Alternating Current Motors in Detail

• Overview/Objectives:
  o Advanced motor component descriptions/details
  o Design, materials and construction
  o Starting and operation
  o Temperature effects on performance
Capacitors
Centrifugal Switching

- Centrifugal Switching
Essential Components
Two Basic Parts of any AC Motor

**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 energy 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
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
  o High Grade Varnish
  o Intended for Air-Cooled or Oil Immersed Cores
  o Approved for NEMA Class F Service*
  o Will Not Survive Lamination Annealing Process
  o Provides Less Resistance Between Laminations

• Core Plate C5
  o Oil and Heat Resistant Inorganic Coating
  o Suited for High Temperature Applications
  o Withstands Lamination Annealing Temperature, Welding Temperature and Typical Burn-Out Temperature

* Per NEMA Standard MG-1
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
  o Number of Turns
  o Size/Shape of Wire
  o Insulation
    – Class F or Class H
    – Enamel or Glass over Enamel
Stator Windings

Random

Form
Stator Windings - Random Wound
Stator Windings
Form Wound
Stator Windings
Form Wound
Stator Windings Manufacturing Process

- 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
<table>
<thead>
<tr>
<th>NEMA Class</th>
<th>Description</th>
<th>Insulation Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>Heavy Film, Single Glass, Epoxy Saturant, Copper Wire</td>
<td>0.013”</td>
</tr>
<tr>
<td>F</td>
<td>Heavy Film, Single Glass, Copper Wire</td>
<td>0.013”</td>
</tr>
<tr>
<td>F</td>
<td>Dual Film, Copper Wire</td>
<td>0.005”</td>
</tr>
</tbody>
</table>
# Form Wound Stator Windings

## Ground Wall Insulating Layers by Voltage Class

<table>
<thead>
<tr>
<th>Voltage</th>
<th>0 to 3kV</th>
<th>3.1 to 5kV</th>
<th>5.1 to 7kV</th>
<th>7.1 to 13.2kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layers ½ Lap Nomex Mica Tape</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>9</td>
</tr>
</tbody>
</table>

The table above provides the number of layers required for different voltage classes, using Nomex and Mica Tape for insulation. The diagram visualizes the winding configuration, showing how the layers are arranged in the stator winding.
Insulation Systems in Random Wound Motors

- Dip & Bake
- Vacuum Impregnate (VI)
- VPI (Vacuum Pressure Impregnation)
Insulation Systems
Random Wound
Insulation Systems in Form Wound Motors

- 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 Standard MW1000)
- Surge (IEEE Standard 522)
  - Individual Coils
  - Wound Stator Before Connect
  - Wound Stator After Connect
- High potential test (NEMA Standard MG1-20, IEEE Standard 112)
- Added Testing for Enduraseal
  - One Minute Megger Dry @ 500VDC (IEEE Standard 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)
Understanding Motor Temperatures
Insulation Class

• F or H*
  o Refers to total temperature the Insulation System is designed to withstand and deliver ‘full’ life
  o Class B: 130°C
    – The ‘previous’ NEMA standard
  o Class F: 155°C
    – Most common insulation class for current AC motors
  o Class H: 180°C
    – Standard for RPM AC motors

* Ref. NEMA Standard MG-1
## Temperature Rise per NEMA MG1-2011

### 20.8.1 Machines with a 1.0 Service Factor at Rated Load

<table>
<thead>
<tr>
<th>Item</th>
<th>Machine Part</th>
<th>Method of Temperature Determination</th>
<th>A</th>
<th>B</th>
<th>F</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Insulated windings</td>
<td>Resistance</td>
<td>60</td>
<td>80</td>
<td>105</td>
<td>125</td>
</tr>
<tr>
<td></td>
<td>1. All horsepower (kW) ratings</td>
<td>Embedded detector*</td>
<td>70</td>
<td>90</td>
<td>115</td>
<td>140</td>
</tr>
<tr>
<td></td>
<td>2. 1500 horsepower and less</td>
<td>Embedded detector*</td>
<td>70</td>
<td>90</td>
<td>115</td>
<td>140</td>
</tr>
<tr>
<td></td>
<td>3. Over 1500 horsepower (1120 kW)</td>
<td>Embedded detector*</td>
<td>65</td>
<td>85</td>
<td>110</td>
<td>135</td>
</tr>
<tr>
<td></td>
<td>a) 7000 volts and less</td>
<td>Embedded detector*</td>
<td>65</td>
<td>85</td>
<td>110</td>
<td>135</td>
</tr>
<tr>
<td></td>
<td>b) Over 7000 volts</td>
<td>Embedded detector*</td>
<td>60</td>
<td>80</td>
<td>105</td>
<td>125</td>
</tr>
<tr>
<td>b</td>
<td>The temperatures attained by cores, squirrel-cage windings, collector rings, and miscellaneous parts (such as brushholders and brushes, etc.) shall not injure the insulation or the machine in any respect.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 20.8.2 Machines with a 1.15 Service Factor at Service Factor Load

<table>
<thead>
<tr>
<th>Item</th>
<th>Machine Part</th>
<th>Method of Temperature Determination</th>
<th>A</th>
<th>B</th>
<th>F</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Insulated windings</td>
<td>Resistance</td>
<td>70</td>
<td>90</td>
<td>115</td>
<td>135</td>
</tr>
<tr>
<td></td>
<td>1. All horsepower (kW) ratings</td>
<td>Embedded detector*</td>
<td>80</td>
<td>100</td>
<td>125</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td>2. 1500 horsepower and less</td>
<td>Embedded detector*</td>
<td>75</td>
<td>95</td>
<td>120</td>
<td>145</td>
</tr>
<tr>
<td></td>
<td>3. Over 1500 horsepower (1120 kW)</td>
<td>Embedded detector*</td>
<td>70</td>
<td>90</td>
<td>115</td>
<td>135</td>
</tr>
<tr>
<td></td>
<td>a) 7000 volts and less</td>
<td>Embedded detector*</td>
<td>70</td>
<td>90</td>
<td>115</td>
<td>135</td>
</tr>
<tr>
<td></td>
<td>b) Over 7000 volts</td>
<td>Embedded detector*</td>
<td>70</td>
<td>90</td>
<td>115</td>
<td>135</td>
</tr>
<tr>
<td>b</td>
<td>The temperatures attained by cores, squirrel-cage windings, collector rings, and miscellaneous parts (such as brushholders and brushes, etc.) shall not injure the insulation or the machine in any respect.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></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 20.27.)
Temperature Rise & Insulation Class Summary

Class B
- 40°C Ambient
- 120°C Total Temp
  - 1.0 SF, 80°C R/Res

Class F
- 140°C Total Temp
  - 1.15 SF, 100°C R/RTD
- 130°C Total Temp
  - 1.15 SF, 90°C R/Res
  - 1.0 SF, 90°C R/RTD
- 145°C Total Temp
  - 1.0 SF, 105°C R/Res
- 155°C Total Temp
  - 1.15 SF, 115°C R/Res
  - 1.0 SF, 115°C R/RTD
- 165°C Total Temp
  - 1.15 SF, 125°C R/RTD
Temperature Rise & Increased Ambient

- **140°C Total Temp**
  - 1.15 SF, 75°C R/RTD

- **130°C Total Temp**
  - 1.15 SF, 65°C R/Res
  - 1.0 SF, 65°C R/RTD

- **120°C Total Temp**
  - 1.0 SF, 55°C R/Res

- **165°C Total Temp**
  - 1.15 SF, 100°C R/RTD

- **155°C Total Temp**
  - 1.15 SF, 90°C R/Res
  - 1.0 SF, 90°C R/RTD

- **145°C Total Temp**
  - 1.0 SF, 80°C R/Res

- **65°C Ambient**
Effect of Altitude on Temperature Rise
NEMA MG 1 - 2011

20.8.4 Temperature Rise for Altitudes Greater than 3300 Feet (1000 Meters)
For machines which operate under prevailing barometric pressure and which are designed not to exceed the specified temperature rise at altitudes from 3300 feet (1000 meters) to 13200 feet (4000 meters), the temperature rises, as checked by tests at low altitudes, shall be less than those listed in 20.8.1 and 20.8.2 by 1 percent of the specified temperature rise for each 330 feet (100 meters) of altitude in excess of 3300 feet (1000 meters).

Example: 6600 ft altitude

\[
1 - \frac{6,600 - 3,300}{33,000} = 0.9
\]

\[80 \times 0.9 = 72\]

Therefore, motor must be sized for 72°C Rise by Res at full load for B Rise
Temperature Effect on Motor Life

- **Insulation life**
  - Heat is the #1 cause of reduced insulation life
  - For every $10^0$ C above rated temperature cuts life by 50%
  - Common overheating sources beyond basic design
    - Overload
    - Inadequate ventilation
    - Dirt buildup
    - Phase unbalance
    - High/Low voltage

- **Bearing life**
  - Bearing temperatures are typically 50-75% of winding temperature
  - Temperature impact ($+10^0$ C = 50% life)
Quiz

• How are starting capacitor circuits typically disconnected once the motor starts?
• Why are rotors and stators typically made of laminated steel?
• What are the two common types of stator windings?
• Every 10°C reached above rated temperature decreases motor life by what %?

- Centrifugal switch
- Lower electrical losses than solid form wound, random wound
- 50%