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Solid-State Soft Start Motor Controller and Starter

Application Note

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Contents

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Introduction

About This Guide

The following material is intended to acquaint the user with the theory and operation of solid-state soft start motor controllers and starters. This material will enable the user to better select the controller or starter and take into consideration the parameters necessary for proper application to a given load.

The reference material provided is for the convenience of the user. It is taken from current handbooks and standards such as NEC, NEMA, IEEE and others. It is intended as reference material for standard applications and may not cover all actual and special applications. Experienced factory application engineers are available to assist users in the application of motor controllers and starters for most motor loads. Specific ratings and external signals used for control and logic are the user's responsibility.

The user must determine the final suitability and acceptability for controllers and starters used on specific equipment.

Basic Motor and Soft Start Theory

Introduction

A solid-state soft start controller or starter controls the starting torque and current of an AC motor electronically.

They can be used in almost any application such as:

■ commercial – HVAC fans and pumps
■ general industrial – fans, pumps, conveyors, material handling and processing equipment
■ others – forest products, mining, metals and printing

The guide provides the basics required to evaluate motor controller and starter application needs.

AC Motors

Cutler-Hammer® soft start controllers and starters operate with standard motors. In most cases, an existing motor sized for another method of soft start, can be directly applied. For new installations the user must understand the nature of the application in terms of the load characteristic requirements and the motor capability when used with a soft start controller or starter.

AC Motor Types

AC motors can be divided into two main types: Induction and Synchronous. In this guide we will only cover the use of a three-phase induction motor and soft starter device, although in some cases a soft starter device may be used with a single-phase motor.

Induction Motors

The induction motor is the simplest and most rugged of all electric motors. The typical varieties are the standard induction motor and the wound rotor motor.

Three-Phase

The three-phase induction motor is divided into four classifications according to NEMA. (Note that there are IEC design standards which differ somewhat from the NEMA versions.) The classification or design, is determined by the locked rotor torque and current, breakdown torque, pull-up torque and the percent slip. The speed-torque curve and characteristics of each design are given below. These characteristics apply for operation from fixed frequency and voltage as normally supplied from commercial utility power sources at 60 Hz.

■ **Design A** motors have a slightly higher breakdown, and lower starting torque than Design B motors. The slip is usually 3 to 5% or less. The major difference between the Design A and Design B motor is that the starting current is limited on the Design B, but not on the Design A. Design A motors are applied to the same applications as Design B motors. Design A motors may be used with solid-state soft start devices.
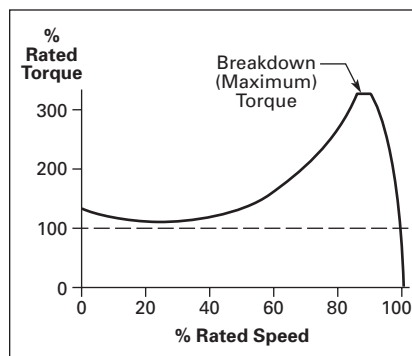
Figure 1. Design A Polyphase Motor

■ **Design B** motors are general purpose type motors and account for the largest share of the induction motors sold. The slip of a Design B motor is approximately 3 to 5% or less. Design B motors are used on applications where starting torque requirements are low such as general industry, fans, blowers and centrifugal pumps and compressors. Design B motors are often used with solid-state soft start devices.
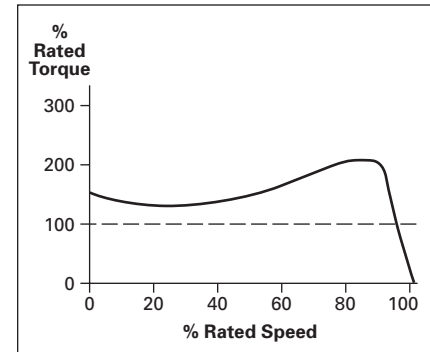
Figure 2. Design B Polyphase Motor

■ **Design C** motors have a high starting torque with a normal starting current and low slip. The Design C motor is usually used where breakaway loads are high at starting, but are normally run at rated full load, and are not subject to high overload demands after running speed has been reached. The slip of the Design C motor is 5% or less. Design C motors are often used where high starting torques under loaded conditions are required including crushers, agitators, reciprocating pumps and high friction conveyors. Care must be exercised when using a Design C motor with a soft start controller or starter to assure that the application starting torque and time to start requirements can be met.

Figure 3. Design C Polyphase Motor

■ **Design D** motors have high slip, high starting torque, low starting current and low full load speed. Because of the high amount of slip, the speed will vary if fluctuating loads are encountered. The slip of this type of motor is approximately 5 to 13%. Design D motors are used on applications with high peak loads with flywheels like punch presses, shears, ho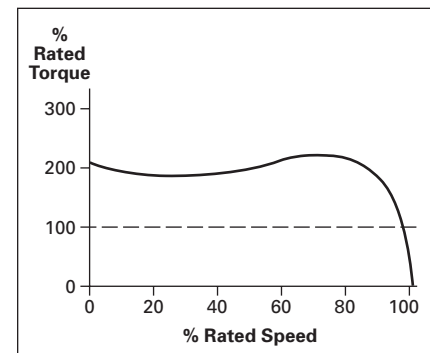ists, oil well pumps and extractors. Care must be exercised when using a Design D motor with a soft start controller or starter, since the limitation of the starting torque or increase of the starting time may cause thermal concerns for the motor and soft start.
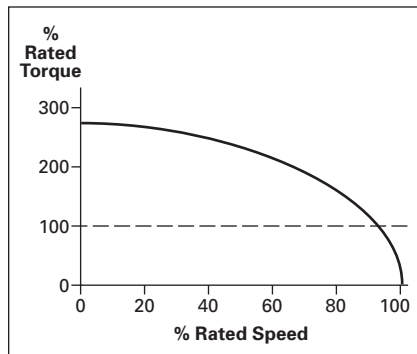

Figure 4. Design D Polyphase Motor

Wound Rotor Motors

The wound rotor motor allows controllable speed and torque compared to the conventional induction motor. Wound rotor motors are generally started with a secondary resistance in the rotor. As the resistance is reduced, the motor will come up to speed. Thus the motor can develop substantial torque while limiting the locked rotor current. The secondary resistance can be designed for continuous service to dissipate the heat produced by continuous operation at reduced speed and frequent start/stops or acceleration of a large inertia load. This external resistance gives the motor a characteristic that results in a large drop in rpm for a small change in load. Reduced speed typically can be provided down to approximately 50% of rated speed, although at a very low efficiency.

These motors are sometimes used (in large horsepower ratings) in slip recovery systems. In these systems the external (secondary) resistance element is replaced with a solid-state circuit to convert the rotor slip energy to useful AC power. These motors can be used with a soft starter in some applications. The use is dependent upon why the motor's secondary resistance was selected and how the use of the soft starter will impact the load requirements. If the rotor resistance was selected to be stepped through various sizes to provide a gentle start, a soft starter can likely be used. If the resistor is just a single value and was selected to give high starting torque, the use of a soft starter might not allow the same level of torque to be generated. The application requirements must be determined.

Enclosures

The basic protective enclosures for AC motors are: open dripproof (ODP), totally enclosed fan cooled (TEFC), totally enclosed non-ventilated (TENV) and totally enclosed air over (TEAO). Other special enclosures available include: pipe-ventilated, weather protected, water cooled and explosion proof.

Ventilation

The system for ventilating motors depends on the type of motor enclosure as mentioned previously and described below:

■ **ODP (Open Dripproof)** – The ODP motor is ventilated (cooled) by means of a shaft mounted internal fan which drives air through the open ends of the motor and discharges it out the sides. These motors are often supplied as protected, fully-guarded or splash-proof.

■ **TEFC (Totally Enclosed Fan Cooled)** – This type of motor is cooled by air passing over the outer frame of the motor. The air is supplied by a shaft mounted fan opposite the shaft end of motor.

■ **TENV (Totally Enclosed Non-Ventilated)** – This type of motor has a shaft mounted internal fan used to circulate air within the motor to prevent hot spots. No external fan or air is supplied. These are suitable for very dirty and contaminant laden environments that would clog most exposed cooling fans. These motors dissipate their heat through their frames and are thus oversized compared to other enclosure types. They are generally available only in smaller hp ratings (up to 7-1/2 hp).

■ **TEAO (Totally Enclosed Air Over)** – This type of motor is cooled by externally provided air blowing over the frame. The air may be supplied by an integrally mounted blower and motor or from a separate source. This type of ventilation provides constant cooling under all operating conditions.

■ **Special Enclosures** – The Pipe-Ventilated motor is available for either an open or totally enclosed type of enclosure and is used in very dirty environments. Ventilating air (supplied by the User) enters and exits the motor through inlet and outlet ducts or pipes. The air is circulated by means either integral or external to the motor.

The Weather-Protected motor uses an open type enclosure for ventilation. The motor is constructed to minimize the entrance of rain, snow and airborne particles to the electrical parts of the motor. External air can be circulated through the motor for cooling.

Totally Enclosed Air-to-Air and Totally Enclosed Water-to-Air cooled enclosures are normally used on high horsepower motors that generate large amounts of heat. A heat exchanger is used for both types to remove the heat generated by the motor. An AC motor driven blower circulates air through the windings and heat exchanger tubes. The heat in the heat exchanger is removed by either an external air system (air-to-air) or water provided by the user (water-to-air cooled).

Explosion Proof motors are designed to operate in hazardous environments such as explosive vapors, coal or grain dust and other classified areas. These are selected on the basis of the appropriate Class, Group, and Division of hazard, as defined by the National Electrical Code (NEC).

Control of AC Motors

The most common control of an AC motor is by using a motor starter. This device connects the motor to the commercial AC power line. It is rated to operate with the typical high starting (inrush) current that occurs when a motor is directly connected to the utility line. A motor starter also contains a protective device known as a motor overload. This device is designed to protect the motor from continued overloads and stalling due to excessive machine loads on starting or jamming when operating.

With the above method of control, AC motors will operate as described by their NEMA (or IEC) characteristics for their design type on industrial AC power. This includes a prescribed overload capability, regulation due to slip, starting inrush current and starting (locked rotor) torque. The load on the driven machine determines the acceleration time and motor load (or overload).

Special control hardware is available to modify some of the above characteristics. Part winding, autotransformer and wye-delta motor starters will reduce the inrush current when starting an AC motor. But using these devices does not provide for a soft controlled stepless start.

Solid-state soft start motor controllers and starters have the ability to control the starting characteristics to match the application requirements, such as acceleration and deceleration time, starting and overload current and motor torque. In addition, motor protection may be provided for a number of potential damaging circumstances by the soft starter (a soft start controller does not provide any motor protection).

Soft Start Basics

Why do we want to use a reduced voltage soft starter?

The first reason is to limit the inrush current that a motor draws from the utility when it is first started. This is a concern because the large starting current may cause the line voltage to dip, impacting other loads which are sensitive to low voltages. There may also be a concern if the utility limits the peak current which can be drawn or charges for exceeding the limit.

The second is reduced mechanical system stress. When the large inrush current occurs, there are significant magnetic forces created in the motor windings. These cause some parts of the winding to be attracted to each other and other parts repulsed. This mechanical shock can damage the winding insulation leading to early failure. The mechanical shock of the high torques produced with the large starting current can cause failure of system elements such as the motor shaft, belting, gear box, drive train and damage to fragile product.
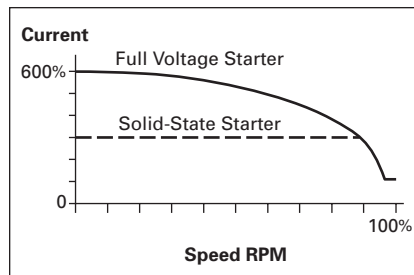

Figure 5. Motor Current vs. Speed

This graph shows the impact of using a soft start. For this motor, the initial current when it is started is 600 percent, or six times the motor's full load current rating. The soft starter can be set to reduce this current, for example in this case to 300 percent. This limits the inrush current on the utility line.
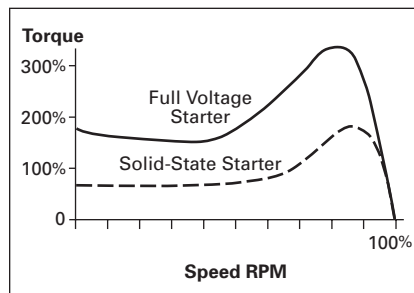
Figure 6. Motor Torque vs. Speed

As a result of the reduction in current, the motor's ability to generate torque is also reduced. The upper curve shows the same motor started across the line. The initial torque is about 180 percent with a peak torque of over 300 percent. With the soft start limiting the current, the torque speed curve is reduced, reducing mechanical stress.

The torque available from the motor at reduced current is equal to the locked rotor or starting torque, times the square of the reduced current divided by the locked rotor current. Thus if we reduce the current from 600 percent to 300 percent, the torque varies as the square of this reduction. The torque is thus reduced to 25 percent of the across the line starting torque.

How Does Torque Vary?

$$T_2 \;=\; T_1 \!\left(\frac{I_2}{I_1}\right)^{\!2} \approx T_1 \!\left(\frac{V_2}{V_1}\right)^{\!2}$$

Where:
T_2 = Torque at recued current/voltage
T_1 = torque at locked rotor current
I_1 = Locked rotor current
I_2 = Reduced current
V_1 = Full voltage
V_2 = Reduced voltage

Some soft starters control voltage instead of current. The torque available varies proportionally with the square of the ratio of the reduced voltage to the normal line voltage.

When the operator depresses the START button, the soft starter logic issues an ON command to the power module, causing the SCRs to turn on and gently increase the voltage across the motor terminals, or the current into the motor based on the adjustments made to the soft start logic. When the SCRs are fully on, the motor reaches full voltage.

A block diagram of a typical soft start starter would look like **Figure 7**.
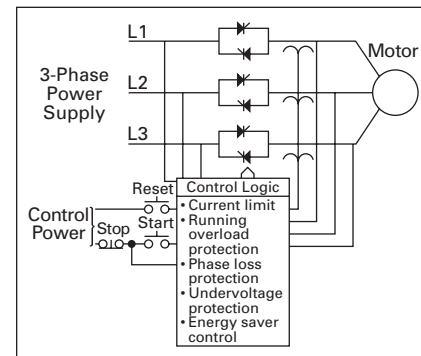
Figure 7. Typical Block Diagram

This solid-state starter utilizes six full current rated SCRs as its power devices. The logic circuit monitors three-phase input voltage, three-phase output voltage, and the three output currents. From these inputs it can provide starting current limitation, running overcurrent protection, phase loss and undervoltage protection.

This starter interfaces with standard control circuits.

In some products a bypass contactor may be closed to provide higher operating efficiency after the SCRs are fully on. **Figure 8** is a single-phase leg of the soft starter with the SCRs turning on and becoming the current path for power to flow from the utility to the motor.
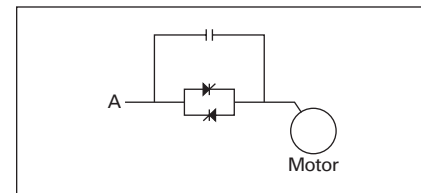
Figure 8. SCRs as Current Path

After the motor has come up to speed, the bypass contactor closes and it becomes the current path for the motor.
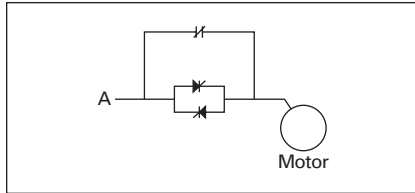
Figure 9. Bypass Contactor as Path

At this time the SCRs no longer conduct any current.

Bypass operation eliminates the SCR losses once the motor is up to speed, resulting in significantly lower heat generation. Soft starters with internal run bypass mode are typically much smaller and lighter than devices without run bypass.

Soft Start Applications

We would like to identify problems that can be solved by the use of a soft starter. One challenge is that it can be difficult for the user to recognize a problem as a problem. Frequently the problem is mistaken for a normal operational or maintenance issue.

It is the intent of this section to help to determine solutions, using soft starters for both new and retrofit installations.

Typical problems can be categorized as mechanical, motor, starting equipment, inrush current, or fragile product related.

Typical mechanical problems are: stretching, squealing or breaking of drive belts; breakage of gear boxes; couplings wearing out prematurely; shaft breakage within the drive train; and, water hammer in hydraulic systems.

To get an idea of the effect of starting torque on the mechanical system, lets consider an automobile. If you were to put the transmission in neutral and quickly press the accelerator to the floor, you would feel the car reacting to the sudden increase in motor torque as it rotates slightly in response to the torque being developed by the engine. This same type of effect is what causes these mechanical problems, except that the torque levels may be considerably greater than those experienced with an automobile.

Motor problems include: motor insulation deterioration or premature winding failure due to the mechanical stresses put on the winding during starting, or the high temperatures imposed by high starting currents; mechanical stresses on the system such as foundation bolts or mounting failures, bearing lock-up and failure, and motor shaft cracking and breakage; coupling failures; and, excessive energy losses due to duty cycle or frequent start/stop operation.

Benefits of Using Soft Start Starters:
- Controlled starting – Limited starting current, reduction of power line disturbance on starting, lower power demand on starting.
- Controlled acceleration – Soft start, adjustable acceleration based on time or load, reduced motor size for pure inertial load acceleration.
- Adjustable torque limiting – Protects machinery from damage, protects process or product.
- Controlled stopping – Soft slow down, timed stopping, fast reversal with much less stress on AC motor than plug reverse.

Typical Fixed Speed Applications:
- Conveyors, belts, chains, screws, bulk material, packaged material
- Fans, blowers, compressors, pumps
- Machine tools, grinders, lathes, stamping presses
- Custom machinery, labelers, packaging machines, bottle washers, wire drawing, textiles, etc.
- Extruders
- Process machinery, kilns, grinders, blenders, agitators. See the section on load types for particular evaluation of specific loads.

Other Reduced Voltage Starting Methods

There are several reduced voltage starting methods that predate solid-state soft start motor controllers and starters. **Table 1** illustrates these methods and their typical applications.

Table 1. Comparison of Electromechanical Soft Starters

Type of Starter	Starting Characteristics in Percent of Full Voltage Values			Transition	Extra Acceleration Steps Available	Advantages	Disadvantages	Applications
	% Line Voltage at Motor	% Motor Locked Rotor Amps	% of Motor Locked Rotor Torque					
Autotrans-former	80 65 50	64 42 25	64 42 25	Closed	No	■ Provides highest torque per ampere of line current ■ 3 different starting torques available through autotransformer taps ■ Suitable for relatively long starting periods ■ Motor current is greater than line current during starting	■ In lower horsepower ratings is most expensive design ■ Low power factor ■ Large physical size	Blowers Pumps Compressors Conveyors
Primary Resistor	65	65	42	Closed	Yes	■ Smooth acceleration – motor voltage increases with speed ■ High power factor during start ■ Less expensive than autotransformer starter in lower horsepower ratings ■ Available with as many as 5 accelerating points	■ Low torque efficiency ■ Resistors give off heat ■ Starting time in excess of 5 seconds requires expensive resistors ■ Difficult to change starting torques under varying conditions	Belt and gear drives Conveyors Textile machines
Part Winding	100	65	48	Closed	Yes (but very uncommon)	■ Least expensive reduced voltage starter ■ Most dual voltage motors can be started part winding on lower voltage ■ Small physical size	■ Unsuited for high inertia, long starting time loads ■ Requires special motor design for voltage higher than 230 volts ■ Motor will not start if the torque demanded by the load exceeds that developed by the motor when the first half of the motor is energized ■ First step of acceleration must not exceed 5 seconds or else motor will overheat	Reciprocating compressors Pumps Blowers Fans
Wye Delta	100	33	33	Open (Closed available for about 30% price adder)	No	■ Suitable for high inertia, long acceleration loads ■ High torque efficiency ■ Ideal for especially stringent inrush restrictions ■ Ideal for frequent starts	■ Requires special motor ■ Low starting torque ■ During open transition there is a high momentary inrush when the delta contactor is closed	Centrifugal compressors Centrifuges

Basic Mechanics

Introduction

In order to apply a soft start properly, certain mechanical parameters must be taken into consideration. This section explains what these parameters are and how to calculate or measure them.

Torque

Torque is the action of a force producing or tending to produce rotation. Unlike work (which only occurs during movement) torque may exist even though no movement or rotation occurs.

Torque consists of a force (Lb.) acting upon a length of a lever arm (Ft.). The product of these two factors produces the term lb-ft, which is the unit of measurement for torque (see **Figure 10**). Mathematically, it is expressed as:

Torque (lb-ft) = Force (Lbs.) x Distance (Ft.)

Example:

Torque = Force x Distance
Torque = 50 Lbs. x 1 Ft.
Torque = 50 lb-ft

Because most power transmission is based upon rotating elements, torque is important as a measurement of the effort required to produce work.
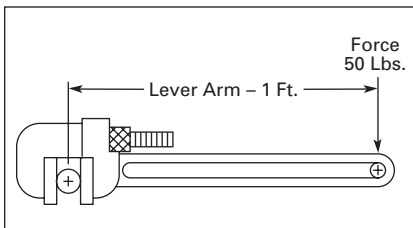

Figure 10. Calculating Torque

Calculating Torque

Acceleration Torque Required for Rotating Motion

Some machines must be accelerated to a given speed in a certain period of time. The torque rating of the motor may have to be increased to accomplish this objective. The following equation may be used to calculate the average torque required to accelerate a known inertia (WK^2). This torque must be added to all the other torque requirements of the machine when determining the motor's required peak torque output.

$$T = \frac{WK^2 x dN}{308t}$$

Where:

T = Acceleration Torque (lb-ft)

WK^2 = Total system inertia (lb-ft^2) that the motor must accelerate. This value includes motor rotor, speed reducer and load.

dN = Change in speed required (rpm)

t = Time to accelerate total system load (seconds)

Note: The number substituted for (WK^2) in this equation must be in units of lb-ft^2.

The same formula can also be rearranged to determine the minimum acceleration time of a given system, or if a motor can accomplish the desired change in speed within the required time period.

Rearranged Equation:

$$t = \frac{WK^2 x dN}{308T}$$

Calculating Horsepower

Note: The following equations for calculating horsepower are to be used for estimating purposes only. These equations do not include any allowance for machine friction, windage or other factors. These factors must be considered when selecting a motor for an application. Once the machine torque is determined, the required horsepower is calculated using the formula:

$$hp = \frac{T x N}{5250}$$

Where:

hp = Horsepower

T = Torque (lb-ft)

N = Speed of motor at rated load (rpm)

If the calculated horsepower falls between standard available motor ratings, select the higher available horsepower rating. It is good practice to allow some margin when selecting the motor horsepower. Also note that the motor's torque output is reduced during a soft start. The load requirements must be related to the soft starter settings.

For many applications, it is possible to calculate the horsepower required without actually measuring the torque. The following equations will be helpful:

Conveyors

$$hp \atop (Vertical) = \frac{F / W (lbs) x V (fpm)}{33,000 x Efficiency}$$

$$hp \atop (Horizontal) = \frac{F / W (lbs) x V (fpm) x Coef}{33,000 x Efficiency}$$

Where:

F/W = force/weight in Lbs.
V = Velocity in feet per minute
Coef. = Coefficient of friction

Fans and Blowers

$$hp = \frac{cfm x Pressure (psi)}{33,000 x Efficiency of Fan}$$

$$hp = \frac{cfm x Pressure (lb-ft^2)}{229 x Efficiency of Fan}$$

$$hp = \frac{cfm x (Inches of Water Gauge)}{6356 x (Efficiency of Fan)}$$

Pumps

$$hp = \frac{gpm x Head (ft.) x (Specific Gravity)}{3960 x (Efficiency of Pump)}$$

Where:

psi = pounds per square inch
cfm = cubic feet per minute
gpm = gallons per minute
Specific gravity of water = 1.0
1 cubic foot per second = 448 gpm
1 psi = a head of 2.309 ft. for water weighing 62.36 lbs. per cu. ft. at 62°F.
Efficiency of fan or pump = %/100

Displacement pump efficiency:
Displacement pumps vary between 85 and 90% efficiency depending on size of pumps.

Centrifugal pump efficiency (at design point):
500 to 1000 gal. per min. = 70 to 75%
1000 to 1500 gal. per min. = 75 to 80%
Larger than 1500 gal. per min. = 80 to 85%

Inertia

Inertia is a measure of a body's resistance to changes in velocity, whether the body is at rest or moving at a constant velocity. The velocity can be either linear or rotational.

The moment of Inertia (WK^2) is the product of the weight (W) of an object and the square of the radius of gyration (K^2). The radius of gyration is a measure of how the mass of the object is distributed about the axis or rotation. Because of the distribution of mass, a small diameter cylindrical part has a much lower inertia than a large diameter part.

The inertia calculations for typical shapes follow.

WK^2 or WR^2

WR^2 refers to the inertia of a rotating member that was calculated by assuming the weight of the object was concentrated around its rim at a distance R (radius) from the center.

WK^2 refers to the inertia of a rotating member that was calculated by assuming the weight of the object was concentrated at some smaller radius, K (termed the radius of gyration). To determine the WK^2 of a part, the weight is normally required.

Calculations

When performing calculations, be consistent with the formulae and units used. Common mistakes are substituting inches for feet, etc.

Cylinders
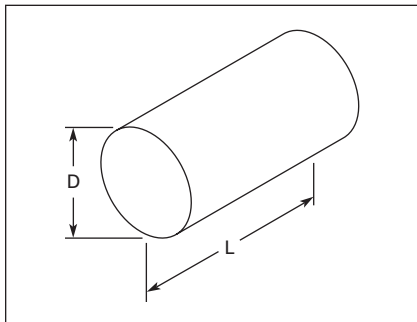
Figure 11. Solid Cylinder

Equations:

$WK^2 = .000681 \times p \times L \times (D)^4$
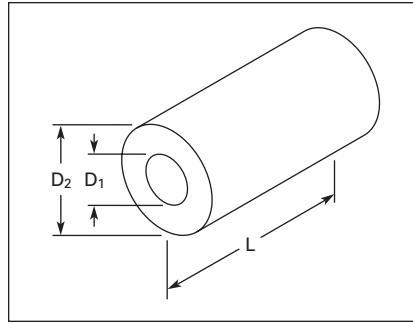
Figure 12. Hollow Cylinder

Equations:

$WK^2 = .000681 \times p \times L \ (D_2{}^4 - D_1{}^4)$

Where:

WK^2 = inertia of a cylinder (lb-ft^2)
p = density of cylinder material in lb-in^3 (see density chart below)
D_1 = inside diameter of cylinder (inches)
D_2 = outside diameter of cylinder (inches)
L = Length of cylinder (inches)

Table 2. Common Material Densities (p)

Aluminum	0.0977
Brass	0.3110
Cast Iron	0.2816
Steel	0.2816
Rubber	0.0341
Paper	0.0250 to 0.0420

Pulley/Gear

To calculate the inertia of a pulley or gear, divide up the piece (shown in **Figure 13**) as shown in **Figure 14**. Using the same equation for calculating hollow cylinders, perform the calculations of each separate part and add them together for a total inertia.

Note: $WK_1{}^2$ and $WK_2{}^2$ are the separate inertia calculations.
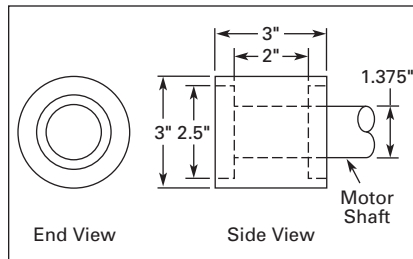
Figure 13. Complete Pulley/Gear

In this example the pulley is made of steel. We will divide it up to calculate as shown.
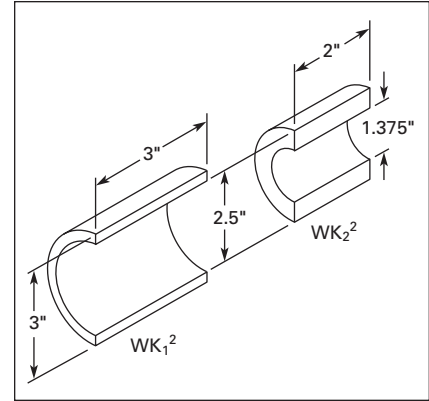
Figure 14. Pulley/Gear Components

Equations:

$WK^2 = .000681 \times p \times L \ (D_2{}^4 - D_1{}^4)$

Calculations:

$WK_1{}^2 = .000681 \times 0.2816 \times 3 \times (3^4 - 2.5^4)$
$= .0241 \ \text{lb-ft}^2$

$WK_2{}^2 = .000681 \times 0.2816 \times 2 \times (2.5^4 - 1.375^4)$
$= .0136 \ \text{lb-ft}^2$

Total Inertia = $WK_1{}^2 + WK_2{}^2 = .0241 + .0136$
$= .0377 \ \text{lb-ft}^2$

WK^2 Reflected to the Motor Shaft

In most mechanical systems not all the moving parts operate at the same speed. If speeds of the various parts have a continuous fixed relationship to the motor speed, the equation can be used to convert all of the various inertia values to an equivalent WK^2 applied to the motor shaft.

WK^2 of Rotating Parts

$$\text{Equivalent } WK^2 = WK^2 \left[\frac{N}{N_M} \right]^2$$

Where:

WK^2 = inertia of the moving part
N = speed of the moving part (rpm)
N_M = speed of the driving motor (rpm)

When using speed reducers, and the machine inertia is reflected back to the motor shaft, the equivalent inertia is equal to the machine inertia divided by the square of the drive reduction ratio.

$$\text{Equivalent } WK^2 = \frac{WK^2}{(DR)^2}$$

Where:

DR = drive reduction ratio = $\dfrac{N_M}{N}$
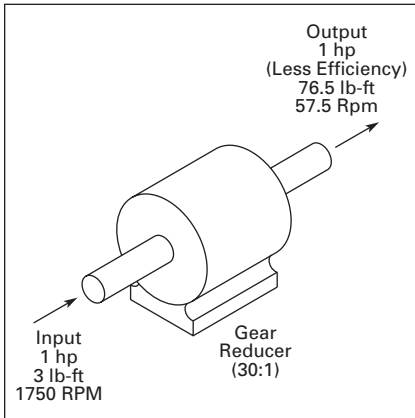
Figure 15. Gear Reducer Characteristics

WK^2 of Linear Motion

Not all driven systems involve rotating motion. The equivalent WK^2 of linearly moving parts can also be reduced to the motor shaft speed as follows:

Equivalent WK$^2 = \dfrac{W(V)^2}{39.5(N_M)^2}$

Where:

W = weight of load (Lbs.)
V = linear velocity of rack and load or conveyor and load (fpm)
N_M = speed of the driving motor (rpm)

This equation can only be used where the linear speed bears a continuous fixed relationship to the motor speed, such as a conveyor.

Speed Reducer Selection

The motor should always be coupled to the driven machine by a power transmission that will permit maximum motor rpm at maximum machine speed. The power transmission may be a simple belt-sheave or sprocket-chain arrangement or a compact gear reducer. In most applications requiring speed reductions greater than 5:1, the gear reducer may be the most economical choice.

Gear Reducer Selection

A gear reducer transmits power by an arrangement of various forms of gears. It provides an efficient, positive method to change speed, direction, and torque. This may mean a change of speed with a corresponding change in torque, or a change in output direction or position. A common result is a combination of the above.

The gear reducer serves as a torque amplifier, increasing the torque by a factor proportional to the reducer ratio, less an efficiency factor. See **Figure 13**.

A 1 hp, 1750 rpm motor has an output torque of 3 lb-ft. If a 30:1 ratio reducer with 85% efficiency is used, the reducer output torque will be 3x30x0.85 = 76.5 lb-ft.

A typical application involves selecting a gear reducer that permits the drive motor to operate at nameplate speed when the driven machine is at maximum speed. The gear reducer should also provide adequate torque to drive the machine.

Application Example

A 1750 rpm motor is selected for a machine which is to operate at 57.5 rpm maximum speed and requires 70 lb-ft of torque.

To find the answer, the following two steps must be accomplished.

1. **Determine the required ratio:**

$\dfrac{\text{Reducer}}{\text{Ratio}} = \dfrac{\text{Maximum Motor rpm}}{\text{Maximum Driven Machine rpm}}$

Reducer Ratio = $\dfrac{1750}{57.5}$ = 30.4 or a 30:1 ratio

Note: When the calculated reducer ratio is not close to a standard speed reducer ratio, a chain, belt or additional gears with further reduction are necessary (located on the input or output side).

2. **Determine the motor torque & horsepower**

A 30:1 gear reducer is selected which is capable of supplying 70 lb-ft of output torque. Since the machine torque requirement is known, this value is divided by the reduction ratio and an efficiency factor, to arrive at the required motor torque (TM).

TM = $\dfrac{\text{Required torque (lb-ft)}}{\text{Reducer Ratio x Efficiency Factory}}$

TM = $\dfrac{70}{30 \times 0.85}$ = 2.75 lb-ft

Since a 1 hp, 1750 rpm motor delivers 3 lb-ft of torque, it is chosen for this application along with a 30:1 gear reducer with a minimum of 70 lb-ft output torque.

Where the reduction ratio permits the use of a chain or belt, the same formulae are used as with the reducers.

Gear Reducer — Overhung Load

An overhung load (OHL) is defined as dead weight the gear reducer bearings can support on an output shaft at a distance equal to the shaft diameter. This distance is measured from the outside end of the bearing housing along the shaft (see **Figure 16**). If the acting load is at a point different from the OHL point, it must be converted to the reference point and compared to the manufacturer's catalog value.
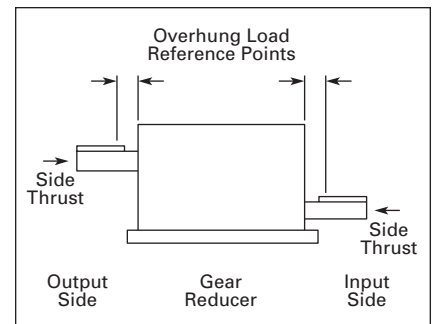
Figure 16. Overhung Load

When a gear reducer is driven by a belt, chain or gear drive, or when the gear reducer drives a driven unit through a belt, chain or gear drive, an overhung load (side thrust) is produced. The overhung load must not exceed the rating of the gear reducer as listed by the manufacturer. The magnitude of the overhung load should always be kept to a minimum. Excessive loads could lead to fatigue failure of either the bearing or shaft. The sprocket or pulley should always be located as close to the gear housing as possible.

Increasing the sprocket or pulley diameter results in a reduced overhung load. Use the following equation to determine the overhung load:

$\dfrac{\text{OHL}}{\text{(lb.)}} = \dfrac{2 \times \text{Shaft Torque (lb-in) x K}}{\text{Diameter (in)}}$

Where:

Diameter is of the sprocket, sheave, pulley or gear.

Note: K is a constant which is:
     1.00 for chain drives
     1.25 for gears or gear-belt drives
     1.50 for V belt drives
     2.50 for flat belt drives

No overhung loads are encountered when the gear reducer is directly coupled to the motor and/or the driven machine shaft. However, care must be taken in aligning the shafts to avoid pre-loading the bearings by misalignment.

Other Gear Issues

1. Service Factor — The application determines the amount of shock load the gearbox will be subjected to. Based on the operating hours per day and the degree of shock loading, the gearbox may need to be oversized with a service factor of up to 250%.

2. Thermal Rating — It is possible that the gearbox will have a mechanical rating larger than its thermal rating. The gearbox manufacturer should advise under what situations this might occur.

Controllers and Starters, Theory and Application

Introduction

Soft Start Controller and Starter Description — A soft start controller or starter gently starts a motor limiting both the initial torque levels and current levels to meet given application or utility power system requirements. Soft start controllers and starters are used with three-phase motors. The controller or starter interfaces with normal operator or machine controls as used in conjunction with a standard across the line starter.

Benefits of Using Soft Start Controllers and Starters

Soft starts are used for a number of reasons, either to provide a required starting characteristic or to prevent or reduce a machine or system related problem such as:

- Mechanical
  - ❑ Belts stretching, squealing, or breaking
  - ❑ Gears breaking
  - ❑ Couplings wearing out
  - ❑ Drive train shafts breaking
- Motor
  - ❑ Motor insulation deterioration or premature winding failure
  - ❑ Foundation bolts and mounting failures
  - ❑ Bearing lock-up and failure
  - ❑ Motor shaft cracking and breaking
  - ❑ Excessive energy consumption
- Starting Equipment
  - ❑ Contact pitting and wear
  - ❑ Coil burnout
  - ❑ Mechanical failure
- Inrush Current
  - ❑ Voltage dips causing electromechanical starter coils to drop out
  - ❑ Soft supply lines may mean the starting current will not be acceptable to the utility
  - ❑ Lighting brown outs or electronic control hiccups
- Fragile Product
  - ❑ Materials chip, crack, spill or break
  - ❑ Positioned products are shifted

Basic Principles of Soft Start Controllers and Starters

The following description applies to the operation of a *soft starter* which is used to control the motor torque or current during the start sequence and also provides, at minimum, motor overload protection. A soft start *controller* does not *control* torque or current nor provide motor protection. An adjustment is provided on the soft start controller for initial starting torque which is based on setting an initial start voltage.

The soft starter controls motor current or torque by controlling the voltage applied to the motor. The voltage is controlled by changing the phase angle at which the silicon controlled rectifiers, SCRs, are gated (or turned) on. Once turned on, the SCRs stay on until the magnitude of the current through them passes through zero each half cycle of the AC waveform.

Conduction phase angle may be considered as beginning at the zero degree crossing of a phase through zero VAC, and progressing back in time towards 180 degrees, as seen in **Figure 17**. At a 180 degree conduction phase angle, full voltage is applied to the motor phase, since the SCR conducts through the full 180 degrees. At 0 degrees no voltage is applied. As the conduction phase angle is gradually phased back from 0 degrees towards 180 degrees on subsequent gatings of the SCRs, the effective voltage to the motor increases, resulting in higher current and motor torque. With the proper feedback and control algorithms, current and torque can be controlled during start and stop.
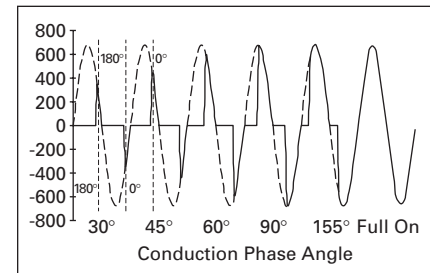
Figure 17. SSRV SCR Phase-Up

The effect of controlling the voltage or current applied to the motor can be seen in **Figure 18** with the starting current being shown at the normal across the line level, and at a current limit level of 500% and 400%. As a result of the current being limited to a lower level, the torque developed by the motor is also limited to a lower level. As was noted in basic theory section of this guide, the torque varies as the square of the motor current. **Figure 18** illustrates this.
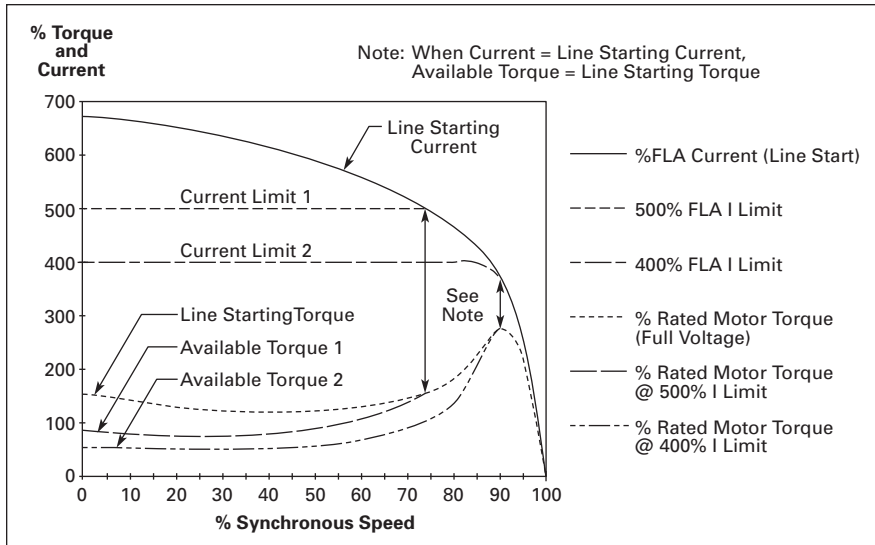
Figure 18. Effects of Current Limiting on Motor Torque

Where:

T_{AV} = available torque at reduced current
T_R = torque at full voltage and line current
I_A = reduced current
I_R = current at full voltage

For example, a motor has an initial across-the-line starting current of 670% and a torque capability of 150% of its nameplate rating at start. If the initial starting current is limited to 500%, the available torque will be limited to 83.5%.

$$T_{AV} = 150\% \left(\frac{500}{670}\right)^2 = 83.5\%$$

This same proportionality holds true across the entire motor start time. The available torque will be reduced until the current being drawn drops below the limited value and equals the normal across-the-line current. At this point the available starting torque equals the normal across-the-line starting torque.

This means that to have a successful motor start the available torque must always be greater than the load's required torque. If the load torque is greater than the available torque the motor will not start.

The second element to be considered is the acceleration time of the motor. The available torque must exceed the load torque by a great enough margin to assure that the motor will have enough acceleration torque available to start in the desired start time.

Load Characteristics

There are three basic components which contribute to the required torque that must be considered. The first is friction, the second inertia, and the third the driven process. Each of these can affect the motor and starter choice. In this guide we are paying specific attention to their effects on the starter selection.

Friction

Friction can determine how difficult it is to initially start the load. The higher the friction at start, the larger the amount of the motor's torque that is required to breakaway the mechanical system and begin rotation. The friction levels at start are often referred to as stiction. After the load begins to rotate, the friction levels tend to decrease, reducing the motor torque requirements.

Inertia

Inertia determines how quickly a load can be accelerated or decelerated. The larger the inertia, the longer the time it will take to accelerate it up to full speed with a given acceleration torque level, or vice versa the larger the acceleration torque required to accelerate it up to full speed in a given time.

Driven Process

Often times the driven process is entirely a frictional load such as a conveyor or an inertial load such as a centrifuge. In some cases the driven process may require torque in addition to that to overcome friction or to accelerate it. For example a centrifugal load will likely have a low friction require-

ment, and may have a low inertia, but has a process torque requirement which varies with the square of speed. When first started the load torque is virtually zero, but as the speed increases the load torque increases quickly until it reaches full load at full speed. A centrifugal pump has low friction and typically low inertia and its driven load requirement varies with speed. The starter would be sized purely on the basis of the driven load. A centrifugal fan has low friction but often high inertia, so the starter would be sized on the basis of both the driven load torque and the acceleration torque requirements.

Typical Soft Start Adjustments

Ramp Start

In order to properly start the motor and minimize time at zero speed when first starting, an initial current or torque level is set for the soft start to apply at start-up. For most applications, this initial value is set to just break away the motor and its load. In the case of a large friction load, a kick start would be used instead, as noted below, because of the large torque required for breakaway.
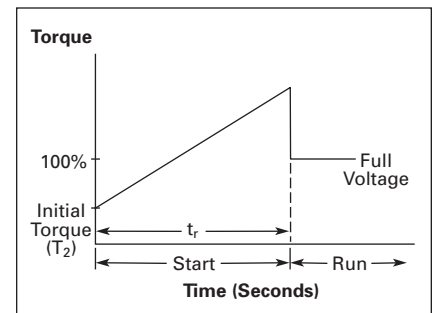
Figure 19. Ramp Start

After the initial step torque is applied, the motor torque is increased linearly by increasing the soft start output voltage over a user selected ramp time (note that the torque generated during this time period can approach the motor's locked rotor value dependent upon the settings and the load requirements). At the completion of the ramp time, the motor and load should be at full speed and the motor current at its normal level.

Solid-State Soft Start Motor Controller and Starter

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Current Limit Start

If a requirement exists for the motor and load to start with a controlled torque level, a current limit start can be chosen. In this case the motor torque level is set and it is held at this value during start-up, until the load requirements fall below this value or the ramp time expires.
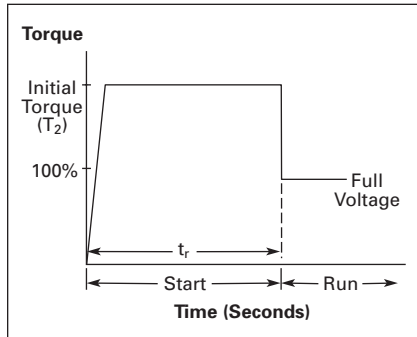
Figure 20. Current Limit Start

Kick Start

A kick start allows the motor to draw greater current at start to develop additional torque to breakaway a high friction load. After a time delay the current is reduced to the normal preset starting level. The kick start current level and time duration are programmable.
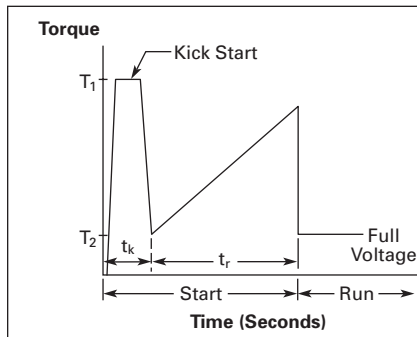
Figure 21. Kick Start

Ramp Stop

In some high friction load applications, the user may desire that the load does not stop suddenly. A ramp stop can be applied to lengthen the stopping period beyond the normal coast down value. This stop works by gradually decreasing the motor voltage thus extending the stop time.
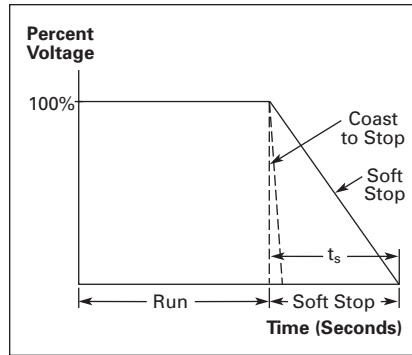
Figure 22. Ramp Stop

Note: This is not an electronic brake function, and cannot make the load stop faster than its normal coast-to-stop time. This feature can only extend the stop time. In some applications the motor will come to a stop in less than the selected stop time, if the load torque requirements are too high and the stop time is set too long.

Motor Application Considerations

Motor Sizing

Motors are sized for use with a soft starter or controller as they would be for any other reduced voltage starting device. If a large number of starts will be made in a short period of time, the motor must be able to thermally and mechanically withstand this. In many cases the soft start will be better for the motor because of the reduction in winding stress.

Multiple Motor Operation

The use of multiple motors connected to one soft starter is not recommended because of loss of motor protection. If it is desired to do this, individual overload protection must be supplied for each motor.

Motor Protection

Motor overload protection is provided as required as a standard feature of a soft starter. Soft start controllers do not provide any motor overload protection and require separate user supplied overload devices as required by the applicable codes.

Installation Compatibility

The successful application of a soft starter or controller requires the assurance that it will be compatible with the environment in which it will be installed. The following are some of the aspects of compatibility which should be considered.

Cooling Air

Even though a soft starter or controller is very efficient, the heat produced can be substantial. The electronic circuitry is subject to immediate failure if its operating temperature limits are exceeded. Junction temperatures of SCRs typically can only increase 20 – 25°C from full load to failure level, so it is important to remove heat through the usual mechanisms of radiation, conduction (heatsinks) or convection (fans). Soft starters with run bypass mode will significantly reduce the heat generated once the motor is up to speed, reducing enclosure sizes and/or ventilating requirements. The enclosure must be located away from direct sunlight and hot surfaces. The room temperature must be kept within the specified limits and adequate cooling air must be allowed to flow around the enclosure. Excessively moist, corrosive or dirty air must be prevented from entering the enclosure.

Power Factor Correction Capacitors

Power factor correction capacitors must not be connected on the soft starter or controller output or at the motor terminal box. To do so would result in SCR failure. Power factor correction should be done on a plant-wide basis. If capacitors must be located at the soft start input, they should be connected as far upstream from the soft start as possible.

Input Harmonics

During operation no harmonic currents are caused by the use of a soft start. During motor starting, harmonic currents may be drawn from the utility line, but the duration of such is very short.

Load Types and Characteristics

Introduction

The process of selecting a soft start is dependent upon the characteristics of the load to which it is being applied. It is important to understand its torque characteristics and how they vary at start as well as during normal operation.

When considering load characteristics, the following should be evaluated:

■ What type of load is associated with the application?

■ Does the load have a shock component?

■ Are large inertial loads involved?

■ What are the motor considerations?

■ Are there frequent starts and stops?

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Solid-State Soft Start
Motor Controller and
Starter

Application Note

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Motor loads can be classified into three basic components that contribute to load torque, friction, inertia and the driven process, as was noted previously. The driven process can be broken down into a few basic load types.

Load Types

Constant Torque Load

This type of load is frequently encountered. In this group, the torque demanded by the load during start and run is constant. The load requires the same amount of torque at start and during normal operation. Loads of this type are essentially friction loads. In other words, the constant torque characteristic is needed to overcome friction. This load can be difficult to start with a soft starter, and still limit current, because it means that a high level of current must be used to start the load moving and maintain its movement.

Examples of this type of load are conveyors, extruders and surface winders.

Variable Torque Load

With this type of load, the torque is directly proportional to some mathematical power of speed, usually varying linearly with speed or speed squared (Speed^2).

An example of a load which varies linearly with speed is a mixer. Loads that vary as the square of speed are centrifugal fans, pumps and blowers. These types of loads require much lower torque at low speed than at full speed.

Other Functional Considerations

Shock Loads

Soft starts for crushers, separators, grinders, conveyors, winches, cranes and vehicular systems often must manage loads which range from a small fraction of the rated load to several hundred percent.

Under these conditions the soft starter must function properly yet protect the motor and driven equipment. Many soft starters provide additional motor protection beyond that of electromagnetic starters, such as jam, stall and underload. The soft starter must be appropriately sized for the load as well as have its protective features adjusted as required by the application.

Note: A soft start controller does not provide any motor or driven load protection. It only provides a soft start capability.

Inertial Load

A high inertia load may require oversizing of the motor and soft start to account for the heating caused by the long acceleration times.

Duty Cycle

Certain applications may require cyclic overloads or frequent start/stop cycles which may result in severe motor heating if not considered in the selection process.

Most motors and soft starts have a specified duty cycle capability.

Typical Load Torque

Table 3. Typical Load Torque Requirements

Name of Application	Load Torque as Percent of Full-Load Drive Torque		
	Breakaway	Accelerating	Peak Running

Actuators:
  Screw-down (rolling mills)
Positioning
Agitators:
  Liquid
  Slurry
	200
	150
	
	100
	150
		150
		110
		
		100
		100
			125
			100
			
			100
			100

Blowers, centrifugal:
  Valve closed
  Valve open
Blowers, positive-displacement, rotary, bypassed
Calendars, textile or paper
Card machines, textile
	30
	40
	40
	75
	100
		50
		110
		40
		110
		110
			40
			100
			100
			100
			100

Centrifuges (extractors) Chippers, wood, starting empty Compressors, axial-vane, loaded Compressors, reciprocating, start unloaded Conveyors, belt (loaded) Conveyors, drag (or apron)	40 50 40 100 150 175	60 40 100 50 130 150	125 200 100 100 100 100

Conveyors, screw (loaded)
Conveyors, Shaker-type (vibrating)
Coolers, hot solids, rotary (loaded)
Cranes, traveling:
  Bridge motion
  Trolley motion
  Hoist motion
	200
	150
	175
	
	100
	100
	50
		100
		150
		140
		
		300
		200
		200
			100
			75
			100
			
			100
			100
			190

Draw presses (flywheel) Drill presses Edgers (starting unloaded) Elevators, bucket (starting loaded) Elevators, freight (loaded) Elevators, man lift	50 25 40 150 100 50	50 50 30 175 125 125	200 150 200 150 100 100

Table 3. Typical Load Torque Requirements — Continued

Name of Application	Load Torque as Percent of Full-Load Drive Torque		
	Breakaway	Accelerating	Peak Running
Elevators, personnel (loaded)	110	150	100
Escalators, stairways (starting unloaded)	50	75	100
Extruders (rubber or plastic)	150	150	100
Fans, centrifugal, ambient:			
Valve closed	25	60	50
Valve open	25	110	100
Fans, centrifugal, hot gases:			
Valve closed	25	60	100
Valve open	25	200	175
Fans, propeller, axial-flow	40	110	100
Feeders, belt (loaded)	100	120	100
Feeders, distributing, oscillating drive	150	150	100
Feeders, screw compacting rolls	150	100	100
Feeders, screw, filter-cake	150	100	100
Feeders, screw, dry	175	100	100
Feeders, vibration motor-driven	150	150	100
Frames, spinning, textile	50	125	100
Grinders, metal	25	50	100
Hoists, skip	100	150	100
Indexers	150	200	150
Ironer, laundry (mangles)	50	50	125
Jointers, woodworking	50	125	125
Kilns, rotary (loaded)	250	125	125
Looms, textile, without clutch	125	125	150
Machines, boring (loaded)	150	150	100
Machines, bottling	150	50	100
Machines, buffing, automatic	50	75	100
Machines, cinder-block, vibrating	150	150	70
Machines, keyseating	25	50	100
Machines, polishing	50	75	100
Mills, flour, grinding	50	75	100
Mills, rolling metal:			
Billet, skelp and sheet, bar	50	30	200
Brass and copper finishing	120	100	200
Brass and copper roughing	40	30	200
Merchant mill trains	50	30	200
Plate	40	30	250
Reels, wire or strip	100	100	100
Rod	90	50	200
Sheet and tin (cold rolling)	150	110	200
Strip, hot	40	30	200
Structural and rail finishing	40	30	200
Structural and rail roughing	40	30	250
Tube	50	30	200
Tube piercing and expanding	50	30	250
Tube reeling	50	30	200
Mills, rubber	100	100	200
Mills, saw, band	50	75	200
Mixers, chemical	175	75	100
Mills, concrete	40	50	100
Mixers, dough	175	125	100
Mixers, liquid	100	100	100
Mixers, sand, centrifugal	50	100	100
Mixers, sand, screw	175	100	100
Mixers, slurry	150	125	100
Mixers, solids	175	125	175
Planers, metalworking	50	150	150
Planers, woodworking	50	125	150
Plows, conveyor, belt (ore)	150	150	200
Positioners, indexing (machine tool)	50	200	100
Presses, pellet (flywheel)	150	75	150
Presses, printing, production type	100	150	150
Presses, punch (flywheel)	150	75	100
Puller, car	150	110	100
Pumps, adjustable-blade, vertical	50	40	125
Pumps, centrifugal, discharge open	40	100	100
Pumps, oil-field, flywheel	150	200	200
Pumps, oil, lubricating	40	150	150
Pumps, oil fuel	40	150	150
Pumps, propeller	40	100	100

Table 3. Typical Load Torque Requirements — Continued

Name of Application	Load Torque as Percent of Full-Load Drive Torque		
	Breakaway	Accelerating	Peak Running
Pumps, reciprocating, positive-displacement	175	30	175
Pumps, screw-type, started dry	75	30	100
Pumps, screw-type, primed, discharge open	150	100	100
Pumps, slurry-handling, discharge open	150	100	100
Pumps, turbine, centrifugal, deep-well	50	100	100
Pumps, vacuum (paper-mill service)	60	100	150
Pumps, vacuum (other applications)	40	60	100
Pumps, vacuum, reciprocating	150	60	150
Pumps, vane-type, positive-displacement	150	150	175
Rolls, bending	150	150	100
Rolls, crushing (sugarcane)	50	110	125
Rolls, flaking	30	50	100
Sanders, woodworking, disk or belt	30	50	100
Saws, band, metalworking	30	50	100
Saws, circular, metal, cutoff	25	50	150
Saws, circular, wood, production	50	30	150
Saws, edger (see Edgers)			
Saws, gang	60	30	150
Screens, centrifugal (centrifuges)	40	60	125
Screens, vibrating	50	150	70
Separators, air (fan-type)	40	100	100
Shakers, foundry or car	50	150	70
Shears, flywheel-type	50	50	120
Shovels, dragline, hoisting motion	50	150	100
Shovels, dragline, platform motion	50	100	100
Shovels, large, digging motion	50	200	200
Shovels, large, platform motion	50	100	100
Tension-maintaining drives	100	100	100
Textile machinery	150	100	90
Tools, machine	100	150	100
Tools, machine, broaching, automatic	50	150	150
Tools, machine, lathe, metal production	50	200	200
Tools, machine, mill, boring production metal	100	125	100
Tools, machine, milling, production	100	100	100
Tools, machine, planer, production, metal (See Planers, metalworking)			
Tools, machine, shaper, metal, automatic	50	75	150
Vehicles, freight	200	200	200
Vehicles, passenger	100	400	200
Walkways, mechanized	50	50	100
Washers, laundry	25	75	100
Winches	125	150	100

Controller and Starter Selection

Selection Considerations

When selecting a soft starter or controller for an application, the following points should be considered:

Environment

The environment in which the motor and soft start will be placed is of prime concern. Conditions such as ambient temperature, cooling air supply, the presence of gas, moisture and dust should all be considered when choosing the soft start, its enclosure and protective features.

Torque Requirements

The starting, peak and acceleration torques are to be considered. Starting torque requirements can vary from a small percentage of the full load to a

value several times full-load torque. The peak torque varies because of a change in load conditions or mechanical nature of the machine. The motor torque available to the driven machine must be more than that required by the machine from start to full speed. The greater the excess torque, the more rapid the acceleration potential.

Duty Cycle

Selecting the proper soft start also depends on whether the load is steady, varies, follows a repetitive cycle of variation or has pulsating torques. The duty cycle, which is defined as a fixed repetitive load pattern over a given period of time, is expressed as the ratio of on-time to the cycle period. When the operating cycle is such that the soft start starts and stops frequently, the duty cycle becomes a factor.

Heating

The temperature of a motor or controller is a function of ventilation and losses. Frequent starts or high ambient temperatures need to be considered.

Selecting a Soft Start for a Machine

The application of a soft start and motor to power a machine can be both a mechanical and electrical issue. When applying the soft start, the speed-torque characteristics available at the motor's shaft must be considered, and how well these characteristics suit the machine.

Three essential parameters are:

1. Breakaway Torque

2. Process Torque

3. Accelerating Torque

Breakaway Torque

This is the torque required to start the machine in motion. It is usually greater (except for centrifugal pumps and fans) than the torque required to maintain motion (process torque). Breakaway torque combined with process torque frequently determines the soft start selection. Typical breakaway torques for various machine types are given in **Table 3**.

Note: Many soft starts have a selectable kick start feature which allows a large pulse of current for a very short period of time to break away the machine, after which the current level is reduced to the preset level.

Process (Running) Torque

This is the torque required to pull, push, compress, stretch or otherwise process or act upon the material being transported by or through the machine. On some machines, process torque may be so significant as to determine the motor power rating. On other machines, this load may be insignificant. This includes any peaks required during normal operation such as a work piece entering the machine or material property change.

Most machines can be classified into the following load types:

- **Constant torque** — load varies linearly with speed.
- **Variable torque** — load varies as the square of speed.

Care must be exercised if the properties of the machine or material change periodically, for example icing on an outdoor conveyor, or the settling of sludge in a pump when shut down, to select the motor and soft start to account for these conditions.

Accelerating Torque

This is the torque required to bring the machine to an operating speed within a given time. With most machines, the load is largely friction and this will need to be all that is considered, since the acceleration torque requirements will be small. However, certain machines classified as "high inertia" with flywheel, bull gears or other large rotating masses may require motor and soft start selection based upon the power required to accelerate the load within a given time.

Acceleration time is directly proportional to the total inertia and inversely proportional to the torque available.

Measuring Machine Torque

To measure the torque required to drive a machine, fasten a pulley securely to the shaft which the motor is to drive. Fasten one end of a cord to the outer surface of the pulley and wrap a few turns of the cord around the pulley. Tie the other end of the cord to a spring scale. See **Figure 23**.
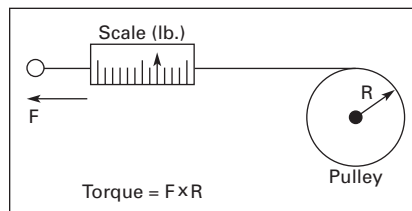
Figure 23. Measuring Torque

Pull gently on the scale until the shaft turns. Do not yank. The force in pounds or ounces, indicated on the scale, multiplied by the radius of the pulley (measured from the centerline of the machine shaft) in inches gives the torque value in lb-in or oz-in. On some machines, this torque may vary as the shaft rotates. The highest value of torque must be used when selecting a motor.

The running torque required by a machine will be approximately equal to the starting torque if the load is composed almost entirely of friction. If the load is primarily inertia or windage, the characteristics of the inertia or windage producing elements must be determined.

Most machines require a higher torque value to break away, but once running, the torque requirement will decrease.

Refer to specific soft starter or controller specifications in the product sections of the Cutler-Hammer catalog to match the driven machine requirements.

Soft Start Application Questions

1. **Does the environment have an explosive atmosphere** — If the atmosphere is classified by the NEC to be hazardous or semi-hazardous (Division I or Division II), the soft start must be located in a separate room away from the explosive environment.

2. **Does the environment have any magnetic dust present?** The soft start must be placed away from the magnetic dust, as it is also most likely to be conductive and could cause short circuits on printed circuit boards and power components.

3. **Will the soft start be subject to harsh chemicals or washdown?** If the soft start will be subject to washdown or harsh chemicals, the appropriate enclosure must be selected or the soft starter must be located in a clean environment.

4. **What is the start duty cycle of the machine?** If more frequent than permitted in the soft start catalog, an oversized starter will be required.

5. **What is the type of load?** Variable torque loads are typical of centrifugal pumps and fans where torque varies as the square of speed or a mixer where torque varies linearly with speed. Constant torque loads are typical of conveyors, stamping presses and extruders. The torque required by the load remains constant regardless of motor speed. The load inertia needs to be specified.

Additional Questions

After running through the above, you will find that a high percentage of applications can be satisfied by using a standard soft starter or controller. There are some additional questions which need to be answered for proper application.

1. **What is the input power that will be connected to the soft start?** The input voltage and frequency must be identified.

2. **What are the nameplate ratings of the motor** — The first cut choice of the soft start is based on the motor's current and voltage ratings. The choice is then refined based on the machine load requirements and knowledge of the prior starting method.

Soft Starter Application Data Worksheet

This worksheet is to assist you in determining the information required for selecting the proper soft starter.

Application:

Motor nameplate ratings:

____ Horsepower	____ Voltage	____ Service factor
____ RPM	____ Full load amps	____ Locked rotor code
____ Efficiency	____ NEMA design type	

Operating environment

    ____ Altitude in feet   ____ Ambient temperature

Total inertia at the motor shaft   ____ lb-ft^2

Duty cycle   ____ starts per hour

Load torque requirement (Attach curve if available)

    Starting ____ ft-lbs   Running ____ ft-lbs   Peak ____ ft-lbs

Motor torque-speed data (Attach curve if available)

    Locked rotor torque ____ ft-lbs   Pull up torque ____ ft-lbs

    Breakdown torque ____ ft-lbs

What is the required ramp time at start ____ sec

What is the required ramp time at stop ____ sec

Utility required inrush current limit ____ amps

Existing starter data

    ❏ Auto transformer, taps used   ❏ Full Voltage Starter

    ❏ Wye Start — Delta Run   ❏ Part winding starter

Time to full speed ____ sec   Peak current ____ amps

Solid-State Soft Start Motor Controller and Starter

F**:**T•N | Cutler-Hammer

Formulae, Conversions and Tables

Introduction

This section of your Application Note provides a rich resource of formulae, conversions and tables:

- How to Calculate Torque
- How to Calculate Horsepower
- How to Calculate Surface Speed
- How to Calculate Horsepower for Pumps
- How to Calculate Horsepower for Fans and Blowers
- How to Calculate Horsepower for Conveyors
- How to Calculate Accelerating Torque
- How to Calculate Maximum Motor Torque
- How to Calculate WK^2
- How to Calculate Equivalent WK^2 at Motor Shaft
- Electrical Formulae
- Induction Motor Formulae
- Tables of Conversions and Abbreviations

How to Calculate Torque

$$\text{Torque (lb-ft)} = \frac{hp \times 5250}{Speed(rpm)}$$

How to Calculate Horsepower

Definition:

1 horsepower = 550 ft-lb per second.

For Rotating Objects

$$hp = \frac{\text{Torque (lbs-ft) x Speed (rpm)}}{5250}$$

$$hp = \frac{\text{Torque (in-lbs) x Speed (rpm)}}{63,000}$$

For Object or Material in Linear Motion

$$hp = \frac{\text{Force (Lbs.) x Velocity (In./min.)}}{396,000}$$

$$hp = \frac{\text{Force (Lbs.) x Velocity (Ft./min.)}}{33,000}$$

Tension may be substituted for force in the above formulae.

How to Calculate Surface Speed

Surface speed (Ft./min) = rpm x Radius (Ft.) x 6.283.

How to Calculate Horsepower for Pumps

$$hp = \frac{\text{Flow x Head x Specific Gravity}}{3960 \text{ x Efficiency of Pump}}$$

(Flow in gal./min.; Head in Ft.)
Head in feet is pressure (lbs/in^2) x 2.307.

$$\frac{\text{Specific}}{\text{Gravity}} = \frac{\text{Density of Fluid}}{\text{Density of Water}}$$

Density of water = 62.43 lbs/ft^3 at 39.2°F (4°C)

Specific Gravity of Water = 1.0

Efficiency is expressed as a decimal. (Efficiency of 0.85 is 85% efficient).

Table 4. Typical Values of Efficiency for Centrifugal Pump

Gallons per Minute	Efficiency
500 to 1000	0.70 to 0.75
1000 to 1500	0.75 to 0.80
over 1500	0.80 to 0.85

Typical values of efficiency for positive displacement pumps:
Efficiency = 85 to 90.

Effects of Changing Pump Speed; for Centrifugal Pumps:
$hp = K_1(rpm)^3$
Horsepower is proportional to cube of speed.

$Torque = K_2(head)$
Torque is constant at all speeds with a constant head.

$Flow = K_3(rpm)$
Flow is directly proportional to speed.

How to Calculate Horsepower for Fans and Blowers

$$hp = \frac{\text{Flow x Pressure}}{33,000 \text{ x Efficiency of Fan}}$$

(Flow in Ft^3/min.; Pressure in Lbs/in^2)

$$hp = \frac{\text{Flow x Pressure}}{229 \text{ x Efficiency of Fan}}$$

(Flow in Ft^3/min.; Pressure in Lbs/ft^2)

$$hp = \frac{\text{Flow x Pressure}}{6356 \text{ x Efficiency of Fan}}$$

(Flow in Ft^3/min.; Pressure in inches of water gauge)

Efficiency is expressed as a decimal (efficiency of 0.85 is 85% efficient).

How to Calculate Horsepower for Conveyors

$$\begin{array}{c}hp \\ \text{(Vertical)}\end{array} = \frac{\text{F x V}}{33,000 \text{ x Efficiency}}$$

$$\begin{array}{c}hp \\ \text{(Horizontal)}\end{array} = \frac{\text{F x V x Coef. of Friction}}{33,000 \text{ x Efficiency}}$$

Where:

F = Force (Lbs)
V = Velocity (Ft/min)
Eff. = Efficiency

Coef. of Friction:

Ball or Roller Slide = 0.02
Dovetail Slide = 0.20
Hydrostatic Ways = 0.01
Rectangle Ways with Gib = 0.1 – 0.25

How to Calculate Accelerating Torque

In addition to the torque required to drive a load at a steady speed, torque is required to accelerate the load inertia from standstill to operating speed. The torque required for acceleration is determined by the inertia and the required rate of acceleration. The following formula is used to calculate acceleration torque (torque required above load torque) of a rotating member:

$$T = \frac{(WK^2)(dN)}{308t}$$

where:

T = acceleration torque (lb-ft)

WK^2 = total system inertia (lb-ft^2) that the motor must accelerate. This value includes motor rotor, reducer, and load. See "How to Calculate WK^2" that follows.

dN = change in speed required (rpm)

t = time to accelerate total system load (seconds)

The formula can also be arranged to calculate acceleration time given inertia, available torque and required speed change.

$$t = \frac{(WK^2)(dN)}{308T}$$

The accelerating force required for linear motion is given by:

$$\text{Accelerating Force (F)} = \frac{W(dV)}{1933t}$$

where:

W = weight (Lbs.)
dV = change in velocity (fpm)
t = time (seconds) to accelerate weight

For motor selection, this force must be converted to motor torque and added to the torque required for accelerating the rotating parts of the machine. See also "How to Calculate WK^2" that follows. The weight of the linear moving parts can be converted to an equivalent WK^2 at the motor shaft, eliminating the force calculations.

How to Calculate Maximum Motor Torque

Maximum Motor Torque = Running Torque + Accelerating Torque

How to Calculate WK^2

The factor WK^2 (inertia) is the weight of a rotating object multiplied by the square of the radius of gyration K. For weight in pounds and radius of gyration in feet, WK^2 is in $lbs\text{-}ft^2$.

For a solid cylinder:

$$WK^2 = \frac{\text{Density x Length x Diameter}^4}{1467}$$

where:

Density of material is in pounds per cubic inch. Length and diameter are in inches. Given weight in pounds and diameter in feet:

$$WK^2 = \frac{\text{Weight x Diameter}^2}{8}$$

For a hollow cylinder:

$$WK^2 = \frac{\text{Density x Length x (OD}^4 - \text{ID}^4)}{1467}$$

where:

Density of materials is in pounds per cubic inch. Length and diameter are in inches. Given weight in pounds and diameter in feet:

$$WK^2 = \frac{\text{Weight x (OD}^2 + \text{ID}^2)}{8}$$

Table 5. Density Values for Common Materials

Material	Density lb/in^3
Aluminum	0.0924
Bronze	0.3200
Cast Iron	0.2600
Nylon	0.0510
Paper	0.0250 to 0.0420
Steel	0.2820
Rubber	0.0341

WK^2 of Solid Steel Cylinders One Inch Long

Table 6 lists values of WK^2 in $lb\text{-}ft^2$ for one inch long solid steel cylinders of various diameters. For cylinders longer or shorter than one inch, multiply the value given by the actual length in inches. Values can be determined for diameters not listed by moving the decimal point in the diameter in either direction and moving the decimal point in the corresponding value of WK^2 four places in the same direction for every one place the decimal is moved in the diameter.

For hollow cylinders, subtract the WK^2 given for the inside diameter from the WK^2 given from the outside diameter.

The WK^2 are for steel with a density of 0.2820 Lbs. per In.^{3}. For other materials, multiply the WK^2 from the table by:

$$\frac{\text{Lbs per In}^3 \text{ of material}}{0.2820}$$

How to Calculate Equivalent WK^2 at Motor Shaft

In most mechanical systems not all of the moving parts operate at the same speed. If speeds of the various parts have a continuous fixed relationship to the motor speed, the following formulae can be used to convert all of the various inertia values to an equivalent WK^2 applied to the motor shaft.

For rotating parts:

$$\text{Equivalent } WK^2 = WK^2 \left[\frac{N}{N_M}\right]^2$$

where:

WK^2 = inertia of the moving part ($lbs\text{-}ft^2$)
N = speed of the moving part (rpm)
N_M = speed of the driving motor (rpm)

When using speed reducers, and the machine inertia is reflected back to the motor shaft, the equivalent inertia is equal to the machine inertia divided by the square of the drive reduction ratio.

$$\text{Equivalent } WK^2 = \frac{WK^2}{(DR)^2}$$

where:

DR = drive reduction ration N_M/N

For linear motion:

Not all driven systems involve rotating motion. The equivalent WK^2 of linearly moving parts can also be reduced to the motor shaft speed as follows:

$$\text{Equivalent } WK^2 = \frac{W(V)^2}{39.5(N_M)^2}$$

where:

W = weight of load (Lbs.)
V = linear velocity of moving parts (feet per minute)
N_M = speed of the driving motor (rpm)

Electrical Formulae

Ohms Law

Amperes = Volts/Ohms, or I = E/R
Ohms = Volts/Amperes, or R = E/I
Volts = Amperes x Ohms, or E = IR

Power in DC Circuits

Watts = Volts x Amperes, or W = EI

$$\text{Horsepower (hp)} = \frac{\text{Volts x Amperes}}{746}$$

$$\text{Kilowatts (kW)} = \frac{\text{Volts x Amperes}}{1000}$$

$$\text{Kilowatts Hrs (kWh)} = \frac{\text{Volts x Amperes x Hrs}}{1000}$$

Power in AC Circuits

Kilovolt-Amperes(kVA)

$$\text{kVA (1 ph)} = \frac{\text{Volts x Amperes}}{1000}$$

$$\text{kVA (3 ph)} = \frac{\text{Volts x Amperes x 1.73}}{1000}$$

Kilowatts (kW)

$$\text{kW (1 ph)} = \frac{\text{Volts x Amperes x PF}}{1000}$$

$$\text{kW (3 ph)} = \frac{\text{Volts x Amperes x PF x 1.73}}{1000}$$

Kilovolt-Amperes Reactive (kVAR)

kVAR = kVA SIN Θ

Power Factor

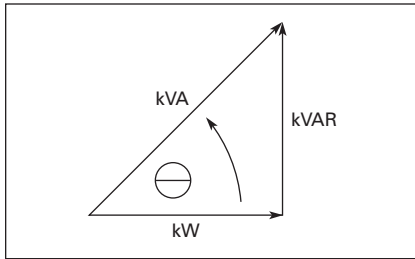$$PF = \Delta \, COS \, \Theta = \frac{kW(input)}{kVA(input)}$$

Figure 24. Power Factor

Induction Motor Formulae

Synchronous Speed

$$\text{Sync. rpm} = \frac{120f}{p}$$

where:

p = number of poles
f = frequency (Hz)

Operating Speed

rpm = Sync rpm - Slip rpm

$$\text{Slip rpm} \approx \frac{2 \times \text{percent load}}{p}$$

For Three-Phase Motors

Current (Amps)

$$= \frac{hp \times 746}{\sqrt{3} \times Volts \times Efficiency \times PF}$$

$$= \frac{hp \times 431}{Volts \times Efficiency \times PF}$$

Locked Rotor Current (Amps)

$$\frac{hp \times start \; kVA \, / \, hp \times 1000}{Volts \times \sqrt{3}}$$

At frequencies other than 60 Hz, LRA can be estimated by:

$$LRA = LRA \text{ at } 60 \text{ Hz} \times \frac{f}{60}$$

For Any Motor

$$kW \text{ (input)} = \frac{hp \times 0.746}{efficiency}$$

$$kW \text{ (output)} = hp \times 0.746$$

Tables of Conversions and Abbreviations

Table 6. WK^2 of Steel Cylinders One Inch Long

Diameter in Inches	WK^2	Diameter in Inches	WK^2	Diameter in Inches	WK^2	Diameter in Inches	WK^2	Diameter in Inches	WK^2
1	0.000192	41	543.9	81	8286	121	41262	161	129336
2	0.00308	42	598.8	82	8703	122	42643	162	132579
3	0.01559	43	658.1	83	9135	123	44059	163	135883
4	0.049278	44	721.4	84	9584	124	45510	164	139249
5	0.12030	45	789.3	85	10048	125	46995	165	142676
6	0.2494	46	861.8	86	10529	126	48517	166	146166
7	0.46217	47	939.3	87	11028	127	50076	167	149720
8	0.78814	48	1021.8	88	11544	128	51672	168	153339
9	1.262	49	1109.6	89	12077	129	53305	169	157022
10	1.924	50	1203.07	90	12629	130	54978	170	160772
11	2.818	51	1302.2	91	13200	131	56689	171	164588
12	3.991	52	1407.4	92	13790	132	58440	172	168472
13	5.497	53	1518.8	93	14399	133	60231	173	172424
14	7.395	54	1636.7	94	15029	134	62063	174	176446
15	9.745	55	1761.4	95	15679	135	63936	175	180537
16	12.61	56	1893.1	96	16349	136	65852	176	184699
17	16.07	57	2031.9	97	17041	137	67811	177	188933
18	20.21	58	2178.3	98	17755	138	69812	178	193239
19	25.08	59	2332.5	99	18490	139	71858	179	197618
20	30.79	60	2494.7	100	19249	140	73948	180	202071
21	37.43	61	2665.2	101	20031	141	76083	181	206599
22	45.09	62	2844.3	102	20836	142	78265	182	211203
23	53.87	63	3032.3	103	21665	143	80493	183	215883
24	63.86	64	3229.5	104	22519	144	82768	184	220640
25	75.19	65	3436.1	105	23397	145	85091	185	225476
26	87.96	66	3652.5	106	24302	146	87463	186	230391
27	102.30	67	3879.0	107	25232	147	89884	187	235386
28	118.31	68	4115.7	108	26188	148	92355	188	240461
29	136.14	69	4363.2	109	27173	149	94876	189	245619
30	155.92	70	4621.7	110	28183	150	97449	190	250858
31	177.77	71	4891.5	111	29222	151	100075	191	256182
32	201.8	72	5172	112	30289	152	102750	192	261589
33	228.2	73	5466	113	31385	153	105482	193	267081
34	257.2	74	5772	114	32511	154	108268	194	272660
35	288.8	75	6090	115	33667	155	111107	195	278325
36	323.2	76	6422	116	34853	156	114002	196	284078
37	360.7	77	6767	117	36071	157	116954	197	289920
38	401.3	78	7125	118	37320	158	119962	198	295852
39	445.3	79	7498	119	28601	159	123028	199	301874
40	492.78	80	7885	120	39914	160	126152	200	307988

Table 7. Standard Abbreviation Descriptions

Temperature	deg. = degrees C = Celsius (Centigrade) F = Fahrenheit Btu = British Thermal Unit	**Work/Inertia**	ft-lb = foot pound WK^2 = moment of inertia $N{\cdot}m^2$ = Newton meters^2 r = radius k = radius of gyration
Length	Yd. = yard m = meter mm = millimeter (1/1000 of a meter) cm = centimeter (1/100 of a meter) In. = inch Ft. = feet km = kilometer	**Area**	Ft.^{2} = square foot sq. m = square meter mil = unit of length of angular measurement mm^2 = square millimeter In.^{2} = square inch
Weight	Oz. = ounce Lb. = pound kg = kilogram gm = gram	**Rotation/Rate**	FPM = feet per minute FPS = feet per second m/s = meters per seconds mph = miles per hour cfm = cubic feet per minute
Electrical	Ω = Ohms ϕ = Phase V = Volts A = Amperes mA = milliamperes μA = microamperes kV = kilovolts mV = millivolts kVA = kilovolt-amps kVAR = kilovolt-amps reactive Hz = Hertz, cycle per second	**Mathematic** **Pressure**	π = "pi" rad. = radians ρ = Density $\sum$ = Summation Δ = Change kg per sq. cm = kilograms per square centimeter Hg = Mercury Symbol PSI = pounds per square inch PSF = pounds per square foot
Power/Energy	hp = horsepower W = watt kW = kilowatt kWH = kilowatt-hours J = Joule	**Volume**	cu. = cubic In.^{3} = cubic inch gal. = gallon Ft.^{3} = cubic foot ml = milliliter fl. oz = fluid ounce (U.S.)

Table 8. Useful Conversion Constants

To Convert From	To	Multiply By
Area		
In.^{2}	cm^2	6.4516
Ft.^{2}	m^{2}①	9.2903 x 10^{-2}
Yd.^{2}	m^{2}①	0.83613
Ft.^{2}	Yd.^{2}	0.11111
Energy		
Btu (thermochemical)	Joule (J)①	1054.4
Btu (thermochemical)	kWH	2.9288 x 10^{-4}
calorie (thermochemical)	Joule (J)①	4.184
hp-hr	kWH	1.341
ft-lb	Joule (J)①	1.3558
ft-lb	Btu	1.2859 x 10^{-3}
ft-lb	kWH	3.7662 x 10^{-7}
kWH	Joule (J)①	3.6 x 10^6
Flow — Mass		
lb/hp-hr②	kg/Joule①	1.6897 x 10^{-7}
lb-hr	kg/hr	45359
lb/min	kg/sec①	7.5599 x 10^{-3}
lb/sec	kg/sec①	0.45359
oz/min	g/min	28.35
Flow — Vol.		
gpm	liter/min	3.7854
gpm	m^3/sec①	6.309 x 10^{-5}
in^3/sec	cm^3/sec	16.387
gal/hp-hr②	m^3/Joule①	1.4101 x 10^{-9}
ft^3/sec	m3/sec①	2.8317 x 10^{-2}
cfm	m3/hr	1.699
Force		
kg	Newtons (N)①	9.8067
oz (avoirdupois)	Newtons (N)①	0.27801
lb (avoirdupois)	Newtons (N)①	4.4482
gm	Newtons (N)①	9.8067 x 10^{-3}
kg	lb (avoirdupois)	2.2046
ton (2000 Lb.)	Newton①	8896.4
ton (2000 Lb.)	kg	907.18
oz (avoirdupois)	gm	28.35
lb (avoirdupois)	gm	453.59
Length		
Ft.	meter (m)①	0.3048
In.	cm	2.54
mile (statute)	km	1.6093
mil	mm	2.54 x 10^{-2}
Mass		
Lb. (avoirdupois)	kg①	0.45359
Lb. (avoirdupois)	gm	453.59
Oz. (avoirdupois)	gm	28.35
slug	kg①	14.594
ton (2000 lb)	kg①	907.18
ton (metric)	kg①	1000
Power		
hp (550 ft-lb/sec)	watt①	745.7
ton (refrigeration)	watt	3516.8
ton (refrigeration	hp	4.7161
hp (550 ft-lb/sec)	hp (metric)	1.0139
Btu/min (thermochemical)	watt	17.573
Btu/sec (thermochemical)	hp (550 ft-lb/sec)	1.4139
calorie/sec (thermochemical)	watt①	4.184
To	**To Convert From**	**Divide By**

To Convert From	To	Multiply By
Pressure		
PSI	kPa	6.8948
ft of water (39.2°F)	kPa	2.989
gm/cm^2	Pa①	98.067
in Hg (32°F)	kPa	3.3864
atmosphere	kPa	101.33
atmosphere	PSI	14.696
in Hg (32°F)	PSI	0.49115
ft of water (39.2°F)	PSI	0.43351
in of water (39.2°F)	PSI	3.6126 x 10^{-2}
in of water (39.2°F)	kPa	0.24908
mm Hg @ 0°C (=Torr)	kPa	0.13332
mm Hg @ 0°C (=Torr)	PSI	1.9337 x 10^{-2}
Temp.		
°F	°C①	$t°_c = (t°_f - 32)/1.8$
°C①	°F	$t°_f = (1.8)(t°_c) + 32$
°C①	°K①	$t°_k = t°_c + 273.15$
°F	°R	$t°_r = t°_f + 459.67$
Torque		
lb-in	N-m①	0.11298
lb-ft	N-m①	1.3558
oz-ft	N-m①	8.4739 x 10^{-2}
oz-ft	lb-in	0.75
kg-m	N-m①	9.8067
oz-in	gm-cm	72.008
kg-m	lb-in	86.796
dyne-cm	oz-in	1.4161 x 10^{-5}
dyne-cm	N-m①	1 x 10^{-7}
Velocity		
ft/min	mph	1.1364 x 10^{-2}
mph	kWH	1.6093
mph	meter/sec①	0.44704
ft/sec	meter/sec①	0.3048
rpm	radians/sec	0.10472
revolutions/sec	radians/sec	6.2832
Volume		
barrel (oil, 42 gal)	meter^3	15699
barrel (oil, 42 gal)	gallon (U.S. liquid)	42
barrel (42 gal)	liter	158.99
barrel (42 gal)	ft^3	5.6146
gallon (U.S. liquid)	liter	3.7854
gallon (U.S. liquid)	in^3	231
gallon (U.S. liquid)	meter^3	3.7854 x 10-3
quart (U.S. liquid)	in^3	57.75
quart (U.S. liquid)	liter	0.94635
fluid oz (U.S. liquid)	in^3	1.8047
fluid oz (U.S. liquid)	cm^3	29.571
liter	meter^3	1 x 10-3
liter	cm^3	1000
liter	in^3	61.024
In.^{3}	cm^3	16.387
Ft.^{3}	in^3	1728
Ft.^{3}	liter	28.317
To	**To Convert From**	**Divide By**

How to Use

Direct Conversion
Multiply known value by conversion factor to obtain equivalent value in desired units. For example, 203 in^2 is converted to cm^2, as follows:
203 in^2 x 6.4516 = 1309.67cm^2

Inverse Conversion
Divide known value by conversion factor to obtain equivalent value in desired units. For example, 10.82 N-m converted to oz-ft, as follows:
$$\frac{10.82 \text{ N-m}}{8.4739 \times 10^{-2}} = 127.69 \text{ oz-ft}$$

① Indicates Standard International (S) Unit
② Specific fuel consumption (SFC)

Table 9. Fractional Inch to Equivalent Millimeters and Decimals

Inch	Equivalent		Inch	Equivalent	
	mm	Decimal		mm	Decimal
1/64	0.3969	0.0156	33/64	13.0969	0.5156
1/32	0.7938	0.0313	17/32	13.4938	0.5313
3/64	1.1906	0.0469	35/64	13.8906	0.5469
1/16	1.5875	0.0625	9/16	14.2875	0.5625
5/64	1.9844	0.0781	37/64	14.6844	0.5781
3/32	2.3813	0.0938	19/32	15.0813	0.5938
7/64	2.7781	0.1094	39/64	15.4781	0.6094
1/8	3.1750	0.1250	5/8	15.8750	0.6250
9/64	3.5719	0.1406	41/64	16.2719	0.6406
5/32	3.9688	0.1563	21/32	16.6688	0.6563
11/64	4.3656	0.1719	43/64	17.0656	0.6719
3/16	4.7625	0.1875	11/64	17.4625	0.6875
13/64	5.1594	0.2031	45/64	17.8594	0.7031
7/32	5.5563	0.2188	23/32	18.2563	0.7188
15/64	5.9531	0.2344	47/64	18.6531	0.7344
1/4	6.3500	0.2500	3/4	19.0500	0.7500
17/64	6.7469	0.2656	49/64	19.4469	0.7656
9/32	7.1438	0.2813	25/32	19.8438	0.7813
19/64	7.5406	0.2969	51/64	20.2406	0.7969
5/16	7.9375	0.3125	13/16	20.6375	0.8125
21/64	8.3344	0.3181	53/64	21.0344	0.8281
11/32	8.7313	0.3438	27/32	21.4313	0.8438
23/64	9.1281	0.3594	55/64	21.8281	0.8594
3/8	9.5250	0.3750	7/8	22.2250	0.8750
25/64	9.9219	0.3906	57/64	22.6219	0.8906
13/32	10.3188	0.4063	29/32	23.0188	0.9063
27/64	10.7156	0.4219	59/64	23.4156	0.9219
7/16	11.1125	0.4375	15/16	23.8125	0.9375
29/64	11.5094	0.4513	61/64	24.2094	0.9531
15/32	11.9063	0.4688	31/32	24.6063	0.9688
31/64	12.3031	0.4844	63/64	25.0031	0.9844
1/2	12.700	0.5000	—	—	—

Glossary

AC Contactor
An alternating current (AC) contactor is designed for the specific purpose of establishing or interrupting an AC power circuit.

Ambient Temperature
Ambient temperature is the temperature of the medium, such as air, water or earth, into which the heat of the equipment is dissipated.

For self-ventilated equipment, the ambient temperature is the average temperature of the air in the immediate neighborhood of the equipment.

For air or gas cooled equipment with forced ventilation, or secondary water cooling, the ambient temperature is taken as that of the ingoing air or cooling gas.

For self-ventilated enclosed (including oil immersed) equipment, considered as a complete unit, the ambient temperature is the average temperature of the air outside of the enclosure in the immediate neighborhood of the equipment.

Auxiliary Contacts
Auxiliary contacts of a switching device are contacts in addition to the main circuit contacts and operate with the movement of the latter.

Back of a Motor
The back of a motor is the end which carries the coupling or driving pulley (NEMA). This is sometimes called the drive end (D.E.) or pulley end (P.E.).

Base Speed
Base speed is the manufacturer's nameplate rating where the motor will develop rated hp at rated load and voltage.

Bearing (Ball)
A "*ball*" shaped component that is used to reduce friction and wear while supporting rotating elements. For a motor, this type of bearing provides a relatively rigid support for the output shaft.

Bearing (Roller)
A special bearing system with cylindrical rollers capable of handling belted load applications that are too large for standard ball bearings.

Braking
Braking provides a means of stopping an AC motor and can be accomplished in several ways:

1. **Motor Mounted or Separately Mounted Spring Set Brake** – This is a positive action, mechanical, friction device. Normal configuration is such that when the power is removed, the brake is set. This can be used as a holding brake. (**Note**: a separately mounted brake is one which is located on some part of the mechanical drive train other than the motor).

2. **Eddy-Current Brake** – Eddy currents are generated in the brake drum to produce braking torque for retarding or stopping shaft rotation. Braking torque is transmitted by the eddy-current principle when voltage is applied to the brake coil, with the rate of shaft deceleration being determined by the amount of excitation applied to the coil. Braking torque, which is a function of speed and

brake coil excitation, is provided throughout most of the speed range, but drops to zero as the shaft approaches zero rpm. Therefore, this brake cannot serve as a holding brake.

3. **Friction Brake** — An electromagnetic field is established between the brake coil and armature assemblies only while the brake coil is energized. Upon energizing the brake coil, these two assemblies are drawn together and stop shaft rotation by friction. The rate of shaft deceleration is determined by the amount of excitation applied to the coil. As long as excitation is applied to the brake coil, the two assemblies will remain locked together, thereby servicing as a holding brake.

4. **DC Dynamic Braking** — A low DC voltage is applied to the AC motor stator at low speed. A braking torque is developed which will slow the motor down quickly. No braking torque exists if the shaft is at zero speed.

Breakaway Torque

The torque required to start a machine and its load from standstill.

Breakdown Torque

The breakdown torque of an AC motor is the maximum torque which it will develop with rated voltage applied at rated frequency.

C-Face (Motor/Drive Mounting)

This type of motor mounting is used to closely couple pumps and similar applications where the mounting holes in the face are threaded to receive bolts from the pump. Normally, the C-Face is used where a pump or similar item is to be overhung on the motor. This type of mounting is a NEMA standard design and available with or without feet.

Cogging

A condition in which a motor does not rotate smoothly, but "steps" or "jerks" from one position to another during shaft revolution. Cogging is most pronounced at low motor speeds and can cause objectionable vibrations in the driven machine.

Constant Torque Range

A speed range in which the motor is capable of delivering a constant torque, subject to cooling limitations of the motor.

Contactor

A contactor is a two-state (On-Off) device for repeatedly establishing and interrupting an electric power circuit. Interruption is obtained by introducing a gap or a very large impedance.

Contactor Reversing

A method of reversing motor rotation by the use of two separate contactors, one of which produces rotation in one direction and the other produces rotation in the opposite direction. The contactors are electrically (and mechanically) interlocked so that both cannot be energized at the same time.

Continuous Duty

Operation of a motor within the insulation temperature limits after it has reached normal operating (equilibrium) temperature.

Continuous Rating

The continuous rating is the maximum constant load that can be carried continuously without exceeding established temperature rise limitations under prescribed conditions of load and within the limitations of established standards.

Control Circuit

The control circuit of a control apparatus or system is the circuit which carries the electric signals directing the performance of the controller, but does not carry the main circuit power.

Control Device

A control device is an individual device used to control functions.

Control Transformer Winding

A control transformer winding is a voltage transformer utilized to supply voltage suitable for the operation of control devices.

Controller

A device for controlling a motor.

Critical Frequency or Speed

Any frequency or speed at which mechanical resonance occurs in the mechanical drive train or the driven equipment. To avoid damage due to vibration, the machine must be designed to shift the critical speed away from the operating speed.

Current Limit

An electronic method of limiting the maximum current available to the motor. This is adjustable so that the motor's maximum current can be controlled. It can also be preset as a protective device to protect both the motor and controller from extended overloads.

Current Limit Acceleration

A system of control in which acceleration is governed so that the motor current does not exceed an adjustable maximum value.

Current Limiting Fuse

A fuse that, when it is melted by a current within its specified current limiting range, abruptly introduces a high impedance to end the current flow.

Current Relay

A current relay functions at a predetermined value of current. It may be an overcurrent relay, an undercurrent relay, or a combination of both.

Definite Purpose Motor

A definite purpose motor is any motor design, listed and offered in standard ratings with standard operating characteristics and mechanical construction, for use under service conditions other than usual or for use on a particular type of application (NEMA).

D-Flange (Motor Mounting)

This type of motor mounting is used when the motor is to be built as part of the machine. The mounting holes of the flange are not threaded. The bolts protrude through the flange from the motor side. Normally D-Flange motors are supplied without feet since the motor is mounted directly to the driven machine.

di/dt

The rate of change in current versus time.

Dimension Drawing

A dimensioned or outline drawing (base plan, floor plan, etc.) is one which shows the physical space and mounting requirements of a piece of equipment. It may also indicate ventilation requirements and space provided for connections or the location to which connections are to be made.

dv/dt

The rate of change in voltage versus time. Specially designed resistor-capacitor networks can help protect the SCRs from excessive dv/dt which can result form line voltage spikes, line disturbances and circuit configurations with extreme forward conducting or reverse blocking requirements.

Duty Cycle

The relationship between the operating and resting times or repeatable operation at different loads.

Dwell

The time spend in one state before moving to the next. In motion control applications for example, a dwell time may be programmed to allow time for a tool change or part clamping operation.

Eddy-Current

The electrical current induced in metallic components from the change in magnetic fields. Motor stators are often laminated to reduce the eddy-current effect.

Eddy-Current Brake

An eddy-current brake consists of a rotating member keyed to a straight through, double extension shaft and a field coil assembly. The brake rotor rotates at the speed of the prime mover until the field coil is energized. Rotation of the rotor is retarded, by controlling the current in the field coil.

Efficiency

Ratio of power output to power input indicated as a percent. In motors, it is the effectiveness of which a motor converts electrical power into mechanical power.

EMF

The acronym for electromotive force, which is another term for voltage or potential difference.

Enable

To allow an action or acceptance of data by applying an appropriate signal to the appropriate input.

Enclosure

Enclosure refers to the housing in which the controller is mounted. Enclosures are available in designs for various environmental conditions:

1. **NEMA Type 1** — A general purpose enclosure of either a ventilated or a non ventilated variety. It is used for most indoor applications and is intended to protect limited amounts of falling dirt and accidental human contact with the electrical circuit.

2. **NEMA Type 4** — A watertight enclosure, required whenever the unit is subjected to a great amount of water from any angle. It is normally used in areas that are repeatedly hosed down. These enclosures are not designed to be submerged.

3. **NEMA Type 7** — An enclosure designed for an indoor hazardous location, Class I (air), Group A, B, C, or D, per the National Electrical Code. This hazardous environment is one in which flammable gases or vapors are or may be present in the air in quantities sufficient to produce explosive or ignitable mixtures. This explosion proof enclosure shall be of such substantial construction that is will withstand the internal pressures resulting from explosions without bursting, permanently distorting or loosening its joints.

4. **NEMA Type 9** — An enclosure designed for hazardous locations, Class II, Groups E, F, and G per the National Electrical Code. The atmosphere in which this controller must operate may contain carbon black, coal or coke dust, flour, starch or grain dust.

5. **NEMA Type 12** — Designed for industrial use. This enclosure is intended for use in applications where it is desirable to exclude such materials as cooling oil, seepage, dust, lint, fibers, and filings. This is a non-ventilated enclosure with an oil resistant, synthetic gasket between the case and the cover. The cover is hinged to swing horizontally and is held in place with suitable fasteners which require the use of a tool.

6. **JIC** — Joint Industry Conference enclosures are similar in specifications to the NEMA Type 4 and Type 12 enclosures. The most obvious difference is the way the seal is obtained. They are suitable for the use of the standard NEMA Type 4 and NEMA Type 12 enclosures.

7. Explosion proof enclosures normally meet some, or all of the following specifications: Class I, Group D; Class II, Groups E, F and G; NEMA Type 7 and NEMA Type 9.

   a. Class I, Group D is designed to meet the application requirements of the NEC and is in accordance with the latest specifications of Underwriters Laboratories, Inc., for locations having atmospheres containing gasoline, hexane, naphtha, benzine, butane, propane, alcohol, acetone, benzol, lacquer solvent vapors or natural gas.

   b. Class II, Groups E, F and G is designed to meet the application requirements of the NEC and is in accordance with UL requirements for atmospheres containing metal dust, including aluminum, magnesium and their commercial alloys: and other metals or similar hazardous characteristics, such as carbon black, coal or coke dust, flour, starch or grain dusts.

Fault Current

Fault current is a current which results from the loss of insulation between conductors or between a conductor and ground.

Force

The tendency to change the motion or position of an object with a push or pull. Force is measured in ounces or pounds.

Frame Size

The physical size of motor, usually consisting of NEMA defined "D" and "F" dimensions at a minimum. The "D" dimension is the distance in quarter inches from the center of the motor shaft to the bottom of the mounting feet. The "F" dimension relates to the distance between the centers of the mounting feet holes.

Front of a Motor

The end opposite the coupling or driving pulley (NEMA). This is sometimes called the opposite pulley end (O.P.E.).

Full Load Current

The input current to a motor operated at its full load torque and nameplate voltage and frequency.

Full Load Speed

The speed that the output shaft of the motor attains with rated load connected at rated voltage.

Full Load Torque

The full load torque of a motor is the torque necessary to produce rated horsepower at full load speed.

Gate

The control element of an SCR (silicon controlled rectifier) commonly referred to as a thyristor. When a small positive voltage is applied to the gate momentarily, the SCR will conduct current (when the anode is positive with respect to the cathode of the SCR). Current conduction will continue, even after the gate signal is removed, as long as the anode/cathode voltage relationship is maintained.

General Purpose Motor

This motor has a continuous Class B insulation rating and NEMA B design, listed and offered in standard ratings with standard operating characteristics and mechanical construction, for use under usual service conditions without restriction to a particular application or type of application (NEMA).

Head

A measurement of pressure, usually expressed in feet of water. A 30 foot head is the pressure equivalent to the pressure found at the base of a column of water 30 feet high.

Heater Coil (Thermal Overload Relay)

A heater coil is a part of a thermal overload relay that is intended to produce heat when conducting current. Heater coils are sometimes referred to as heaters, thermal units, current elements or heater elements.

Horsepower

A measure of the amount of work that a motor can perform in a given period of time.

Hysteresis Loss

The resistance offered by materials to becoming magnetized results in energy being expended and a corresponding loss. Hysteresis loss in a magnetic circuit is the energy expended to magnetize and demagnetize the core.

Induction Motor

An alternating current motor in which the primary winding, on one member (usually the stator), is connected to the power source. A secondary on the other member (usually the rotor) carries the induced current. There is no physical electrical connection to the secondary winding, its current is induced.

Inertia

A measure of a body's resistance to changes in velocity, whether the body is at rest or moving at a constant velocity. The velocity can be either linear or rotational. The moment of inertia (WK^2) is the product of the weight (W) of an object and the square of the radius of gyration (K^2). The radius of gyration is a measure of how the mass of the object is distributed about the axis of rotation. WK^2 is usually expressed in units of lb-ft^2.

Integral Horsepower Motor

A motor built in a frame having a continuous rating of 1 hp or more.

Interconnection Diagram

An interconnection diagram is a diagram which shows only the external connections between controllers and associated machinery and equipment.

Intermittent Duty

A motor that never reaches equilibrium temperature, but is permitted to cool down between operations. For example, a crane, hoist or machine tool motor is often rated for 15 or 30 minute duty.

Interrupting Capacity

The interrupting capacity is the maximum value of current that a contact assembly is required to successfully interrupt at a specified voltage for a limited number of operations under specified conditions.

Jogging

Jogging is a means of accomplishing momentary motor movement by repetitive application of power.

Kick Start

The momentary application of a high initial starting torque to break away a hard to start load. After a short duration, the starting torque or current limit level returns to the preset value.

Kinetic Energy

The energy of motion possessed by a body.

Linear Acceleration/Deceleration

A circuit that controls the rate at which the motor is to accelerate or decelerate upon a start or stop command.

Locked Rotor Current

Steady state current taken from the line with the rotor at standstill (at rated voltage and frequency). This is the current when starting the motor and load.

Locked Rotor Torque

The minimum torque that a motor will develop at rest for all angular positions of the rotor application of rated voltage and frequency.

Megohm Meter

A device used to measure an insulation system's resistance. This is usually measured in megohms and tested by passing a low current at high voltage through the motor windings and measuring the resistance of the various insulation systems.

Modular Construction

The major circuit elements are mounted in replaceable modules, which can readily be removed and replaced.

Module

A unit of circuit elements usually packaged so it can be readily replaced.

Multi Motor Operation

A system in which one controller operates two or more motors simultaneously.

Multi-Speed Motor

An induction motor that can operate at two, three, or four discrete (fixed) speeds by the selection of various stator winding configurations.

NEC

The National Electrical Code is the recommendation of the National Fire Protection Association for electrical safety and property protection and is revised every three years. City, county, or state regulations may differ from these code regulations and take precedence over NEC rules.

NEMA

The National Electrical Manufacturers Association is a non-profit organization, organized and supported by manufacturers of electrical equipment and supplies. Some of the standards NEMA promulgates cover: horsepower ratings, speeds, frame sizes and dimensions, torques and enclosures.

No Load

The state of machine rotating at normal speed under rated conditions, but when no output is required from it.

OFF Delay

Off delay signifies that the timing period of a time delay relay is initiated upon de-energization of its coil.

ON Delay

On delay signifies that the timing period of a time delay relay is initiated upon energization of its coil.

Operating Overload

Operating overload is the overcurrent to which an electric apparatus is subjected in the course of the normal

operating conditions that it may encounter. For example, those currents in excess of running current which occur for a short time as a motor is started or jogged, are considered normal operating overloads for a control apparatus.

Open Machine (Motors)

A machine having ventilating openings which permit passage of external cooling air over and around the windings of the machine.

1. Dripproof is an open machine in which the ventilating openings are so constructed that successful operation is not interfered with when drops of liquid or solid particles strike or enter the enclosure at any angle from 0 to 15 degrees downward from vertical.

2. Splash proof is an open machine in which the ventilating openings are so constructed that successful operation is not interfered with when drops of liquid or solid particles strike or enter the enclosure at any angle not greater than 100 degrees downward from the vertical.

3. Semiguarded is an open machine in which part of the ventilating openings in the machine, normally in the top half, are guarded as in the case of a "guarded machine", while the other parts are left open.

4. Guarded (NEMA) is an open machine in which all openings giving direct access to live metal or rotating parts (except smooth rotating surfaces) are limited in size by the structural parts of by the screens, baffles, grilles, expanded metal or other means to prevent accidental contact with hazardous parts. Openings giving direct access to such live or rotating parts shall not permit the passage of a cylindrical rod 0.75 inch in diameter.

5. Dripproof Guarded is a dripproof machine whose ventilating openings are guarded in accordance with the definition of a guarded machine.

6. Open Externally Ventilated is one which is ventilated by means of a separate motor driven blower mounted machine enclosure. This machine is sometimes known as a blower-ventilated or a force-ventilated machine.

7. Open Pipe Ventilated is basically an open machine except that openings for admission of ventilating air are so arranged that inlet ducts or pipes can be connected to them. Air may be circulated by means integral with the machine or by means external to the machine (separately or forced ventilated).

8. Weather Protected is an open enclosure divided into two types:

   a. Type 1 enclosures have ventilating passages constructed to minimize the entrance of rain, snow, airborne particles and prevent passage of a 0.75 in. diameter cylindrical rod.

   b. Type 2 enclosures provide additional protection through the design of their intake and exhaust ventilating passages. The passages are so arranged that wind and airborne particles blown into the machine can be discharged without entering directly into the electrical parts of the machine. Additional baffling is provided to minimize the possibility of moisture or dirt being carried inside the machine.

Overcurrent Relay

An overcurrent relay operates when the current through the relay, during its operating period, is equal to or greater than its setting.

Overload Capacity

The ability of the controller to withstand currents beyond the system's continuous rating. It is normally specified as a percentage of full load current for a specified time period.

Overload Relay

An overload relay is an overcurrent relay which operates at a predetermined value of current in order to prevent overheating of the motor.

Phase Control

The process of varying the point within the electrical cycle at which thyristor gating occurs to begin forward conduction.

Pickup Voltage or Current

The pickup voltage or current of a magnetically operated device is the minimum voltage or current at which the device operates.

Plugging

Plugging refers to a type of motor braking provided by reversing phase sequence so that the motor develops a counter-torque which exerts a retarding force to brake the motor.

Power

Work done per unit of time. Measured in horsepower or watts:

1 hp = 33,000 ft-lb/min. = 746 watts

Power Factor

Power factor is the ratio of the total input kW divided by the total input kVA.

Printed Circuit Board

A board for mounting of separately manufactured components which has the connections made by printed circuitry.

Pull-Up Torque

The minimum torque available after initial motor start to accelerate the load to full speed (where breakdown torque occurs), expressed in percent of running torque.

Pulse

A pulse is a signal of relatively short duration.

Pump Control

A special feature on a soft starter which provides a special shaped ramp start and stop to reduce the potential for water hammer in a pump system.

Pushbutton

A pushbutton is a switch having a manually operable plunger, rocker or button for actuating the switch.

Reactance

The opposition to the flow of current made by an inductor or a capacitor.

Relay

An electrically controlled device that causes electrical contacts to change status. Open contacts will close and closed contacts will open when rated voltage is applied to the coil of relay.

Remote Control

Remote control is a control function which provides for initiation or change or a control function from a remote point.

Reset

To reset is to restore a mechanism, stored characteristics or device to a prescribed state.

Reversing

Changing the direction of rotation of the motor rotor. An AC motor is reversed by reversing the connection of two legs on the three-phase power line.

Rotor

The rotating member of a machine with a shaft.

Rotor Time Constant

The inductance divided by the resistance of the motor rotor.

Schematic Diagram (Elementary Diagram)

A schematic or elementary diagram is one that shows all circuits and devices of a controller. The diagram does not show the physical arrangement of the devices or the actual wiring to the devices.

Service Factor

When used on a motor nameplate, a number which indicates how much above the nameplate rating a motor can be loaded without causing serious degradation (i.e., a motor with 1.15 S.F. can produce 15% greater torque than one with 1.0 S.F.).

Service of a Controller

The service of a controller is the specific application in which the controller is to be used; for example:

1. General Purpose

2. Definite Purpose

   a. Crane and hoist
   b. Elevator
   c. Machine tool, etc.

Shock Load

The load seen by a clutch, brake or motor in a system which transmits high peak loads. This type of load is present in crushers, separators, grinders, conveyors, winches and cranes.

Silicon Controlled Rectifier (SCR)

A solid-state switch, sometimes referred to as a thyristor. The SCR has an anode, cathode and control element called the gate. The device provides controlled rectification since it can be turned on at will. The SCR can rapidly switch large currents at high voltages. It is small in size and low in weight.

Slip

The difference between rotating magnetic field speed (synchronous speed) and rotor speed of AC induction motors. Usually expressed as a percentage of synchronous speed.

Soft Start

A thyristor controlled device for reducing motor inrush current by gradually increasing the line voltage at start from zero to full voltage.

Soft Start Controller

A soft start device which provides no motor protection. Usually used in conjunction with an electromagnetic motor starter.

Soft Starter

A soft start device which provides motor overload protection and may also provide undervoltage, jam or stall protection.

Solid-State Reduced Voltage

A technique for reduction of line voltage for motor starting by use of a semiconductor device, normally a thyristor (SCR).

Special Purpose Motor

A motor with special operating characteristics, special mechanical construction or both, designed for a particular application and not falling within the definition of a general purpose of definite purpose motor (NEMA).

SSRV

Sold-state reduced voltage.

Starting Torque

The torque exerted by the motor during the starting period (a function of speed or slip).

Stator

The stationary portion of the magnetic circuit and the associated windings and leads of a rotating machine.

Surge

A transient wave of current, voltage or power in an electric circuit. **Note:** A transient has a high rate of change of current or voltage in the system.

Surge Protection

The process of absorbing and clipping voltage transients on an incoming AC line or control circuit. MOVs (Metal Oxide Varistors) and specially designed RC (resistor-capacitor) networks are usually used to accomplish this.

Switch

A switch is a device for opening and closing, or for changing the connections of a circuit. **Note:** A switch is understood to be manually operated, unless otherwise stated.

Synchronous Speed

The speed of an AC induction motor's rotating magnetic field. It is determined by the frequency applied to the stator and the number of magnetic poles present in each phase of the stator windings. Mathematically, it is expressed as: Sync Speed (RPM) = 120 x Applied Frequency (Hz)/Number of Poles per Phase.

System Efficiency

System efficiency is the ratio of the mechanical power supplied to load to the total input power under specified operating conditions. The input power includes requirements for auxiliary functions, such as phase control, switching equipment, overload protection and fans.

Thermal Overload Relay

A thermal overload relay functions (trips) by means of a thermal response to current.

Thermal Protector (Rotating Machinery)

A protective device assembled as an integral part of a machine that protects the machine against overheating due to an overload condition.

Notes:

1. It may consist of one or more temperature sensing elements integral with the machine and a control device external to the machine;

2. When a thermal protector is designed to perform its function by opening the circuit to the machine and then automatically closing the circuit after the machine cools to a satisfactory operating temperature, it is an automatic reset thermal protector;

3. When a thermal protector is designed to perform its function by opening the circuit to the machine but must be reset manually to close the circuit, it is a manual reset thermal protector.

Thyristor

A three junction semiconductor device that can be switched from the OFF-state to the ON-state by a logic signal. Also known as a silicon controlled rectifier.

Time Delay

Time delay means that a time interval is purposely introduced in the performance of a function.

Torque

A turning force applied to a shaft, tending to cause rotation. Torque is normally measured in pound feet and is equal to the force applied, times the radius through which it acts.

Totally Enclosed Machine (Motor)

A totally enclosed machine is one so enclosed as to prevent the free exchange of air between the inside and the outside of the case, but not sufficiently enclosed to be termed airtight.

1. Totally Enclosed Fan-Cooled is a totally enclosed machine equipped for exterior cooling by means of a fan or fans integral with the machine, but external to the enclosing parts.

2. Explosion Proof is a totally enclosed machine whose enclosure is designed and constructed to withstand an explosion of a specified gas or vapor which may occur within it, and to prevent the ignition of the specified gas or vapor surrounding the machine by sparks, flashes or explosions of the specified gas or vapor, which may occur within the machine casing.

3. Dust-Ignition-Proof is a totally enclosed machine whose enclosure is designed and constructed in a manner which will exclude ignitable amounts of dust or amounts that might affect performance or rating, and will not permit arcs, sparks or heat, otherwise generated or liberated inside of the enclosure, to cause ignition of exterior accumulations or atmospheric suspensions of a specific dust on, or in, the vicinity of the enclosure.

4. Waterproof is a totally enclosed machine constructed so that it will keep out water sprayed onto it. Leakage may occurred around the shaft, but will be prevented from entering the oil reservoir. Provision is made for automatically draining the machine. The means for automatic draining may be a check valve or a tapped hole at the lowest part of the frame which will serve for application of a drain pipe.

5. Totally Enclosed Water Cooled is a totally enclosed machine which is cooled by circulating water, the water or water conductors coming in direct contact with the machine parts.

6. Totally Enclosed Water-Air Cooled is a totally enclosed machine which is cooled by circulating air which, in turn, is cooled by circulating water. It is provided with a water cooled heat exchanger for cooling the internal air and a fan, or fans integral with the rotor shaft or separate, for circulating the internal air.

7. Totally Enclosed Air to Air Cooled is a totally enclosed machine which is cooled by circulating the internal air through a heat exchanger which, in turn, is cooled by circulating external air. It is provided with an air to air heat exchanger for cooling the internal air, a fan or fans integral with the rotor shaft, or separate for circulating the internal air and a separate fan for circulating the external air.

8. Totally Enclosed Fan Cooled Guarded is a totally enclosed fan cooled machine, in which all openings giving direct access to the fan are limited in size by the design of the structural parts of by screens, grilles, expanded metal, etc., to prevent accidental contact the with the fan. Such openings shall not permit the passage of a cylindrical rod, 0.75 inch in diameter, and a probe shall not contact the blades, spokes or other irregular surfaces of the fan.

9. Totally Enclosed Air-Over is a totally enclosed machine intended for exterior cooling by a ventilating means external to the machine.

Transient

A momentary deviation in an electrical or mechanical system.

Trigger Circuit

The circuit used to gate a thyristor that causes it to conduct current.

Undervoltage Protection

Undervoltage or low voltage protection is the effect of a device, operative on the reduction or failure of voltage, to cause and maintain the interruption of power to the main circuit. The main objective of the device is to prevent restarting of the equipment on an undervoltage condition.

Ventilated Enclosure

A ventilated enclosure is provided with means to permit circulation of sufficient air to remove an excess of heat, fumes, or vapors.

Voltage Relay

A voltage relay operates at a predetermined value of voltage. It may be an overvoltage relay, an undervoltage relay, or a combination of both.

Wiring (or Connection) Diagram

A wiring, or connection diagram is one which locates, and identifies electrical devices, terminals and interconnecting wiring in an assembly.

Work

A force moving an object over a distance. Measured in foot pounds (ft-lbs).

Work = Force x Distance.