Motors 101 and Considerations on Variable Speed Systems

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MOTORS 101

5 MOTOR HELPERS:

• Output
  • HP
  • kW
• Speed
  • RPM
• Enclosure
  • ODP
  • TEFC
• Voltage / Phase
• Frame
  • Size
  • Foot / Flange
  • Terminal Box Position
MOTORS 101

5 MOTOR HELPERS:

- Output
  - HP
  - kW

1HP = 746 Watts
Or...
1HP = 0.746 kW

Motor HP = (Torque * RPM) / 5252
# 5 MOTOR HELPERS:

- **Speed**
  - RPM

<table>
<thead>
<tr>
<th>#Poles</th>
<th>60Hz</th>
<th>50Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>3600 RPM</td>
<td>3000 RPM</td>
</tr>
<tr>
<td>4</td>
<td>1800 RPM</td>
<td>1500 RPM</td>
</tr>
<tr>
<td>6</td>
<td>1200 RPM</td>
<td>1000 RPM</td>
</tr>
<tr>
<td>8</td>
<td>900 RPM</td>
<td>750 RPM</td>
</tr>
</tbody>
</table>

... and so on and so forth

\[
\text{RPM} = \frac{(\text{Frequency} \times 120)}{\# \text{ Poles}}
\]
MOTORS 101

5 MOTOR HELPERS:

• Enclosure
  • ODP
    • Open Drip Proof

• TEFC
  • Totally Enclosed Fan Cooled

• TENV
  • Totally Enclosed Non-Ventilated

• TEXP / FCXP
  • Totally Enclosed, Fan Cooled, Explosion Proof

ENCLOSURE CAN MEAN A LOT OF THINGS...
ODP – Open Drip Proof

These motors are cooled by a continuous flow of the surrounding air through the internal parts of the motor.

Motors can handle some dripping water from overhead or no more than 15 degrees off vertical.
These motors are cooled by an external fan.

Ambient air is blown across the outside surface of the motor to carry heat away.

As air doesn’t move thru the inside of the motor, TEFC motors are suitable for dirty, dusty, and outdoor applications.
TENV – Totally Enclosed Non Ventilated

This enclosure characterizes a motor without a cooling fan.

The motor surface area is the heat sink. Heat is removed by radiation and convection of heat energy to the environment.
This enclosure characterizes a motor designed to contain an explosion such that the environment in which it is installed is not exposed to heat above the MIE (Minimum Ignition Energy) for the area classification.
### Degree of Protection

<table>
<thead>
<tr>
<th>Degree of Protection</th>
<th>1° Numeral</th>
<th>2° Numeral</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Protection against contacts</td>
<td>Protection against solid objects</td>
</tr>
<tr>
<td><strong>Drip Proof Motors</strong></td>
<td>IP 21</td>
<td>Contact by fingers</td>
</tr>
<tr>
<td></td>
<td>IP 22</td>
<td></td>
</tr>
<tr>
<td></td>
<td>IP 23</td>
<td></td>
</tr>
<tr>
<td></td>
<td>IP 44</td>
<td>Contact with moving parts</td>
</tr>
<tr>
<td><strong>Enclosed Motors</strong></td>
<td>IP 54</td>
<td>Totally protected against contacts</td>
</tr>
<tr>
<td></td>
<td>IP 55</td>
<td></td>
</tr>
<tr>
<td></td>
<td>IP(W)55</td>
<td>Totally protected against contacts</td>
</tr>
<tr>
<td></td>
<td>IP 65</td>
<td>Totally protected against contacts</td>
</tr>
</tbody>
</table>
MOTOR CONSTRUCTION
MATERIAL

• Cast Iron
  • Severe Duty or Mill and Chemical type
    • Use for Paper/Forest Products, Metals, Municipal Water/Waste-water, Cement and Aggregate,
MOTOR CONSTRUCTION
MATERIAL

• Rolled Steel
  • General Purpose – Industry specific – HVAC air handling and pumping is the primary user.
WHAT DO I NEED TO KNOW?

5 MOTOR HELPERS:

• Voltage / Phase

Common / catalog voltages and frequencies are shown. There are others! Actual power available to the motor depends on the utility in the country of installation.

<table>
<thead>
<tr>
<th>Single Phase</th>
<th>Three Phase 60Hz</th>
<th>Three Phase 50Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/120V</td>
<td>3/200 or 208V</td>
<td>3/190V</td>
</tr>
<tr>
<td>1/200V or 208V</td>
<td>3/230V</td>
<td>3/220V</td>
</tr>
<tr>
<td>1/230V</td>
<td>3/380V</td>
<td>3/380V</td>
</tr>
<tr>
<td>1/460V</td>
<td>3/460V</td>
<td>3/400V</td>
</tr>
<tr>
<td></td>
<td>3/575V</td>
<td>3/415V</td>
</tr>
</tbody>
</table>
Among all motor dimensions, six (6) of them are extremely important to make sure the motors will fit the application. These dimensions are standard for all motor manufacturers and determined by NEMA and IEC standards. Since this is a NEMA market, we will concentrate our comments on NEMA frames.
Motors are normally identified by HP, Voltage, Frequency Speed, Enclosure and **FRAME SIZE**

The frame indicates the size of the motor by defining the shaft height

**IEC FRAMES directly indicate the shaft height**

Divide the NEMA frame by 4 and you will have the shaft height

<table>
<thead>
<tr>
<th>NEMA MOTORS</th>
<th>IEC MOTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRAME</td>
<td>SHAFT HEIGHT</td>
</tr>
<tr>
<td>140T</td>
<td>3.5&quot;</td>
</tr>
<tr>
<td>182T</td>
<td>4.5&quot;</td>
</tr>
<tr>
<td>184T</td>
<td>4.5&quot;</td>
</tr>
<tr>
<td>210T</td>
<td>5.25&quot;</td>
</tr>
<tr>
<td>250T</td>
<td>6.25&quot;</td>
</tr>
<tr>
<td>280T</td>
<td>7.0&quot;</td>
</tr>
<tr>
<td>320T</td>
<td>8.0&quot;</td>
</tr>
<tr>
<td>360T</td>
<td>9.0&quot;</td>
</tr>
<tr>
<td>400T</td>
<td>10.0&quot;</td>
</tr>
<tr>
<td>440T</td>
<td>11.0&quot;</td>
</tr>
<tr>
<td>500</td>
<td>12.5&quot;</td>
</tr>
<tr>
<td>580</td>
<td>14.5&quot;</td>
</tr>
</tbody>
</table>
WHAT DO I NEED TO KNOW?

5 MOTOR HELPERS:

• Frame
• Foot / Flange
WHAT DO I NEED TO KNOW?

5 MOTOR HELPERS:

• Frame
  • Terminal Box Position
Variable Speed System Challenges

Common Problems encountered with Variable speed systems:

• Thermal considerations (turn down)
  • Ambient
  • Service Factor
• Common Mode Voltages
  • Bearing Damage (bearing induced premature motor failure)
  • Instrumentation nuisance
Constant Vs. Variable Torque

Speed vs. torque

Load profiles

- Variable Torque Loads
  - centrifugal pumps,
  - fans and blowers
  - \( T \propto N^2 \quad P \propto N^3 \)

- Constant Torque Loads
  - Positive displacement pumps
  - Traction drives,
  - Conveyors & Hoists.
  - \( T = \text{Const.} \quad P \propto N \)
Constant Vs. Variable Torque

Voltage vs. Frequency

Constant Torque Load (Conveyor, trolley etc.)

Variable Torque Load (Pump, fan etc.)

Output Voltage vs. Frequency Graphs:
- Constant Torque Load:
  - Linear relationship between output voltage and frequency.
  - Suitable for applications where constant torque is required.
- Variable Torque Load:
  - Non-linear relationship between output voltage and frequency.
  - Ideal for applications requiring variable torque, like pumps and fans.
Constant Vs. Variable Torque
Motor Performance

**Motor Torque:**

Motor Torque ~ \( (V/Hz)^2 \)

Motor Torque = \( (\text{HP} \times 5252) / \text{RPM} \)

**Example:**
- 100HP Motor running across the line, rides through a voltage dip of 70%.
- 100HP, 1800 RPM motor makes 300 lb*ft of torque
- \( 460V \times 0.70 = 322V \), but frequency is constant
- \( (0.70)^2 = 49\% \)
- Resultant available torque is 147 lb*ft during the ride through (at nominal current and temperature)
Standards of construction:

NEMA MG-1 parts 30 and 31 (and corresponding IEC)

• Points discussed:
  • Basis for rating
  • Base RPM and speed ranges
  • Effects of VFD on motor efficiency
  • Torque
  • Noise and Vibration
  • Voltage stress / voltage peaks
  • Service Factor
  • Thermal performance and operating temperature limits
  • Overloads and Over-speeds
  • Shaft Voltages and Bearing Insulation
Standards of construction:

NEMA MG-1 parts 30 and 31 (and corresponding IEC)

• Points NOT discussed:
  • Minimum motor efficiency
  • Insulation system materials or construction type
  • Required minimum or maximum speeds
  • Winding wire type (spike resistant)
  • Shielding in the stator (Faraday)
  • Required conductor between motor and VFD
  • Required grounding or bonding.
Basis of Thermal Rating

Class F insulation system has a total temperature limit of 155°C (311°F)

Motor Total temperature is =
(Ambient) + (NEMA Hot Spot Allowance) + (Temperature Rise)

155°C = 40°C (104°F) ambient + 10°C hot spot + maximum 105°C temperature rise.

• What if your installation is hotter than 104°F / 40°C rise?

How slow can you go?
Basis of Thermal Rating

Most **ODP** motors are good for 1000:1 Variable Torque, and less than 2:1 Constant Torque.

Most **Rolled Steel TEFC** motors are good for 1000:1 Variable Torque, and 2:1 Constant Torque.

Most **Cast Iron TEFC** motors are good for 1000:1 Variable Torque and 10:1 Constant Torque.

Most **TENV** motors are good for 1000:1 VT and CT.
Basis of Thermal Rating

WEG **Rolled Steel TEFC** motors are good for 1000:1 Variable Torque, and 4:1 Constant Torque.

WEG **NEMA Premium Cast Iron TEFC** motors are good for 1000:1 Variable Torque and 20:1 Constant Torque up to 200HP and 4:1 CT above 200HP

WEG **Super Premium Cast Iron TEFC** motors are good for 1000:1 Variable Torque and 100:1 Constant Torque up to 100HP and 20:1 CT above 100HP

WEG **TENV** motors are good for 1000:1 VT and CT
Bearing Currents Causes & Solutions

- **Stator to Frame capacitive currents**
  - Higher frequencies caused by switching
  - Standard ground is not the desire return path to the drive
  - May take path through bearings, shaft and driven load
  - **Best solution** *excellent low impedance return path back to the VFD (VFD Cable & Ground straps)*

- **Stator to Rotor capacitive currents**
  - Created in rotor looking for path to source (VFD)
  - Path of least resistance may be:
    - Through driven equipment bearings
    - Through motor bearings
    - **Best solution** is motor drive end shaft ground brush plus *Excellent Low impedance return path to VFD*

- **Motor circulating currents**
  - Caused by asymmetry in Magnetic field axially along the rotor
  - Typically low frequencies on Sine wave (very large motors) and higher frequencies on VFD
  - **Best solution** – Insulated ODE bearing and DE Shaft Ground brush plus *Excellent low impedance return path to VFD*
Stray Currents

- While stray currents have been seen in all sizes of motors and applications, from fractional HP fans to several thousand HP machines, they are typically seen in larger motors (above 444T) and poorly grounded systems.

- Typically stray currents manifest themselves in the form of fluted or frosted bearings which is the result the current circulating between the shaft and the stationary side of the bearing like millions of small arc welds. This bearing will get noisy and eventually fail.

- The Path to ground could be the motor bearings or through the driven equipment bearings so it is not always the motor that fails.

Fluting caused by electric discharges within the bearing
Low impedance bonding conductor:

- **VFD (shielded) Cable** – This should always be applied with VFD’s to insure an excellent low impedance, high Frequency return path back to the drive.
When do I Apply the solutions? (Cont.)

- **Insulated Opposite Drive End Bearing** – Recommended on motors over 100 Hp (404T and larger), however, they may be applied to lower HP’s if specific application experience dictates.
When do I Apply the solutions? (Cont)

- **Ground Brush on Drive end** – usually used in conjunction with insulated bearings to conduct rotor currents around the bearing and prevent rotor currents from finding a better return path through the driven equipment. This still assumes the motor frame is the best return path to the drive. Can be applied to motors under 125HP without insulating ODE.
Thank you for your Time