CT430 - Soft Starters on Motor Applications

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Topics

- Traditional Motor Starting Methods
- Soft Starter Methods
- Motor Characteristic Information
- Applications
- Additional Resources
Topics

Traditional Motor Starting Methods

Soft Starter Methods

Motor Characteristic Information

Applications

Additional Resources
 Reasons for Soft Motor Starting

- Minimize mechanical damage of system components and product
  - Belts, Gears, Drive Shafts and Keyways
  - Reduced Product Spillage
  - Water Hammer and Mechanical Vibration

- Better Energy “Management”
  - Limit in-rush current
    - Optimize the size of transformers / generators / switch gear
  - Meet Power Company Requirements / Rebate programs
  - Manage Control under Power Distribution Limitations
  - Energy Cost Reduction (Peak Demand Charges)
Selection Process

1. What is the application?
   - Conveyor
   - High Inertia
   - Pump
   - Shock Load

2. What motor to select?
   - Motor to handle the load
   - Handle long start times if high inertial loads
   - If possible, know the power source

3. What starting method to choose?
Motor Starting Methods

**Full Voltage (DOL)**
- Simplest Starting Solution
- Full torque applied...motor
  - Mechanical wear
  - ≥6x inrush current
- No Starting Choices

**Soft Start**
- Simple Starting and Stopping
- Limited Control at various speeds
- Reduced torque and current during starting

**VFD (AC Drive)**
- Complete Continuous Control at any Speed
- Full torque at any speed without sacrificing current

Unlimited starting possibilities when sized properly

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Up to 17 different starting/stopping modes
Motor Starting Methods

**Full Voltage (DOL)**
- Simplest Starting Solution
- Full torque applied...motor
  - Mechanical wear
  - ≥6x inrush current
  - Peak demand charges
- Limited functionality
  - Unless used with advanced Overload
- **Finite Mechanical Life**
  - Contacts will wear out

**Soft Start**
- Simple Starting and Stopping
- Limited Control at various speeds
- Reduced torque and current during starting
- Simple...adjust and setup
- Reduced installation costs
  - Smaller footprint
  - None to minimal need for harmonic/EMC mitigation
- Highly efficient when running at full speed
- Energy Saver Performance for light loads

**VFD (AC Drive)**
- Complete **Continuous Control** at any Speed
- Full torque at any speed without sacrificing current
- Highly efficient motor and application performance
- More complex setup and install
  - Larger footprint
  - Impact on Power Quality
    - EMC remediation
  - Application Considerations
    - Motors types
    - Lead Lengths
    - Wire Type
    - Ambient Conditions

**No Starting Choices**

**Unlimited starting possibilities when sized properly**

**Up to 17 different starting/stopping modes**
How does Full Voltage (DOL) work?

- Full voltage, current and torque applied immediately
- Power is immediately removed when shut off
- High starting torque can cause damage to mechanical system
- High current can cause problems in the electrical system and can also cause decreased system capacity

**Full Voltage (DOL)**

![Diagram of Full Voltage (DOL) system](image)
A VFD converts AC line voltage to DC voltage and then inverts it back to a pulsed DC whose RMS value simulates an AC voltage.

Most VFDs utilize a full wave diode-bridge or SCR rectifier bridge to convert the AC line to DC voltage (DC bus).

Many VFDs have DC inductors to improve power factor and reduce harmonics.

Typically Insulated Gate Bipolar Transistors (IGBTs) are used to invert the DC Bus voltage.
How does an AC Drive work?

- Most common VFDs manufactured utilize pulse width modulation (PWM) to create the output sine wave.

- During acceleration, the inverter applies different frequencies to the motor. It also changes the voltage in proportion to the frequency. (unlike SMCs)

- The inverter produces rated torque from 0 to rated speed. (unlike SMCs)

- Inverter output can be any frequency below or above the line frequency -- up to the limits of the inverter or mechanical system. (unlike SMCs)
How does a Soft Starter work?

**Soft Start (SMC)**

- 3 pairs of back-to-back Silicon-Controlled Rectifiers (SCRs) are used to start and stop the motor.
  - SCRs only, NO AC Front End, NO DC Bus, NO IGBTs
- Back-to-back orientation of SCRs allow control of AC line every half cycle
- Regulates voltage from 0 volts up to line voltage. Line frequency is not controlled.
How does a Soft Starter work?

**Soft Start (SMC)**

- **Voltage** controls the current and torque.
  - The % change in motor torque is approximately proportional to the square of the % change in applied voltage.
    \[
    \text{% Torque} \propto \text{% Voltage}^2
    \]
- Current is directly related to the voltage applied to the motor.
- Voltage is ramped up to full voltage or limited to provide current limited starts.
- Line frequency (50 /60Hz) is always applied to the motor.
Topics

Traditional Motor Starting Methods

Soft Starter Methods

Motor Characteristic Information

Applications

Additional Resources
How do these methods work?

\[
\% \text{ Torque} \propto \% \text{ Voltage}^2
\]

\[
\frac{\text{Voltage (Applied)}}{\text{Voltage (Maximum)}} = \frac{\text{Current (Drawn)}}{\text{Current (Maximum)}}
\]

<table>
<thead>
<tr>
<th>Starting Type</th>
<th>% Voltage Applied During Start</th>
<th>% Full Load Starting Torque</th>
<th>% Full Load Rated Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Voltage</td>
<td>100</td>
<td>100</td>
<td>600</td>
</tr>
<tr>
<td>Wye-delta Starting</td>
<td>58</td>
<td>33</td>
<td>200</td>
</tr>
<tr>
<td>Soft Start with various current limit settings</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>150%</td>
<td>25</td>
<td>6</td>
<td>150</td>
</tr>
<tr>
<td>200%</td>
<td>33</td>
<td>11</td>
<td>200</td>
</tr>
<tr>
<td>250%</td>
<td>42</td>
<td>18</td>
<td>250</td>
</tr>
<tr>
<td>300%</td>
<td>50</td>
<td>25</td>
<td>300</td>
</tr>
<tr>
<td>350%</td>
<td>58</td>
<td>34</td>
<td>350</td>
</tr>
<tr>
<td>400%</td>
<td>67</td>
<td>49</td>
<td>400</td>
</tr>
<tr>
<td>450%</td>
<td>75</td>
<td>56</td>
<td>450</td>
</tr>
</tbody>
</table>
How does a Soft Starter work?

**SMC Soft Start**

How do these methods work?

- **Torque (ftlb)**
  - 100%
  - 72%
  - 25%

- **Speed - RPM**
  - 0
  - 100%

- **Voltage**
  - 100%
  - 85%
  - 50%

- **%FLA (amps)**
  - 600%
  - 510%
  - 300%

**Current**

**Torque**

Full Load

Torque required by the load

How does a Soft Starter work?
Full Voltage

- Not a common Starting mode.
- NOTE: Full voltage required to accelerate the motor may be a sign of other problems (i.e. Initial Torque of > 90%)
- Used as a Solid State Contactor for High cycle rates
Soft Starter Modes of Operation

Soft Start
- Primarily used to limit mechanical stress
- Constant or exponentially increasing load
  (Compressors, Pumps, Conveyors)

Soft Start/Current Limit with Kick Start
- Kick Start is needed to overcome static condition
- Example when used:
  - Cold system components
  - Loaded conveyor
Soft Starter Modes of Operation

**Current Limit**
- Primarily used to limit line disturbances
- Constant or very lightly loaded motor
- Good on high inertia applications
  (Bandmills, Fans, Centrifuge, Ball Mill, Washers)

**Pump Control**
- Legacy version of torque control optimized for centrifugal loads
- Simple to apply but some considerations
- Exponentially increasing load such as Compressors, Pumps, Conveyors
Soft Starter Modes of Operation

Sensorless Linear Acceleration (Linear Speed) Starting Mode:

“Patented” Sensor-less Linear Acceleration Starting Mode

- Accomplished via Advanced Motor Speed Estimation Algorithm
  - No external feedback required - reduces cost and potential for failure
  - Provides exacting motor acceleration control under varying load conditions

- Simple to set up
  - 2 parameters required to configure: Ramp Time and Initial Torque
    (used as reference)
  - Reduces/eliminates the need for the Dual Ramp mode

- Always uses the minimum amount of energy needed to accelerate the motor in the time requested
  (regardless of the loading condition)
Stopping Modes of Operation

Soft Stop
- Reduces voltage to stop
- Longer than coast
- Good for gradually stopping a motor

Motor Braking
- Internal or external means
- Stops motor faster than coast
- Saves time for maintenance of equipment.
Soft Starter: *Choosing a Power Platform*

**Internal Bypass**
- Ideal for small spaces
  - Smallest total footprint
- Easy selection and application
- Lowest total installed cost

**Solid State**
- Ideal for critical performance in tough environmental conditions
- Allows for Specialized Control
- External Bypass offers operational flexibility and redundancy

*Hybrid Power Structure*  
*Solid State Power Structure*
Soft Starter Bypass

**Internal Bypass**
- Typically IEC rated
- Smaller overall footprint
- Soft start operates cooler

**External Bypass**
- Choice of contactor
- Good for rough environments
- If the control wiring is correct, can also be utilized as emergency bypass
Topics

- Traditional Motor Starting Methods
- Soft Starter Methods
- Motor Characteristic Information
- Applications
- Additional Resources
Are All Motors the Same?

### Table 102 - Typical Characteristics and Applications of Fixed Frequency Medium AC Squirrel-cage Induction Motors

<table>
<thead>
<tr>
<th>Polyphase Characteristics</th>
<th>Torque (% Rated Load Torque)</th>
<th>Locked Rotor Current (% Rated Load Current)</th>
<th>Slip</th>
<th>Typical Applications</th>
<th>Relative Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Locked Rotor Torque</strong></td>
<td><strong>Pull-up Torque</strong></td>
<td><strong>Breakdown Torque</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design A</td>
<td>70…275(2)</td>
<td>65…190(2)</td>
<td>175…300(2)</td>
<td>Not Defined</td>
<td>0.5…5%</td>
</tr>
<tr>
<td>Normal locked rotor torque and high locked rotor current</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design B</td>
<td>70…275(2)</td>
<td>65…190(2)</td>
<td>175…300(2)</td>
<td>600…800</td>
<td>0.5…5%</td>
</tr>
<tr>
<td>Normal locked rotor torque and normal locked rotor current</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design C</td>
<td>200…285(2)</td>
<td>140…195(2)</td>
<td>190…225(2)</td>
<td>600…800</td>
<td>1…5%</td>
</tr>
<tr>
<td>High locked rotor torque and high locked rotor current</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design D</td>
<td>275</td>
<td>Not Defined</td>
<td>275</td>
<td>600…800</td>
<td>≥5%</td>
</tr>
<tr>
<td>High locked rotor torque and high slip</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IEC Design H</td>
<td>200…285(2)</td>
<td>140…195(2)</td>
<td>190…225(2)</td>
<td>800…1000</td>
<td>1…5%</td>
</tr>
<tr>
<td>High locked rotor torque and high locked rotor current</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IEC Design N</td>
<td>75…190(2)</td>
<td>60…146(2)</td>
<td>160…200(2)</td>
<td>800…1000</td>
<td>0.5…3%</td>
</tr>
</tbody>
</table>

(1) These characteristics represent common usage of the motors — for further details, consult the specific performance standards for the complete requirements.

(2) Higher values are for motors having lower horsepower ratings.
Are All Motors the Same?

Typical NEMA Design A Speed/Torque Curve

- Starting Current: High
- Starting Torque: High
- Breakdown Torque: High
- Full-load Slip: Low

Applications: Fans, blowers, pumps, machine tools, or other applications with high starting torque requirements and an essentially constant load.

Typical NEMA Design B Speed/Torque Curve

- Starting Current: Normal
- Starting Torque: Normal
- Breakdown Torque: Normal
- Full-load Slip: Normal

Applications: Fans, blowers, pumps, machine tools, or other applications with normal starting torque requirements and an essentially constant load.
Are All Motors the Same?

**Typical NEMA Design C Speed/Torque Curve**
- Starting Current: Low
- Starting Torque: High
- Breakdown Torque: Low
- Full-load Slip: Low

Applications: The higher starting torque of NEMA Design C motors makes them advantageous for use on hard-to-start loads such as plunger pumps, conveyors, and compressors.

**Typical NEMA Design D Speed/Torque Curve**
- Starting Current: Normal
- Starting Torque: High
- Breakdown Torque: None
- Full-load Slip: High (5...13%)  

Applications: The combination of high starting torque and high slip make NEMA Design D motors ideal for use on very high inertia loads and/or in applications where a considerable variation in load exists. These motors are commonly used on punch presses, shears, cranes, hoists, and elevators.
Basic Information

Ask for a speed torque curve of the SMC
**Basic Information**

Ask for motor information

<table>
<thead>
<tr>
<th>REL. S.O.</th>
<th>FRAME</th>
<th>HP</th>
<th>TYPE</th>
<th>PHASE/HERTZ</th>
<th>RPM</th>
<th>VOLTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>449T</td>
<td>200</td>
<td>P</td>
<td></td>
<td>3/60</td>
<td>1190</td>
<td>460</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>AMPS</th>
<th>DUTY</th>
<th>AMB °C/INSUL.</th>
<th>S.F.</th>
<th>NEMA DESIGN</th>
<th>CODE LETTER</th>
<th>ENCL.</th>
</tr>
</thead>
<tbody>
<tr>
<td>225</td>
<td>CONT</td>
<td>40/F</td>
<td>1.15</td>
<td>B</td>
<td>G</td>
<td>TEFC</td>
</tr>
</tbody>
</table>

Table 430.7(B) of NEC for locked-rotor indicating code letters.
Table 430.7(B) of NEC for locked-rotor indicating code letters.

<table>
<thead>
<tr>
<th>Code Letter</th>
<th>Kilovolt-Amperes per Horsepower with Locked Rotor</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0-3.14</td>
</tr>
<tr>
<td>B</td>
<td>3.15-3.54</td>
</tr>
<tr>
<td>C</td>
<td>3.55-3.99</td>
</tr>
<tr>
<td>D</td>
<td>4.0-4.49</td>
</tr>
<tr>
<td>E</td>
<td>4.5-4.99</td>
</tr>
<tr>
<td>F</td>
<td>5.0-5.59</td>
</tr>
<tr>
<td>G</td>
<td>5.6-6.29</td>
</tr>
<tr>
<td>H</td>
<td>6.3-7.09</td>
</tr>
<tr>
<td>J</td>
<td>7.1-7.99</td>
</tr>
<tr>
<td>K</td>
<td>8.0-8.99</td>
</tr>
<tr>
<td>L</td>
<td>9.0-9.99</td>
</tr>
<tr>
<td>M</td>
<td>10.0-11.19</td>
</tr>
<tr>
<td>N</td>
<td>11.2-12.49</td>
</tr>
<tr>
<td>P</td>
<td>12.5-13.99</td>
</tr>
<tr>
<td>R</td>
<td>14.0-15.99</td>
</tr>
<tr>
<td>S</td>
<td>16.0-17.99</td>
</tr>
<tr>
<td>T</td>
<td>18.0-19.99</td>
</tr>
<tr>
<td>U</td>
<td>20.0-22.39</td>
</tr>
<tr>
<td>V</td>
<td>22.4 and up</td>
</tr>
</tbody>
</table>
In this case, 100 HP, 460 VAC, 3 phase, motor code G

Locked-rotor current \[= \frac{\text{Locked-rotor kVA}}{\sqrt{3} \times kV} \]
\[= \frac{100 \times 6.29}{1.73 \times 0.46} \]
\[= \frac{629}{0.7958} \]
\[= 790.39 \text{ Amps} \]

Or Locked Rotor Current / Rated Load Current
\[= \frac{725}{114} \]
\[= 635\% \text{ starting current of FLA} \]
## Topics

- Traditional Motor Starting Methods
- Soft Starter Methods
- Motor Characteristic Information
- Applications
- Additional Resources
Application Examples
Pump Control

Water hammer prevention/reduction

- Soft start / stop method for soft power situations
- Pump control follows the pump S-curve
- Linear acceleration/deceleration
Fan

Variable torque load

- Start with closed dampers
- Soft start ramps the voltage
- Linear acceleration/deceleration
Conveyor

Constant torque application

- Soft start / stop common starting
- Linear acceleration/deceleration
- Reduce shock to the system
High Inertia Loads

Long starts for large mass

- Current limit method is common
- Coast or some kind of braking stop
- Heat generation
Two types of Wye-Delta starters

- **Open Transition**

- **Closed**
Wiring the Soft Starter Inside the Delta

Two connections scenarios with the soft starters

(A) SMC wired Inside-the-Delta with 6 lead Y-D motor
(B) SMC Wired to 3 Lead Delta Motor

Inside-The-Delta
Line
Slow Speed

Slow Speed – Common:
SMC-50 Enhanced Slow Speed:
Application Considerations

- Understand the System Dynamics
  - High inertia applications
  - No load/Light Load *(Good applications)*
  - Fan, centrifugal pump, conveyors, Compressors
  - Full load *(Not recommended)*
  - Extruders, positive displacement pumps, Inclined Conveyors (Overhauling load), Lifts, Elevators (unless hydraulic)
  - Retro-fit applications
  - Motor may have been designed for full voltage only
  - Not a replacement for a mechanical device (Clutch)
Application Considerations

- **Power Source Sizing Guidelines**
  - Ideally, the source would be sized for a full voltage start. (Somewhat impractical today)
  - When sizing for use with a Generator it is critical that the generator is able to stay in proper regulation under starting or braking loads.
  - **Rule of thumb**: Avoid sizing the supply for anything less the 300% of the motors FLA.

- **SCR Fusing** (Very Fast Acting Semiconductor type)
  - Protect SCRs, not typically rated for branch circuit protection
  - Use is not suggested in High Inertia, Braking, or Pump stop applications
    (Applications with Start times > 30 seconds)
“Rules of Thumb”

- For **Soft Starter** applications, some general guidelines include:
  - Full speed operation
  - Reduction of mechanical wear and damage to system
  - Lightly or moderately loaded applications
  - Lower starting torque applications
  - Limiting current is prime reason for starting method
Application, Application, Application!

- Selection guides are correct for 90% of applications.
  - Simply choose based on voltage, horsepower, and insure that the motor FLA fits the products operating range

- 10% of applications require a closer look.
  - In applications where the actual run current is less than 40% of the FLA, choose the current range that best fits the nominal running current without exceeding the HP range for the product.
  
  - **Thermal Analysis** may be required to determine proper size for the following:
    - Extended starting times
    - Aggressive Duty Cycle (> 10 times/hr)
    - Operation in elevated ambient temperatures
    - LRA > 600% (i.e. High efficiency motors, Design A)
**Problem:** A towline conveyor at the end of a production line had frequent damage to the gearbox caused by the starting torque from across-the-line starting of the motor. There were also frequent spills during starting and stopping. Occasionally, the conveyor needed to be started under heavy load. This towline application had a variety of starting requirements that other soft starters could not satisfy. Investing in a variable speed drive was not cost effective.
**Problem:** A centrifuge required a reduced voltage start because of power company restrictions. The high torque during starting was causing damage to the gearbox. A shorter stopping time than the present fifteen minute coast-to-rest was desired. The long stop time caused delays in the production process. A Wye-Delta starter with a mechanical brake was currently in use. A zero speed switch was used to release the brake. The mechanical brake required frequent maintenance and replacement, which was costly and time consuming. Both the mechanical brake and zero speed switches were worn out and required replacement.
**Problem:** Because of the remote location of the facility and power distribution limitations, a reduced voltage starter was needed on a bandsaw application. The saw was turned off only during shift changes. When the saw blade became dull, the current drawn by the motor increased. Therefore, an ammeter was required. Metering the application for jam conditions was a necessity. In addition, single phasing of the motor was a problem because of distribution limitations.
Application Examples

**Problem:** A bandsaw required 25 minutes to coast to a stop to routinely change the saw blade. A braking package was required to reduce the stopping time. Other methods using dedicated braking devices were investigated but were unacceptable because of overly complex installation. These methods required additional panel space for the brake module, brake contactors, and timers. Because of potential alignment problems, it was dangerous to bring the saw up to full speed after installing a new blade.
Topics

- Traditional Motor Starting Methods
- Soft Starter Methods
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Additional Resources

- SMC Family Brochure
- Whitepapers
- Blogs
- Tech Data Documents

https://www.rockwellautomation.com/global/literature-library/overview.page
https://www.rockwellautomation.com/global/news/blog/overview.page
Wizards

https://ab.rockwellautomation.com/motor-control/lv-soft-starters/smc-50#resources
1. What is the application?
   - Conveyor
   - High Inertia
   - Pump
   - Shock Load

2. What motor to select?
   - Motor to handle the load
   - Handle long start times if high inertial loads
   - If possible, know the power source

3. What starting method to choose?
Questions???
Thank you!
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