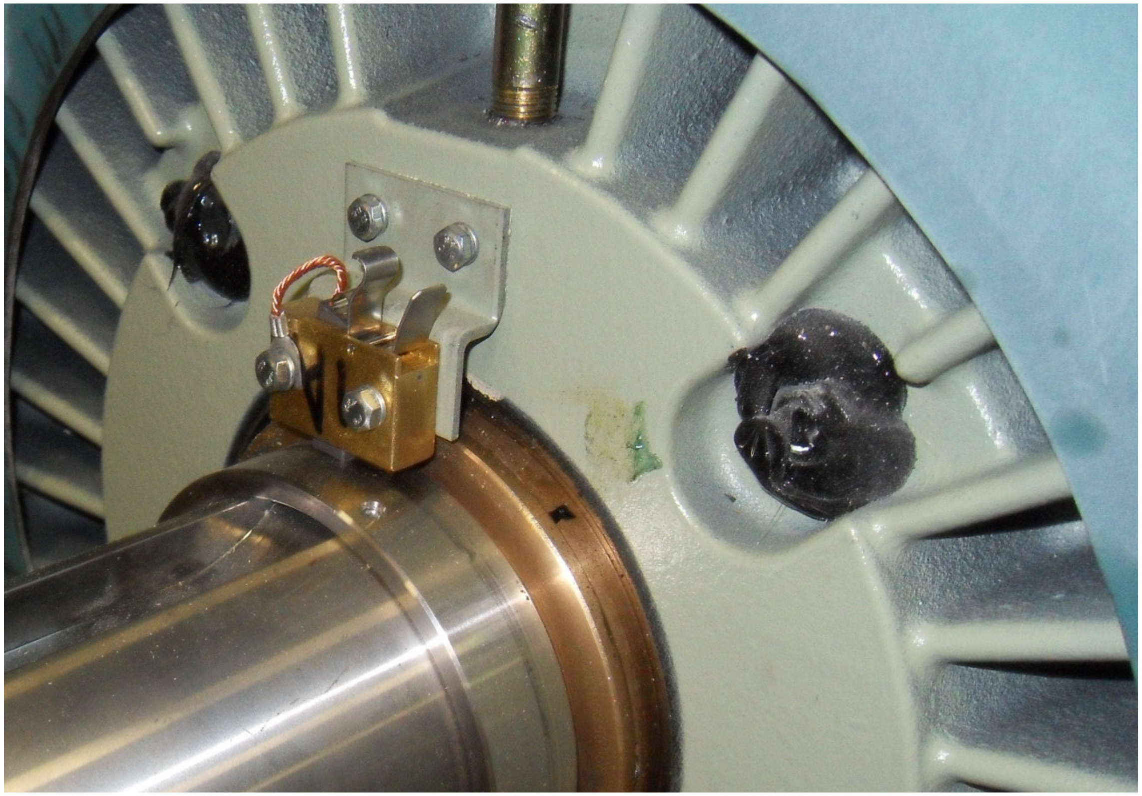


Fig. 10 - One insulated bearing and shaft grounding brush and good high frequency grounding from motor to load and from motor to drive. This solution reduces or eliminates all bearing current components both sine wave and inverter induced.

Insulated bearings and shaft Ground



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Inverter Duty Motors

- **NEMA MG1 Part 30 vs Part 31**
  - Part 30: Constant Speed Motors used on ASD’s
    - Part 30 is an application guide to be used by purchasers when applying a motor built to Part 12 or Part 20 on an ASD
  - Part 31: Definite Purpose Inverter Fed Polyphase Motors
    - Part 31 is for use by manufacturers as a guideline to design and apply a motor specifically for ASD operation, thus “Definite Purpose”. This section is also meant to be used as a guide for users just as Part 12 and Part 20 are.

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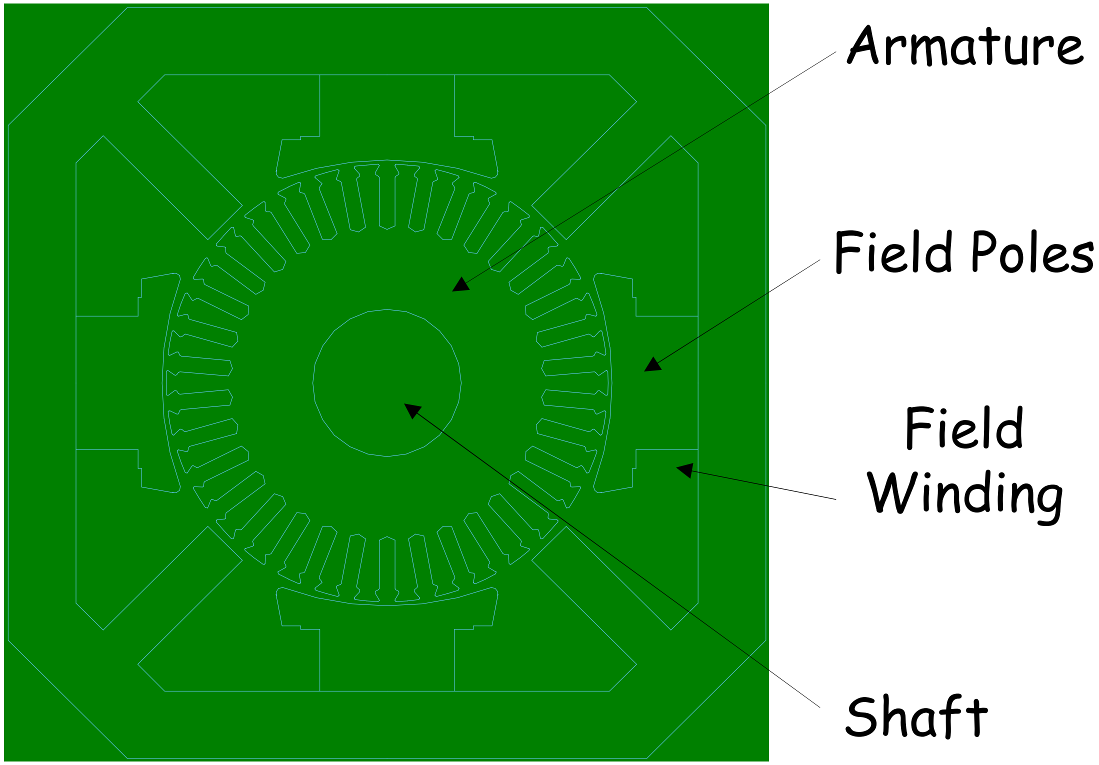
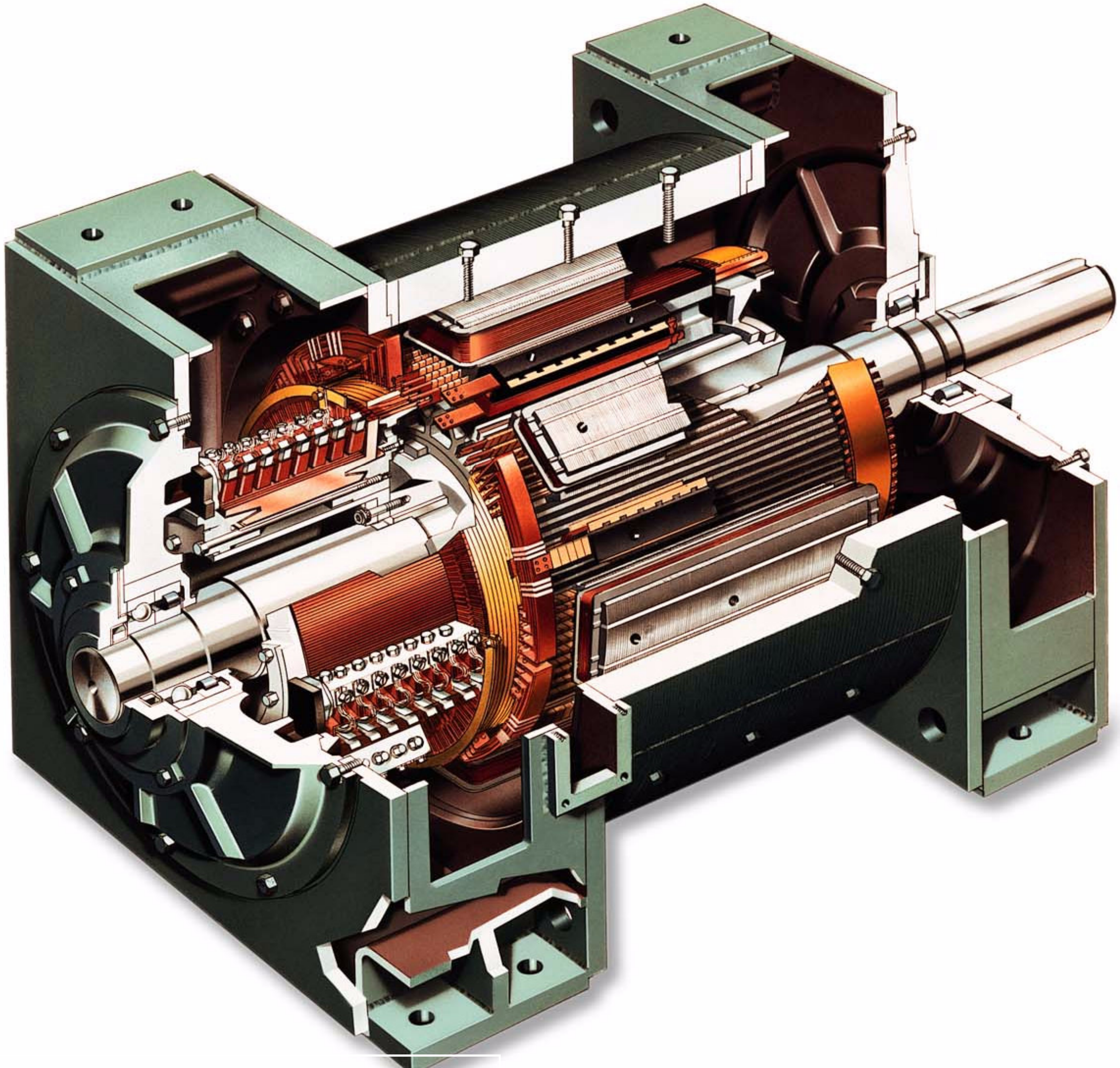
Motor Technologies: DC Motors

- **Typical wound field DC motor cross section**
- **Speed varied by controlling Field Current and Armature Voltage**
- **Torque controlled simply by current**



Motor Technologies: DC Motors



Motor Configurations

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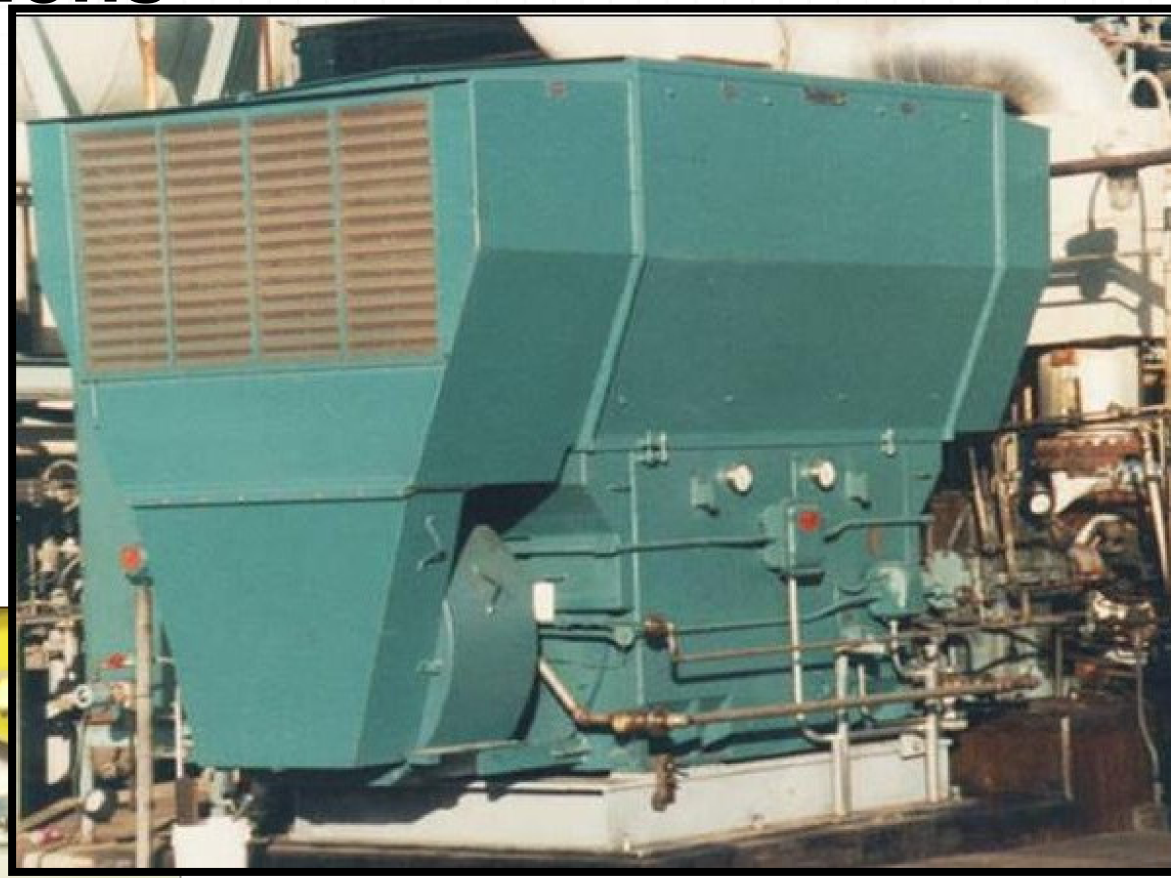
Motor Configurations



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