Large Induction Motors - How They Work, Are Designed and Constructed

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Induction Machines Overview Outline

• Intro and general features
• Induction Motor Basics
  ✓ How they work
  ✓ Design effects
• Selecting MV Induction Motors
  ✓ Voltage and Power Output Ratings
  ✓ Mechanical Design Characteristics – Torque, Speed Range
  ✓ Loads & Starting
• MV Motor Construction
  ✓ Frames, Rotors, Stator Windings
  ✓ Enclosure, bearings and environment
• Example Induction Motors and Applications
• Motor accessories
• Final Summary
INDUCTION MOTOR - Intro

• The Work horse of industry
• Most often used device for producing rotary power
• Known for Simplicity & Ruggedness
• Lowest cost per HP for MV Motor
• Up to practical size limit of about 20,000 kw
Inside an Induction Motor

Basic frame + Top hat (4-types) = ODP / WPII / TEAAC / TEWAC
Large Induction Motors: - How They Work, How They Are Designed and Constructed

Induction Motor Exploded View
Inside an Induction Motor

- Main Terminal Box
- Air Housing
- Stator Core
- Stator Windings
- Rotor with Windings & Fan
- Stator Frame
- Anti-friction or Sleeve Bearings
- Aux Term Box
How Induction Machines are Built and Work
INDUCTION MOTOR Construction

- **Stator**
  - Iron core with slots
  - Copper windings connected to AC power source

- **Squirrel Cage Rotor**
  - Conductors arranged like bars in a squirrel cage
  - Imbedded into an iron core
  - Iron core is mounted on motor shaft
Squirrel Cage Induction Motor Rotor
Rugged, Simple, Reliable

- Rotor bars in slots of rotor – copper, copper alloy or aluminum
- Connected through end ring
- Supported on shaft “spider support”
INDUCTION MOTOR STARTING CHARACTERISTICS

Example Current and Torque vs. Speed at 100% Volts
Induction Motor Speed-Torque Profile
At applied frequency

Locked Rotor Tq

Peak [Breakdown] Torque, BDT

Sync Rpm = 120 x Freq. #Poles

Rated Torque

Rated Slip RPM = Sync - Rated RPM

Sync RPM

Rated RPM

RPM

Torque

Pull Up Torque

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www.tmeic.com
INDUCTION MOTOR ROTOR & STATOR DESIGN

Rotor design affects

- Speed-torque curve shape
- Current-speed curves
- Power factor speed curves
- Efficiency-load curves

Stator design affects

- Number of poles (synchronous speed)
- Rated line volts & frequency
INDUCTION MOTOR SPEED TORQUE
NEMA STANDARDS EXAMPLES

- NEMA Design B  “standard” starting torque
- NEMA Design C  high starting torque
- NEMA Design D  highest start torque, lowest inrush amps, high slip
Simplified Squirrel Cage Induction Motor Representation

- Model is of transformer with turns ratio N1:N2, and shorted secondary
- Line voltage applied: magnetizes core, makes volts at secondary [Vss]
- Secondary amps flow through shorting ring, creating rotor magnetic field
- Magnetic Forces in Stator attract to rotor magnetic fields and rotor turns
- Torque capability goes up or down with SQUARE of Line volts
MOTOR THEORY

• Motor torque created by attraction between magnetic poles on the stator and magnetic poles INDUCED on the rotor
  ✓ Same with all motors AC or DC
  ✓ Attraction must be tangential to rotor surface, resultant vector

• Also radial magnetic forces across the air gap
  ✓ Radial forces are repulsion between stator & rotor
  ✓ Contributes no rotational force

Torque = \( F_t \times R \)
Key Ideas

- Stator magnet flux is produced by 3 phase winding inserted in slots of the stator laminations.

- Peak magnetic flux sinusoidal wave “rotates” around the air gap.

- Number of winding coils per phase = number of poles.
• Most of the heat created is in the rotor and air gap.

• Cooling the rotor requires forcing air thru the rotor and out of the “air” gap between the stator and rotor.

Cooling slots in the rotor
INDUCTION MOTOR SPEED TORQUE
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Sync RPM = 120 F / p

Torque = F_t x R

Stator Iron and Windings

Three phase power to Stator

Stator flux wave direction

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WOUND ROTOR INDUCTION MOTOR

- Used for High inertia loads and high HP on weak power systems
- Stator similar to squirrel cage motor
- Rotor circuit is now 3 phase winding connected through slip rings
- Connect external resistance to rotor to start and RPM at Peak Torque
- Heat loss of rotor circuit largely external
- Modern LV VFD Converter and Inverter can give variable speed with slip power recovery [SPR]
WOUND ROTOR INDUCTION MOTOR

Typical Characteristic Curves

Starting Performance – Wound Rotor Induction Motor
Wound Rotor vs Squirrel Cage Induction Motor Construction & Equivalent Circuit Comparison

Squirrel Cage rotor, current & Torque fixed by Motor design

Wound rotor, current and torque set by external resistor or control
### Induction Motors - Summary Electrical Relationships

<table>
<thead>
<tr>
<th>Area</th>
<th>Effect / Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Starting Amps</td>
<td>Starting Amps falls directly with volts</td>
</tr>
<tr>
<td>2 Torque capacity</td>
<td>Rises and falls as the SQUARE of volts</td>
</tr>
<tr>
<td>3 Slower Motor</td>
<td>More poles = more magnetizing amps = poorer power factor [always lagging]</td>
</tr>
<tr>
<td>4 Motor Diameter and Length effect on torque</td>
<td>Torque &amp; speed [power] go up with rotor diameter² x length</td>
</tr>
<tr>
<td>5 Slip: % Difference of running speed and sync speed</td>
<td>NO Slip = No rotor amps, no torque!</td>
</tr>
<tr>
<td>6 Slip and Efficiency</td>
<td>High slip = high losses, low efficiency</td>
</tr>
</tbody>
</table>

![Diagram showing electrical relationships of an induction motor](image)

- **Stator** (X1, R1, Xm)
- **Rotor** (X2s, R2/slip)
- **Torque Producing Volts**
- **Line Volts**
- **% TORQUE**
- **Possible Const Torque Load**
- **600 Amps @100% Volts**
- **480 Amps @80% Volts**
- **34% Torque @80% Volts**
Motor Selection Process

Requirements for motors

Electrical specifications
- Rating (output, voltage, Hz, RPM)
- Starting method & condition
- Load torque characteristic
- Temperature rise limitation
- Power source condition
- Noise limitations

Mechanical specification
- Enclosure type
  (Protection and cooling)
- Bearing type
- Environmental condition
  (Amb. Temp., Corrosive and Explosive area classification..)

Industry / Application Standard

Electrical design

Mechanical design

Final motor design
# Large Induction Motors: - How They Work, How They Are Designed and Constructed

## Chart Relating Motors and Controls to Load Type [MEMSA 2013]

<table>
<thead>
<tr>
<th>Load Type / Application</th>
<th>Constant Torque Loads</th>
<th>Variable Torque Loads</th>
<th>In Between Loads</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Conveyors</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Uphill, Level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Down hill</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crushers, Vertical Mills</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grinding Mills</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAG Mill</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ball, Rod Mill</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Pressure Mills</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excavators</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Draglines</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shovels</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drills</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recip Compressors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pumps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fans</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrifugal Compressors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyclones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slurry Pumps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Separators / Cyclones</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Special Load Characteristics
- High Starting Torque
- Load Power Regeneration
- Above Base Speed Option

### Control Requirement
- Variable Speed
- Starting on Strong Utility
- Starting on Weak Utility

### Legend of Applicable Controls
- 1. Full Voltage Starter [Contactor, Breaker]
- 2. Reactor Reduced Voltage Starter
- 3. AutoTrans Reduced Voltage Starter
- 4. Solid-State Reduced Voltage Starters
- 5. VFD - Full HP rated 110% OL
- 6. VFD - Full HP rated 150% OL
- 7. VFD - Full HP rated >150% OL
- 8. VFD - Start Duty Rated
- 9. WR Motor - Full speed
- 10. WR Motor - SPR, PWM Drive

### Special Note / Suffix
- C Clutch May be required
- R VFD with Regen Converter
- PR Starting mode Pressure Relief
- NR Not Recommended
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Pick Motor Voltage
Based on kW Load & Available Power

- **3 kV and 4160 Volts**
  - 40 kW
  - 65 kW
  - 150 kW
  - 400 kW
  - 5000 kW

- **6 kV and 6600 Volts**
  - 10 kW
  - 2000 kW
  - 12,000 kW
  - 7500 kW
  - 10,000 kW

- **10 kV to 13,200 Volts**
  - 12,000 kW
  - 18,000 kW
  - 5000 kW
  - 10,000 kW

**Rating Possible**
- 40 kW
- 65 kW
- 150 kW
- 400 kW
- 5000 kW

**Rating Appropriate**
- 10 kW
- 2000 kW
- 12,000 kW
- 7500 kW
- 10,000 kW
- 12,000 kW
- 18,000 kW
- 5000 kW
Define Load Torque Inertia & Speed

• Starting torque required
• Fixed or variable Operating speed
• Load torque versus speed curves
  ✓ Zero Speed Breakaway Torque required
  ✓ Variable Torque [pump, fan centrifugal Compressor]
  ✓ Constant Torque [Conveyor, Reciprocating Compressor]
Starting 1 (Motor starting characteristics and starting time)

Starting time(s) = \( Wk^2 \times \text{Delta RPM} / (308 \times \text{Torque}) \)
Starting and Rotor Heating

• Starting from utility frequency – rotor heats, windings stress from high amps.

• Must limits number of starts per hour

• Design includes calculation of maximum allowed inertia in design – bigger inertia require bigger motor.

• Soft-starters [reduced line volts] do not help heating, but lower amps and stresses

• No limits on starting on VFD power!
MV Motor Insulation

- Voltage Class – 3, 5, 6, 8, 10, 15 kv – on sine wave power
- Thermal class – Defines TOTAL allowed temp, & allowable temperature rise over ambient

<table>
<thead>
<tr>
<th>Insulation Class</th>
<th>Allowable Total Temp for 20000 Hour Life, Deg C</th>
<th>Allowable Rise over 40 C Ambient (From NEMA table 20.8.1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>105°</td>
<td>60°</td>
</tr>
<tr>
<td>B</td>
<td>130°</td>
<td>80°</td>
</tr>
<tr>
<td>F</td>
<td>155°</td>
<td>105°</td>
</tr>
<tr>
<td>H</td>
<td>180°</td>
<td>125°</td>
</tr>
</tbody>
</table>
Temperature Rise and Insulation Class
Per MG1 12.42.1 for TEFC

Class B 130C Max
- 130C Max Temp of winding
- 40C Amb
-10C Hot Spot
80C Rise Δ at Full Load

Class F 155C Tot = 105C Rise

Common Spec for MV motors – Class F Ins with Class B Rise – Why?
Temperature rise 1.0 sf

### Temperature Rise, Degrees C

<table>
<thead>
<tr>
<th>Method of Temperature Determination</th>
<th>Class of Insulation System</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Resistance</td>
<td>60</td>
</tr>
<tr>
<td>Embedded detector*</td>
<td>70</td>
</tr>
<tr>
<td>Embedded detector*</td>
<td>65</td>
</tr>
<tr>
<td>Embedded detector*</td>
<td>60</td>
</tr>
</tbody>
</table>

*Embedded detectors are located within the slot of the machine and can be either resistance elements or thermocouples. For machines equipped with embedded detectors, this method shall be used to demonstrate conformity with the standard. (See 20.28)

An additional 10 deg C are allowed when temperature is measured by RTD

Key word is **RISE**
**Temperature rise ASD**

### Table 31-2

<table>
<thead>
<tr>
<th>Insulation Class</th>
<th>Resistance</th>
<th>Embedded Detector</th>
<th>Resistance</th>
<th>Embedded Detector</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>70</td>
<td>80</td>
<td>60</td>
<td>70</td>
</tr>
<tr>
<td>B</td>
<td>100</td>
<td>110</td>
<td>80</td>
<td>90</td>
</tr>
<tr>
<td>F*</td>
<td>130</td>
<td>140</td>
<td>105</td>
<td>115</td>
</tr>
<tr>
<td>H*</td>
<td>155</td>
<td>170</td>
<td>125</td>
<td>140</td>
</tr>
</tbody>
</table>

*Where a Class F or H insulation system is used, special consideration should be given to bearing temperature, lubrication etc.
Insulation Life

Insulation Average Expected Life vs Temperature

Curves and tests show: double insulation life for each 10\(^\circ\) C reduction in operating temperature.
Stator coil insulation

- Slot wedge: glass polyester laminated plate
- Spacer (under slot wedge)
- Mica insulated wire
- Main insulation: Half lapped Mica tape
- Resistance temperature detector (R.T.D) or Spacer between coils
- Semi-conductive tape (for prevention of corona discharge)
- Spacer (bottom of slot)
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Form-Wound Stator coil
MV Motor Stator Coil Forming and Insulation
Stator Core with Form Wound Coils
Form Wound Stator Coil
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**Stator core**

- Two coils per slot
- Bracing on end turns
- VPI solidifies the winding
Stator core

- RTD leads exiting the stator windings
- Close-up of bracing
- All areas shown are VPI protected
Stator Core with Windings in Place

Before VPI
Vacuum Pressure Impregnation Facility & Benefits

- Large Tank capacity
- VPI Stators Up to ~50 MW
- Provides High Reliability
- VPI Provides Excellent
  - Mechanical Strength
  - Thermal Rating
  - Moisture Resistance
  - Chemical Resistance
Vacuum Pressure Impregnation Process

Variation of Capacitance during the process for Impregnation

- Vacuum part of cycle draws out moisture from stator windings and assembly.
- Resin is added at atmospheric pressure.
- Pressurization part of cycle forces resin into all voids.
- Winding capacitance increases and levels off, indicating finish to VPI process.
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STATOR CORE AFTER VPI

- Winding is now a solid mass, giving protection from forces during operation & starting.
- Moisture from environment is locked out.
LV Stator
Contrast with Form-Wound

- Random Wound Construction
- Shown Before Dipping
- Used in LV motors only
- Non-VPI construction [dip in resin & bake] is not as tough as VPI
Large Induction Motors: - How They Work, How They Are Designed and Constructed

Rotor Shaft, Core Support and Air Baffle
Rotor laminations

- Rotor core iron ready for stacking
Copper bars are trimmed and finished in lathe. End ring will be brazed to the bar ends.
Assembled Rotors

Finished Aluminum Cast Rotor with Cooling Fins

Complete Copper Bar Rotor
**Rotor core**

- **Copper bars, swaged into slot**
- **Upset lamination pressure fingers** tighten rotor core, reduce noise
- **Swaging** produces tight bar fit and avoids sparking and reduces noise
Completed Rotors

Note Corrosion-Resistant Coating

Low Speed
With Radial Fan

High Speed
With Axial Fan
Motor Enclosures and Application
Fabricated Frame

Cast Frame
For TEFC or TENV
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CAE Analysis Technology

Designs for Each Motor as an Electro-Mechanical System

- Cooling air analysis
- Natural frequency analysis
- End turn Deformation analysis
- Electro-magnetic analysis
- Rotor dynamics analysis
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Typical Components of TEFC Fin-Frame Induction Motor
Typical Components of Top Hat Induction Motor
Stator & Frame Assembly

- Completely wound and insulated stator is lowered into machined stator frame.
- Specially designed stator mounting method minimizes vibration issues.
- Maintenance and repairs are simplified by mounting method.
Frames Dimensions, Mounting, Enclosures, and Cooling
Motor Frame Size Numbering, IEC Conventions

Example Frame 500 - 1800

<table>
<thead>
<tr>
<th>Motor Frame Size Numbering</th>
<th>Example C Dimension for Standard TMEIC frames</th>
</tr>
</thead>
<tbody>
<tr>
<td>250</td>
<td>280</td>
</tr>
</tbody>
</table>

“2F” = 1800, foot spacing in mm

“C” = 500, shaft height in mm
Mounting Type (per IEC60034-7)
Designation for machines with horizontal shafts (IM B..)

<table>
<thead>
<tr>
<th></th>
<th>IM B3</th>
<th>IM B5</th>
<th>IM B35</th>
</tr>
</thead>
</table>

Designation for machines with vertical shafts (IM V..)

<table>
<thead>
<tr>
<th></th>
<th>IM V1</th>
<th>IM V3</th>
<th>IM V5</th>
<th>IM V6</th>
</tr>
</thead>
</table>

* TMEIC standard
### Physical & Environmental Protection type: IEC60034-5

<table>
<thead>
<tr>
<th>First characteristic numeral</th>
<th>Second characteristic numeral</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 Non-protected machine</td>
<td>0 Non-protected machine</td>
</tr>
<tr>
<td>1 Machine protected against solid objects greater than 50 mm</td>
<td>1 Machine protected against dripping water</td>
</tr>
<tr>
<td>2 Machine protected against solid objects greater than 12 mm</td>
<td>2 Machine protected against dripping water when tilted up to 15deg</td>
</tr>
<tr>
<td>3 Machine protected against solid objects greater than 2.5 mm</td>
<td>3 Machine protected against spraying water</td>
</tr>
<tr>
<td>4 Machine protected against solid objects greater than 1.0 mm</td>
<td>4 Machine protected against splashing water</td>
</tr>
<tr>
<td>5 Dust-protected machine</td>
<td>5 Machine protected against water jets</td>
</tr>
<tr>
<td>6 Dust-tight machines</td>
<td>6 Machine protected against heavy seas</td>
</tr>
<tr>
<td>7 Machine protected against the effects of immersion</td>
<td>7 Machine protected against the effects of immersion</td>
</tr>
<tr>
<td>8 Machine protected against the effects of continuous submersion</td>
<td>8 Machine protected against the effects of continuous submersion</td>
</tr>
</tbody>
</table>
### Complete designation

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC 8 A 1 W 7</td>
<td>Cooling type: IEC60034-6</td>
</tr>
</tbody>
</table>

### Simplified designation

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC 8 1 W</td>
<td></td>
</tr>
</tbody>
</table>

**3.1.1 CODE LETTERS**

- **International Cooling**

**3.1.2 CIRCUIT ARRANGEMENT**

- Designated by a characteristic numeral in accordance with clause 4

**3.1.3 PRIMARY COOLANT**

- Designated by a characteristic letter in accordance with clause 5
- Omitted for simplified designation if it is A for air

**3.1.4 METHOD OF MOVEMENT OF PRIMARY COOLANT**

- Higher temperature
- Designated by a characteristic numeral in accordance with clause 6

**3.1.5 SECONDARY COOLANT**

- If applicable, designated by a characteristic letter in accordance with clause 5
- Omitted for simplified designation if it is A for air

**3.1.6 METHOD OF MOVEMENT OF SECONDARY COOLANT**

- Lower temperature
- If applicable, designated by a characteristic numeral in accordance with clause 6
- Omitted in case of the simplified designation if it is 7 with water (W) for secondary coolant.
Open Drip Proof (ODP, IP22, IC01)

- Inexpensive
- Applicable only clean and well ventilated room
- Winding is well cooled (Small motor size)
- Noise abatement difficulty
DP Drip Proof fully guarded
DPSV Drip Proof Separately Ventilated
NEMA Weather-Protected Type-II
(WPII, IP24W, IC01)

- Suitable for outdoor use, but not common outside North America
- More expensive than ODP but still reasonable
- Winding is well cooled (Small motor size)
WP

- Weather Protected with top hat
TENV

- Totally Enclosed Non Ventilated
Totally Enclosed Fan Cooled (TEFC, IP55, IC411)

- Inexpensive
- Suitable for outdoor use
- Not available for large capacity range
TEAO • Totally Enclosed Air Over (axial fan)
TEFC • Totally Enclosed Fan Cooled
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TEAO
- Totally Enclosed Air Over (radial fan)

TEBV
- Totally Enclosed Blower Ventilated
Totally Enclosed Air to Air Cooled (TEAAC, IP55, IC611)

- Suitable for outdoor use, and common outside North America
- Expensive
- Winding is not well cooled (larger motor size than ODP)
- Not available for extremely large capacity motor
- Noise abatement difficulty (Small cooling fan leads to large motor size)
TEAAC

- Totally Enclosed Air to Air Cooled
- Separate fan for external air
TEAAC • Totally Enclosed Air to Air Cooled
TEAAC
Totally-Enclosed-Air-Air Cooled
Totally Enclosed Water to Air Cooled (TEWAC, IP55, IC81W)

- Suitable for outdoor use, but needs cooling water
- Expensive
- Winding is well cooled (Same motor size with ODP)
- Available for extremely large capacity motor
- Easy noise abatement
TEWAC • Totally Enclosed Water to Air Cooled
Wound Rotor Induction Motor [WRIM]

Details of 3-Ph Rotor Slip Rings
Bearings
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Anti-Friction Bearings

- Inexpensive comparing with sleeve bearings
- Less friction loss
- Relatively short lubricant changing interval (several months)
- Not usually suitable for very high-speed or high shaft load
- Limited bearing life (100,000 hours except for 2 pole as for TMEIC)
Self lubricated sleeve bearings

- Long bearing life
- Long lubricant changing interval (one year)
- Expensive compared with anti-friction bearings
- More friction loss
- Not suitable for very high-speed and highly-loaded applications
- Not suitable for high ambient temperature applications
Pressure Lubricated Sleeve Bearings

- Long bearing life
- Covers high-speed and highly-loaded range
- No shut down is required for lubricant changing
- Expensive comparing with anti-friction bearings or self lube
- More friction loss
- Requires forced lubrication pump system
Motor Accessories
Inverter duty motor design

- **Insulation reinforcement** for inverter surge voltages
- **Close attention to cooling** for torque load over speed range
- **Thermal redundancy** for heat loss caused by harmonics
- **Shaft current protection** (bearing electric discharge erosion)
  - Normally non-drive end bearing insulation plus earth brush on drive shaft end.
  - For hazardous area, both bearings are insulated and adoption of insulated coupling.

Grounding brush
Motor terminal box requirements

- Standard type
- Phase isolation type
- Phase segregated type

For Accessories

For Space heater
ACCESSORIES (Space heaters)

Space heater is used to avoid dew in the motor frame to protect winding insulation during the storage. Low surface temperature is required in hazardous area.
ACCESSORIES (Temperature measurement)

Winding RTD
(resistance temperature detector)

Bearing RTD or Thermocouple

Dial type bearing thermometer
ACCESSORIES (Vibration measurement)

Bearing housing vibration sensor & it’s mounting provision

Non-contacting shaft vibration sensor
(Bentley Nevada)
ACCESSORIES (Surge protection)

Surge arresters

Surge capacitors
[Not for use with VFD]

Accessories typically mounted in motor main terminal box
ACCESSORIES - CTs for Insulation failure detection

Neutral leads needs to be brought out to main terminal box
Large Induction Motors: - How They Work, How They Are Designed and Constructed

Example BUSY Motor Junction Box w/ LA, Surge Cap, and CT’s!
Testing and Special Requirements
### Induction Motor Standard Tests

#### TMEIC Example Test Selection Sheet

<table>
<thead>
<tr>
<th>Test and inspection item</th>
<th>Shop test</th>
<th>Witness test</th>
<th>Test record</th>
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</thead>
<tbody>
<tr>
<td>1. Measurement of winding resistance</td>
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<tr>
<td>2. Measurement of secondary voltage</td>
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<tr>
<td>3. Characteristic tests</td>
<td></td>
<td></td>
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<tr>
<td>a. No load test</td>
<td>☐</td>
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<tr>
<td>b. Locked rotor test</td>
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<td>4. Load characteristics at rated voltage and frequency</td>
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<td>5. Temperature rise test</td>
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<td>6. Measurement of vibration</td>
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<td>7. Check of direction of rotation</td>
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<td>8. Measurement of air gap</td>
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<td>9. Measurement of noise level</td>
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<td>10. Measurement of insulation resistance</td>
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<td>11. High voltage test</td>
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<td>12. Measurement of shaft voltage</td>
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<tr>
<td>13. Appearance check and dimensional inspection</td>
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</tbody>
</table>

**Note:**
- ☐: Applied
- ☐: Not applicable
- ☐: Applied by request
API 541 (American Petroleum Institute) standard

Required for many motors in use in Oil & Gas Industry

1. Max. 650% locked rotor current limitation
2. Max. 85dB(A) noise limitation
3. Sleeve bearing requirement
4. Very strict vibration limits
5. A4000 series heat treated forged steel shaft requirements
6. Lots of option test items
7. Data sheet is very detailed! Many users don’t / won’t fill out for RFQ
Hazardous Area Classifications

• Defines areas where dangerous gases or particles could be ignited by spark or high equipment temps

• NEC Art. 505 defines for North America, while IEC 60079 defines for other parts of the world

• Frequency, concentration, type of explosive mixtures and areas are defined.

• Motor construction and design standards are applied to certify conformity for use
High RPM Machines

- 2-Pole Construction with Base Speed of 3600 RPM at 60 Hz
- “Stiff Shaft” 2-pole moves all resonance RPMs above 3600
- By VFD, high stator frequency makes direct drive of High-Speed Compressors possible.
- Motor Balance and vibration ultra critical
- Super-high RPM requires magnetic bearings

Synchronous Motor:
- 10MW & over / 4000～8000min-1

Induction Motor:
- 2～10MW / 4000～15000min-1

Merits of Variable Speed Motor Drive Systems:
- Energy Saving
- Omission of Gear
Thermal Vector
As motor warms – what happens to vibration levels?

Bad - increasing

Good – not increasing
Thermal Vector
Temperature effects on Mechanical balance – API 541

• **API 541 4.3.3.11** The magnitude of the resultant vector (filtered 1X vibration) change from no load to rated temperature shall not exceed 0.60 mils for shaft vibration and 0.05 ips for the bearing housing vibration. Appendix E outlines the procedure for determining the resultant vector change.

• **API 541 Appendix E** also limits *maximum* vibration level to 1.2 mills
Causes of Mechanical Vibration

1. Mechanical asymmetry including Installation Factors:
   - Static or dynamic unbalanced rotational mass.
   - Uneven support for the motor, such as a soft foot.

2. Design, Construction
   - Bearings not properly supported in the end shield.
   - Resonance with the support base.
   - Loss of axial clearance due to thermal expansion

3. Operation & Maintenance
   - Operating in the region of the critical speed.
   - Damaged bearings.
   - Dirt, dust accumulation in rotor
2 Pole Induction Motors - Example TMEIC Features

- High reliability, proven technology and manufacturing process
- **Low Vibration** by using
  1. Spring Support Stator &
  2. Stiff Shaft Rotor (as option)
- Advanced Technology by FEM Analysis
Standard Motor Junction Box
Large Induction Motors: - How They Work, How They Are Designed and Constructed

Junction Box with Arrestors and Caps
Induction Motors Compared With Sync Motors

**Induction Motors**

**Similarities:** Follow rotating 3-phase magnetic flux wave, RPM is dependent on frequency of source

**Differences:**
- **AC Rotor field**, *induced* by transformer action
- Rotor field depends on AC line voltage
- Actual torque producing speed differ from sync speed by slip %
- Always runs lagging p.f.
- Torque falls ~ Volts

**Synchronous Motors**

- **DC Rotor Field**, ext. fed or generated by DC exciter
- Rotor field set independently
- Always turns exactly at sync speed
- Can run leading or lagging pf
- Torque falls ~ Volts
Large Induction Motors: - How They Work, How They Are Designed and Constructed

SM & IM Speed-Capacity Range

- Synchronous Motor
- Induction Motor

Capacity (MW)

Rotating speed (min⁻¹)
LIFE AND RELIABILITY OF MOTORS

• Motor life determined by integrity of 3 interfaces
  ✓ Dielectric integrity
    ❖ insulate conducting and non-conducting parts
  ✓ Rotational integrity
    ❖ separate moving from stationary parts
  ✓ Mechanical integrity
    ❖ withstand mechanical stresses of shaft torques, impact loads, mounting stresses, reversing and vibrational forces

• Influenced by thermal & mechanical considerations
  ✓ temperature of motor
  ✓ cleanliness of environment
  ✓ quality of maintenance
Thanks!