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Introduction

Welcome to another course in the STEP 2000 series, **S**iemens **T**echnical **E**ducation **P**rogram, designed to prepare our distributors to sell Siemens Energy & Automation products more effectively. This course covers **Basics of AC Drives** and related products.

Upon completion of **Basics of AC Drives** you should be able to:

- Explain the concept of force, inertia, speed, and torque
- Explain the difference between work and power
- Describe the construction of a squirrel cage AC motor
- Identify the nameplate information of an AC motor necessary for application to an AC Drive
- Describe the operation of a three-phase rotating magnetic field
- Calculate synchronous speed, slip, and rotor speed
- Describe the relationship between V/Hz, torque, and current
- Describe the basic construction and operation of a PWM type AC drive
- Describe features and operation of the Siemens MICROMASTER and MASTERDRIVE VC
- Describe the characteristics of constant torque, constant horsepower, and variable torque applications

This knowledge will help you better understand customer applications. In addition, you will be able to describe products to customers and determine important differences between products. You should complete **Basics of Electricity** before attempting **Basics of AC Drives**. An understanding of many of the concepts covered in **Basics of Electricity** is required for **Basics of AC Drives**.

If you are an employee of a Siemens Energy & Automation authorized distributor, fill out the final exam tear-out card and mail in the card. We will mail you a certificate of completion if you score a passing grade. Good luck with your efforts.

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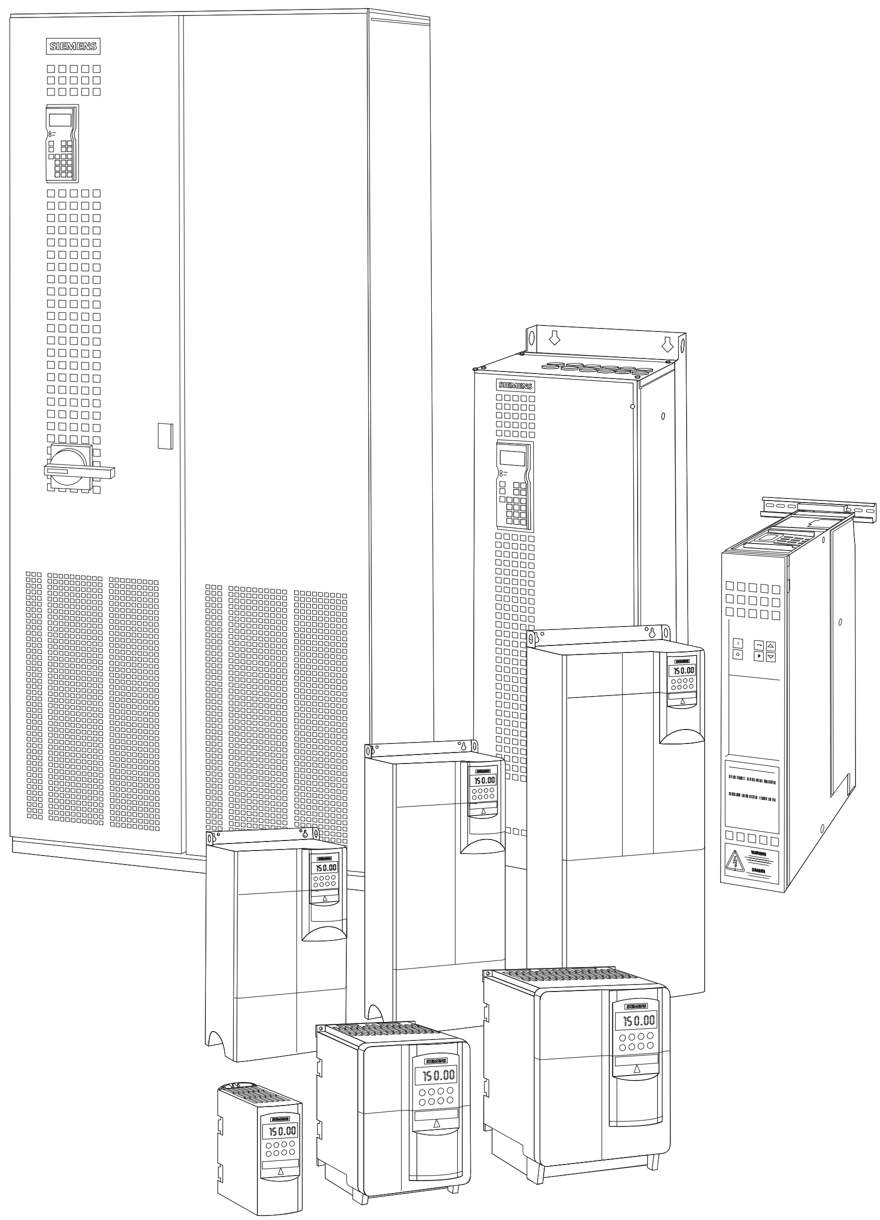
National Electrical Manufacturers Association is located at 2101 L. Street, N.W., Washington, D.C. 20037. The abbreviation "NEMA" is understood to mean National Electrical Manufacturers Association.

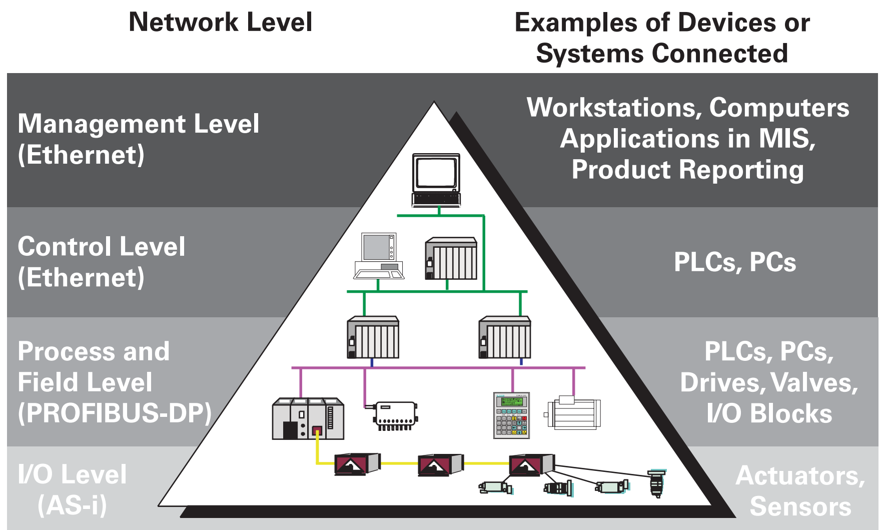
Siemens AC Drives and Totally Integrated Automation

This course focuses on several Siemens AC drives, which include the MICROMASTER and MASTERDRIVE VC, which are important elements of the TIA strategy.



Totally Integrated Automation

Totally Integrated Automation (TIA) is more than a concept. TIA is a strategy developed by Siemens that emphasizes the seamless integration of automation products. The TIA strategy incorporates a wide variety of automation products such as programmable controllers, computer numerical controls, Human Machine Interfaces (HMI), and drives which are easily connected via open protocol networks.

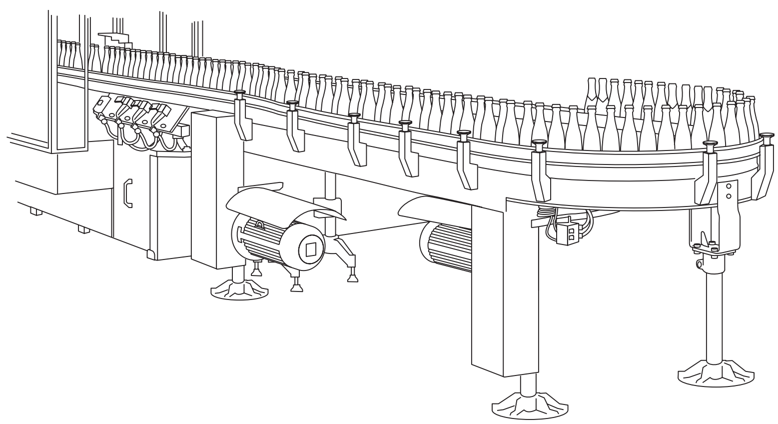


PROFIBUS DP

An important aspect of TIA is the ability of devices to communicate with each other over various network protocols, such as Ethernet and PROFIBUS DP. PROFIBUS DP is an open bus standard for a wide range of applications in various manufacturing and automation applications. Siemens AC drives can easily communicate with other control devices such as programmable logic controllers (PLCs) and personal computers (PCs) through the PROFIBUS-DP communication system and other various protocols.

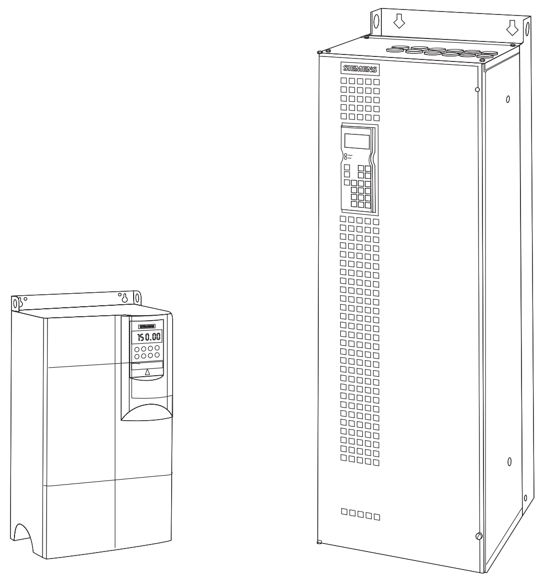
Mechanical Basics

In many commercial, industrial, and utility applications electric motors are used to transform electrical energy into mechanical energy. Those electric motors may be part of a pump or fan, or they may be connected to some other form of mechanical equipment such as a conveyor or mixer. In many of these applications the speed of the system is determined primarily by its mechanical design and loading. For an increasing number of these applications, however, it is necessary to control the speed of the system by controlling the speed of the motor.



Variable Speed Drives

The speed of a motor can be controlled by using some type of electronic drive equipment, referred to as variable or adjustable speed drives. Variable speed drives used to control DC motors are called DC drives. Variable speed drives used to control AC motors are called AC drives. The term inverter is also used to describe an AC variable speed drive. The inverter is only one part of an AC drive, however, it is common practice to refer to an AC drive as an inverter.



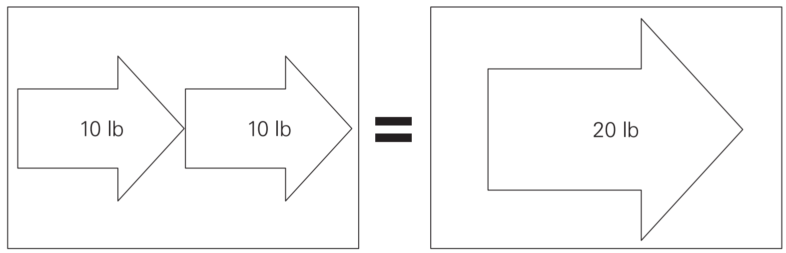
Before discussing AC drives it is necessary to understand some of the basic terminology associated with drive operation. Many of these terms are familiar to us in some other context. Later in the course we will see how these terms apply to AC drives.

Force

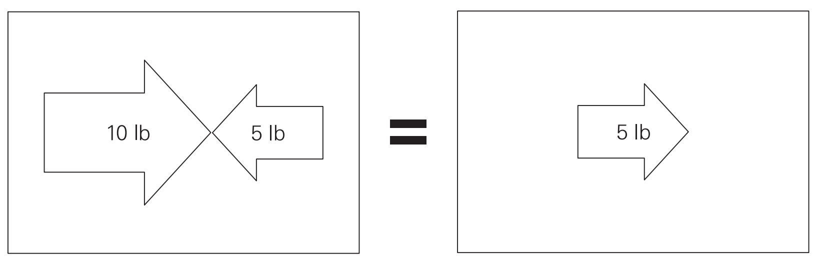
In simple terms, a force is a push or a pull. Force may be caused by electromagnetism, gravity, or a combination of physical means.

Net Force

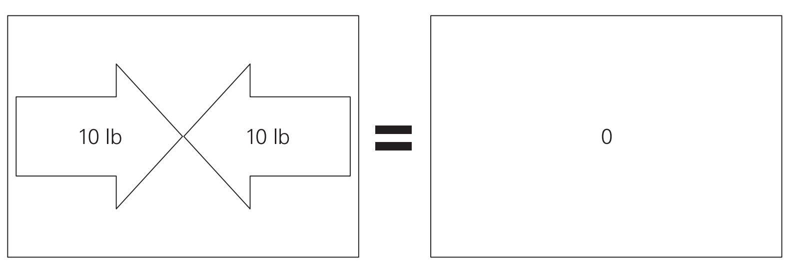
Net force is the vector sum of all forces that act on an object, including friction and gravity. When forces are applied in the same direction they are added. For example, if two 10 lb forces were applied in the same direction the net force would be 20 lb.



If 10 lb of force were applied in one direction and 5 lb of force applied in the opposite direction, the net force would be 5 lb and the object would move in the direction of the greater force.



If 10 lb of force were applied equally in both directions, the net force would be zero and the object would not move.



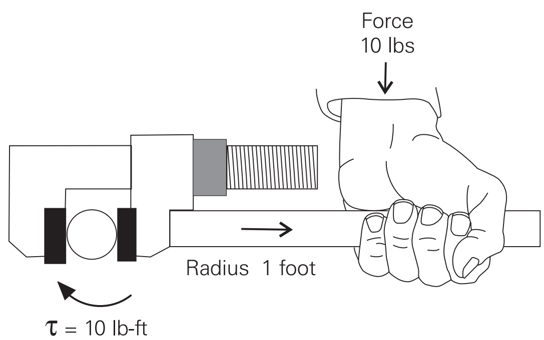
Torque

Torque is a twisting or turning force that tends to cause an object to rotate. A force applied to the end of a lever, for example, causes a turning effect or torque at the pivot point.

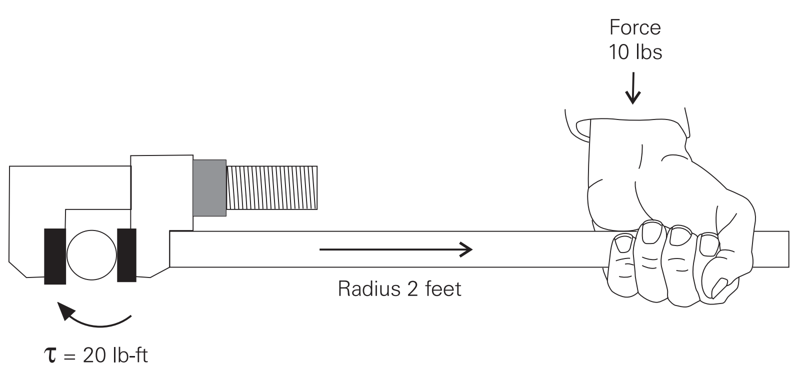
Torque (τ) is the product of force and radius (lever distance).

Torque (τ) = Force x Radius

In the English system torque is measured in pound-feet (lb-ft) or pound-inches (lb-in). If 10 lbs of force were applied to a lever 1 foot long, for example, there would be 10 lb-ft of torque.



An increase in force or radius would result in a corresponding increase in torque. Increasing the radius to 2 feet, for example, results in 20 lb-ft of torque.



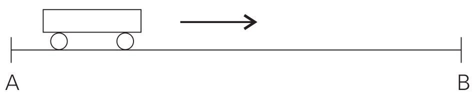
Speed

An object in motion travels a given distance in a given time. Speed is the ratio of the distance traveled to the time it takes to travel the distance.

$$\text{Speed} = \frac{\text{Distance}}{\text{Time}}$$

Linear Speed

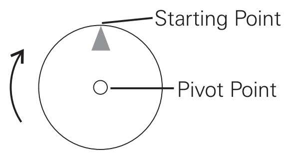
The linear speed of an object is a measure of how long it takes the object to get from point A to point B. Linear speed is usually given in a form such as meters per second (m/s). For example, if the distance between point A and point B were 10 meters, and it took 2 seconds to travel the distance, the speed would be 5 m/s.



Linear Motion

Angular (Rotational) Speed

The angular speed of a rotating object is a measurement of how long it takes a given point on the object to make one complete revolution from its starting point. Angular speed is generally given in revolutions per minute (RPM). An object that makes ten complete revolutions in one minute, for example, has a speed of 10 RPM.



Rotational Motion

Acceleration

An object can change speed. An increase in speed is called acceleration. Acceleration occurs only when there is a change in the force acting upon the object. An object can also change from a higher to a lower speed. This is known as deceleration (negative acceleration). A rotating object, for example, can accelerate from 10 RPM to 20 RPM, or decelerate from 20 RPM to 10 RPM.

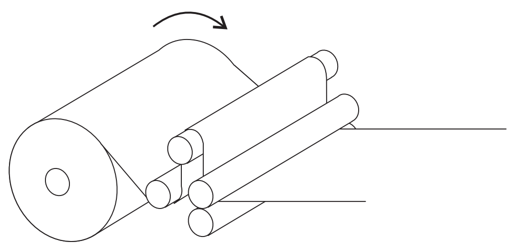
Acceleration

Deceleration

Law of Inertia

Mechanical systems are subject to the law of inertia. The law of inertia states that an object will tend to remain in its current state of rest or motion unless acted upon by an external force. This property of resistance to acceleration/deceleration is referred to as the moment of inertia. The English system of measurement is pound-feet squared (lb-ft^2).

If we look at a continuous roll of paper, as it unwinds, we know that when the roll is stopped, it would take a certain amount of force to overcome the inertia of the roll to get it rolling. The force required to overcome this inertia can come from a source of energy such as a motor. Once rolling, the paper will continue unwinding until another force acts on it to bring it to a stop.



Friction

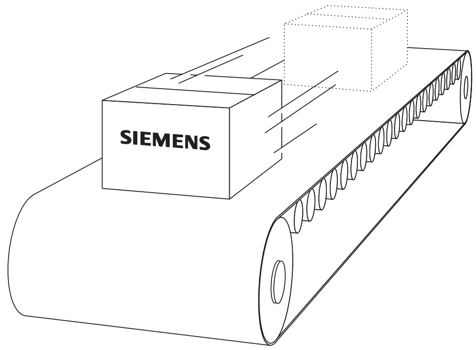
A large amount of force is applied to overcome the inertia of the system at rest to start it moving. Because friction removes energy from a mechanical system, a continual force must be applied to keep an object in motion. The law of inertia is still valid, however, since the force applied is needed only to compensate for the energy lost.

Once the system is in motion, only the energy required to compensate for various losses need be applied to keep it in motion. In the previous illustration, for example: these losses include:

- Friction within motor and driven equipment bearings
- Windage losses in the motor and driven equipment
- Friction between material on winder and rollers

Work

Whenever a force of any kind causes motion, work is accomplished. For example, work is accomplished when an object on a conveyor is moved from one point to another.



Work is defined by the product of the net force (F) applied and the distance (d) moved. If twice the force is applied, twice the work is done. If an object moves twice the distance, twice the work is done.

$$W = F \times d$$

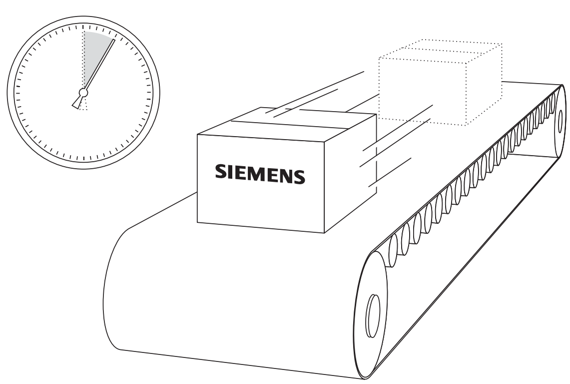
Power

Power is the rate of doing work, or work divided by time.

$$\text{Power} = \frac{\text{Force x Distance}}{\text{Time}}$$

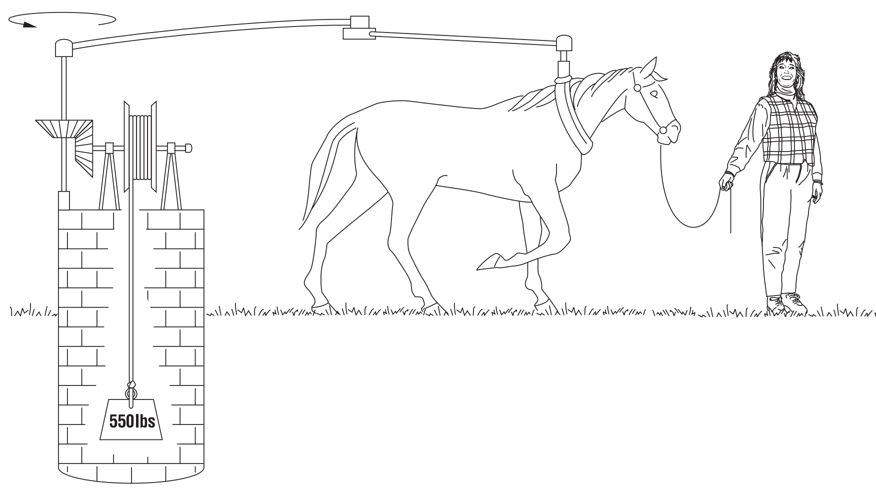
$$\text{Power} = \frac{\text{Work}}{\text{Time}}$$

In other words, power is the amount of work it takes to move the package from one point to another point, divided by the time.



Horsepower

Power can be expressed in foot-pounds per second, but is often expressed in horsepower (HP). This unit was defined in the 18th century by James Watt. Watt sold steam engines and was asked how many horses one steam engine would replace. He had horses walk around a wheel that would lift a weight. He found that each horse would average about 550 foot-pounds of work per second. One horsepower is equivalent to 500 foot-pounds per second or 33,000 foot-pounds per minute.



The following formula can be used to calculate horsepower when torque (lb-ft) and speed (RPM) are known. It can be seen from the formula that an increase of torque, speed, or both will cause a corresponding increase in horsepower.

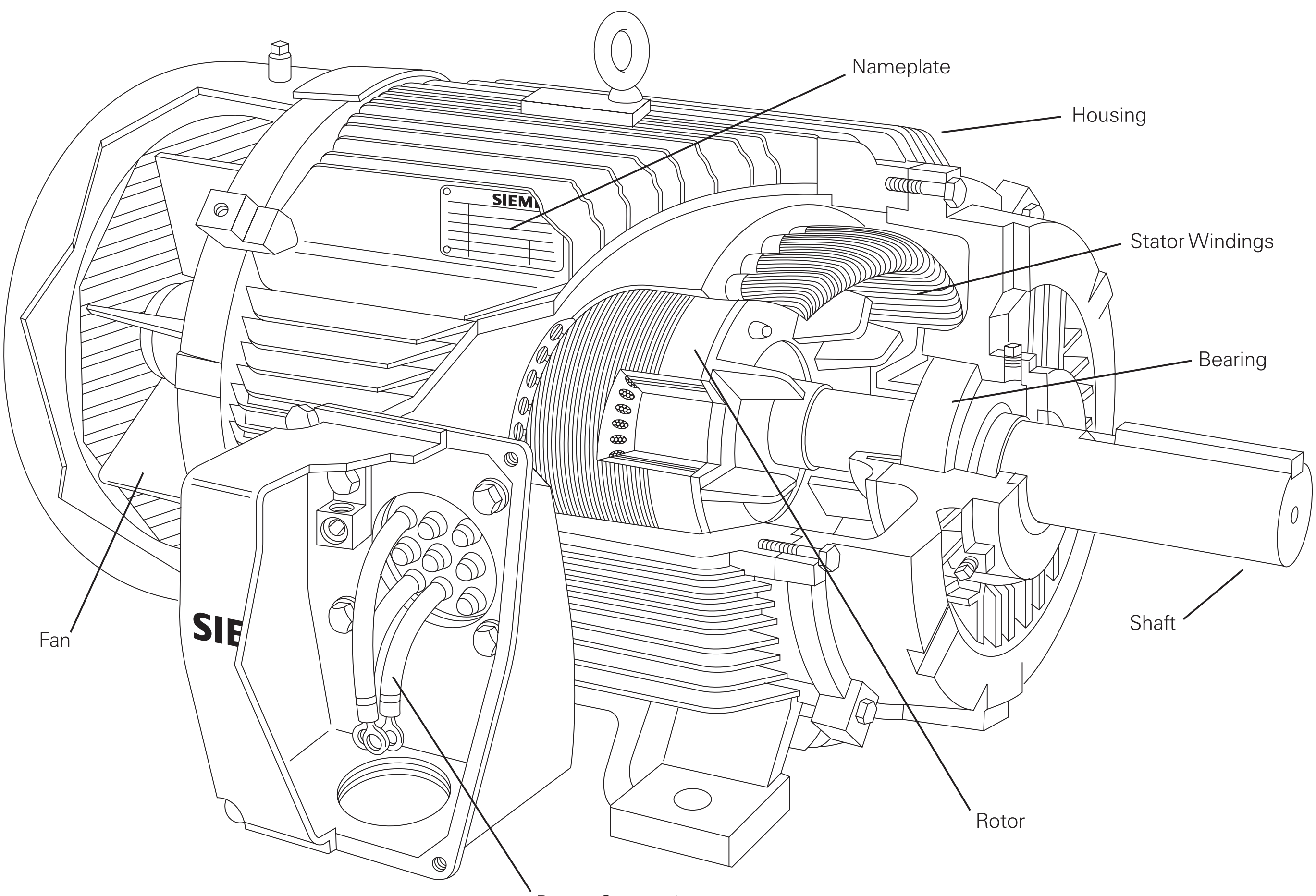
$$HP = \frac{T \times RPM}{5250}$$

Review 1

1. A ____________ is a push or a pull.
2. An object has 20 pounds of force applied in one direction and 5 pounds of force applied in the opposite direction. The net force is ____________ pounds.
3. A twisting or turning force that causes an object to rotate is known as ____________ .
4. If 40 pounds of force were applied to a lever 2 feet long, the torque would be ____________ lb-ft.
5. The law of ____________ states that an object will tend to remain in its current state of rest or motion unless acted upon by an external force.
6. ____________ is the ratio of distance traveled and time.
7. The speed of a rotating object is generally given in ____________ per ____________ .

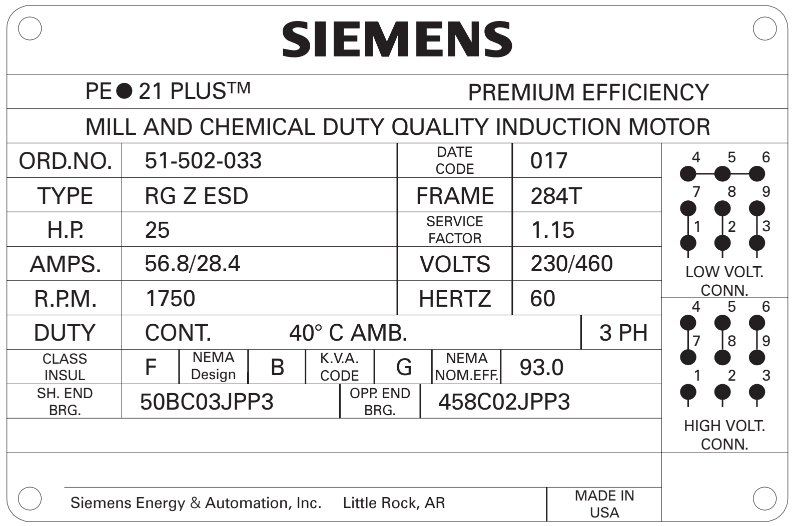
AC Motor Construction

AC induction motors are commonly used in industrial applications. The following motor discussion will center around three-phase, 460 VAC, asynchronous, induction motors. An asynchronous motor is a type of motor where the speed of the rotor is other than the speed of the rotating magnetic field. This type of motor is illustrated. Electromagnetic stator windings are mounted in a housing. Power connections, attached to the stator windings, are brought out to be attached to a three-phase power supply. On three-phase, dual-voltage motors nine leads are supplied for power connections. Three power connection leads are shown in the following illustration for simplicity. A rotor is mounted on a shaft and supported by bearings. On self-cooled motors, like the one shown, a fan is mounted on the shaft to force cooling air over the motor.



Nameplate

The nameplate of a motor provides important information necessary when applying a motor to an AC drive. The following drawing illustrates the nameplate of a sample 25 horsepower AC motor.



Connections

This motor can be used on 230 VAC or 460 VAC systems. A wiring diagram indicates the proper connection for the input power leads. The low voltage connection is intended for use on 230 VAC with a maximum full load current of 56.8 Amps. The high voltage connection is intended for use on 460 VAC with a maximum full load current of 28.4 Amps.

Base Speed

Base speed is the nameplate speed, given in RPM, where the motor develops rated horsepower at rated voltage and frequency. It is an indication of how fast the output shaft will turn the connected equipment when fully loaded and proper voltage is applied at 60 hertz. The base speed of this motor is 1750 RPM at 60 Hz. If the connected equipment is operating at less than full load, the output speed will be slightly greater than base speed.

It should be noted that with European and Asian motors and many special motors, such as those used in the textile industry, base speed, frequency and voltage may be different than standard American motors. This is not a problem, however, because the voltage and frequency supplied to a variable speed drive does not have to be the same as the motor. The supply voltage to a variable speed drive has nothing to do with motor voltage, speed or frequency. A variable speed drive can be set up to work with any motor within a reasonable size range and rating.

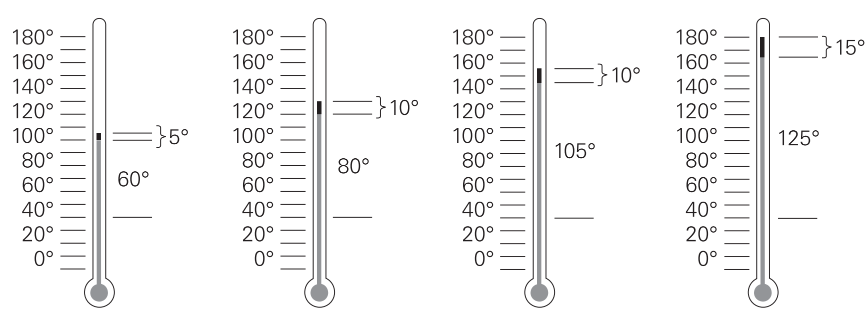
Service Factor

A motor designed to operate at its nameplate horsepower rating has a service factor of 1.0. Some applications may require a motor to exceed the rated horsepower. In these cases a motor with a service factor of 1.15 can be specified. The service factor is a multiplier that may be applied to the rated power. A 1.15 service factor motor can be operated 15% higher than the motor's nameplate horsepower. Motors with a service factor of 1.15 are recommended for use with AC drives. It is important to note, however, that even though a motor has a service factor of 1.15 the values for current and horsepower at the 1.0 service factor are used to program a variable speed drive.

Insulation Class

The National Electrical Manufacturers Association (NEMA) has established insulation classes to meet motor temperature requirements found in different operating environments. The four insulation classes are A, B, F, and H. Class F is commonly used. Class A is seldom used. Before a motor is started, its windings are at the temperature of the surrounding air. This is known as ambient temperature. NEMA has standardized on an ambient temperature of 40° C, or 104° F for all motor classes.

Temperature rises in the motor as soon as it is started. The combination of ambient temperature and allowed temperature rise equals the maximum winding temperature in a motor. A motor with Class F insulation, for example, has a maximum temperature rise of 105° C. The maximum winding temperature is 145° C (40° ambient plus 105° rise). A margin is allowed for a point at the center of the motor's windings where temperature is higher. This is referred to as the motor's hot spot.



Class A
60° C Rise
5° C Hot Spot

Class B
80° C Rise
10° C Hot Spot

Class F
105° C Rise
10° C Hot Spot

Class H
125° C Rise
15° C Hot Spot

The operating temperature of a motor is important to efficient operation and long life. Operating a motor above the limits of the insulation class reduces the motor's life expectancy. A 10° C increase in the operating temperature can decrease the life expectancy of a motor as much as 50%.

NEMA Design

The National Electrical Manufacturers Association (NEMA) has established standards for motor construction and performance. The nameplate on page 20 is for a motor designed to NEMA B specifications. NEMA B motors are commonly used with AC drives. Any NEMA design (A, B, C, or D) AC motor will work perfectly well with a properly sized variable speed drive.

Efficiency

AC motor efficiency is expressed as a percentage. It is an indication of how much input electrical energy is converted to output mechanical energy. The nominal efficiency of this motor is 93.0%.

Converting KW to HP

Motor manufacturers may also use kilowatts (KW) instead of horsepower.

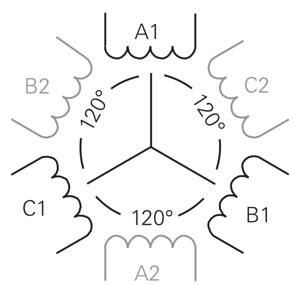
To convert KW to HP use the following equation:

$$HP = 1.341 \times KW$$

$$HP = 24$$

Developing A Rotating Magnetic Field

A rotating magnetic field must be developed in the stator of an AC motor in order to produce mechanical rotation of the rotor. Wire is coiled into loops and placed in slots in the motor housing. These loops of wire are referred to as the stator windings. The following drawing illustrates a three-phase stator. Phase windings (A, B, and C) are placed 120° apart. In this example, a second set of three-phase windings is installed. The number of poles is determined by how many times a phase winding appears. In this example, each phase winding appears two times. This is a two-pole stator. If each phase winding appeared four times it would be a four-pole stator.



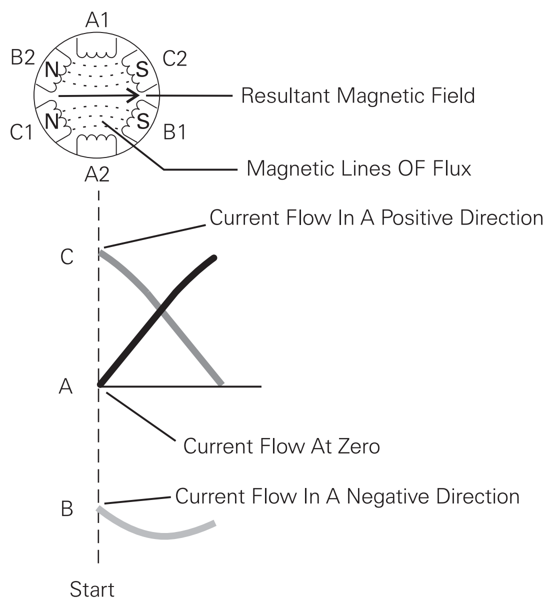
2-Pole Stator Winding

Magnetic Field

When AC voltage is applied to the stator, current flows through the windings. The magnetic field developed in a phase winding depends on the direction of current flow through that winding. The following chart is used here for explanation only. It assumes that a positive current flow in the A1, B1 and C1 windings result in a north pole.

Winding	Current Flow Direction	
	Positive	Negative
A1	North	South
A2	South	North
B1	North	South
B2	South	North
C1	North	South
C2	South	North

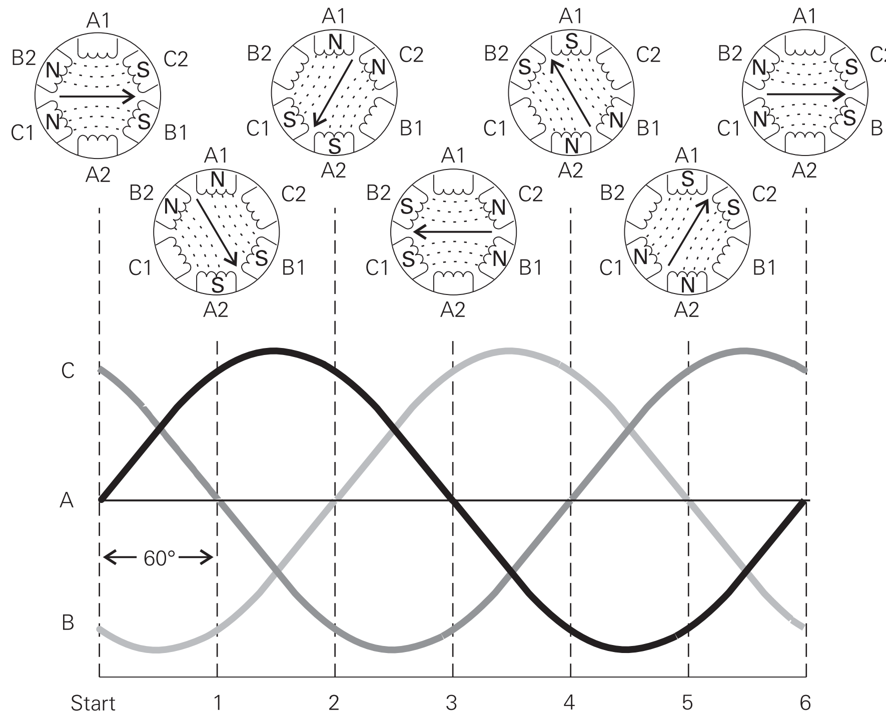
It is easier to visualize a magnetic field if a time is picked when no current is flowing through one phase. In the following illustration, for example, a time has been selected during which phase A has no current flow, phase B has current flow in a negative direction and phase C has current flow in a positive direction. Based on the above chart, B1 and C2 are south poles and B2 and C1 are north poles. Magnetic lines of flux leave the B2 north pole and enter the nearest south pole, C2. Magnetic lines of flux also leave the C1 north pole and enter the nearest south pole, B1. A magnetic field results indicated by the arrow.



The amount of flux lines (Φ) the magnetic field produces is proportional to the voltage (E) divided by the frequency (F). Increasing the supply voltage increases the flux of the magnetic field. Decreasing the frequency increases the flux.

$$\Phi \approx \frac{E}{F}$$

If the field is evaluated in 60° intervals from the starting point, it can be seen that at point 1 the field has rotated 60°. Phase C has no current flow, phase A has current flow in a positive direction and phase B has current flow in a negative direction. Following the same logic as used for the starting point, windings A1 and B2 are north poles and windings A2 and B1 are south poles. At the end of six such intervals the magnetic field will have rotated one full revolution or 360°.



Synchronous Speed

The speed of the rotating magnetic field is referred to as synchronous speed (NS). Synchronous speed is equal to 120 times the frequency (F), divided by the number of poles (P).

$$NS = \frac{120F}{P}$$

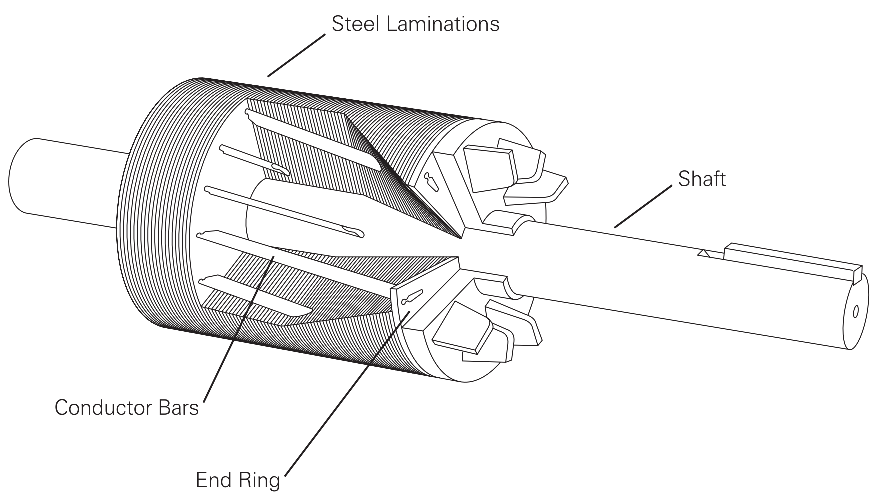
If the applied frequency of the two-pole stator used in the previous example is 60 hertz, synchronous speed is 3600 RPM.

$$NS = \frac{120 \times 60}{2}$$

$$NS = 3600 \text{ RPM}$$

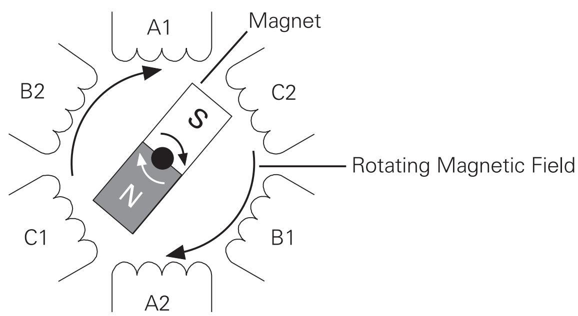
Rotor Construction

The most common type of rotor is the “squirrel cage” rotor. The construction of the squirrel cage rotor is reminiscent of rotating exercise wheels found in cages of pet rodents. The rotor consists of a stack of steel laminations with evenly spaced conductor bars around the circumference. The conductor bars are mechanically and electrically connected with end rings. A slight skewing of the bars helps to reduce audible hum. The rotor and shaft are an integral part.



Rotating Magnet

There is no direct electrical connection between the stator and the rotor or the power supply and the rotor of an induction motor. To see how a rotor works, a magnet mounted on the shaft can be substituted for the squirrel cage rotor. When the stator windings are energized a rotating magnetic field is established. The magnet has its own magnetic field that interacts with the rotating magnetic field of the stator. The north pole of the rotating magnetic field attracts the south pole of the magnet and the south pole of the rotating magnetic field attracts the north pole of the magnet. As the rotating magnetic field rotates, it pulls the magnet along causing it to rotate. This type of design is used on some motors and is referred to as a permanent magnet synchronous motor.

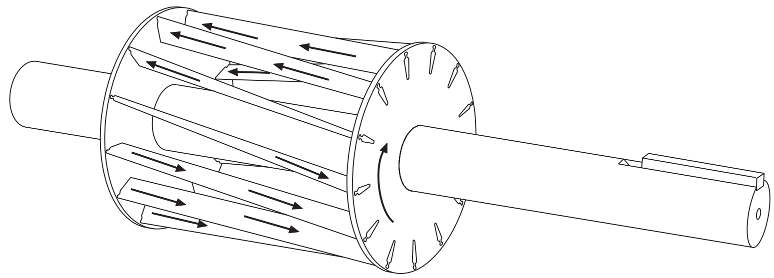


Rotation of a Squirrel Cage Rotor

The squirrel cage rotor of an AC motor acts essentially the same as the magnet. When a conductor, such as the conductor bars of the rotor, passes through a magnetic field a voltage (emf) is induced in the conductor. The induced voltage causes current flow in the conductor. The amount of induced voltage (E) depends on the amount of flux (Φ) and the speed (N) at which the conductor cuts through the lines of flux. The more lines of flux, or the faster they are cut, the more voltage is induced. Certain motor constants (k), determined by construction also affect induced voltage. These constants, such as rotor bar shape and construction, do not change with speed or load.

$$E = k\Phi N$$

Current flows through the rotor bars and around the end ring. The current flow in the conductor bars produces magnetic fields around each rotor bar. The squirrel cage rotor becomes an electromagnet with alternating north and south poles. The magnetic fields of the rotor interact with the magnetic fields of the stator. It must be remembered that the current and magnetic fields of the stator and rotor are constantly changing. As the stator magnetic field rotates, the rotor and shaft follow.



Slip

There must be a relative difference in speed between the rotor and the rotating magnetic field. The difference in speed of the rotating magnetic field, expressed in RPM, and the rotor, expressed in RPM, is known as slip.

Slip is necessary to produce torque. If the rotor and the rotating magnetic field were turning at the same speed no relative motion would exist between the two, therefore no lines of flux would be cut, and no voltage would be induced in the rotor. Slip is dependent on load. An increase in load will cause the rotor to slow down or increase slip. A decrease in load will cause the rotor to speed up or decrease slip. Slip is expressed as a percentage.

$$\% \text{ Slip} = \frac{NS - NR}{NS} \times 100$$

For example, a four-pole motor operated at 60 Hz has a synchronous speed of 1800 RPM. If the rotor speed at full load were 1750 RPM, the slip is 2.8%.

$$\% \text{ Slip} = \frac{1800 - 1750}{1800} \times 100$$

$$\% \text{ Slip} = 2.8\%$$

Review 2

1. Given an AC motor with the following: a nameplate amps of 10/5, and volts of 230/460, the full load amps at 460 volts is ____________ amps.

2. A motor which is permitted to exceed the rated horsepower by 15% has a service factor of ____________.

3. A motor with a rating of 37 KW would have an equivalent horsepower rating of ____________ HP.

4. Stator windings in a three-phase, two-pole motor are placed ____________ degrees apart.

5. The synchronous speed of a four-pole stator with 60 Hertz applied is ____________ RPM.

   The synchronous speed of a four-pole stator with 50 Hertz applied is ____________ RPM.

6. ____________ is the relative difference in speed between the rotor and the rotating magnetic field.

NEMA Rotor Characteristics

The National Electrical Manufacturers Association (NEMA) classifies motors according to locked rotor torque and current, pull up torque, breakdown torque and percent slip. In addition, full-load torque and current must be considered when evaluating an application.

Most NEMA terms and concepts apply to motors operated from 60 Hz power lines, not variable speed drive operation. In following sections we will see how an AC variable speed drive can improve the starting and operation of an AC motor.

Locked Rotor Torque

Locked rotor torque, also referred to as starting torque, is developed when the rotor is held at rest with rated voltage and frequency applied. This condition occurs each time a motor is started. When rated voltage and frequency are applied to the stator there is a brief amount of time before the rotor turns.

Locked Rotor Current

Locked rotor current is also referred to as starting current. This is the current taken from the supply line at rated voltage and frequency with the rotor at rest.

Pull Up Torque

Pull up torque is the torque developed during acceleration from start to the point breakdown torque occurs.

Breakdown Torque

Breakdown torque is the maximum torque a motor develops at rated voltage and speed without an abrupt loss of speed.

Full-Load Torque

Full-load torque is the torque developed when the motor is operating with rated voltage, frequency and load.

Full-Load Current

Full-load current is the current taken from the supply line at rated voltage, frequency and load.

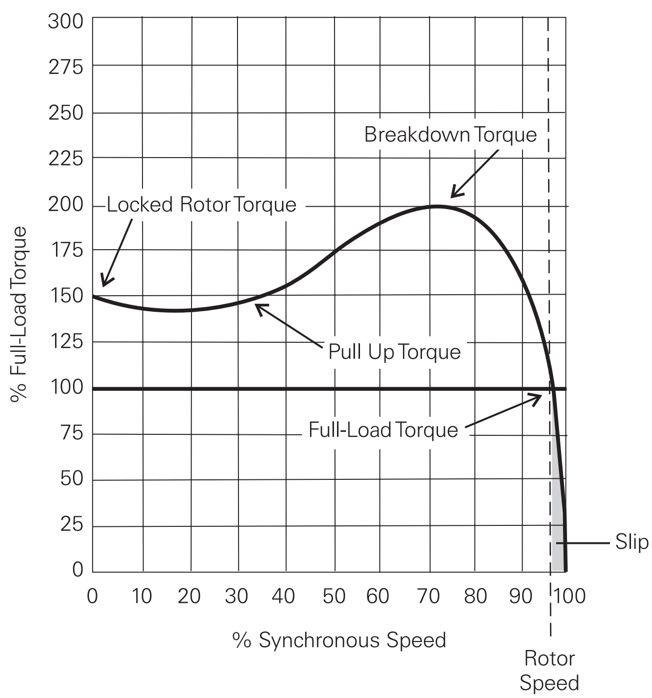
NEMA Classifications

Three-phase AC motors are classified by NEMA as NEMA A, B, C and D. NEMA specifies certain operating characteristics for motors when started by applying rated voltage and frequency (across the line starting). A NEMA B motor, for example, typically requires 600% starting current and 150% starting torque. These considerations do not apply to motors started with an AC drive. NEMA B design motors are the most common and most suitable for use on AC drives.

NEMA B Speed and Torque

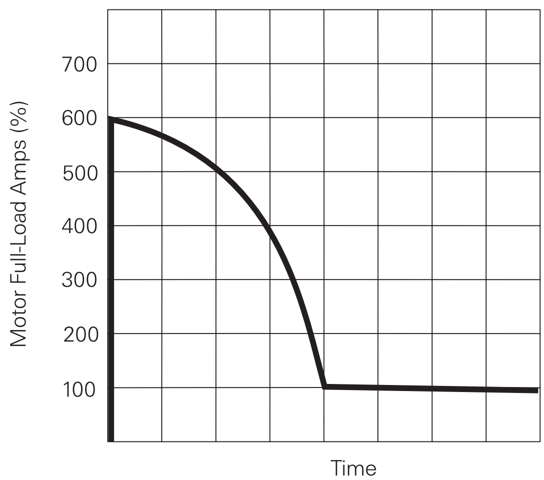
A graph similar to the one illustrated below is used to show the relationship between motor speed and torque of a NEMA B motor. When rated voltage and frequency are applied to the motor, synchronous speed goes to 100% immediately. The rotor must perform a certain amount of work to overcome the mechanical inertia of itself and the connected load.

Typically a NEMA B motor will develop 150% torque to start the rotor and load. As the rotor accelerates the relative difference in speed between synchronous speed and rotor speed decreases until the rotor reaches its operating speed. The operating speed of a NEMA B motor with rated voltage, frequency and load is approximately 97% (3% slip) of synchronous speed. The amount of slip and torque is a function of load. With an increase in load there is a corresponding increase in slip and torque. With a decrease in load there is a corresponding decrease in slip and torque.



Starting Current

When a motor is started, it must perform work to overcome the inertia of the rotor and attached load. The starting current measured on the incoming line (I_S) is typically 600% of full-load current when rated voltage and frequency is first applied to a NEMA B motor. Stator current decreases to its rated value as the rotor comes up to speed. The following graph applies to "across the line" operation, not variable speed drive operation.

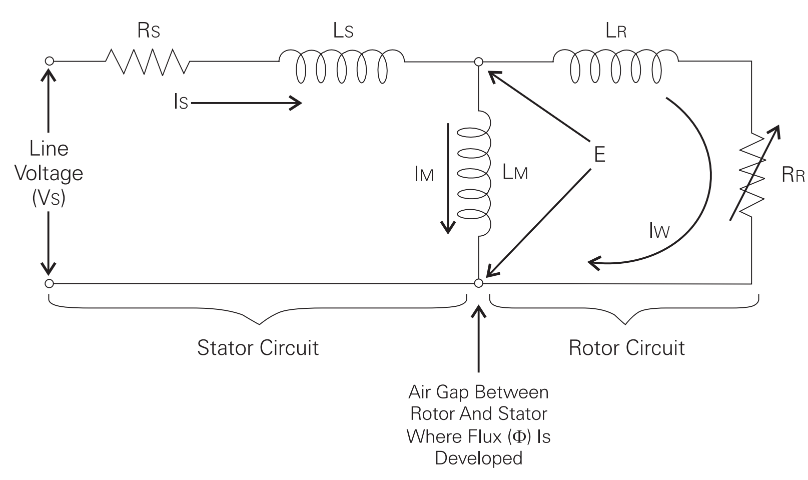


Electrical Components Of A Motor

Up to this point we have examined the operation of an AC motor with rated voltage and frequency applied. Many applications require the speed of an AC motor to vary, which is easily accomplished with an AC drive. However, operating a motor at other than rated voltage and frequency has an effect on motor current and torque. In order to understand how a motor's characteristics can change we need a better understanding of both AC motors and AC drives.

The following diagram represents a simplified equivalent circuit of an AC motor. An understanding of this diagram is important in the understanding of how an AC motor is applied to an AC drive.

V_S	Line voltage applied to stator power leads
R_S	Stator resistance
L_S	Stator leakage inductance
I_S	Stator current
E	Air gap or magnetizing voltage
L_M	Magnetizing inductance
I_M	Magnetizing current
R_R	Rotor resistance (varies with temperature)
L_R	Rotor leakage inductance
I_W	Working or torque producing current



Line Voltage

Voltage (V_S) is applied to the stator power leads from the AC power supply. Voltage drops occur due to stator resistance (R_S). The resultant voltage (E) represents force (cemf) available to produce magnetizing flux and torque.

Magnetizing Current

Magnetizing current (I_M) is responsible for producing magnetic lines of flux which magnetically link with the rotor circuit. Magnetizing current is typically about 30% of rated current. Magnetizing current, like flux (Φ), is proportional to voltage (E) and frequency (F).

$$I_M = \frac{E}{2\pi F L_M}$$

Working Current

The current that flows in the rotor circuit and produces torque is referred to as working current (I_W). Working current is a function of the load. An increase in load causes the rotor circuit to work harder increasing working current (I_W). A decrease in load decreases the work the rotor circuit does decreasing working current (I_W).

Stator Current

Stator current (I_S) is the current that flows in the stator circuit. Stator current can be measured on the supply line and is also referred to as line current. A clamp-on ammeter, for example, is frequently used to measure stator current. The full-load ampere rating on the nameplate of a motor refers to stator current at rated voltage, frequency and load. It is the maximum current the motor can carry without damage. Stator current is the vector sum of working current (I_W) and magnetizing current (I_M). Typically magnetizing current (I_M) remains constant. Working current (I_W) will vary with the applied load which causes a corresponding change in stator current (I_S).

$$I_S = \sqrt{I_M^2 + I_W^2}$$

Voltage And Frequency

Volts per Hertz

A ratio exists between voltage and frequency. This ratio is referred to as volts per hertz (V/Hz). A typical AC motor manufactured for use in the United States is rated for 460 VAC and 60 Hz. The ratio is 7.67 volts per hertz. Not every motor has a 7.67 V/Hz ratio. A 230 Volt, 60 Hz motor, for example, has a 3.8 V/Hz ratio.

$$\frac{460}{60} = 7.67 \text{ V/Hz} \qquad \frac{230}{60} = 3.8 \text{ V/Hz}$$

Flux (Φ), magnetizing current (I_M), and torque are all dependent on this ratio. Increasing frequency (F) without increasing voltage (E), for example, will cause a corresponding increase in speed. Flux, however, will decrease causing motor torque to decrease. Magnetizing current (I_M) will also decrease. A decrease in magnetizing current will cause a corresponding decrease in stator or line (I_S) current. These decreases are all related and greatly affect the motor's ability to handle a given load.

$$\Phi \approx \frac{E}{F}$$

$$T = k\Phi I_W$$

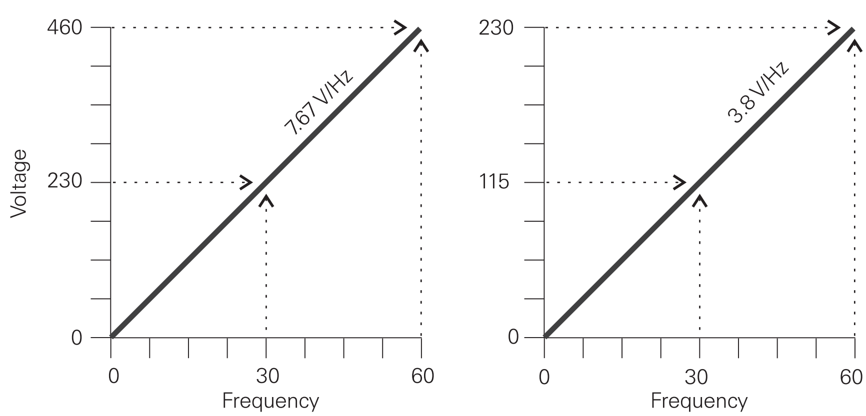
$$I_M = \frac{E}{2\pi F L_M}$$

Constant Torque

AC motors running on an AC line operate with a constant flux (Φ) because voltage and frequency are constant. Motors operated with constant flux are said to have constant torque. Actual torque produced, however, is determined by the demand of the load.

$$T = k\Phi I w$$

An AC drive is capable of operating a motor with constant flux (Φ) from approximately zero (0) to the motor's rated nameplate frequency (typically 60 Hz). This is the constant torque range. As long as a constant volts per hertz ratio is maintained the motor will have constant torque characteristics. AC drives change frequency to vary the speed of a motor and voltage proportionately to maintain constant flux. The following graphs illustrate the volts per hertz ratio of a 460 volt, 60 hertz motor and a 230 volt, 60 Hz motor. To operate the 460 volt motor at 50% speed with the correct ratio, the applied voltage and frequency would be 230 volts, 30 Hz. To operate the 230 volt motor at 50% speed with the correct ratio, the applied voltage and frequency would be 115 volts, 30 Hz. The voltage and frequency ratio can be maintained for any speed up to 60 Hz. This usually defines the upper limits of the constant torque range.



$$\frac{460}{60} = 7.67\ V/Hz \qquad \frac{230}{60} = 3.8\ V/Hz$$

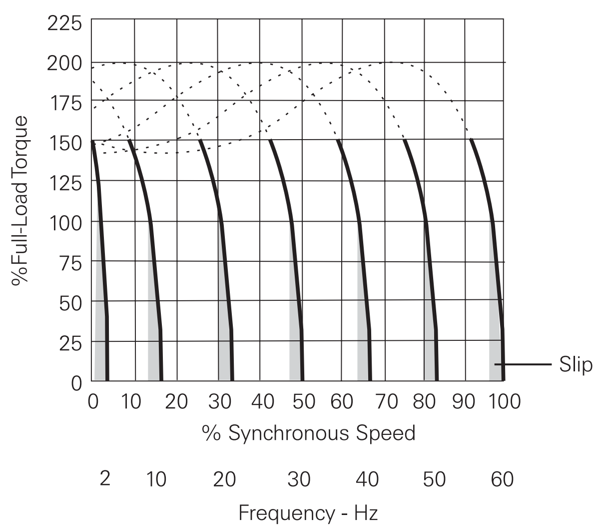
$$\frac{230}{30} = 7.67\ V/Hz \qquad \frac{115}{30} = 3.8\ V/Hz$$

Reduced Voltage and Frequency Starting

You will recall that a NEMA B motor started by connecting it to the power supply at full voltage and frequency will develop approximately 150% starting torque and 600% starting current. An advantage of using AC drives to start a motor is the ability to develop 150% torque with a starting current of 150% or less. This is possible because an AC drive is capable of maintaining a constant volts per hertz ratio from approximately zero speed to base speed, thereby keeping flux (Φ) constant. Torque is proportional to the square of flux developed in the motor.

$$T \approx \Phi^2$$

The torque/speed curve shifts to the right as frequency and voltage are increased. The dotted lines on the torque/speed curve illustrated below represent the portion of the curve not used by the drive. The drive starts and accelerates the motor smoothly as frequency and voltage are gradually increased to the desired speed. Slip, in RPM, remains constant throughout the speed range. An AC drive, properly sized to a motor, is capable of delivering 150% torque at any speed up to the speed corresponding to the incoming line voltage. The only limitations on starting torque are peak drive current and peak motor torque, whichever is less.



Some applications require higher than 150% starting torque. A conveyor, for example, may require 200% starting torque. If a motor is capable of 200% torque at 200% current, and the drive is capable of 200% current, then 200% motor torque is possible. Typically drives are capable of producing 150% of drive nameplate rated current for one (1) minute. A drive with a larger current rating would be required. It is appropriate to supply a drive with a higher continuous horsepower rating than the motor when high peak torque is required.

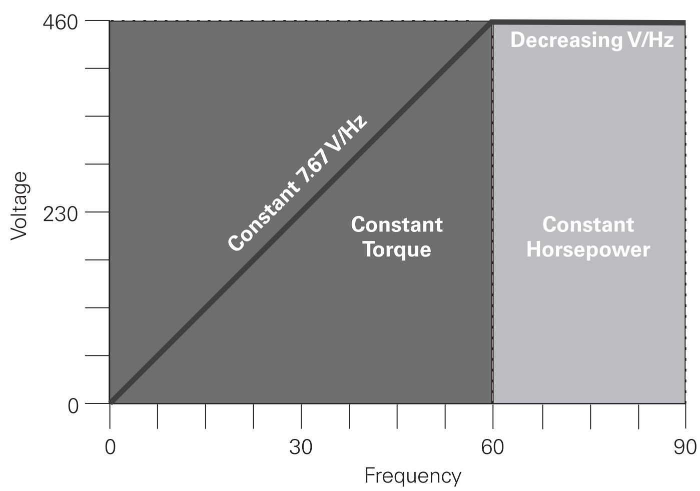
Constant Horsepower

Some applications require the motor to be operated above base speed. The nature of these applications requires less torque at higher speeds. Voltage, however, cannot be higher than the available supply voltage. This can be illustrated using a 460 volt, 60 Hz motor. Voltage will remain at 460 volts for any speed above 60 Hz. A motor operated above its rated frequency is operating in a region known as a constant horsepower. Constant volts per hertz and torque is maintained to 60 Hz. Above 60 Hz the volts per hertz ratio decreases.

Frequency	V/Hz
30 Hz	7.67
60 Hz	7.67
70 Hz	6.6
90 Hz	5.1

Flux (Φ) and torque (T) decrease:

$$\Phi \approx \frac{E}{F} \qquad T = k\Phi I_W$$



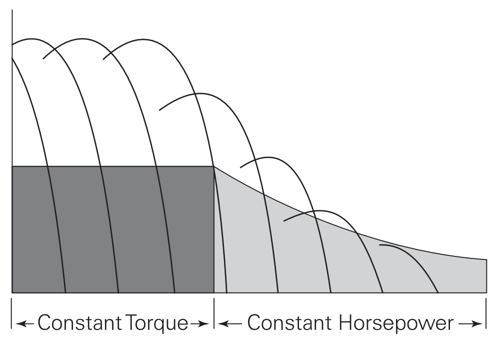
Horsepower remains constant as speed (N) increases and torque (T) decreases in proportion. The following formula applies to speed in revolutions per minute (RPM).

$$\text{HP (remains constant)} = \frac{\text{T (decreases)} \times \text{N (increases)}}{5250}$$

Field Weakening

Motors operated above base frequency can also be said to be in field weakening. Field weakening occurs whenever there is an increase in frequency without a corresponding increase in voltage. Although an AC drive could be setup for field weakening at any speed, it typically only occurs beyond base frequency.

We have seen that below base speed, in the constant torque region, a motor can develop rated torque at any speed. However, above base speed, in the constant horsepower region, the maximum permissible torque is greatly reduced.



Field Weakening Factor

A field weakening factor (F_{FW}) can be used to calculate the amount of torque reduction necessary for a given extended frequency.

$$F_{FW} = \left(\frac{\text{Rated Frequency}}{\text{Extended Frequency}} \right)^2$$

For example, a 60 Hz motor can only develop 44% rated torque at 90 Hz and 25% rated torque at 120 Hz.

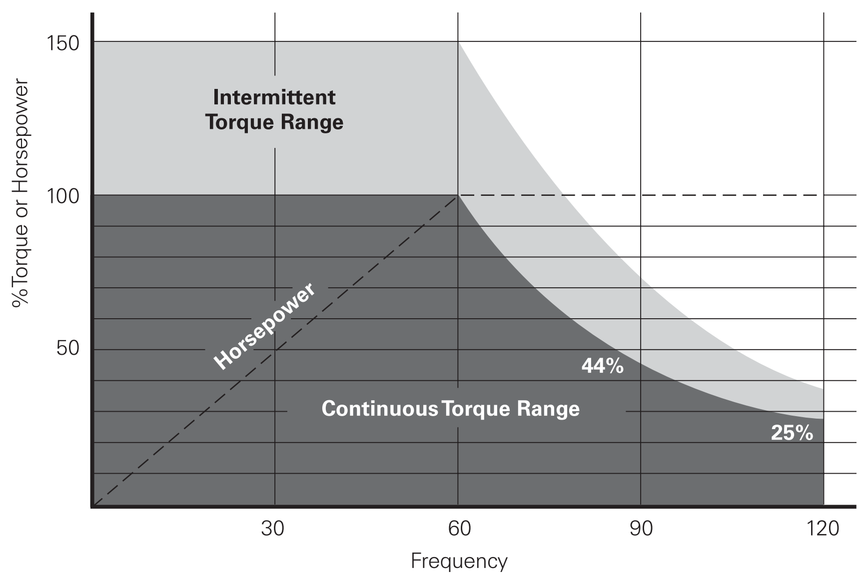
$$F_{FW} = \left(\frac{60}{90} \right)^2 = 44\%$$

$$F_{FW} = \left(\frac{60}{120} \right)^2 = 25\%$$

Selecting a Motor

AC drives often have more capability than the motor. Drives can run at higher frequencies than may be suitable for an application. In addition, drives can run at low speeds. Self-cooled motors may not develop enough air flow for cooling at reduced speeds and full load. Consideration must be given to the motor.

The following graph indicates the speed and torque range of a sample motor. Each motor must be evaluated according to its own capability. The sample motor can be operated continuously at 100% torque up to 60 Hz. Above 60 Hz the V/Hz ratio decreases and the motor cannot develop 100% torque. This motor can be operated continuously at 25% torque at 120 Hz. The motor is also capable of operating above rated torque intermittently. The motor can develop as much as 150%* torque for starting, accelerating or load transients, if the drive can supply the current. At 120 Hz the motor can develop 37.5% torque intermittently.

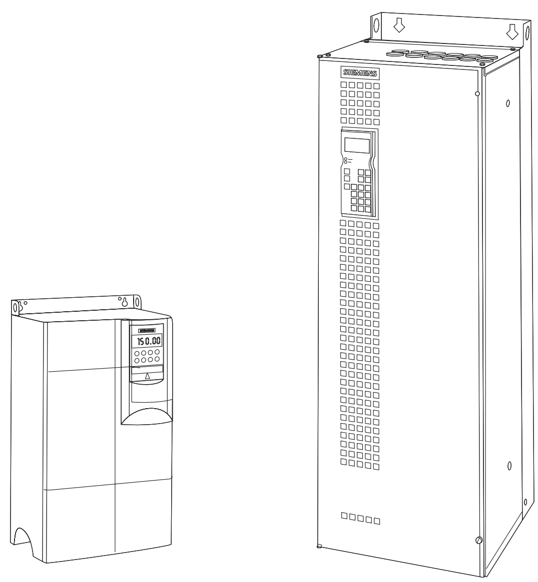


The sample motor described above is capable of operating at 100% rated torque continuously at low frequencies. Many motors are <u>not</u> capable of operating continuously at 100% continuous torque at low frequencies. Each motor must be evaluated before selecting it for use on an AC drive.

* Torque may be higher than 150% if the drive is capable of higher current.

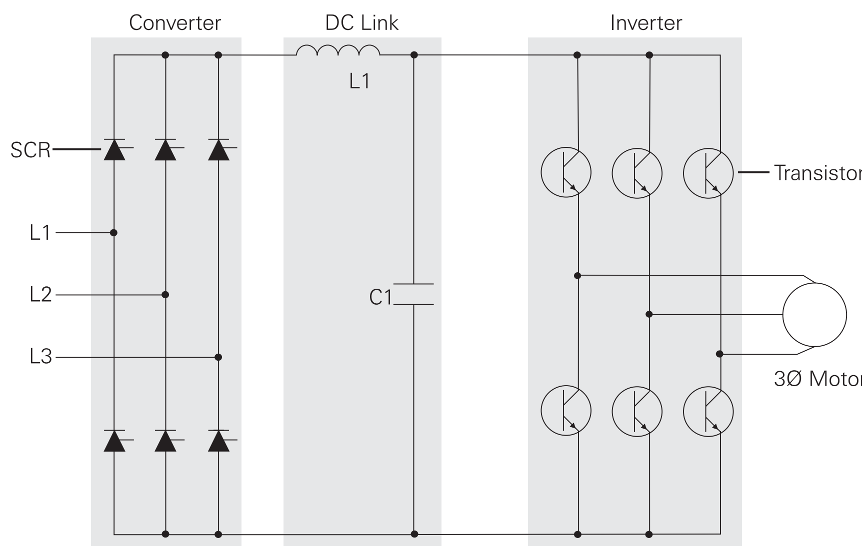
Basic AC Drives

AC drives, inverters, and adjustable frequency drives are all terms that are used to refer to equipment designed to control the speed of an AC motor. The term SIMOVERT is used by Siemens to identify a **SI**emens **MO**tor in**VERT**er (AC drive). AC drives receive AC power and convert it to an adjustable frequency, adjustable voltage output for controlling motor operation. A typical inverter receives 480 VAC, three-phase, 60 Hz input power and in turn provides the proper voltage and frequency for a given speed to the motor. The three common inverter types are the variable voltage inverter (VVI), current source inverter (CSI), and pulse width modulation (PWM). Another type of AC drive is a cycloconverter. These are commonly used for very large motors and will not be described in this course. All AC drives convert AC to DC, and then through various switching techniques invert the DC into a variable voltage, variable frequency output.

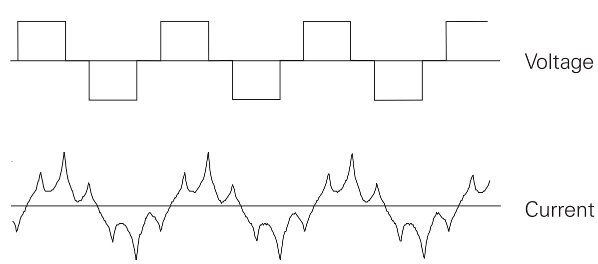


Variable Voltage Inverter (VVI)

The variable voltage inverter (VVI) uses an SCR converter bridge to convert the incoming AC voltage into DC. The SCRs provide a means of controlling the value of the rectified DC voltage from 0 to approximately 600 VDC. The L1 choke and C1 capacitor(s) make up the DC link section and smooth the converted DC voltage. The inverter section consists of six switching devices. Various devices can be used such as thyristors, bipolar transistors, MOSFETS, and IGBTs. The following schematic shows an inverter that utilizes bipolar transistors. Control logic (not shown) uses a microprocessor to switch the transistors on and off providing a variable voltage and frequency to the motor.

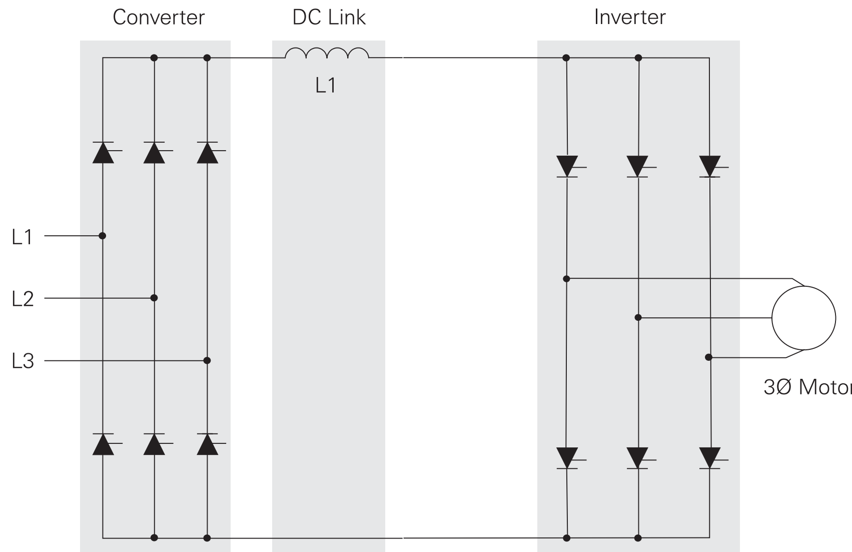


This type of switching is often referred to as six-step because it takes six 60° steps to complete one 360° cycle. Although the motor prefers a smooth sine wave, a six-step output can be satisfactorily used. The main disadvantage is torque pulsation which occurs each time a switching device, such as a bipolar transistor, is switched. The pulsations can be noticeable at low speeds as speed variations in the motor. These speed variations are sometimes referred to as cogging. The non-sinusoidal current waveform causes extra heating in the motor requiring a motor derating.

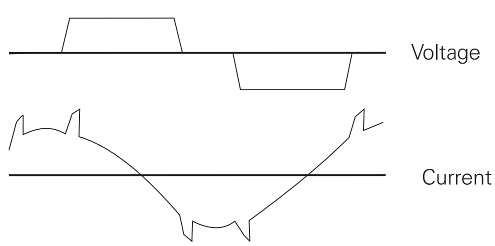


Current Source Inverter

The current source inverter (CSI) uses an SCR input to produce a variable voltage DC link. The inverter section also uses SCRs for switching the output to the motor. The current source inverter controls the current in the motor. The motor must be carefully matched to the drive.

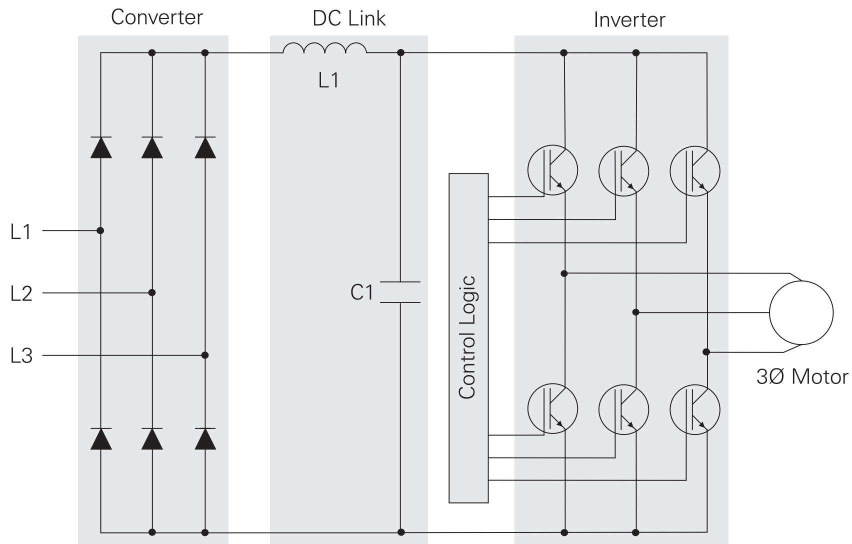


Current spikes, caused by switching, can be seen in the output. At low speeds current pulses can causes the motor to cog.



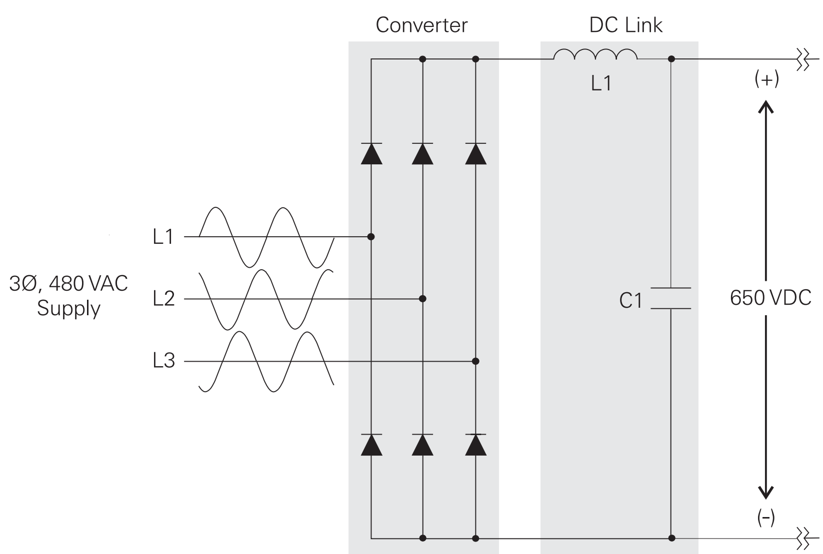
Pulse Width Modulation

Pulse width modulation (PWM) drives, like the Siemens MICROMASTER and MASTERDRIVE VC, provide a more sinusoidal current output to control frequency and voltage supplied to an AC motor. PWM drives are more efficient and typically provide higher levels of performance. A basic PWM drive consists of a converter, DC link, control logic, and an inverter.



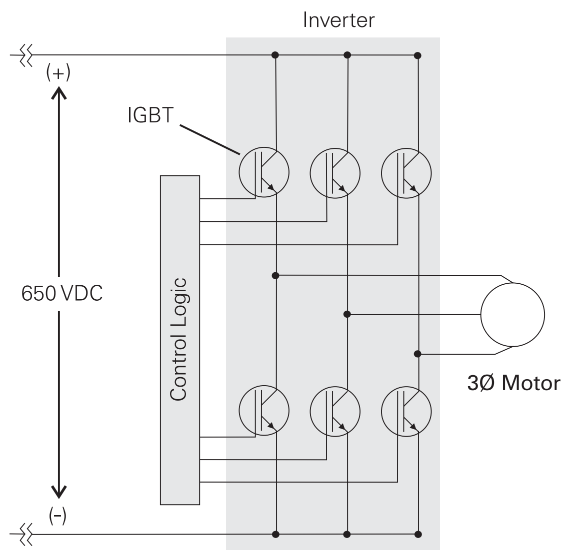
Converter and DC Link

The converter section consists of a fixed diode bridge rectifier which converts the three-phase power supply to a DC voltage. The L1 choke and C1 capacitor(s) smooth the converted DC voltage. The rectified DC value is approximately 1.35 times the line-to-line value of the supply voltage. The rectified DC value is approximately 650 VDC for a 480 VAC supply.



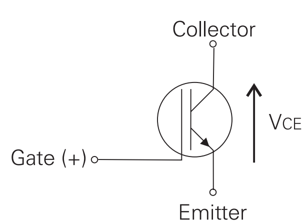
Control Logic and Inverter

Output voltage and frequency to the motor are controlled by the control logic and inverter section. The inverter section consists of six switching devices. Various devices can be used such as thyristors, bipolar transistors, MOSFETS and IGBTs. The following schematic shows an inverter that utilizes IGBTs. The control logic uses a microprocessor to switch the IGBTs on and off providing a variable voltage and frequency to the motor.



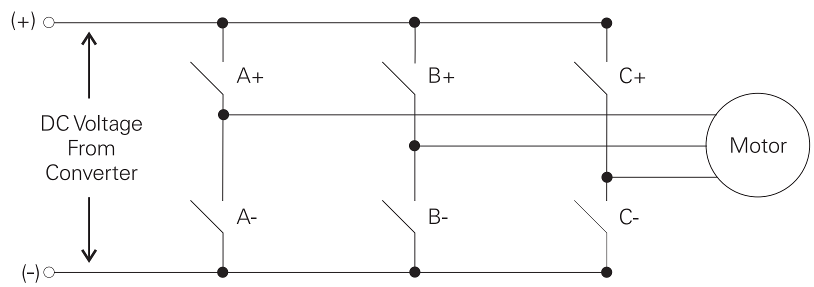
IGBTs

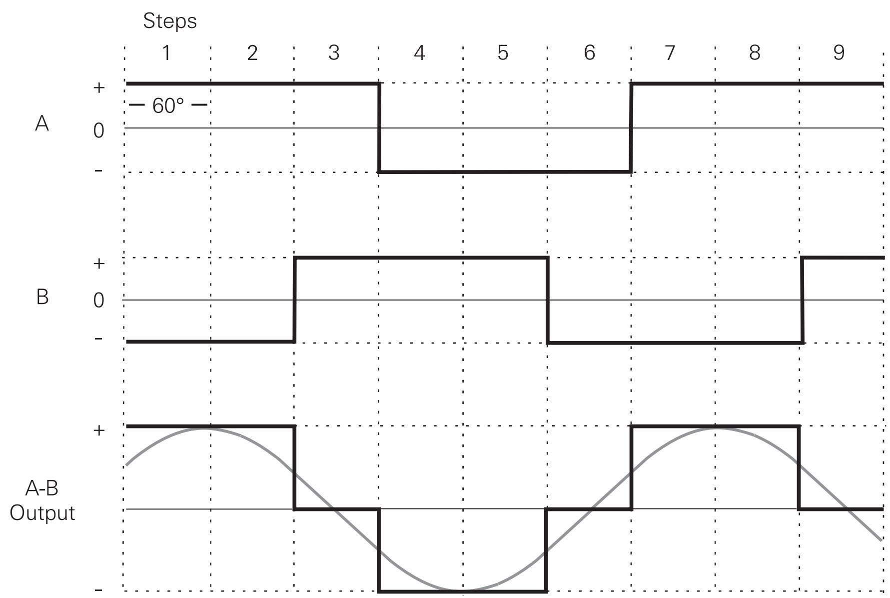
IGBTs (insulated gate bipolar transistor) provide a high switching speed necessary for PWM inverter operation. IGBTs are capable of switching on and off several thousand times a second. An IGBT can turn on in less than 400 nanoseconds and off in approximately 500 nanoseconds. An IGBT consists of a gate, collector and an emitter. When a positive voltage (typically +15 VDC) is applied to the gate the IGBT will turn on. This is similar to closing a switch. Current will flow between the collector and emitter. An IGBT is turned off by removing the positive voltage from the gate. During the off state the IGBT gate voltage is normally held at a small negative voltage (-15 VDC) to prevent the device from turning on.



Using Switching Devices to Develop AC Output

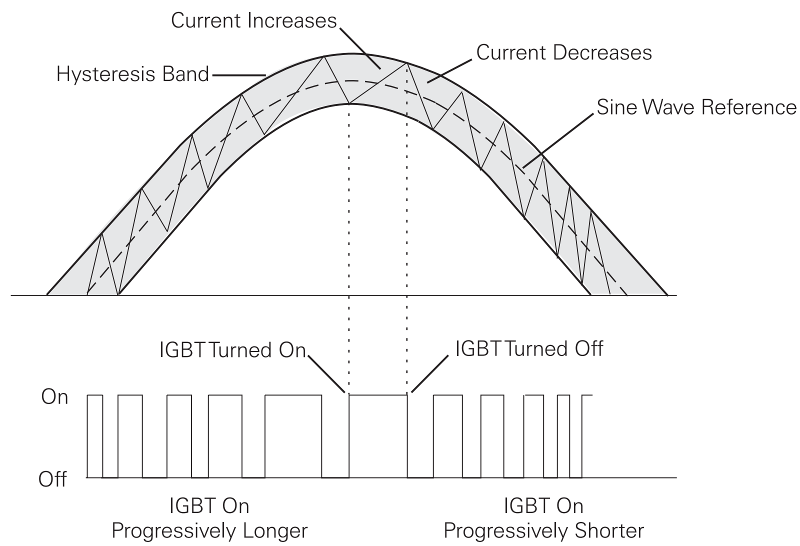
In the following example, one phase of a three-phase output is used to show how an AC voltage can be developed. Switches replace the IGBTs. A voltage that alternates between positive and negative is developed by opening and closing switches in a specific sequence. For example, during steps one and two A+ and B- are closed. The output voltage between A and B is positive. During step three A+ and B+ are closed. The difference of potential from A to B is zero. The output voltage is zero. During step four A- and B+ are closed. The output voltage from A to B is negative. The voltage is dependent on the value of the DC voltage and the frequency is dependent on the speed of the switching. An AC sine wave has been added to the output (A-B) to show how AC is simulated.





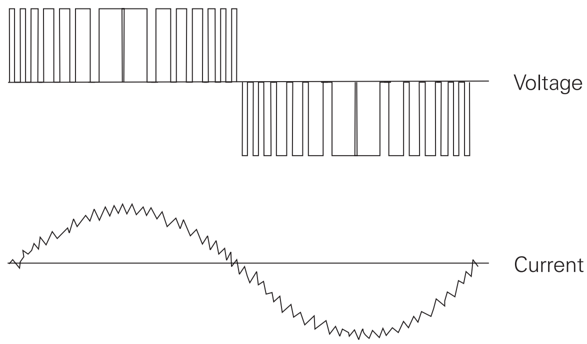
PWM Output

There are several PWM modulation techniques. It is beyond the scope of this book to describe them all in detail. The following text and illustrations describe a typical pulse width modulation method. An IGBT (or other type switching device) can be switched on connecting the motor to the positive value of DC voltage (650 VDC from the converter). Current flows in the motor. The IGBT is switched on for a short period of time, allowing only a small amount of current to build up in the motor and then switched off. The IGBT is switched on and left on for progressively longer periods of time, allowing current to build up to higher levels until current in the motor reaches a peak. The IGBT is then switched on for progressively shorter periods of time, decreasing current build up in the motor. The negative half of the sine wave is generated by switching an IGBT connected to the negative value of the converted DC voltage.

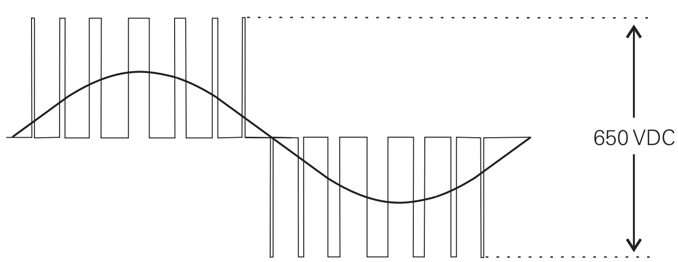


PWM Voltage and Current

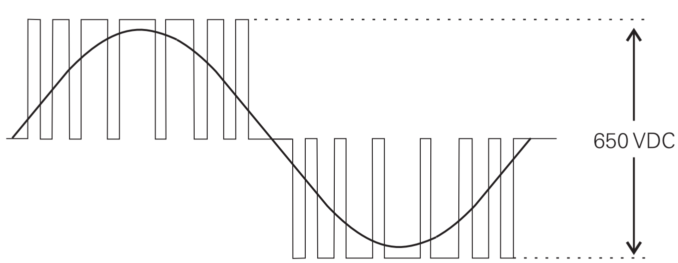
The more sinusoidal current output produced by the PWM reduces the torque pulsations, low speed motor cogging, and motor losses noticeable when using a six-step output.



The voltage and frequency is controlled electronically by circuitry within the AC drive. The fixed DC voltage (650 VDC) is modulated or clipped with this method to provide a variable voltage and frequency. At low output frequencies a low output voltage is required. The switching devices are turned on for shorter periods of time. Voltage and current build up in the motor is low. At high output frequencies a high voltage is required. The switching devices are turned on for longer periods of time, allowing voltage and current to build up to higher levels in the motor.



Shorter "On" Duration, Lower Voltage



Longer "On" Duration, Higher Voltage

Review 3

1. The volts per hertz ratio of a 460 volt, 60 Hz motor is ____________ .

2. An increase in voltage will cause flux (Φ) to ____________, and torque (T) capability to ____________ .

3. A motor operated within a speed range that allows a constant volts per hertz ratio is said to be constant ____________ .

   a. horsepower   b. torque

4. If torque decreases proportional to speed (RPM) increasing, then ____________ is constant.

5. Siemens uses the term ____________ to identify a Siemens inverter (AC drive).

6. On a PWM drive with a 480 VAC supply, the approximate voltage after being converted to DC is ___________ VDC.

7. IGBTs are capable of being switched several ____________ a second.

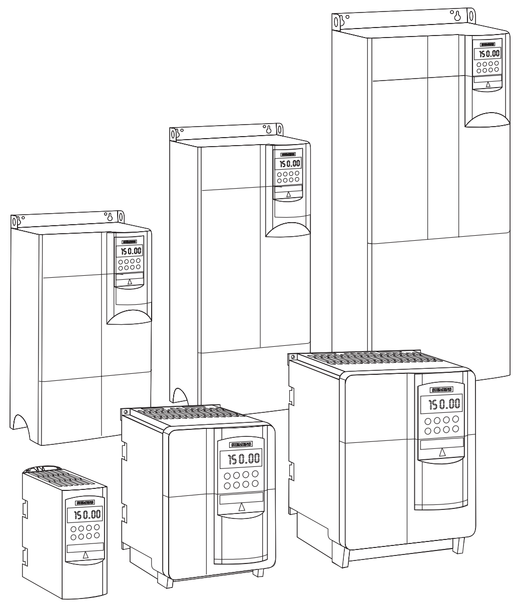
   a. times   b. hundred times
   c. thousand times   d. million times

8. A PWM output is preferred to a six-step output because ____________

   a. PWM provides a more sinusoidal output
   b. Cogging is more noticeable on a six-step
   c. The non-sinusoidal waveform of a six-step increases motor heat
   d. a, b, and c

Siemens MICROMASTER

Siemens offers a broad range of AC drives. In the past, AC drives required expert set-up and commissioning to achieve desired operation. The Siemens MICROMASTER offers "out of the box" commissioning with auto tuning for motor calibration, flux current control, vector control, and PID (Proportional-Integral-Derivative) regulator loops. The MICROMASTER is controlled by a programmable digital microprocessor and is characterized by ease of setup and use.



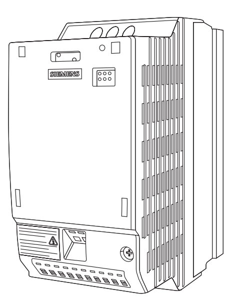
Features

The MICROMASTER is suitable for a variety of variable-speed applications, such as pumps, fans, and conveyor systems. The MICROMASTER is compact and its range of voltages enable the MICROMASTER to be used all over the world.

Feature	MICROMASTER		
	410	420	440
Input Voltage	1Ø AC 100V to 120V ±10% 1Ø AC 200 to 240 VAC ÷10%	1Ø AC 200V to 240V ±10% 3Ø AC 200V to 240V ±10% 3Ø AC 380V to 480V ±10%	1Ø AC 200V to 240V ±10% 3Ø AC 200V to 240V ±10% 3Ø AC 380V to 480V ±10% 3Ø AC 500V to 600V ±10%
Output Voltage	0 to Approximate Input Value	0 to Approximate Input Value	0 to Approximate Input Value
Input Frequency	47 to 63 Hz	47 to 63 Hz	47 to 63 Hz
Output Frequency	0 Hz to 650 Hz	0 Hz to 650 Hz	0 Hz to 650 Hz
Power Range	1/6 to 1 HP	1/6 to 15 HP	1/6 to 100 HP
Overload Capacity	Up to 150% of rated output current for 60 s, followed by 85 for 240 s, cycle time 300 s	150 s of rated load current for a period of 60 s within 300 s	150% of rated load current for a period of 60 s within 300 s or 200% of rated load current for a period of 3 s within 60 s.
Control	V/f	V/f. FCC	V/f, FCC, Vector (sensorless and optional closed loop), torque
Inputs	3 digital, 1 analog	3 digital, 1 analog	6 digital, 2 analog, 1 PTC
Outputs	1 relay	1 analog, 1 relay	2 analog, 3 relay
Serial Interface	RS-485 for use with USS protocol	RS-485 for use with USS protocol, optional RS232	RS-485 for use with USS protocol, optional RS232
Braking	DC braking, compound braking	DC Braking, compound braking	DC Braking, compound braking, fully-rated integral brake chopper

MICROMASTER 410

The MICROMASTER 410 is available in two frame sizes (AA and AB) and covers the lower end of the performance range. It has a power rating of 1/6 HP to 1 HP. The MICROMASTER 410 features a compact design, fanless cooling, simple connections, an integrated RS485 communications interface, and easy startup.



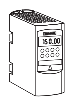
Frame Size AA
100 - 120 VAC 1Ø or
200 - 240 VAC 1Ø or 3Ø
1/6 HP to 1/2 HP

Frame Size AB
100 - 120 VAC 1Ø
3/4 HP
200 - 240 VAC 1Ø or 3Ø
3/4 HP to 1 HP

MICROMASTER 420

The MICROMASTER 420 is available in three frame sizes (A, B, and C) with power ratings from 1/6 HP to 15 HP. Among the features of the MICROMASTER 420 are the following:

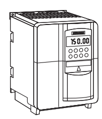
- Flux Current Control (FCC)
- Linear V/Hz Control
- Quadratic V/Hz Control
- Flying Restart
- Slip Compensation
- Automatic Restart
- PI Feedback for Process Control
- Programmable Acceleration/Deceleration
- Ramp Smoothing
- Fast Current Limit (FCL)
- Compound Braking



Frame Size A

200 VAC to 240VAC 1/3Ø
1/6 HP to 1 HP

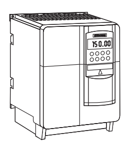
380 VAC to 480VAC 3Ø
1/2 HP to 2 HP



Frame Size B

200 VAC to 240VAC 1/3Ø
1.5 HP to 3 HP

380 VAC to 480VAC 3Ø
3 HP to 5 HP



Frame Size C

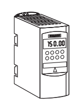
200 VAC to 240VAC 1/3Ø
4 HP to 7.5 HP

380 VAC to 480VAC 3Ø
7.5 HP to 15 HP

MICROMASTER 440

The MICROMASTER 440 is available in six frame sizes (A - F) and offers higher power ranges than the 420, with a corresponding increase in functionality. For example, the 440 has three output relays, two analog inputs, and six isolated digital inputs. The two analog inputs can also be programmed for use as digital inputs. The 440 also features Sensorless Vector Control, built-in braking chopper, 4-point ramp smoothing, and switchable parameter sets.

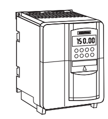
Frame Size A



200 VAC to 240VAC 1/3Ø
1/6 HP to 1 HP

380 VAC to 480VAC 3Ø
1/2 HP to 2 HP

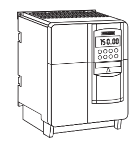
Frame Size B



200 VAC to 240VAC 1/3Ø
1.5 HP to 3 HP

380 VAC to 480VAC 3Ø
3 HP to 5 HP

Frame Size C

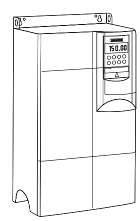


200 VAC to 240VAC 1/3Ø
4 HP to 7.5 HP

380 VAC to 480VAC 3Ø
7.5 HP to 15 HP

500 VAC to 600VAC 3Ø
1 HP to 15 HP

Frame Size D

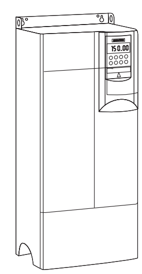


200 VAC to 240VAC 1/3Ø
10 HP to 20 HP

380 VAC to 480VAC 3Ø
20 HP to 30 HP

500 VAC to 600VAC 3Ø
20 HP to 30 HP

Frame Size E

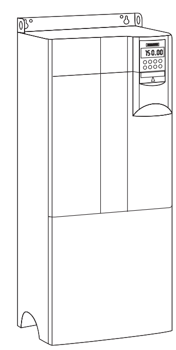


200 VAC to 240VAC 1/3Ø
25 HP to 30 HP

380 VAC to 480VAC 3Ø
40 HP to 50 HP

500 VAC to 600VAC 3Ø
40 HP to 50 HP

Frame Size F



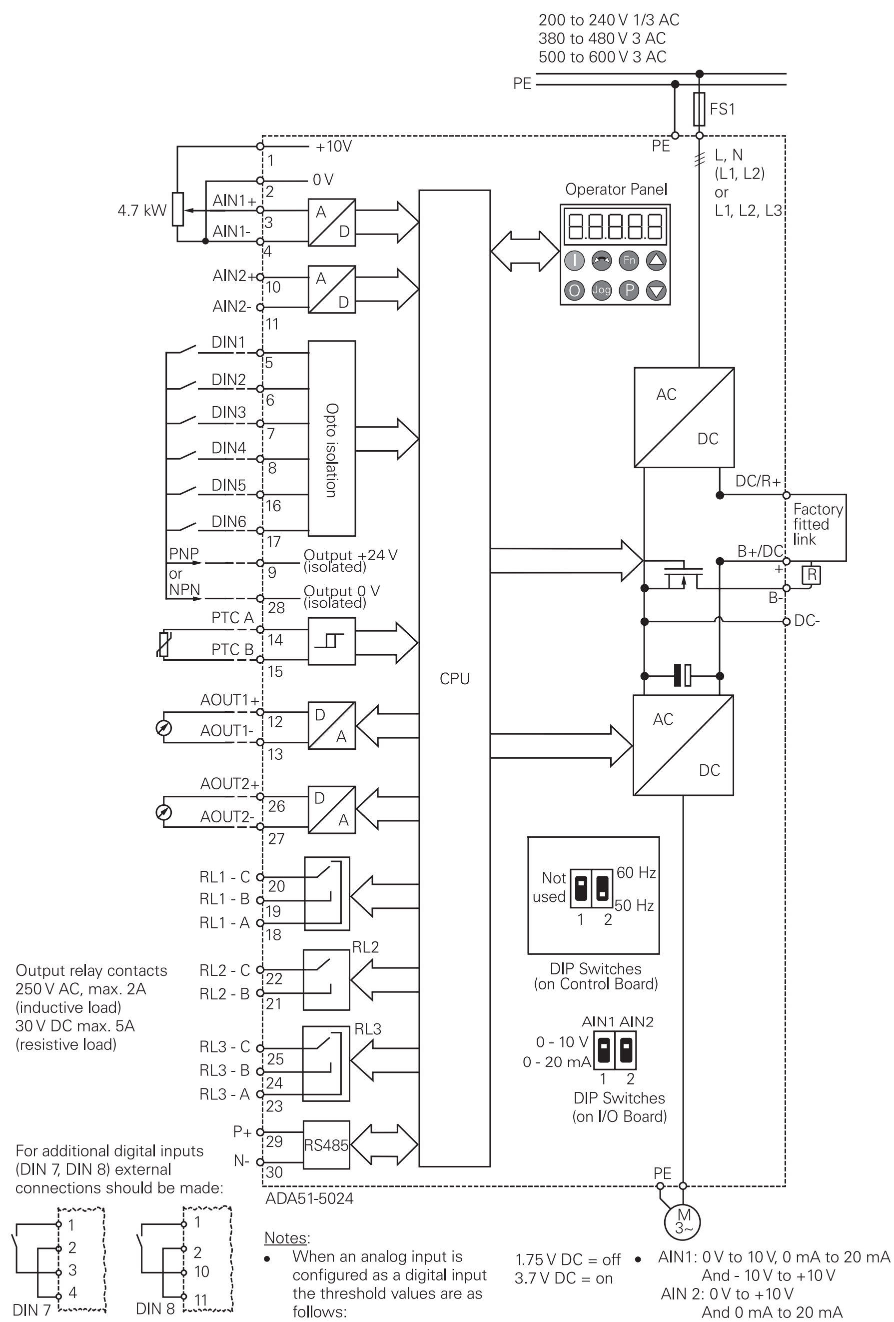
200 VAC to 240VAC 1/3Ø
50 HP to 60 HP

380 VAC to 480VAC 3Ø
60 HP to 100 HP

500 VAC to 600VAC 3Ø
60 HP to 100 HP

Design

In order to understand the MICROMASTER's capabilities and some of the functions of an AC drive we will look at the 440. It is important to note; however, that some features of the MICROMASTER 440 are not available on the 410 and 420. The MICROMASTER has a modular design that allows the user configuration flexibility. The optional operator panels and PROFIBUS module can be user installed. There are six programmable digital inputs, two analog inputs that can also be used as additional digital inputs, two programmable analog output, and three programmable relay output.

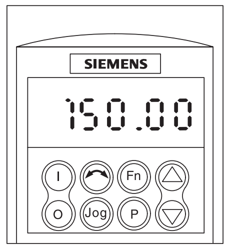


Operator Panels

There are two operator panels, the Basic Operator Panel (BOP) and Advanced Operator Panel (AOP). Operator panels are used for programming and drive operation (start, stop, jog, and reverse).

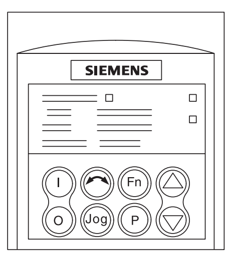
BOP

Individual parameter settings can be made with the Basic Operator Panel. Parameter values and units are shown on a 5-digit display. One BOP can be used for several units.



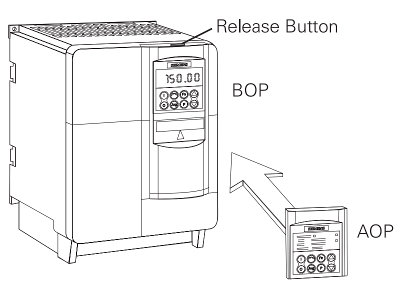
AOP

The Advanced Operator Panel enables parameter sets to be read out or written (upload/download) to the MICROMASTER. Up to ten different parameter sets can be stored in the AOP. The AOP features a multi-line, plain text display. Several language sets are available. One AOP can control up to 31 drives.



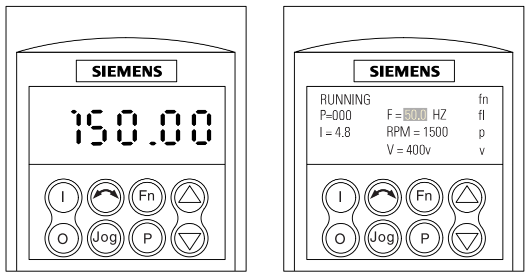
Changing Operator Panels

Changing operator panels is easy. A release button above the panel allows operator panels to be interchanged, even under power.



Parameters

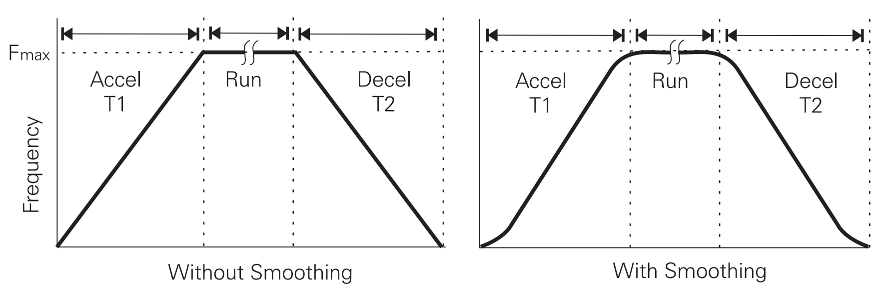
A parameter is a variable that is given a constant value. Standard application parameters come preloaded, which are good for many applications. These parameters can easily be modified to meet specific needs of an application. Parameters such as ramp times, minimum and maximum frequencies, and operation modes are easily set using either the BOP or AOP. The "P" key toggles the display between a parameter number and the value of the parameter. The up and down pushbuttons scroll through parameters and are used to set a parameter value. In the event of a failure the inverter switches off and a fault code appears in the display.



Ramp Function

A feature of AC drives is the ability to increase or decrease the voltage and frequency to a motor gradually. This accelerates the motor smoothly with less stress on the motor and connected load. Parameters P002, P003 and P004 are used to set a ramp function. Acceleration and deceleration are separately programmable from 0 to 650 seconds. Acceleration, for example, could be set for 10 seconds and deceleration could be set for 60 seconds.

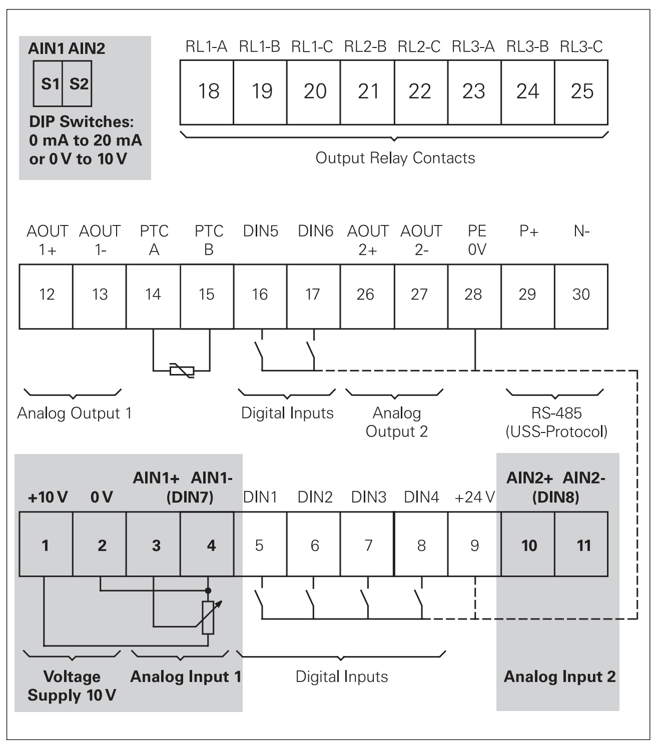
Smoothing is a feature that can be added to the acceleration/deceleration curve. This feature smooths the transition between starting and finishing a ramp. Minimum and maximum speed are set by parameters P012 and P013.



Analog Inputs

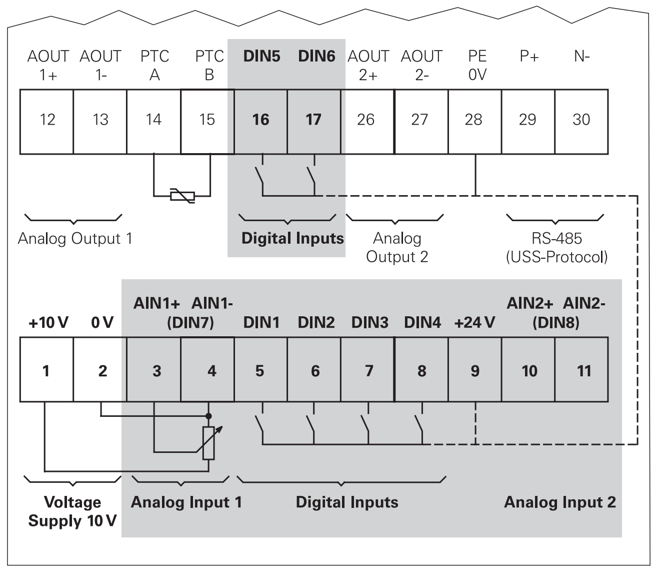
The MICROMASTER 440 has two analog inputs (AIN1 and AIN2), allowing for a PID control loop function. PID control loops are used in process control to trim the speed. Examples are temperature and pressure control. Switches S1 and S2 are used to select a 0 mA to 20 mA or a 0 V to 10 V reference signal. In addition, AIN1 and AIN2 can be configured as digital inputs.

In the following example AIN1 is set up as an analog reference that controls the speed of a motor from 0 to 100%. Terminal one (1) is a +10 VDC power supply that is internal to the drive. Terminal two (2) is the return path, or ground, for the 10 Volt supply. An adjustable resistor is connected between terminals one and two. Terminal three (3) is the positive (+) analog input to the drive. Note that a jumper has been connected between terminals two (2) and four (4). An analog input cannot be left floating (open). If an analog input will not be used it must be connected to terminal two (2). The drive can also be programmed to accept 0 to 20 mA, or 4 to 20 mA speed reference signal. These signals are typically supplied to the drive by other equipment such as a programmable logic controller (PLC).



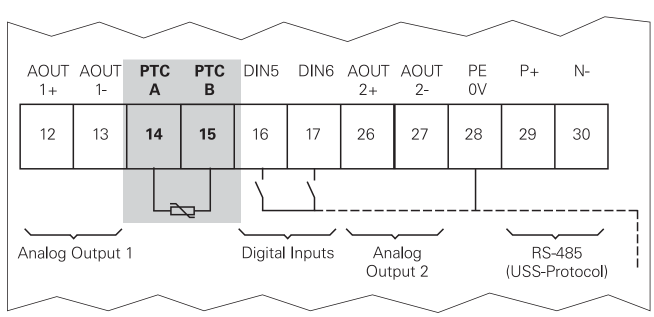
Digital Inputs

The MICROMASTER 440 has six digital inputs (DIN1 - DIN6). In addition AIN1 (DIN7) and AIN2 (DIN8) can be configured as digital inputs. Switches or contacts can be connected between the +24 VDC on terminal 9 and a digital input. Standard factory programming uses DIN1 as a Start/Stop function. DIN 2 is used for reverse, while DIN3 is a fault reset terminal. Other functions, such as preset speed and jog, can be programmed as well.



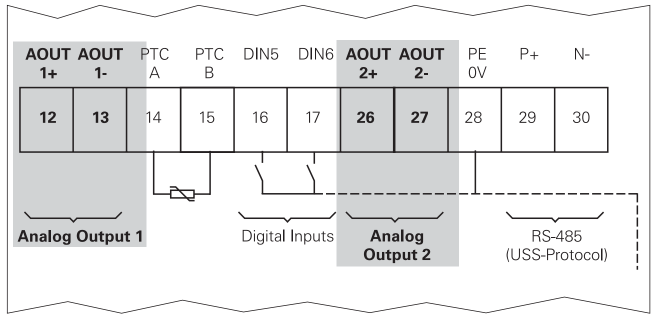
Thermistor

Some motors have a built in thermistor. If a motor becomes overheated the thermistor acts to interrupt the power supply to the motor. A thermistor can be connected to terminals 14 and 15. If the motor gets to a preset temperature as measured by the thermistor, the driver will interrupt power to the motor. The motor will coast to a stop. The display will indicate a fault has occurred. Virtually any standard thermistor as installed in standard catalog motors will work. Snap-action thermostat switches will also work.



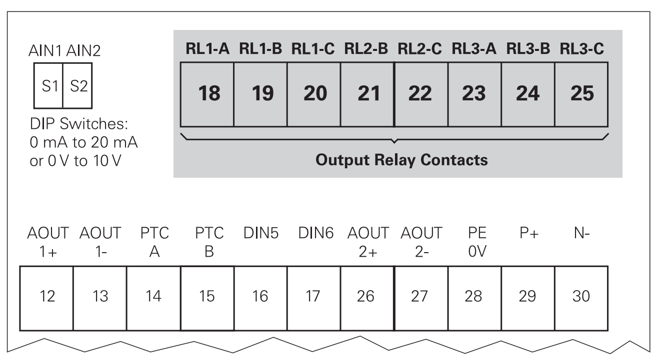
Analog Outputs

Analog outputs can be used to monitor output frequency, frequency setpoint, DC-link voltage, motor current, motor torque, and motor RPM. The MICROMASTER 440 has two analog outputs (AOUT1 and AOUT2).



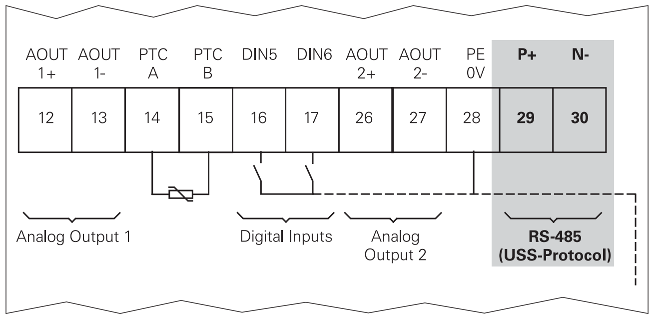
Relay Output

There are three programmable relay outputs (RL1, RL2, and RL3) on the MASTERDRIVE 440. Relays can be programmed to indicate various conditions such as the drive is running, a failure has occurred, converter frequency is at 0 or converter frequency is at minimum.



Serial Communication

The MICROMASTER 440 has an RS485 serial interface that allows communication with computers (PCs) or programmable logic controllers (PLCs). The standard RS485 protocol is called USS protocol and is programmable up to 57.6 K baud. Siemens PROFIBUS protocol is also available. It is programmable up to 12 M baud. Contact your Siemens sales representative for information on USS and PROFIBUS protocol.



Current Limit

The MICROMASTER 440 is capable of delivering up to 150% of drive rated current for 60 seconds within a period of 300 seconds or 200% of drive rated current for a period of 3 seconds within a period of 60 seconds. Sophisticated speed/time/current dependent overload functions are used to protect the motor. The monitoring and protection functions include a drive overcurrent fault, a motor overload fault, a calculated motor over temperature warning, and a measured motor over temperature fault (requires a device inside the motor).

Low Speed Boost

We learned in a previous lesson that a relationship exists between voltage (E), frequency (F), and magnetising flux (Φ). We also learned that torque (T) is dependent on magnetising flux. An increase in voltage, for example, would cause an increase in torque.

Some applications, such as a conveyor, require more torque to start and accelerate the load at low speed. Low speed boost is a feature that allows the voltage to be adjusted at low speeds. This will increase/decrease the torque. Low speed boost can be adjusted high for applications requiring high torque at low speeds. Some applications, such as a fan, don't require as much starting torque. Low speed boost can be adjusted low for smooth, cool, and quiet operation at low speed. An additional starting boost is available for applications requiring high starting torque.

$\Phi \approx \frac{E}{F}$ $T = k\Phi I_W$

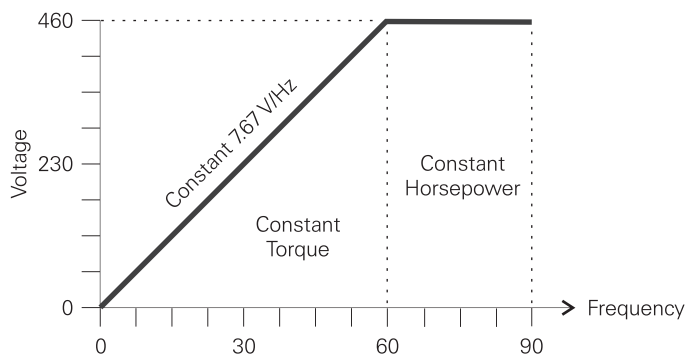
Control Modes

The MICROMASTER has four modes of operation:

Linear voltage/frequency (410, 420, 440)
Quadratic voltage/frequency (410, 420, 440)
Flux Current Control (FCC) (440)
Sensorless vector frequency control (440)
Closed loop vector control (440 with encoder option card)

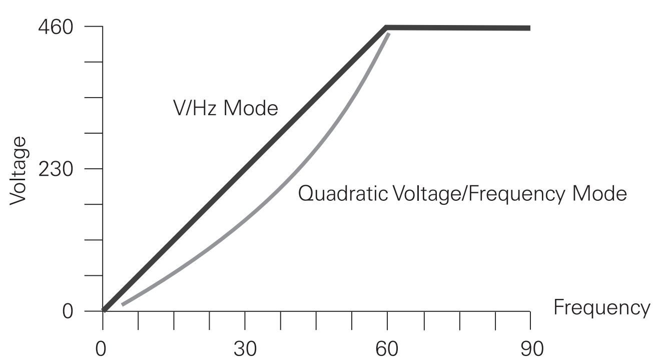
Linear Voltage/Frequency

The MICROMASTER can operate utilizing a standard V/Hz curve. Using a 460 VAC, 60 Hz motor as an example, constant volts per hertz is supplied to the motor at any frequency between 0 and 60 Hz. This is the simplest type of control and is suitable for general purpose applications.



Quadratic Operation

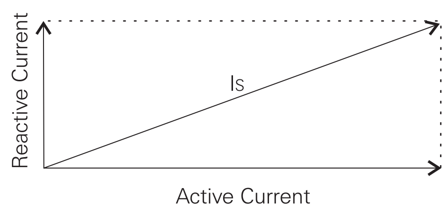
A second mode of operation is referred to as a quadratic voltage/frequency curve. This mode provides a V/Hz curve that matches the torque requirements of simple fan and pump applications.



Flux Current Control

Stator current (I_S) is made up of active and reactive current. The reactive current component of stator current produces the rotating magnetic field. The active current produces work. Motor nameplate data is entered into the drive. The drive estimates motor magnetic flux based on the measured reactive stator current and the entered nameplate data. Proprietary internal computer algorithms attempt to keep the estimated magnetic flux constant.

If the motor nameplate information has been correctly entered and the drive properly set up, the flux current control mode will usually provide better dynamic performance than simple V/Hz control. Flux current control automatically adapts the drive output to the load. The motor is always operated at optimum efficiency. Speed remains reliably constant even under varying load conditions.



$$I_S = \sqrt{I_M^2 + I_W^2}$$

Sensorless Vector Control

In the past, the dynamic response of a DC motor was generally considered significantly better than an AC motor. An AC motor, however, is less expensive and requires less maintenance than a DC motor. Using a complex mathematical motor model and proprietary internal computer algorithms vector control is able to exert the necessary control over an AC motor so that its performance is equal to that of a DC motor. Vector control, flux vector, and field orientation are terms that describe this specialized control technique of AC drives.

Vector control systems facilitate independent control of flux producing and torque producing elements in an induction motor. Sensorless vector control calculates rotor speed based on the motor model, calculated CEMF, inverter output voltage, and inverter output current. This results in improved dynamic performance compared to other control methods.

When motor speed is calculated at very low speeds, based on a small CEMF and known corrections for stator resistance, slight variations in stator resistance and other parameters will have an effect on speed calculation. This makes vector control without a tachometer impractical below a few hertz.

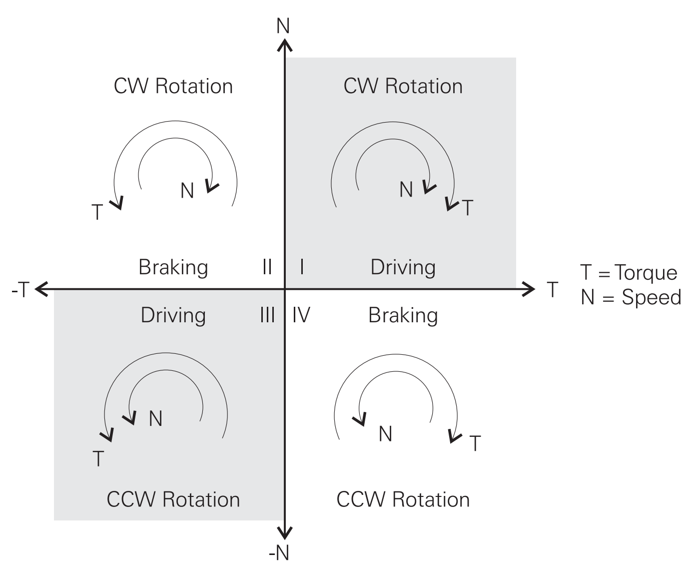
Siemens sensorless vector control drives do operate smoothly to low speed. Sensorless vector control drives will produce full torque below a few hertz, and 150% or more torque at all speeds.

There are some complicated techniques used to accomplish this low speed torque with sensorless vector control. Expert setup and commissioning may be required to achieve desired operation at low speed.

Parameters for static torque, flux adaptation, slip compensation, and other concepts are complex and beyond the scope of this course.

Single-Quadrant Operation

In the speed-torque chart there are four quadrants according to direction of rotation and direction of torque. A single-quadrant drive operates only in quadrants I or III (shaded area). Quadrant I is forward motoring or driving (CW). Quadrant III is reverse motoring or driving (CCW). Reverse motoring is achieved by reversing the direction of the rotating magnetic field. Motor torque is developed in the positive direction to drive the connected load at a desired speed (N). This is similar to driving a car forward on a flat surface from standstill to a desired speed. It takes more forward or motoring torque to accelerate the car from zero to the desired speed. Once the car has reached the desired speed your foot can be let off the accelerator a little. When the car comes to an incline a little more gas, controlled by the accelerator, maintains speed.

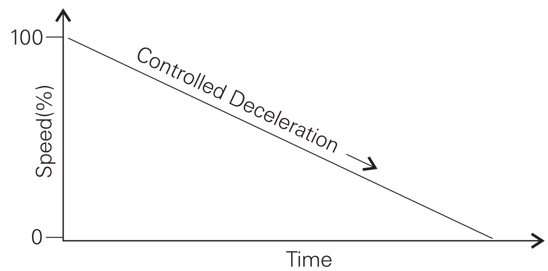


Coast-to-Stop

To stop an AC motor in single-quadrant operation voltage and frequency can simply be removed and the motor allowed to coast to a stop. This is similar to putting a car in neutral, turning off the ignition and allowing the car to coast to a stop.

Controlled Deceleration

Another way is to use a controlled deceleration. Voltage and frequency are reduced gradually until the motor is at stop. This would be similar to slowly removing your foot from the accelerator of a car. The amount of time required to stop a motor depends on the inertia of the motor and connected load. The more inertia the longer it will take to stop.



DC Injection Braking

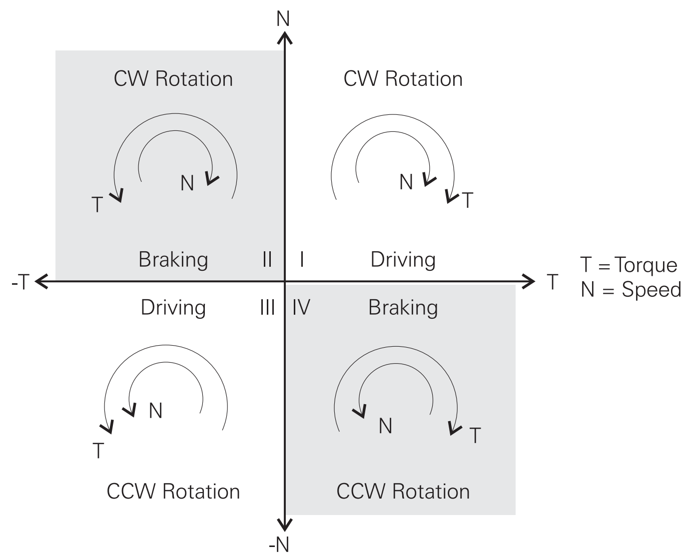
The DC injection braking mode stops the rotating magnetic field and applies a constant DC voltage to the motor windings, helping stop the motor. Up to 250% of the motor's rated current can be applied. This is similar to removing your foot from the accelerator and applying the brakes to bring the car to a stop quickly.

Compound Braking

Compound braking uses a combination of the controlled deceleration ramp and DC injection braking. The drive monitors bus voltage during operation and triggers compound braking when the bus exceeds a set threshold point. As the motor decelerates to a stop a DC voltage is periodically applied to the motor windings. The excess energy on the bus is dissipated in the motor windings. This is similar to alternately applying the brakes to slow a car, then allowing the mechanical inertia of the engine to slow the vehicle until the car is brought to a stop.

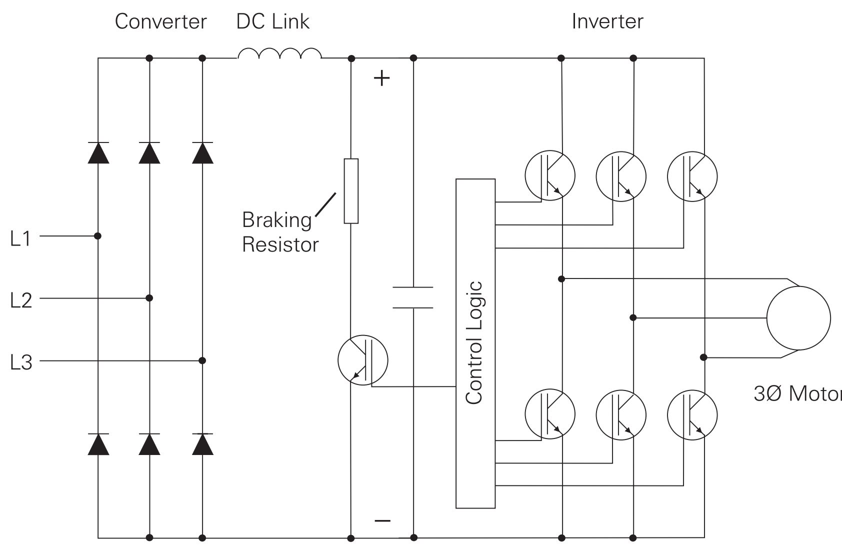
Four-Quadrant Operation

The dynamics of certain loads may require four-quadrant operation. When equipped with an optional braking resistor the Siemens MICROMASTER is capable of four-quadrant operation. Torque will always act to cause the rotor to run towards synchronous speed. If the synchronous speed is suddenly reduced, negative torque is developed in the motor. The motor acts like a generator by converting mechanical power from the shaft into electrical power which is returned to the AC drive. This is similar to driving a car downhill. The car's engine will act as a brake. Braking occurs in quadrants II and IV.



Pulsed Resistor Braking

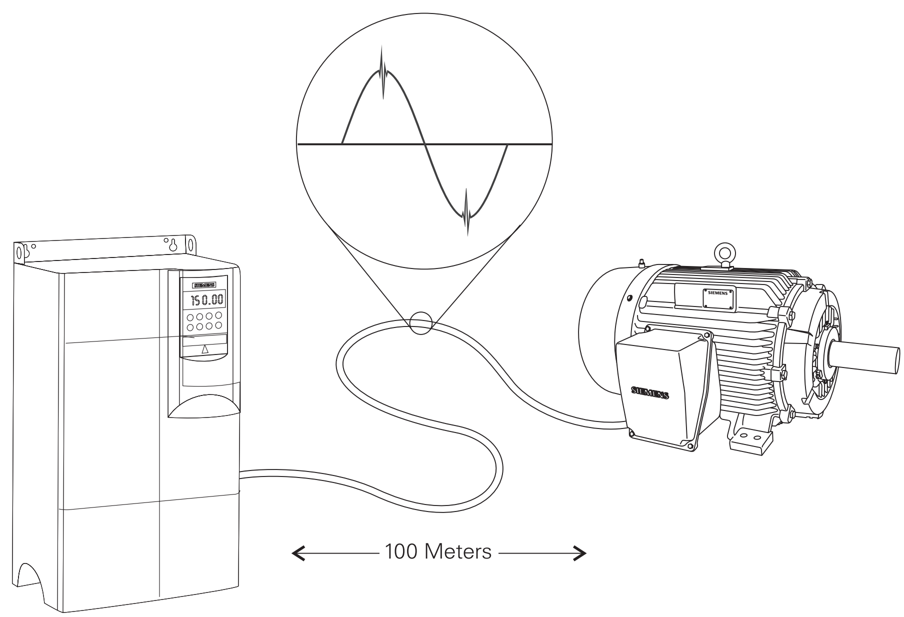
In order for an AC drive to operate in quadrant II or IV, a means must exist to deal with the electrical energy returned to the drive by the motor. Electrical energy returned by the motor can cause voltage in the DC link to become excessively high when added to existing supply voltage. Various drive components can be damaged by this excessive voltage. An optional braking resistor is available for the Siemens MICROMASTER. The braking resistor is connected to terminals B+ and B-. The braking resistor is added and removed from the circuit by an IGBT. Energy returned by the motor is seen on the DC link. When the DC link reaches a predetermined limit the IGBT is switched on by the control logic. The resistor is placed across the DC link. Excess energy is dissipated by the resistor, reducing bus voltage. When DC link voltage is reduced to a safe level the IGBT is switched off, removing the resistor from the DC link. This is referred to as pulsed resistor braking. This process allows the motor to act as a brake, slowing the connected load quickly.

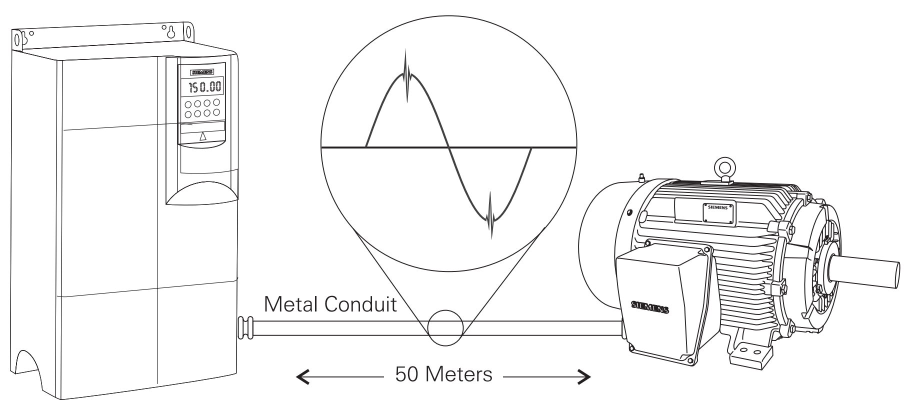


Distance to Motor

All motor cables have line-to-line and line-to-ground capacitance. The longer the cable, the greater the capacitance. Some types of cables, such as shielded cable or cables in metal conduit, have greater capacitance. Spikes occur on the output of all PWM drives because of the charging current of the cable capacitance. Higher voltage (460 VAC) and higher capacitance (long cables) result in higher current spikes. Voltage spikes caused by long cable lengths can potentially shorten the life of the inverter and the motor.

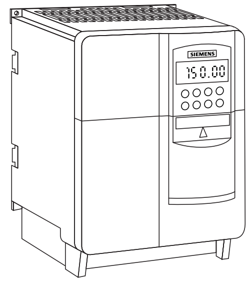
The maximum distance between a motor and the MICROMASTER, when unshielded cable is used, is 100 meters (328 feet). If shielded cable is used, or if cable is run through a metal conduit, the maximum distance is 50 meters (164 feet). When considering an application where distance may be a problem, contact your local Siemens representative.





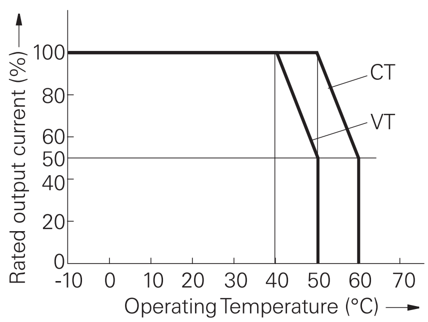
Enclosures

The National Electrical Manufacturers Association (NEMA) has specified standards for equipment enclosures. The MICROMASTER is supplied in a protected chassis and a NEMA Type 1 enclosure.



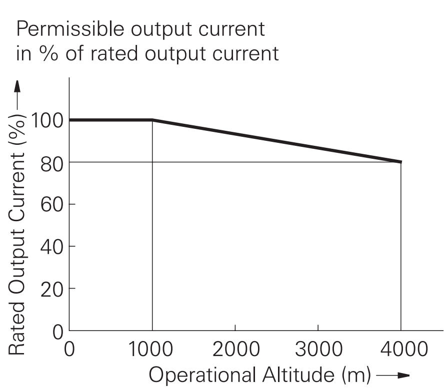
Ambient Temperature

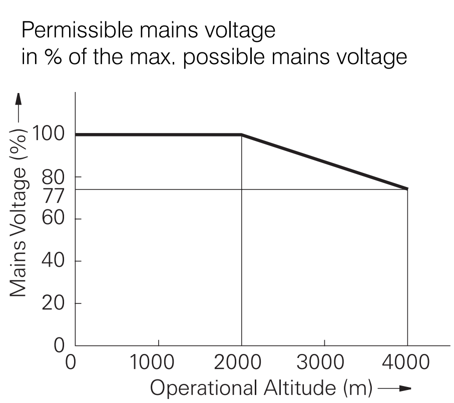
The MICROMASTER is rated for operation in an ambient temperature of 0 to 40° C for variable torque drives and 0 to 50°C for constant torque drives. The drive must be derated to operate at higher ambient temperatures.



Elevation

The MICROMASTER is rated for operation below 1000 meters (3300 feet). At higher elevations the air is thinner, consequently the drive can't dissipate heat as effectively and the drive must be derated. In addition, above 2000 meters (6600 feet) the supply voltage must be reduced.





Review 4

1. The ____________ key on the BOP and AOP is used to toggle between a parameter number and value.

2. The maximum acceleration/deceleration ramp time on the MICROMASTER is ____________ seconds.

3. A mode of operation which provides a V/Hz curve that matches the torque requirements of simple fan and pump applications is ____________ .

   a. Linear voltage/frequency
   b. Quadratic voltage/frequency
   c. FCC
   d. Sensorless vector frequency

4. ____________ uses internal computer algorithms to control an AC motor so that its performance is equal to that of DC motor.

   a. Linear voltage/frequency
   b. Quadratic voltage/frequency
   c. FCC
   d. Sensorless vector control

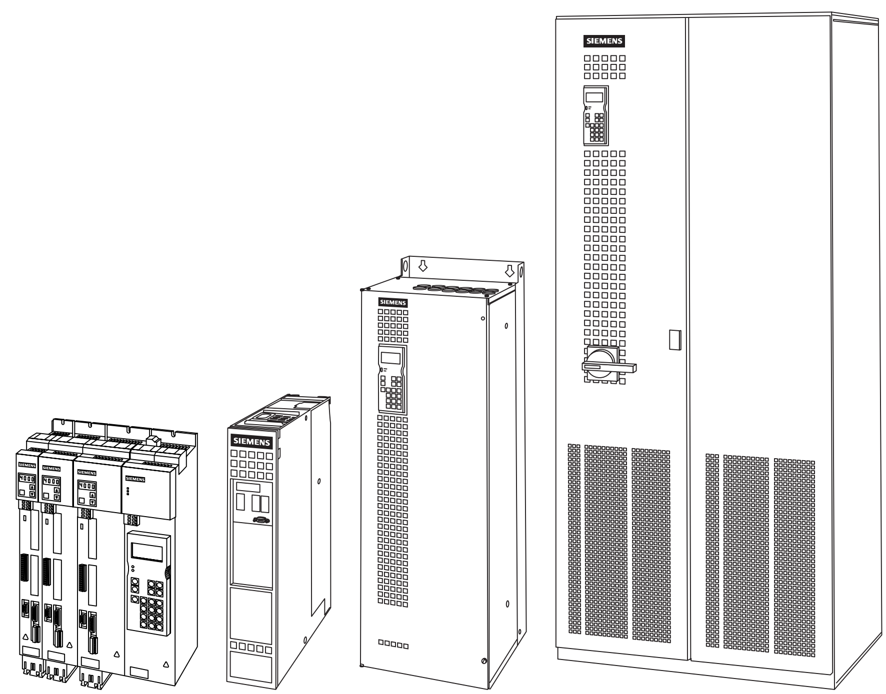
5. Forward regeneration occurs in quadrant ______ .

6. The maximum distance between a MICRMASTER and a motor is ____________ meters when unshielded cable is used.

7. 380 VAC to 480 VAC, Frame size B of the MICRAMASTER 420 is available in power ratings from ____________ to ____________ HP.

Siemens MASTERDRIVE

Siemens MASTERDRIVES provide an excellent solution for industrial applications worldwide. In addition to standard air cooled units, water cooled versions can be used in areas with high ambient temperature or where external air cooling is unavailable. MASTERDRIVES can be used for variable-speed control on motors rated from 1 to 5,000 HP. MASTERDRIVES are available for all major worldwide 3-phase supply voltages: 380-460, 500-575, and 660-690 volts. The Siemens MASTERDRIVES can also be referred to by a model series number, 6SE70.



Compact Plus	Compact	Chassis	Cabinet
1 - 25 HP	5 - 50 HP	50 - 1000 HP	50 - 5,000 HP

Versions

There are two versions of the MASTERDRIVES product: vector control (VC) and motion control (MC).

Vector Control (VC)

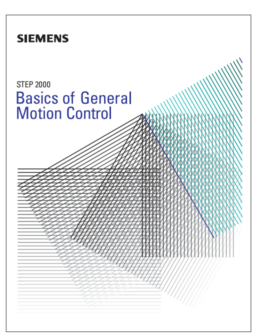
One mode of operation in the MASTERDRIVES is vector control (VC), which is the focus of this part of the course. In the past, the dynamic response of a DC motor was generally considered significantly better than an AC motor. An AC motor, however, is less expensive and requires less maintenance than a DC motor. Using a complex mathematical motor model and proprietary internal computer algorithms vector control is able to exert the necessary control over an AC motor so that its performance is equal to that of a DC motor. Vector control, flux vector, and field orientation are terms that describe this specialized control technique of AC drives.

Vector control drives have 4-quadrant operation and control torque and speed continuously through zero speed, and can hold a motor stationary against an applied torque. Speed control is exact, even with varying loads. Speed control reaction time is $\leq$ 45 ms without tach feedback, and $\leq$ 20 ms with tach feedback. Maximum torque is available up to base speed. Torque control reaction time is $\leq$ 10 ms in torque control with feedback.

Motion Control (MC)

A second mode of operation available on the MASTERDRIVES is motion control (MC). Servo drives are designed to operate with a specific motor and are designed to achieve speed precision and fast response to a speed change. Servo applications typically have rapid start-stop cycles, require zero speed holding torque and high accelerating torque from zero speed, and are used positioning applications. In a packaging machine, for example, material may have to start and stop at various positions along a conveyor system.

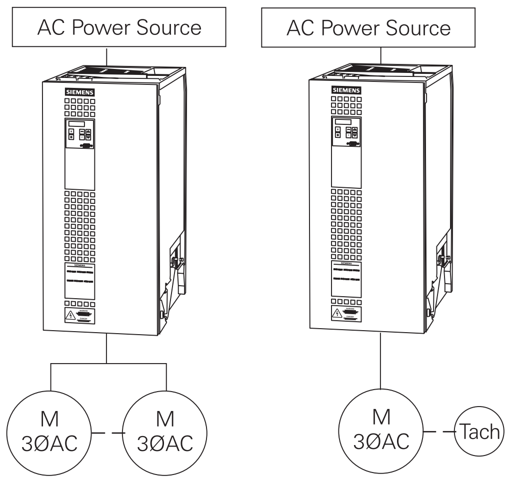
The STEP 2000 course, **Basics of General Motion Control**, provides more information on the Siemens motion control (MC) drive.



AC - AC (Converter)

The terms AC - AC and DC - AC refers to hardware methods of configuring MASTERDRIVES. AC - AC in the MASTERDRIVE VC family refers to a single drive, connected to an AC source, controlling an AC motor, an AC motor with a tach, or multimotor applications.

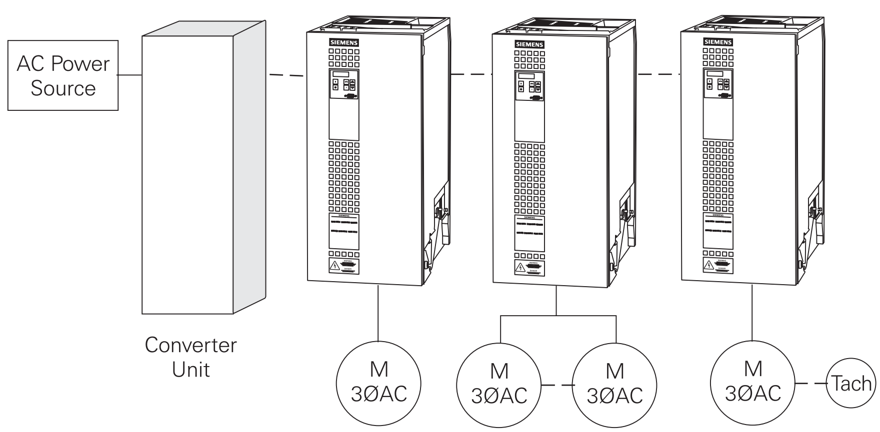
AC - AC Versions



DC - AC (Inverter)

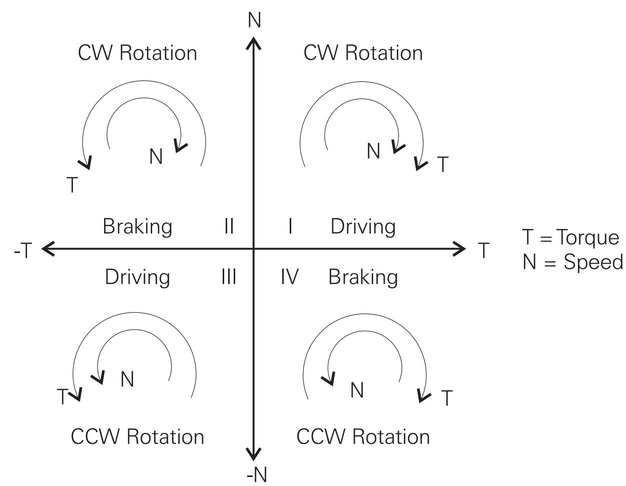
The MASTERDRIVE VC can also be configured so that a common DC bus supplies power to several AC inverters. Common DC bus systems also allow single and multimotor combinations. This is referred to as DC-AC. An advantage to this system is that energy regenerated by one inverter can be consumed by another inverter on the same bus.

DC - AC Version



Braking Choices

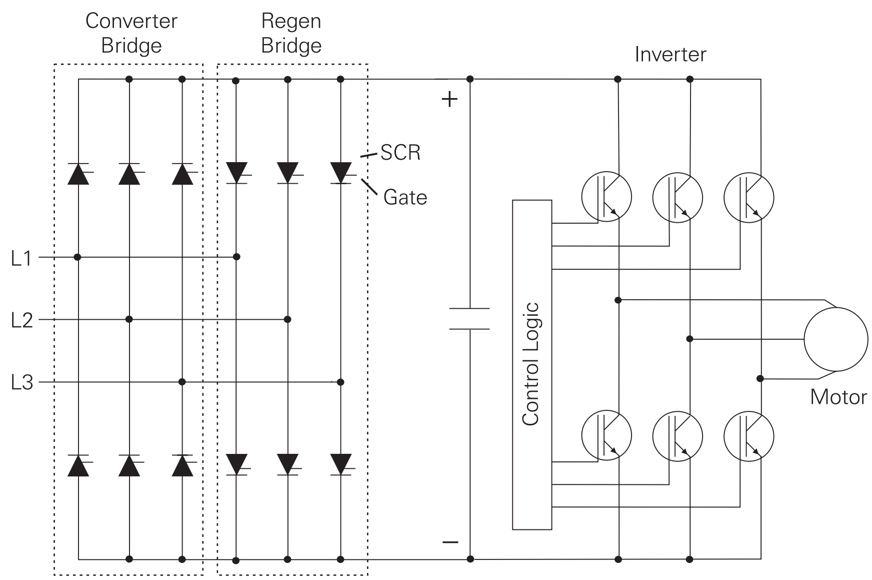
The dynamics of certain loads require four-quadrant operation. Torque will always act to cause the rotor to run towards synchronous speed. If the synchronous speed is suddenly reduced, negative torque is developed in the motor. This could occur, for example when a stop command is initiated and the drive tries to slow down to bring the motor to a stop. The motor acts like a generator by converting mechanical power from the shaft into electrical power which is returned to the AC Drive. This is known as regeneration, and helps slow the motor. Braking occurs in quadrants II and IV. When equipped with an optional braking unit, Siemens MASTERDRIVEs are capable of four-quadrant operation.



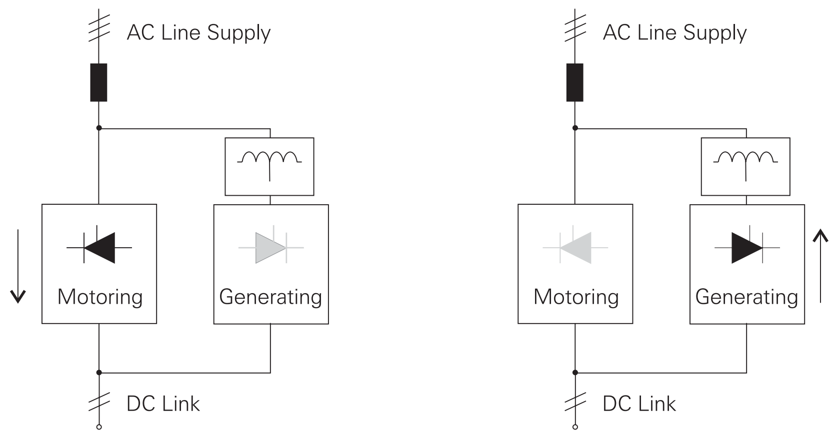
One method of dealing with negative torque and the current it produces is controlled deceleration. Voltage and frequency is reduced gradually until the motor is at stop. This would be similar to slowly removing your foot from the accelerator of a car. Many applications, however, require the motor to stop quicker, and the drive must be capable of handling the excess energy produced by motor when this is done.

Rectifier Regenerative Front End

Another method of dealing with excessive regeneration is with a rectifier regenerative front end. Diodes in the converter section are replaced with SCRs and a second regen bridge is added. An SCR functions similarly to a diode rectifier, except that it has a gate lead, which is used to turn the SCR on. This allows the control logic to control when the converter bridge and regen bridge are turned on.



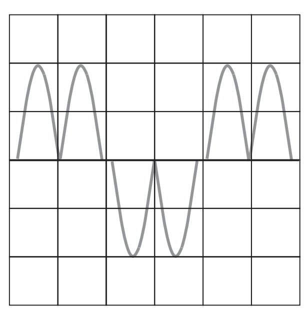
A simplified block diagram provides a clearer view of the regen process. When the motor needs motoring energy to accelerate or maintain speed against the inertia of a load, the converter bridge is turned on. When the motor is in the regenerative mode, it acts like a generator, supplying electrical energy back to the DC link. When the DC link voltage reaches a predetermined level the motoring SCRs are switched off and the regen (generating) SCRs are switched on.



Motoring Phase Control On
Motoring

Motoring Phase Control Off
Regen

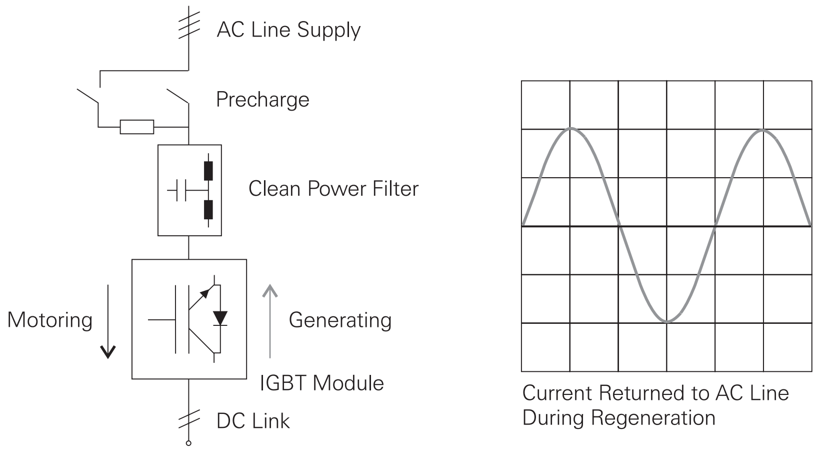
This allows the excess energy to be returned to the AC line in the form of AC current.



Current Returned to AC Line
During Regeneration

ACTIVE FRONT END

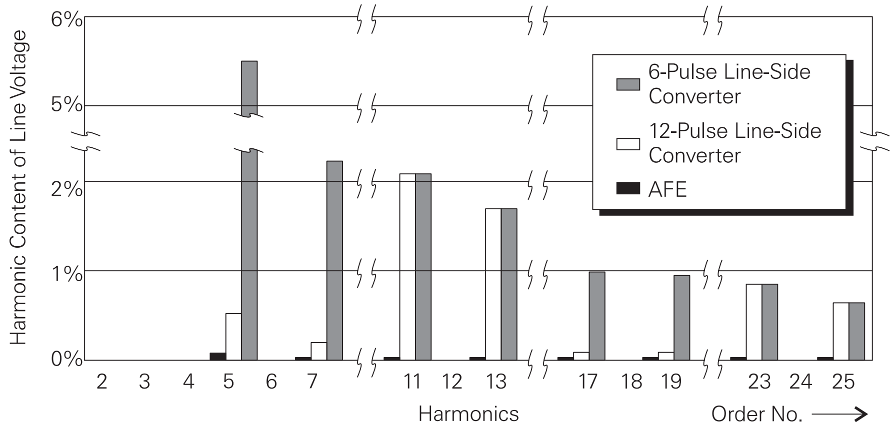
An ACTIVE FRONT END (AFE) is another option available to control regenerative voltage. With this option the diodes in the converter bridge are replaced with IGBT modules and a Clean Power Filter. The IGBT, controlled by control logic, operates in both motoring and regenerating modes.



Current Returned to AC Line
During Regeneration

Harmonics are created by electronic circuits, such as the non-linear loads of adjustable speed drives. Harmonics can cause problems to connected loads. The base frequency is said to be the fundamental frequency or first harmonic. Additional harmonics that are superimposed on the fundamental frequency are usually whole number multiples of the first harmonic. The fifth harmonic of a 60 Hz power supply, for example, is 300 Hz (60 x 5).

A distinct advantage of Siemens MASTERDRIVES equipped with AFE and a Clean Power Filter is they are optimally harmonized with each other to eliminate harmonics and provide a clean power supply. In addition, the Siemens AFE allows for capacitive KVAR production which effectively compensates for other inductive loads in an industrial plant. This helps reduce the overall utility bill.



Programming and Operating Sources

Access is gained to the MASTERDRIVE VC for programming operating parameters and motion profiles from the following sources:

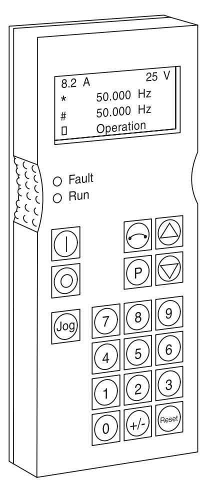
Operator Control Panel (OP1S)
Parameterization Unit (PMU)
Various Serial Interfaces
PC Based Software (Simovis)

PMU, OP1S, and HMI Panels

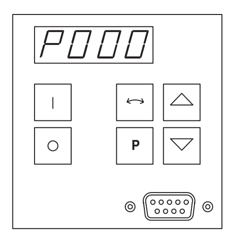
The MASTERDRIVE can be programmed and operated by the PMU, OP1S, or other SIMATIC HMI device such as the TP170A (shown), TP170B, OP27, or MP370.

Parameters, such as ramp times, minimum and maximum frequencies, and modes of operation are easily set. The changeover key ("P") toggles the display between a parameter number and the value of the parameter. The up and down pushbuttons scroll through parameters and are used to select a parameter value, once the "P" key sets the parameter. The OP1S has a numbered key pad for direct entry. The TP170A uses a touch-sensitive screen for control and monitoring.

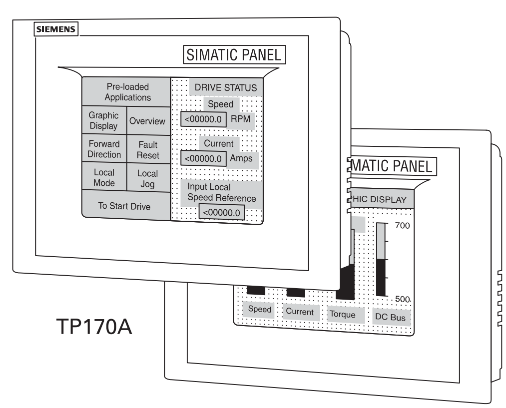
Serial communication is available through RS232 or RS485 connections. The OP1S can be mounted directly on the PMU or up to 200 meters away. An additional 5 volt power supply is required for remote operation over 5 meters. The TP170A is powered from the drive and standard PROFIBUS connections.



OP1S



PMU

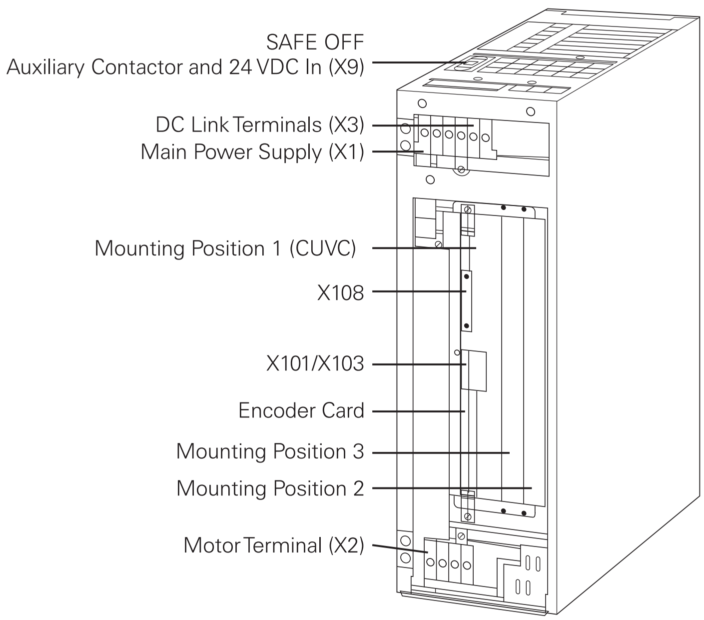


TP170A

MASTERDRIVE Compact, Chassis, and Cabinet Units

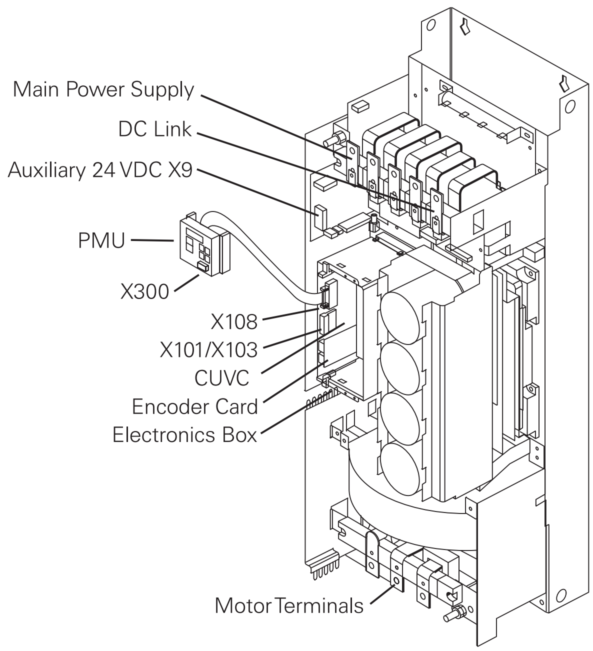
Compact Drive

The compact drive is available with ratings from 3 to 50 HP (5.6 to 72 amps) at 460 VAC. The following drawing represents is a layout illustration of sizes A, B, and C. Size D is packaged in a larger form. The main power supply (380 - 480 VAC) is connected to X1. The DC link is available at X3. The servomotor is connected to X2.



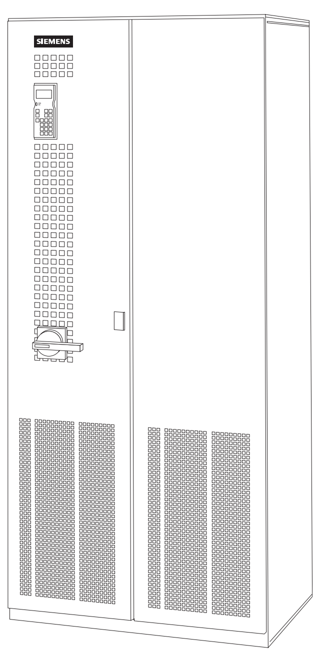
Chassis Drive

The chassis drive uses an open architecture for cabinet mounting. Chassis drives are available with ratings from 60 to 500 HP (83.7 to 590 amps) at 460 VAC. The following drawing illustrates sizes E and F. Size G is packaged in a larger form.



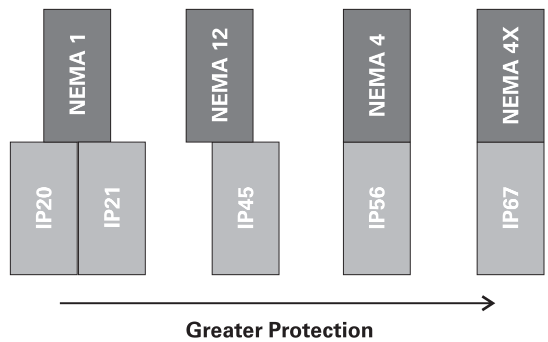
Cabinet Units

Cabinet units, referred to as 6SE71 for IEC standards or 6SE72 for NEMA standards, are ready-wired complete units for single and multimotor applications. All components are accessible from the front of the cabinet. Cabinet units are available with ratings from 50 to 10,000 HP.



IEC and NEMA Protection

Depending on the size of the unit, Siemens MASTERDRIVES are available in a variety of enclosures. In addition to the basic MASTERDRIVE 6SE70 enclosures, drives designated 6SE71 are built to International Electrotechnical Commission (IEC) standards. Drive enclosures designated 6SE72 are built to National Electrical Manufacturers Association (NEMA) standards. IEC and NEMA enclosure standards provide various degrees of protection to personnel and equipment.



IEC Standards

The IEC system of classification consists of the letters IP followed by two numbers. The first number indicates the degree of protection provided by the enclosure with respect to persons and solid objects entering the enclosure. The second number indicates the degree of protection against the ingress of water.

1st Number	Description
0	Not Protected
1	Protected Against Objects Greater than 50 mm
2	Protected Against Objects Greater than 12 mm
3	Protected Against Objects Greater than 2.5 mm
4	Protected Against Objects Greater than 1.0 mm
5	Protected Against Dust
6	Dust Tight
2nd Number	
0	Not Protected
1	Protected Against Dripping Water
2	Protected Against Dripping Water when Tilted up to 15°
3	Protected Against Spraying Water
4	Protected Against Splashing Water
5	Protected Against Water Jets
6	Protected Against Heavy Seas
7	Protected Against the Effects of Immersion for Specific Time and Pressure
8	Protected Against Continuous Submersion Under Conditions Specified by the Manufacturer

P Enclosures Available

MASTERDRIVES are available in the following IP enclosures:

MASTERDRIVE	IP Ratings Available
Compact, Compact Plus	IP20
Chassis	IP00, IP20
Cabinet	IP20, IP21, IP23, IP24, IP43, Prepared for IP54

NEMA Standards

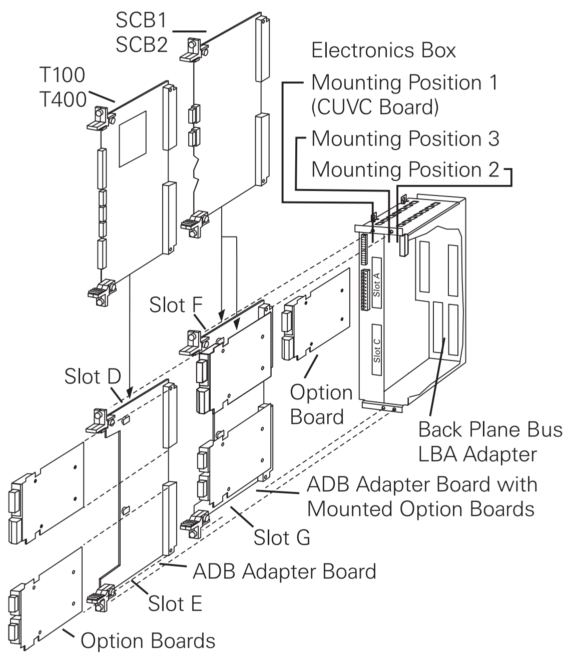
The National Electrical Manufacturers Association (NEMA) also designates, by means of a type number, environmental conditions an enclosure is suited for. MASTERDRIVEs are available in NEMA 1, 4, and 12 enclosures.

NEMA Type	Definition
1	Indoor use primarily to provide a degree of protection against limited amounts of falling dirt.
4	Indoor or outdoor use primarily to provide a degree of protection against windblown dust and rain, splashing water, hose-directed water, and damage from external ice formation.
4X	Indoor or outdoor use primarily to provide a degree of protection against corrosion, windblown dust and rain, splashing water, hose-directed water, and damage from external ice formation.
12	Indoor use primarily to provide a degree of protection against circulating dust, falling dirt, and dripping noncorrosive liquids.

Electronics Box

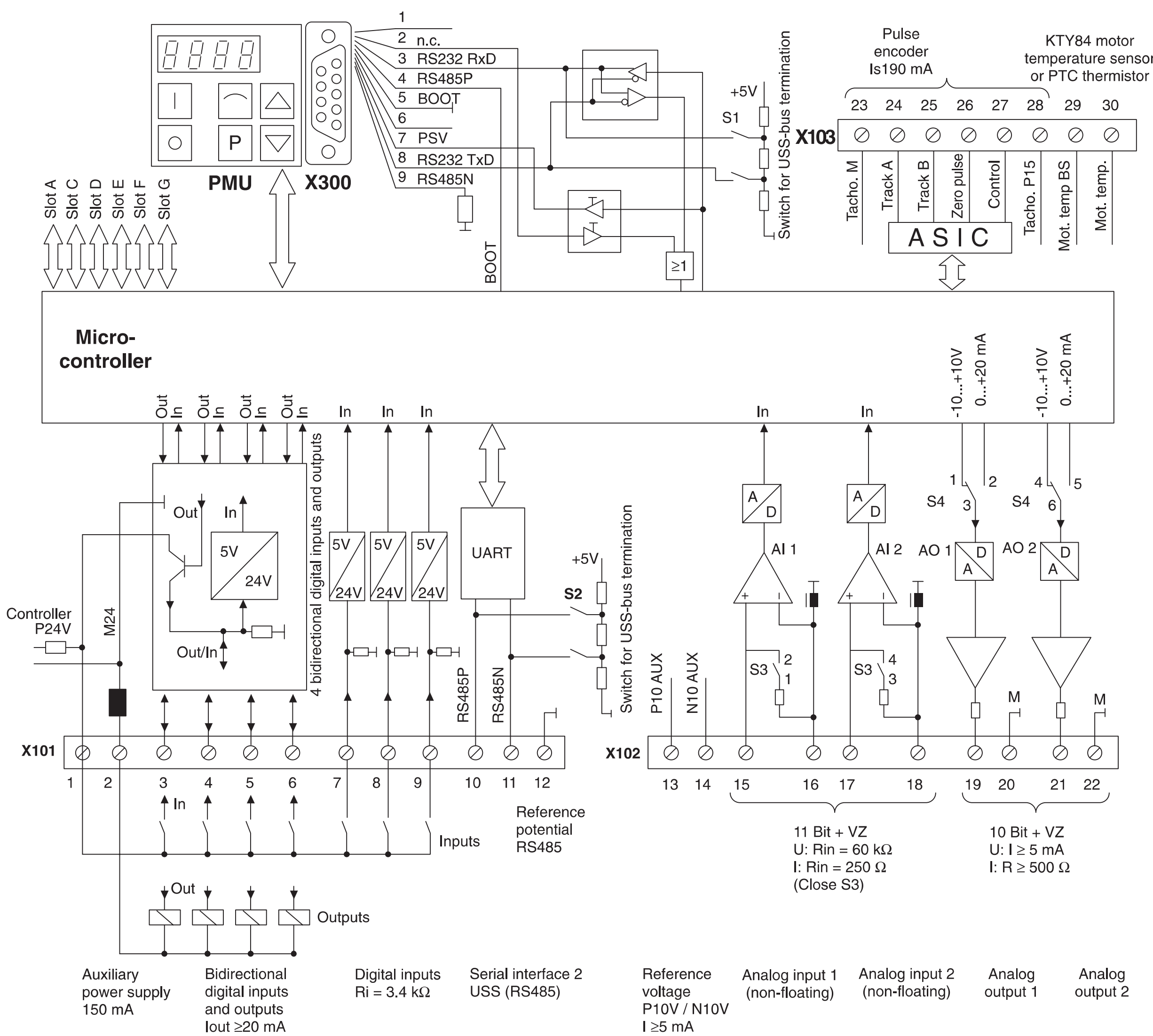
The electronics box contains the CUVC and option boards. The CUVC board is plugged into slot 1. The CUVC board is the central electronic board for all AC-AC and DC-AC 6SE70 VC MASTERDIRVES. It has input and output connections for wiring the control devices of various functions such as start/stop pushbuttons and speed potentiometer. The CUVC board is self-optimizing and has comprehensive diagnostics.

Up to six boards can be installed in the electronics box. An LBA (Local Bus Adapter) is required if mounting positions 2 or 3 are needed. In addition, adapter boards (ADB) are necessary for Slots D and E, and F and G when utilizing the half-size option boards. Option boards are automatically recognized by the drive.



CUVC Control Board

The Siemens MASTERDRIVE can be programmed and operated from the terminal strip located on the CUVC board. The following drawing illustrates a typical terminal arrangement of the CUVC board used in the MASTERDRIVE VC. RS 485 serial communication is available on X101. Programmable binary outputs, used to indicate a condition of the drive, are available on X101. Binary inputs are also available. Starting/stopping the drive and selecting preset speeds are examples of possible binary input functions. The MASTERDRIVE accepts analog inputs (voltage or current) for speed control on X102. There are programmable analog outputs for meter indication. A motor temperature switch can be connected on X103 and is used to stop a drive in the event a motor becomes overheated. Connections are also available for a digital tach. Not all features are available on all versions. Consult detailed product literature for more information.



Communication Options

Communication option boards CBP2, SLB, SCB1, and SCB2 allow high speed communication through RS 485 wires or fiber-optic cables. Peer-to-peer communication allows data to be exchanged between drives and is available using serial communication boards SLB, SCB1, and SCB2, and technology boards T100, T300, and T400. PC and PLC communication is available with SCB2 (USS Protocol) and communication board CBP2 (PROFIBUS). Communication boards are also available to support CAN Bus and DEVICE NET.

The SLB board is used for peer-to-peer communication with other drives via SIMOLINK. SIMOLINK is a high speed (11 mbaud) fiber optic ring bus that allows various data to be passed from one drive to next.

Expansion Boards

Expansion boards are used to expand the number of digital and analog inputs and outputs. In addition to a 120 volt interface that is available, EB1 and EB2 are half-sized expansion boards that provide a number of additional I/O possibilities.

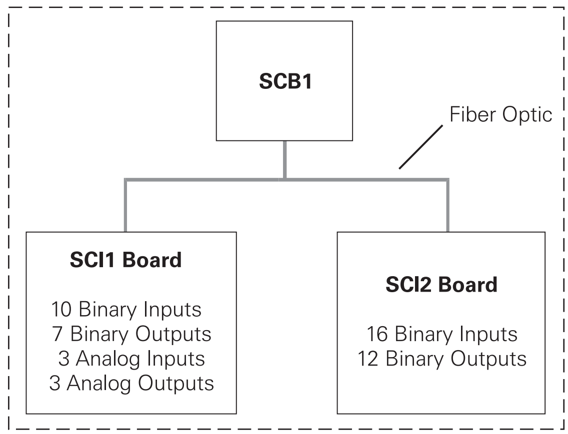
The EB1 board has three digital inputs and four bidirectional digital I/O. Bidirectional I/O can be configured as a digital input or output. One of the analog inputs is used as a voltage or current reference input. Two of the analog inputs can also be configured as digital inputs.

The EB2 board has two digital inputs, one analog input, and one analog output. In addition, the EB2 has four relay contacts. Three of the contacts are normally open (NO) and one of the contacts can be configured as normally open (NO) or normally closed (NC). A maximum of two half-sized EB boards can be used.

I/O	EB1	EB2	120 Volt Interface
Digital Inputs	3	2	5
Bidirectional Digital I/O	4	0	0
Analog Inputs	3	1	0
Analog Outputs	2	1	0
Relay Outputs	0	4	3
Input for 24 V Power Supply	1	1	0

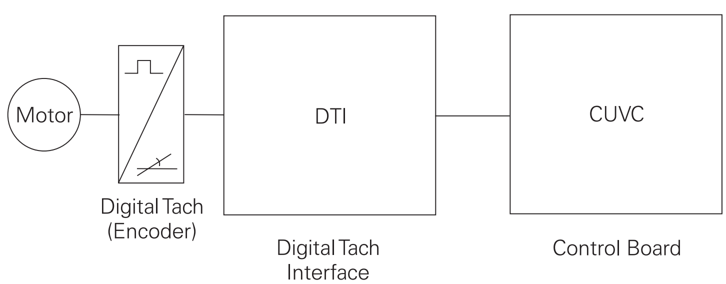
SCB1

In addition to peer-to-peer drive communication the SCB1 can interface with one or two SCI boards. SCI boards provide additional inputs and outputs for drive control. SCI1 has 10 binary inputs, 7 binary outputs, 3 analog inputs, and 3 analog outputs. SCI2 has 16 binary inputs and 12 binary outputs. Inputs and outputs on the SCI1 and SCI2 boards provide more isolation and electromagnetic noise immunity than the standard I/O on the CU boards. SCI1 or SCI2 boards should be used in applications where noise immunity is a concern. The SCB2 board does not interface with SCI boards.



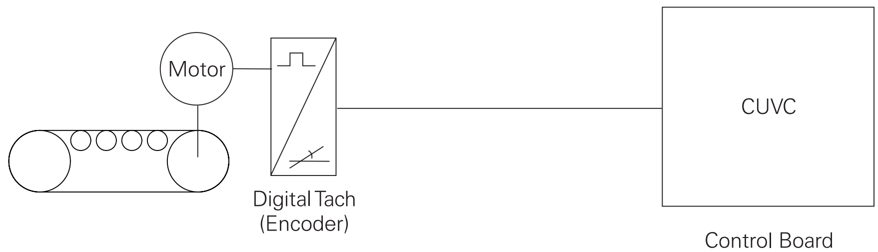
Encoder Interfaces

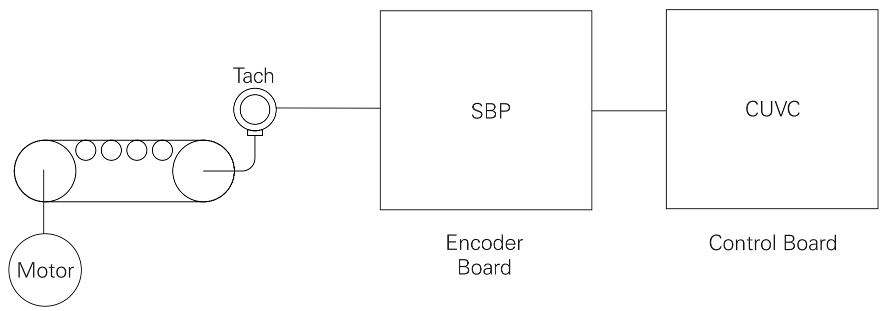
Digital tachometers (encoders) can be used to measure the actual speed of the motor. The Digital Tachometer Interface (DTI) is designed to be used with digital tachometers (encoders) that operate at a voltage other than 11-30 VDC. The DTI is also required for use with HTL encoders with inverted channel, floating HTL encoders, TTL encoders, or encoders with cables greater than 495 feet.



SBP Encoder Board

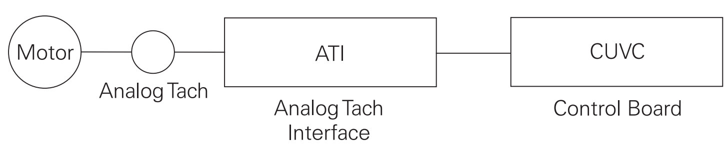
The SBP is an option that can be used to connect a second digital tach to the drive. This option can be used with differential or frequency control. The SBP can also be used to monitor an external encoder, such as might be connected to the driven machine.





Analog Tachometers

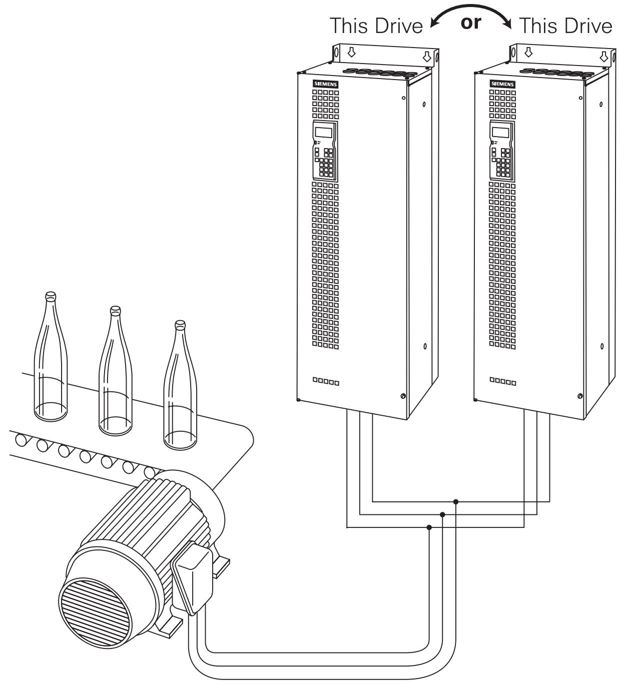
Analog tachometers can also be used to measure the actual motor speed. Analog tachometers generate a DC voltage which is proportional to the speed. The voltage at maximum speed is a function of the actual tachometer, and generally lies between 10 V and 300 V. Closed loop speed control with an analog tach can be applied to a speed range from 1 RPM to 6000 RPM. An analog tach interface (ATI) board is used to connect an analog tach to the CUVC board.



Technology Boards

Technology boards (T100, T400, and TSY) provide application specific control and enhancement. It should be noted that technology boards are not compatible with the optional 120 volt interface card. Technology option boards can be selected for sectional drives, synchronized running, winders, and positioning.

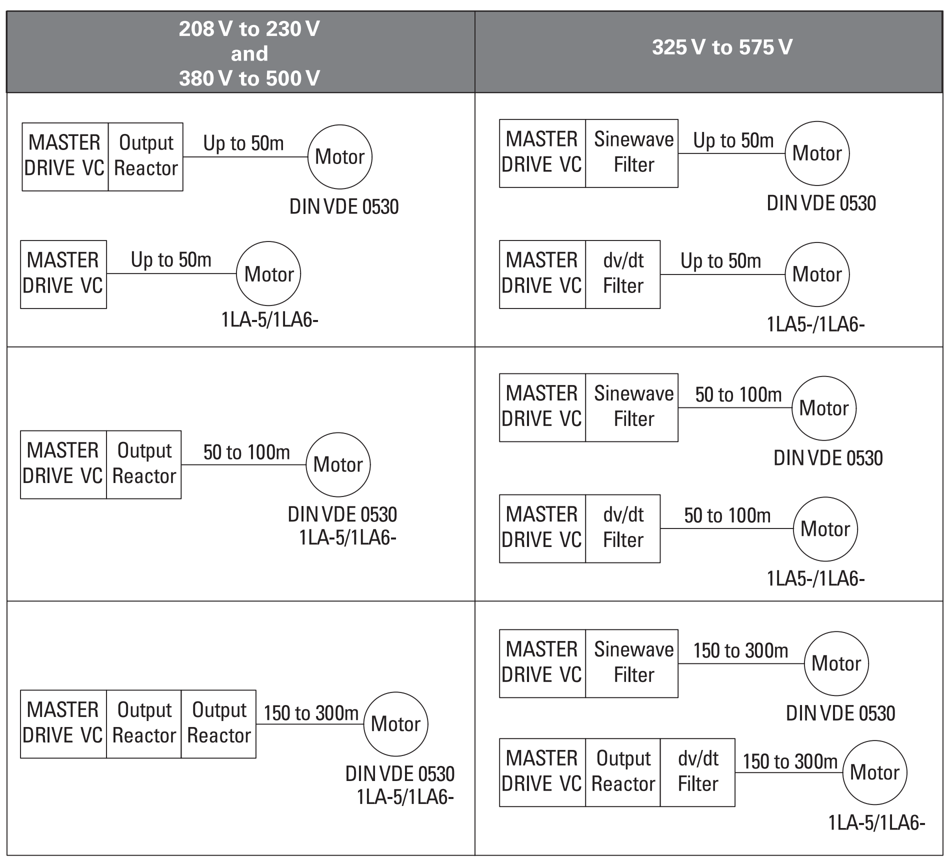
The TSY, for example, allows a drive to synchronize with a frequency. This is ideal for transferring motors across the line, or for synchronizing to the output of another drive for transferring the motor from one drive to another without shutting down a process.



Sinewave Filter and dv/dt Filter

Distance from the drive to the motor must also be taken into consideration. All motor cables have line-to-line and line-to-ground capacitance. The longer the cable, the greater the capacitance. Some types of cables, shielded cable for example, have greater capacitance. Spikes occur on the output of all PWM drives because of the charging current of the cable capacitance. Higher voltage (460 VAC) and higher capacitance (long cables) result in higher current spikes. Voltage spikes caused by long cable lengths can potentially shorten the life of the motor. Spikes are generally the same value regardless of horsepower, therefore; smaller horsepower motors are more susceptible to damage.

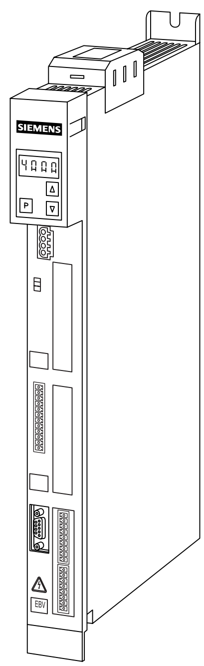
Various devices are available for the MASTERDRIVE VC to protect the inverter and motor. A dv/dt filter, for example, limits motor voltage rise time (dv/dt) and maximum voltage spikes. This allows cable lengths greater than 300 meters. Another device designed to protect the motor from high voltage spikes is a sinewave filter. The sinewave filter generates a sinusoidal motor voltage and output current. It is very important to fully understand the chart, which shows the criteria for selecting the proper output reactor, dv/dt filter, or sinewave filter. Motor life will be shortened if the guidelines are ignored.



Note: A sinewave filter will improve the current waveform but reduces RMS voltage by 20%. Refer to Siemens VC product catalog #DRMS-02051 or contact a Siemens sales representative for assistance on lengths greater than 300m.

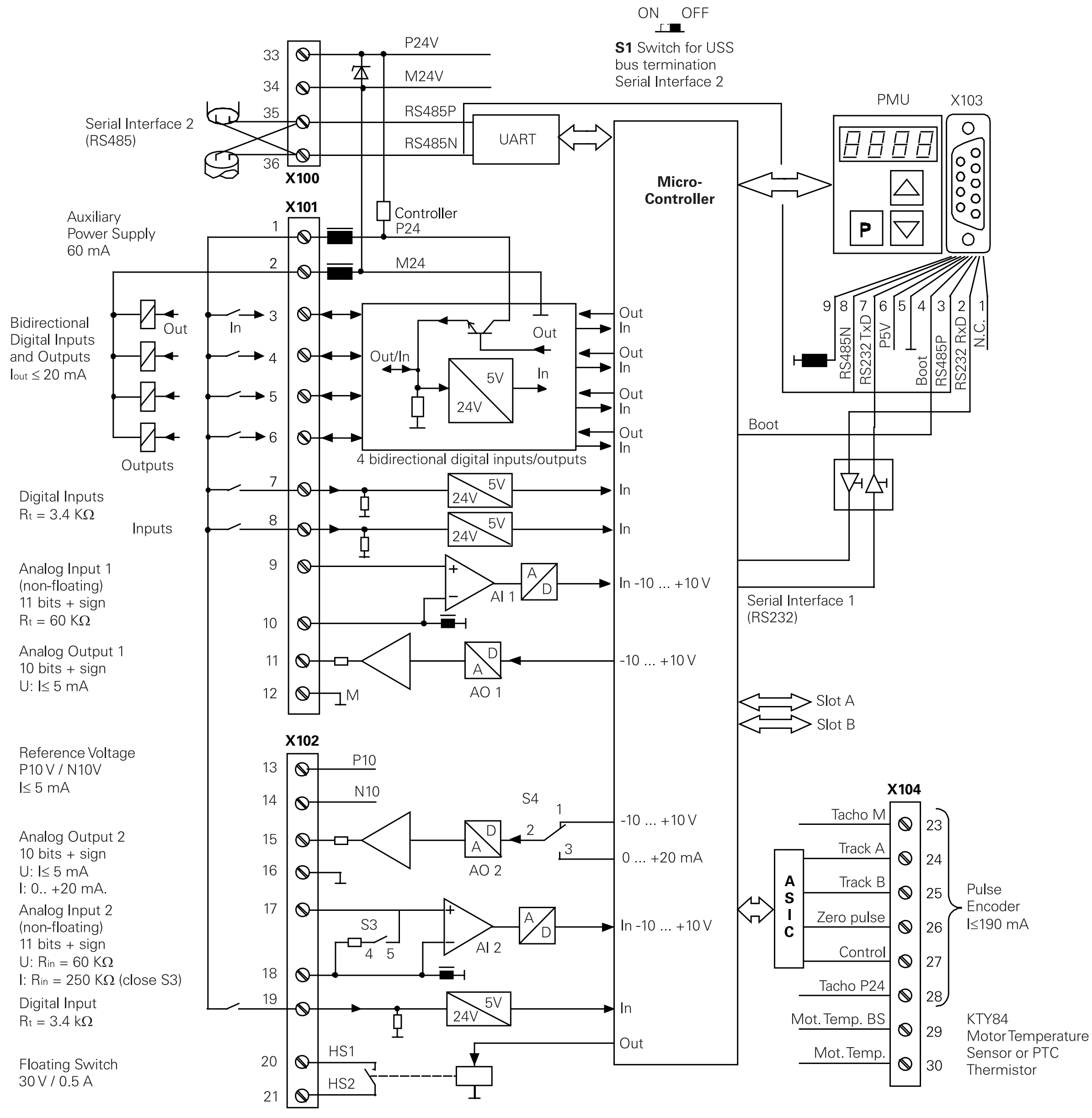
MASTERDRIVE Compact Plus

The Compact Plus is a member of the MASTERDRIVE product line. The Compact Plus offers many of the same features as the larger MASTERDRIVE products in a smaller package. Compact Plus drives are available in ratings from 1 to 25 HP. The Compact Plus is ideally suited for applications requiring high performance where space is at a premium.



Control Terminals

The following schematic illustrates the control wiring for the Compact PLUS. The micro-controller is the "brains" of the drive. The control unit controls all drive functions such as start, stop, acceleration, deceleration, motor voltage and frequency, monitoring, and other functions.



24 Volt Power Supply

When the DC link is charged control voltage is supplied by an internal source. In addition, a 24 volt power supply can be connected to the drive. This enables parameterization and monitoring of the unit even when the DC link voltage has been discharged. The 24 VDC can be cascaded on AC - AC units via terminals 33 and 34 of X100. X100 also provides a connection to cascade a serial USS interface (RS485). Switch S1 is used to turn the USS interface on and off.

X101 and X102 Control Terminals

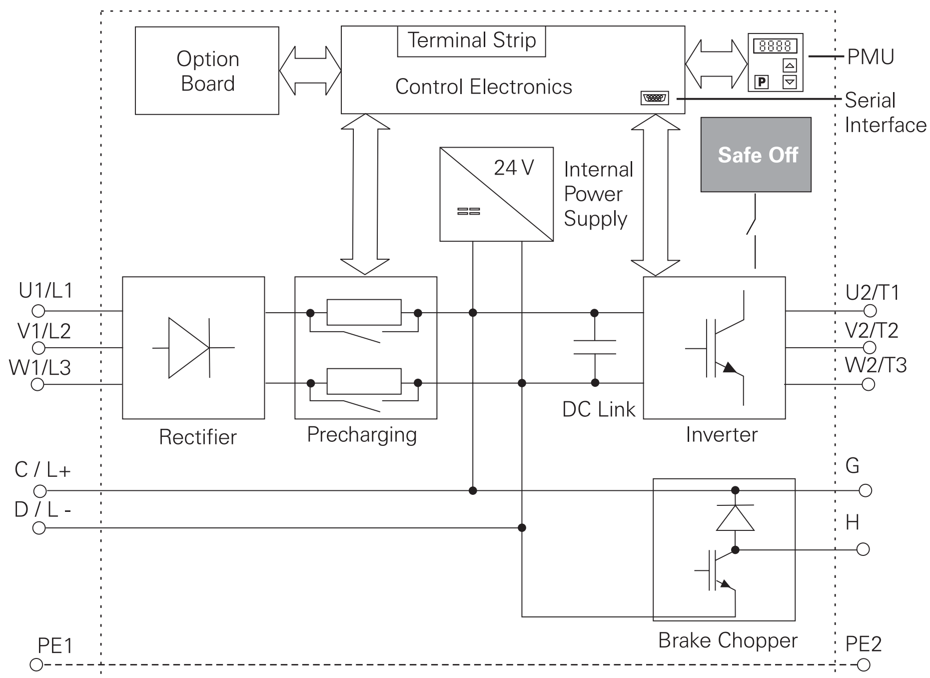
There are four bidirectional digital inputs and outputs. These can be programmed for various functions. Outputs, for example, can be programmed to signal a run or stop condition. Inputs can be programmed as start/stop commands. There are three additional digital inputs, which can be used for high speed inputs with a sampling time of 1 µs. There are two analog inputs and two analog outputs.

X103 Terminal

An OP1S, PC, or other device can be connected to X103 serial port. An internal link to the USS RS485 interface makes it possible to communicate with other devices which are connected to the serial USS interface.

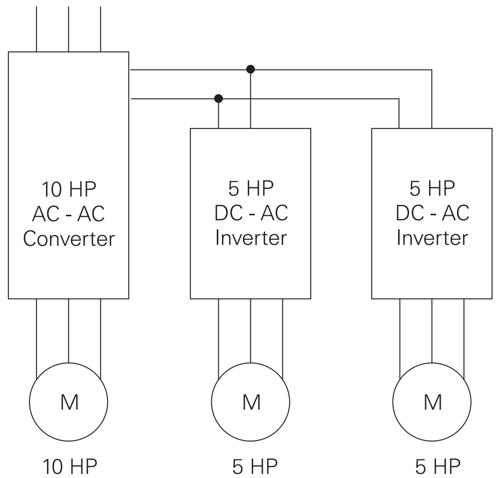
SAFE OFF

SAFE OFF is a function that prevents unintended movement or restarting of a drive after shutdown. This function is available as an option in Compact PLUS drives.



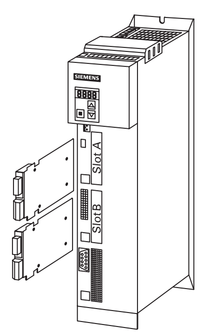
Multi-Motor Systems

Multi-motor drive systems may be implemented with the Compact Plus. Compact Plus AC-AC drive converters can be used to supply power to additional inverters. In the following illustration, for example, a 10 HP converter can also supply two 5 HP inverters.



Option Boards

The capabilities of the Compact Plus can be expanded with the use of option boards. Up to two option boards can be installed in the Compact PLUS unit.



Communication Boards	
CBP2	Communication via PROFIBUS-DP
CBC	Communication via CAN Bus
SLB	Communication between Siemens drives via SIMOLINK
Terminal Expansion Boards	
EB1	4 Bidirectional Digital Inputs/Outputs
	3 Digital Inputs
	2 Analog Outputs
	3 Analog Inputs
EB2	3 Relay Outputs with Make Contacts
	1 Relay Output with Change-Over Contact
	2 Digital Inputs
	1 Analog Output
	1 Analog Input
Pulse Encoder Evaluation	
SBP	Evaluation of an External Encoder (HTL or TTL)

Encoder Board

The SBP is used to connect a second pulse encoder to the drive. The SBP can also be used to monitor an external encoder, such as might be connected to the driven machine.

Communication Boards

There are a number of communication boards available for use with the MASTERDRIVE VC. The CBP2 board is used to connect the drive over the open field bus, PROFIBUS-DP. This protocol gives the MASTERDRIVE VC connection to all of Siemens automation products for a totally integrated solution.

SIMOLINK Board

The SLB board is used for peer-to-peer communication with other drives via SIMOLINK. SIMOLINK is a high speed (11 mbaud) fiber optic ring bus that allows various data to be passed from one drive to the next.

Expansion Boards

Expansion boards are used to expand the number of digital and analog inputs and outputs. Depending on the application, EB1 or EB2 can be selected.

Review 5

1. The Siemens MASTERDRIVE can be referred to by a model series number, ____________ .

2. A MASTERDRIVE configured so that a common bus supplies power to several AC inverters is referred to as ____________ .

3. ____________ ____________ ____________ with a Clean Power Filter is a braking option that returns braking energy to the power source and helps to reduce harmonics.

4. Compact units are available from 3 to ____________ HP.

5. Cabinet units are available from ____________ to 5,000 HP.

6. To help reduce or eliminate voltage spikes that can occur, a ____________ filter should be used with when the distance between a 325 V to 575 V MASTERDRIVE VC and a 1LA5-/1LA6- motor 50 to 100 meters.

7. Compact Plus drives are available from 1 to ____________ HP.

Parameters and Function Blocks

The MASTERDRIVE VC features an extensive parameter set that can easily be adapted to almost any drive task, from simple to complex. A wide scope of parameters include:

- Automatic Restart Function
- Restart on the Fly
- Control Modes
- Technology Functions
- Various Arithmetic Operations
- Acceleration/Deceleration Control

In addition the MASTERDRIVE VC supports a wide range of motors. A database of characteristics for specific motors is available, or characteristics for motors not already identified can be input. The MASTERDRIVE VC also supports a large database of faults and alarms. This provides the operator with a clear indication of what is needed to correct the problem.

There are literally hundreds of parameters within the MASTERDRIVE VC. It is beyond the scope of this course to cover these in any detail. However, it is important to understand how parameters and function blocks work together.

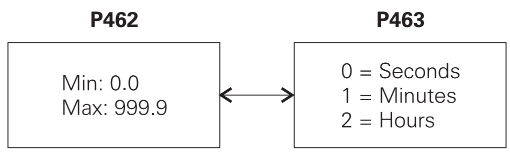
Parameters

A parameter is a variable that is given a constant value for a specific purpose or process. Parameter values are used to provide instructions to the drive. In the Siemens MASTERDRIVE VC each parameter is clearly designated by an assigned number. Parameters are differentiated according to their function:

- Function Parameters (can be read and written)
- Visualization Parameters (can only be read)
- BICO Parameters (can be read and written)

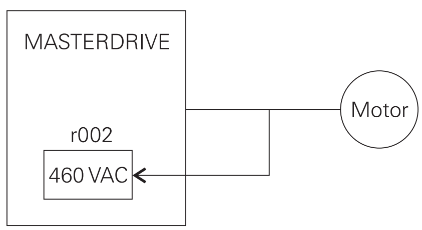
Function Parameters

Acceleration/deceleration times are examples of function parameters. P462 and P463, for example, work together to determine how much acceleration time is needed to accelerate the motor from 0 to 100% speed. P462 can be set between 0.0 to 999.9. P463 can be set for 0, 1, or 2. If P462 were set to 30.00 and P463 were set to 0, then the drive would take 30 seconds to accelerate the motor from 0 to 100% speed.



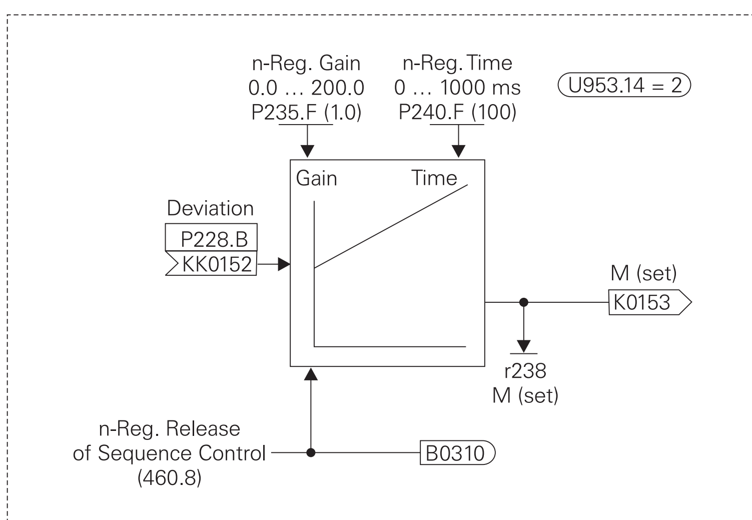
Visualization Parameters

Visualization parameters are used for visualizing internal quantities. These parameters are only displayed and cannot be changed by the operator. Visualization parameters are distinguished by a lower case "r." Parameter r002, for example, displays the value of voltage output to the motor.



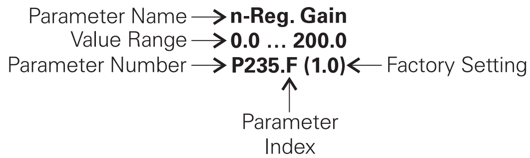
Function Blocks

A function block consists of several parameters grouped together to perform a specific task. The following function block represents one example of how a proportional/integral (PI) controller can be used in speed control of a MASTERDRIVE.



Function Parameters

The response of a function block is determined by function parameters. Proportional gain and integral time, for example, determine the response of a PI-controller. Each parameter has a name, identifying number, value range, and a factory setting. Function parameters can be indexed.



Indexing and Data Sets

In many applications it may be desirable to configure the MASTERDRIVE for variations in operation. For example, there may be a situation in an application where it is desirable to have different acceleration times. Indexed parameters can have up to four different values stored with them. Each value stored is part of a data set. Parameter P462, acceleration time, is an example of indexed parameter. P462 can have four different acceleration times stored. P462 could, for example, have the following values:

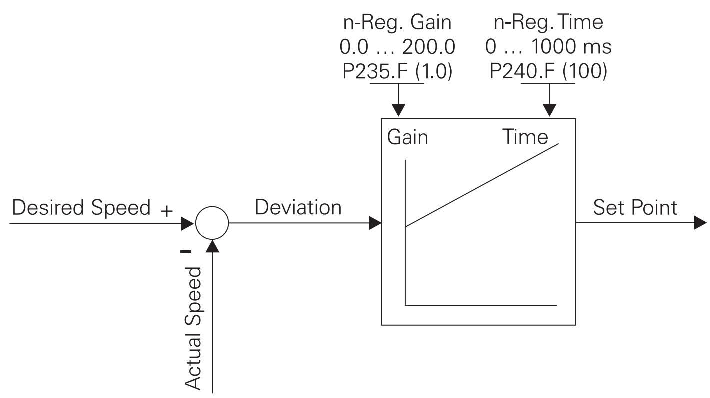
P462.1 = 0.50
P462.2 = 1.00
P462.3 = 3.00
P462.4 = 8.00

If data set 1 is active, the acceleration time is 0.50 seconds. If data set 2 is active, the acceleration time is 1.00 second. Data sets are operator selected and can be changed at any time.

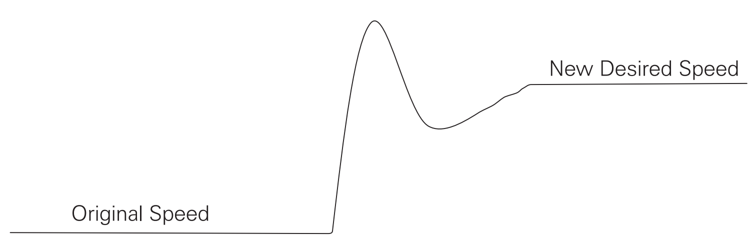
PI-Controller

PI-controllers are commonly used in drive technology. In our example the desired speed and actual speed are input to a summation point. The two signals are opposite in polarity. When the actual speed is equal to the desired speed the deviation, which is input into the PI-controller, is zero (0). Whenever desired speed and actual speed are different there is a deviation.

Changes in load on the motor, for example, can affect motor speed. A sudden increase in load would cause the motor to slow down. This would decrease the feedback from actual speed and the deviation would become more positive. It is also possible that the application may require the motor to slow down or speed up. Until the motor reaches the new desired speed there will be a deviation.

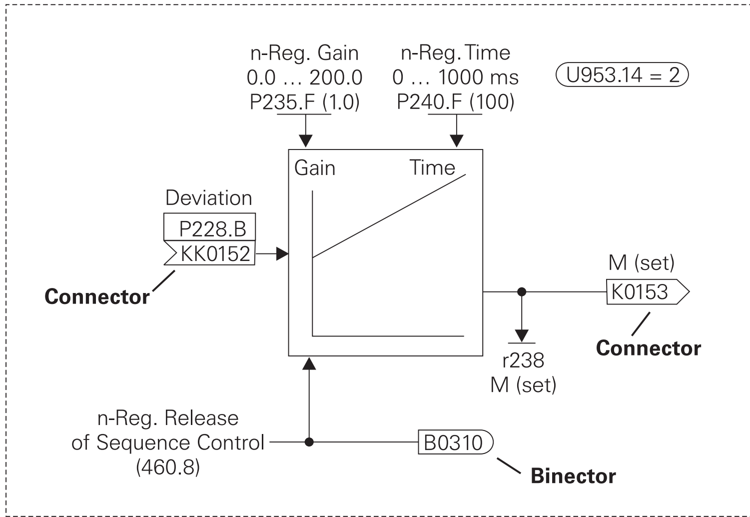


The PI-controller's job is to make speed corrections quickly with a minimal amount of overshoot and oscillation. Parameter P235 (gain) and parameter P240 (time) are used to tune the PI-controller's performance. The end result should be a fast response time with about a 43% initial overshoot. The motor should then settle in to the new desired speed.



Connectors and Binectors

Connectors and binectors are elements used to exchange signals between function blocks. Connectors are used to store analog values. Analog values are stored in the form that is represented by 16 bit or 32 bit words. Binectors are used to store binary (digital) information.

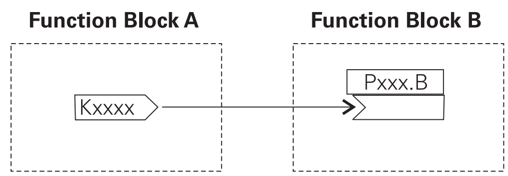


Connectors and binectors are identified by a name and number. Connectors with 16 bit resolution are identified with a “K.” Connectors with 32 bit resolution are identified with a “KK.” Binectors are identified with a “B.”

Connector Name	M(set, n-Reg)
Connector Number (16 Bit)	K0153
Connector Name	n(set, smooth)
Connector Number (32 Bit)	KK0150
Binector Name	Accel active
Binector Number	B0201

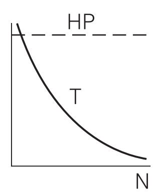
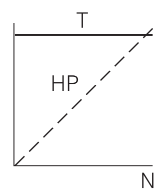
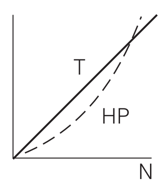
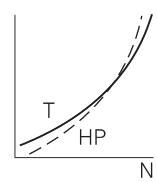
BICO Parameters

BICO is the term used to describe the method of connecting function blocks together. This is performed with **BI**nectors and **CO**nnectors. A connection between two function blocks consists of a connector or binector and a BICO parameter. With BICO parameters you can determine the sources of the input signals of a function block. This allows the user to "softwire" function blocks to meet specific application requirements.



Applications

When applying an AC drive and motor to an application it is necessary to know the horsepower, torque, and speed characteristics of the load. The following chart shows typical characteristics of various loads.

$T \approx \frac{1}{N}$	T = Constant	$T \approx N$	$T \approx N^2$
HP = Constant	$HP \approx N$	$HP \approx N^2$	$HP \approx N^3$
			
Winders Facing lathes Rotary cutting machines	Hoisting gear Belt conveyors Process machines involving forming Rolling mills Planers	Calenders with viscous friction Eddy-current brakes	Pumps Fans Centrifuges

Loads generally fall into one of three categories:

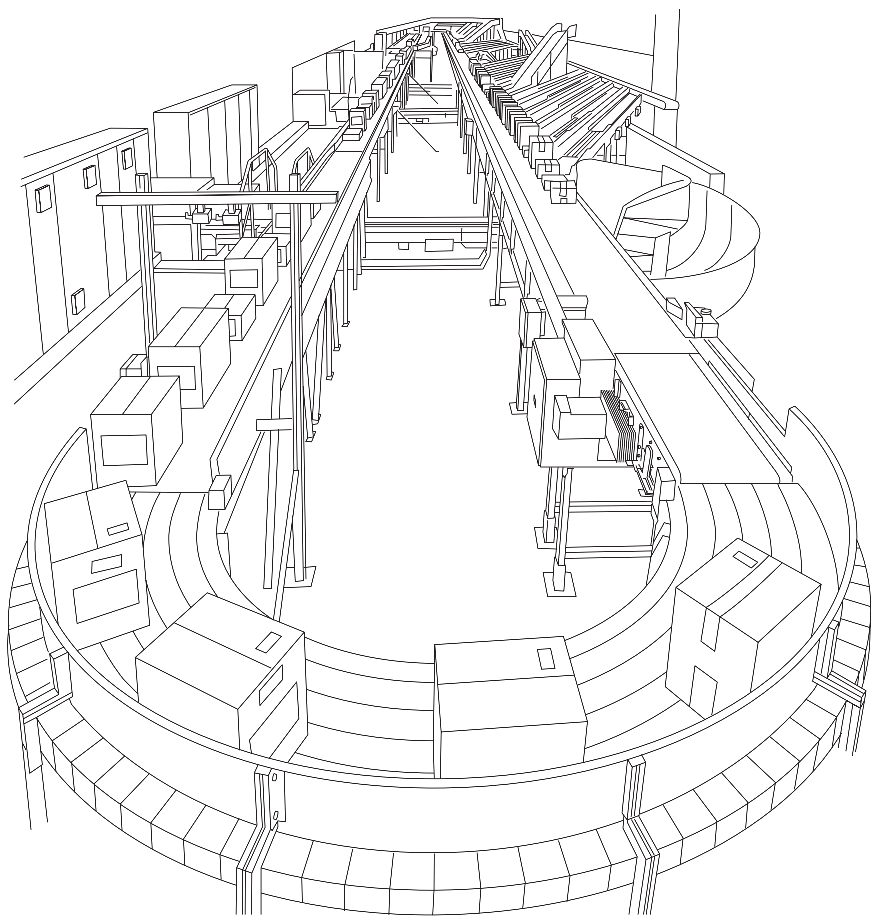
Constant Torque The load is essentially the same throughout the speed range. Hoisting gear and belt conveyors are examples.

Variable Torque The load increases as speed increases. Pumps and fans are examples.

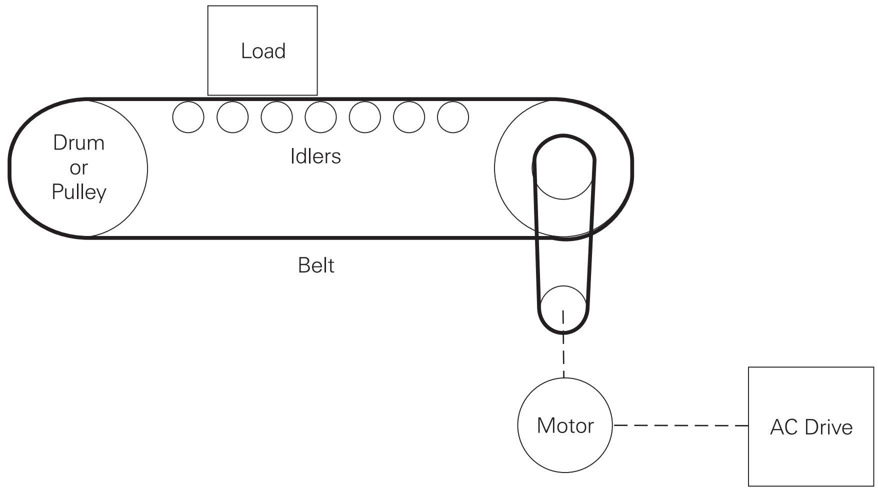
Constant Horsepower The load decreases as speed increases. Winders and rotary cutting machines are examples.

Constant Torque Applications

A constant torque load implies that the torque required to keep the load running is the same throughout the speed range. It must be remembered that constant torque refers to the motor's ability to maintain constant flux (Φ). Torque produced will vary with the required load. Peak torques in excess of 100% can occur at any speed, including zero speed. One example of a constant torque load is a conveyor similar to the one shown below. Conveyors can be found in all sorts of applications and environments, and can take many styles and shapes.



Conveyors are made up of belts to support the load, various pulleys to support the belt, maintain tension, and change belt direction, and idlers to support the belt and load.



Motor Speed

The speed and horsepower of an application must be known when selecting a motor and drive. Given the velocity in feet per minute (FPM) of the conveyor belt, the diameter in inches of the driven pulley, and the gear ratio (G) between the motor and driven pulley, the speed of the motor can be determined. The following formula is used to calculate conveyor speed.

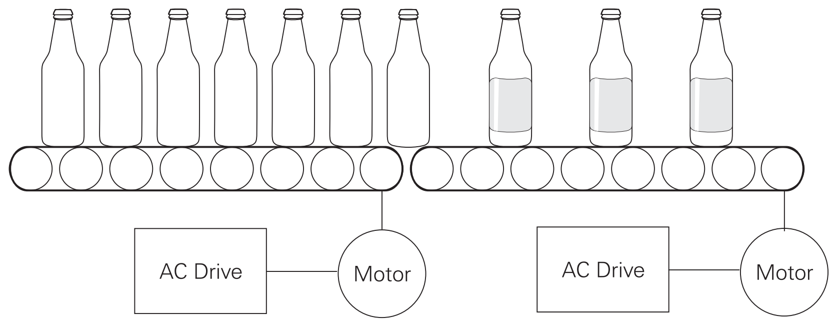
$$\text{Motor RPM} = \frac{\text{Conveyor Velocity (FPM)} \times G}{\pi \, x \left(\frac{\text{Diameter in Inches}}{12} \right)}$$

If, for example, the maximum desired speed of a conveyor is 750 FPM, the driven pulley is 18" in diameter, and the gear ratio between the motor and driven pulley is 4:1, the maximum speed of the motor is 638.3 RPM. It would be difficult to find a motor that would operate at exactly this speed. An AC drive can be used with an eight-pole motor (900 RPM). This would allow the conveyor to be operated at any speed between zero and the desired maximum speed of 750 FPM.

$$\text{Motor RPM} = \frac{750 \times 4}{3.14 \times \left(\frac{18}{12} \right)}$$

Motor RPM = 638 RPM

Another advantage to using AC drives on a conveyor is the ability to run different sections of the conveyor at different speeds. A bottle machine, for example, may have bottles bunched close together for filling and then spread out for labeling. Two motors and two drives would be required. One motor would run the filling section at a given speed and a second motor would run the labeling section slightly faster spreading the bottles out.



Horsepower

Calculating motor horsepower is complicated with many variables, which is beyond the scope of this course. Someone with knowledge of, and experience with conveyor operation would be required to accurately calculate the required horsepower. The horsepower required to drive a conveyor is the effective tension (T_e) times the velocity (V) of the belt in feet per minute, divided by 33,000.

$$HP = \frac{Te \times V}{33{,}000}$$

Effective tension (T_e) is determined by several forces:

- Gravitational weight of the load
- Length and weight of belt
- Friction of material on the conveyor
- Friction of all drive components and accessories
    - pulley inertia
    - belt/chain weight
    - motor inertia
    - friction of plows
    - friction of idlers
- Acceleration force when new material is added to conveyor

If the effective tension of a conveyor were calculated to be 2000 pounds and the maximum speed is 750 FPM, then the required horsepower is 45.5.

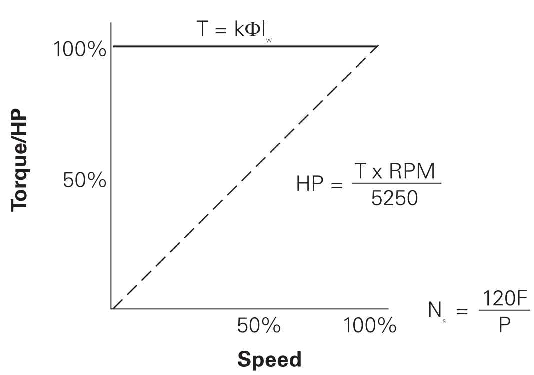
$$HP = \frac{2000 \times 750}{33{,}000}$$

$$HP = 45.5$$

Starting torque of a conveyor can be 1.5 to 2 times full load torque. A motor capable of driving a fully loaded conveyor may not be able to start and accelerate the conveyor up to speed. AC drives can typically supply 1.5 times full load torque for starting. An engineer may need to choose a larger motor and drive in order to start and accelerate the conveyor.

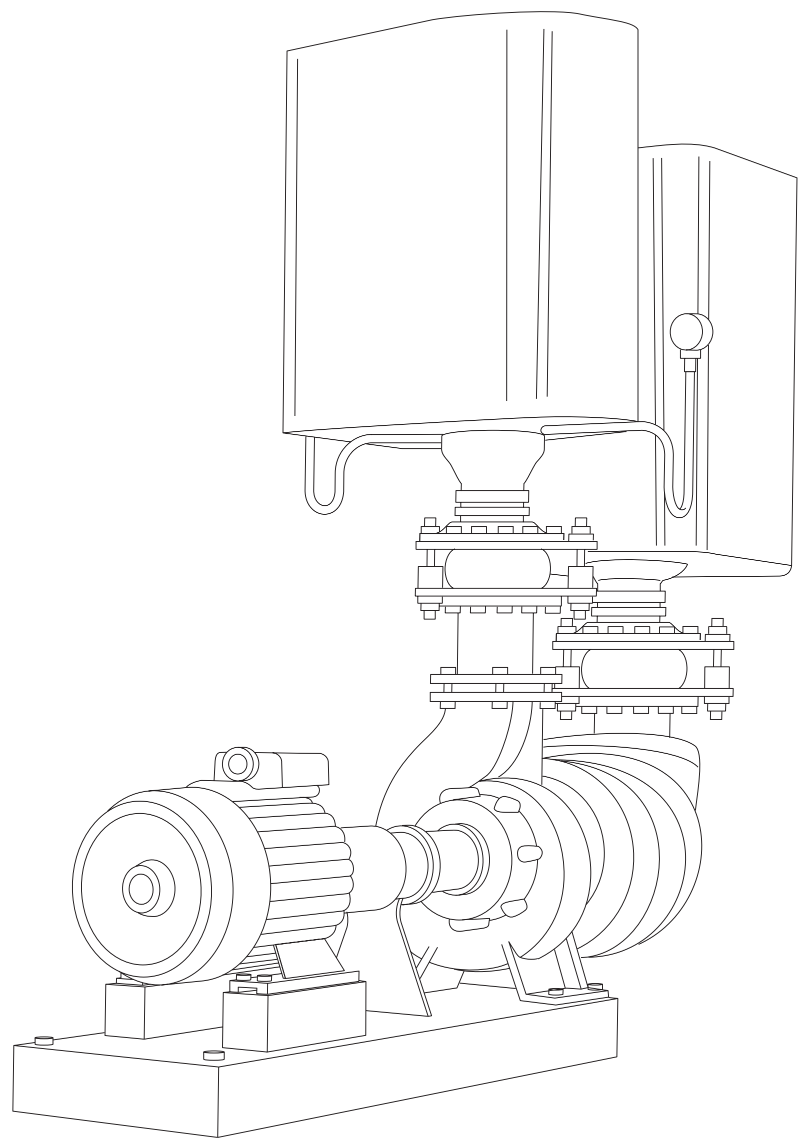
Torque, HP, and Speed

The speed on a conveyor is increased by increasing the AC drive frequency (F) to the motor. Torque (T) is affected by flux (Φ) and working current (IW). The drive will maintain constant flux by keeping the voltage and frequency ratio constant. To do this the drive increases voltage and frequency in proportion. During acceleration working current will increase, however, causing a corresponding increase in torque. Once at its new speed the working current and torque will be the same as its old speed. The conveyor cannot be operated above the rated frequency of the motor (60 Hz) without losing available torque. Since torque is proportional to $(\text{volts/Hz})^2$ any increase in speed will cause available torque to decrease by the square. As a result, the motor will be unable to supply rated torque. Horsepower (HP) is affected by torque and speed. There will be a corresponding increase in horsepower as speed (RPM) increases.



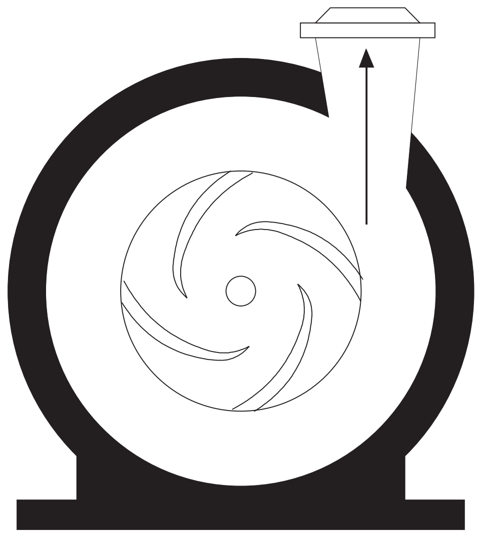
Variable Torque Applications

A variable torque load implies that torque and horsepower increase with an increase in speed. Overloads, as a rule of thumb, are not possible at lower speeds. Peak torques are typically limited to rated torque. Fans and pumps are examples of variable torque. A pump used on a chilled water system is shown below.



Variable Torque Pumps

There are several types of pumps. The most common pump is the end-suction centrifugal pump illustrated below. There are variations of the centrifugal pump. Turbine and propeller pumps are examples. This section deals with variable torque loads. The faster a centrifugal pump turns, the more fluid it pumps and the more torque it requires. It should be noted that not all pumps are variable torque. Reciprocating, positive displacement pumps are constant torque.



Horsepower

Calculating horsepower for a pump application is an involved process that requires someone with a thorough knowledge of the application and pumps. The following information is for illustration only. There are three related horsepower calculations involved in pump applications: liquid, mechanical and electrical.

Hydraulic Head

Hydraulic head is the difference in hydraulic pressure between two points, which actually includes elevation, pressure and velocity. An increase in pump speed would cause increases in pressure and velocity which increases the hydraulic head.

Liquid Horsepower

Liquid horsepower is the hydraulic power transferred to the pumped liquid. The following formula can be used to calculate liquid energy.

Liquid Energy in ft-lb = Total Head x (Gallons x Weight)

Water weighs 8.34 pounds per gallon. If 50 gallons of water per minute were required to be moved through 100 feet of head the energy required would be 41,700 ft-lb/minute.

100 feet x (50 gallons x 8.34) = 41,700 ft-lb/minute

If the pumps speed were increased so that 100 gallons of water were being pumped through 100 feet of head the energy would be 83,400 ft-lb/minute. Twice the energy would be required. The hydraulic head would, in actuality, also increase.

100 feet x (100 gallons x 8.34) = 83,400 ft-lb/minute

The common method of expression is horsepower. One horsepower is equal to 33,000 ft-lb/minute.

Therefore, 41,700 ft-lb/minute is 1.26 HP and 83,400 ft-lb/minute is 2.53 HP.

$$\frac{41{,}700}{33{,}000} = 1.26 \text{ HP} \qquad \frac{83{,}400}{33{,}000} = 2.53 \text{ HP}$$

Mechanical Horsepower

Mechanical horsepower is the horsepower input to the pump and is equal to the liquid horsepower divided by the pump's efficiency. If the liquid horsepower is 2.53 and the pump is 75% efficient the brake horsepower is 3.4 HP.

$$\frac{1.26}{.75} = 1.7 \text{ HP} \qquad \frac{2.53}{.75} = 3.4 \text{ HP}$$

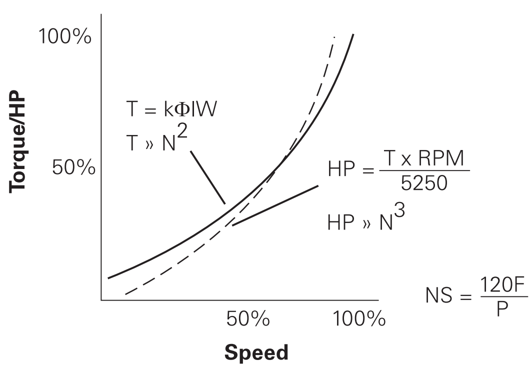
Electrical Horsepower

Electrical horsepower is the horsepower required to run the motor driving the pump and is equal to the mechanical horsepower divided by the motor's efficiency. If the motor is 90% efficient the electrical horsepower is 3.78 HP. It can be seen that with an increase of pump speed there is a corresponding increase in electrical horsepower.

$$\frac{1.7}{.90} = 1.9 \text{ HP} \qquad \frac{3.4}{.90} = 3.8 \text{ HP}$$

Torque, HP, and Speed

The speed on a pump is increased by increasing the AC drive frequency (F) to the motor. Torque (T) is affected by flux (Φ) and working current (IW). The drive will maintain appropriate flux by adjusting the voltage and frequency ratio dependent on speed. During acceleration, working current will increase causing a corresponding increase in torque. In this application, torque increases in proportion to the speed squared. This is due to the increase in hydraulic head as the pump works harder to pump more fluid. Horsepower increases in proportion to the speed cubed due to an increase of torque and speed. The pump cannot be operated above the rated frequency of the motor (60 Hz) because the drive will no longer be able to provide constant flux. As a result, the motor will be unable to supply rated torque. The load's torque requirements increase while the motor's ability to supply torque decreases.



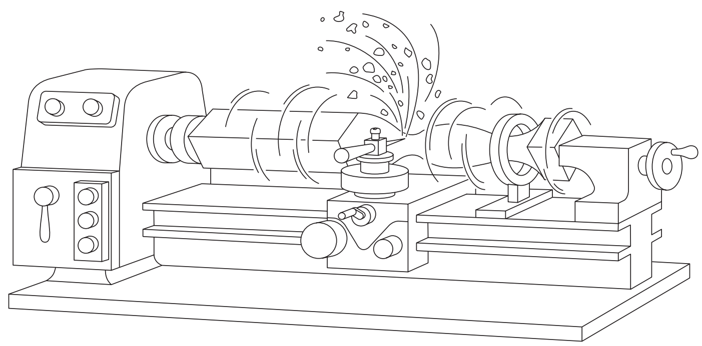
Fans

This same principle applies to fan applications. The horsepower of a fan is determined by dividing the product of air flow (in cubic feet per minute) and pressure by the product of the constant 6356 and fan efficiency. Increasing the speed of the fan increases air flow and pressure, requiring the motor to work harder (IW increases). Torque and horsepower increase.

$$HP = \frac{\text{Flow x Pressure}}{\text{6356 X Fan Efficiency}}$$

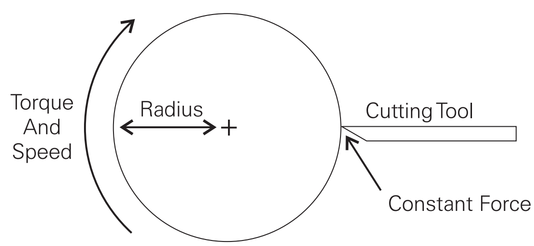
Constant Horsepower Applications

Constant horsepower applications require a constant force as radius changes. A lathe, for example, starts out with a certain diameter object. As the object is cut and shaped the diameter is reduced. The cutting force must remain constant. Another example of a constant horsepower application is a winder where radius increases as material is added to a roll and decreases as material is removed.



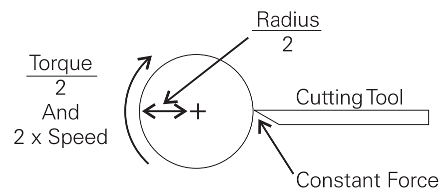
Relationship of Speed, Torque, and Horsepower

Applications, such as lathes, that are driven in a continuous circular motion are sometimes referred to as spindle drives. Horsepower will remain constant in a spindle drive application. The surface speed in feet per minute (FPM) is equal to 2π times the radius (in feet) of the material times the speed in RPM. Surface speed will remain constant as the material is shaped and the radius reduced. Torque is equal to force times radius. Horsepower is equal to torque times speed.



Surface Speed (FPM) = 2π x Radius x Speed (RPM)
Torque = Force x Radius
HP = Torque x Speed

The drive increases the speed (RPM) of the material as the radius is reduced. If the cutting tool has cut away half of the radius, for example, the RPM must double to maintain a constant surface speed (FPM). Reducing the radius by half will cause a corresponding reduction in torque. A doubling of speed (RPM) and a reduction of torque by half causes horsepower to remain constant.

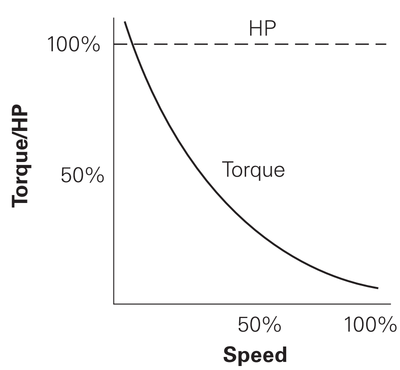


$$\text{Surface Speed (FPM)} = 2\pi \times \frac{\text{Radius}}{2} \times 2 \times \text{Speed (RPM)}$$

$$\text{Torque} = \text{Force} \times \frac{\text{Radius}}{2}$$

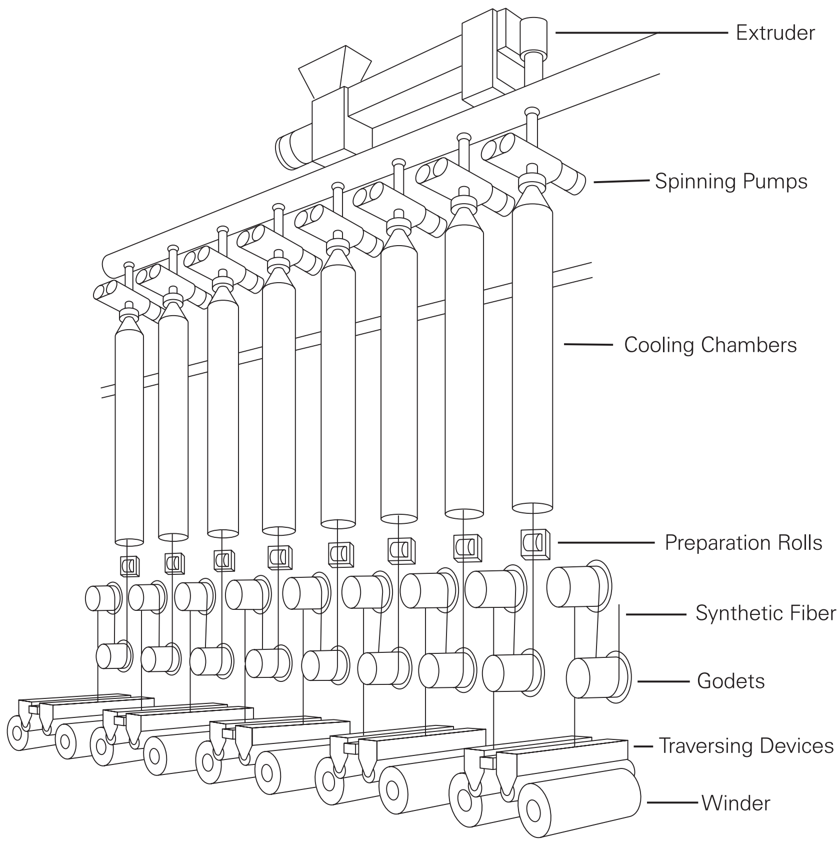
$$\text{HP} = \frac{\text{Torque}}{2} \times \text{Speed}$$

A smaller radius requires less torque to turn. Because torque decreases with a smaller radius, motors operating a constant horsepower application can be run above base speed. A 60 Hz motor, for example, could be run at 90 Hz when the radius is at minimum. RPM must increase to keep surface speed constant. An increase of speed (RPM) and a decrease in torque means horsepower will remain constant.



Multimotor Applications

Many applications require more than one motor. In some instances, one drive can supply two or more motors. When this happens, the current rating of the motors added together cannot be greater than the current rating of the drive. Other applications require multiple motors and drives. A spinning machine for producing synthetic fibers, illustrated below, is one example of a multimotor, multidrive application. Various motors run the extruder, spinning pumps, preparation rolls, godets, traversing devices and winders. One drive may supply all the spinning pump motors or all the godet motors or individual motor control for each pump or godet may be used.



Review 6

1. Parameters that can be read only are referred to as ____________ parameters.

2. A function block consists of several ____________ grouped together to perform a specific task.

3. ____________ is the term used to describe the method of connecting function blocks together.

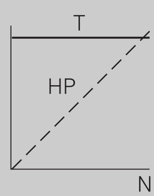
4. An application, such as a conveyor, where the torque remains essentially the same throughout the speed range is referred to as ____________ torque.

5. Operating a motor above base frequency causes the motor's ability to produce torque to ____________ .

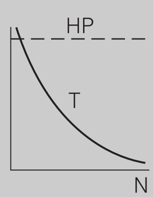
   a. increase b. decrease

6. Fans and pumps are examples of ____________ torque applications.

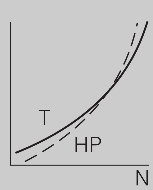
7. Identify the category of the following speed, torque, and horsepower graphs.



a. ____________ ____________



b. ____________ ____________



c. ____________ ____________

Review Answers

Review 1 1) force; 2) 15; 3) torque; 4) 80; 5) inertia; 6) Speed; 7) revolutions per minute

Review 2 1) 5; 2) 1.15; 3) 49.6; 4) 120; 5) 1800, 1500; 6) Slip

Review 3 1) 7.67; 2) increase, increase; 3) b; 4) horsepower; 5) SIMOVERT; 6) 650; 7) c; 8) d

Review 4 1) P; 2) 650; 3) b; 4) d; 5) II; 6) 100; 7); 3 to 5

Review 5 1) 6SE70; 2) DC - AC; 3) Active Front End; 4) 50; 5) 50; 6) dv/dt; 7) 25

Review 6 1) visualization; 2) parameters; 3) BICO; 4) constant; 5) b; 6) variable; 7) constant torque, constant horsepower, variable torque

Final Exam

The final exam is intended to be a learning tool. The book may be used during the exam. After completing the test, mail the tear-out answer sheet in for grading. A grade of 70% or better is passing. Upon successful completion of the test a certificate will be issued.

1. ____________ is a twisting or turning force that causes an object to rotate.

   a. Torque　　c. Inertia
   b. Friction　　d. Acceleration

2. If 50 pounds of force were applied to a lever 3 feet long, the torque would be ____________ lb-ft.

   a. 16.7　　c. 47
   b. 53　　d. 150

3. The rate of doing work is called ____________ .

   a. inertia　　c. power
   b. speed　　d. energy

4. A motor with a rating of 60 KW would have an equivalent rating of ____________ HP.

   a. 45　　c. 65
   b. 80　　d. 120

5. Magnetic lines of flux (Φ) in an AC motor are proportional to ____________ .

   a. voltage divided by frequency
   b. frequency divided by voltage
   c. rotor speed divided by synchronous speed
   d. synchronous speed divided by rotor speed

6. A four-pole motor operating at 50 Hz has a synchronous speed of ____________ RPM.

a. 1500 c. 1800
b. 3000 d. 3600

7. A motor with a synchronous speed of 900 RPM and a rotor speed of 850 RPM has ____________ % slip.

a. 3 c. 5.5
b. 9.4 d. 20

8. The most common and most suitable NEMA design motor for use on AC drives is NEMA ____________ .

a. A c. C
b. B d. D

9. ____________ torque is also referred to as starting torque.

a. Pull up c. Breakdown
b. Accelerating d. Locked rotor

10. A NEMA B motor that is started by connecting it to the power supply at rated voltage and frequency has a typical starting current of ____________ %.

a. 100 c. 200
b. 150 d. 600

11. The temperature rise of a motor with Class F insulation is ____________ °C with a 10° C hot spot.

a. 60 c. 80
b. 105 d. 125

12. The volts per hertz ratio of a 460 VAC, 60 Hz motor is ____________ V/Hz.

a. 3.8 c. 5.1
b. 7.67 d. 9.2

13. A motor operated within a speed range that allows a constant volts per hertz ratio is said to be ____________ .

a. constant hp c. constant torque
b. variable torque d. variable flux

14. The section of an AC drive that controls output voltage and frequency to an AC motor is the ____________ .

a. converter
b. DC link
c. inverter
d. L1 choke

15. Frame size C, 480 volt, MICROMASTER 420 drives are available with power ratings from ____________ to ____________ horsepower.

a. 1/2 to 2
b. 7.5 to 15
c. 3 to 50
d. 60 to 500

16. To get four-quadrant operation with a Siemens MICROMASTER an optional ____________ must be used.

a. DC injection brake
b. converter bridge
c. 4-digit LED display
d. braking resistor

17. ____________, in conjunction with a Clean Power Filter, provides regenerative control and reduces harmonics.

a. Active Front End
b. Rectifier Regenerative Front End
c. 6-Pulse Converter
d. 12-Pulse Converter

18. ____________ is the term used with the Siemens MASTERDRIVE VC to describe the method of connecting function blocks together.

a. AFE
b. Binector
c. BICO
d. SBP

19. A centrifugal pump is a ____________ application.

a. constant torque
b. constant flux
c. constant HP
d. variable torque

20. If a conveyor has an effective tension (T_E) of 1000 pounds, and a maximum speed of 100 FPM, the required horsepower is ___________ HP.

a. 3
b. 25
c. 10
d. 45

Notes

Notes

Notes

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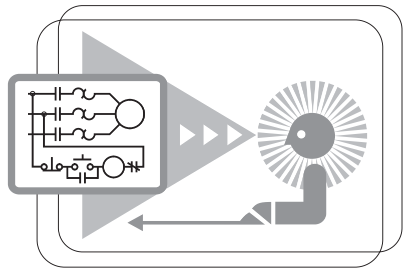

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