Siemens STEP 2000 Course

General Motion Control

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Table of Contents

Introduction 2
Totally Integrated Automation 4
Motion Control 5
Mechanical Basics 13
Servomotor Construction 25
Servomotor Ratings 33
Speed-Torque Characteristics 39
Siemens Servomotors 44
Servomotor Accessories 46
Encoders and Resolvers 49
Pulse Width Modulation 55
Siemens MASTERDRIVE MC Family 63
MASTERDRIVE MC Compact PLUS 64
MASTERDRIVE MC Compact and Chassis 73
Technology Options 78
Cables 87
Applications 88
Selection 95
SIMODRIVE 97
Review Answers 99
Final Exam 100

Introduction

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

Upon completion of **Basics of General Motion Control** you should be able to:

- Explain the concepts of force, inertia, speed, and torque
- Explain the difference between work and power
- Describe the construction of a servomotor
- Identify the nameplate information of a servomotor necessary for application to a MASTERDRIVE MC
- Describe the operation of a three-phase rotating magnetic field
- Describe the relationship between V/Hz, torque, and current
- Describe the operation of an encoder
- Describe the basic construction and operation of a PWM type MASTERDRIVE MC
- Describe features and operation of the Siemens MASTERDRIVE MC
- Describe basic motion control 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** and **Basics of AC Drives** before attempting **Basics of General Motion Control**. An understanding of many of the concepts covered in **Basics of Electricity** and **Basics of AC Drives** is required for **Basics of General Motion Control**.

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.

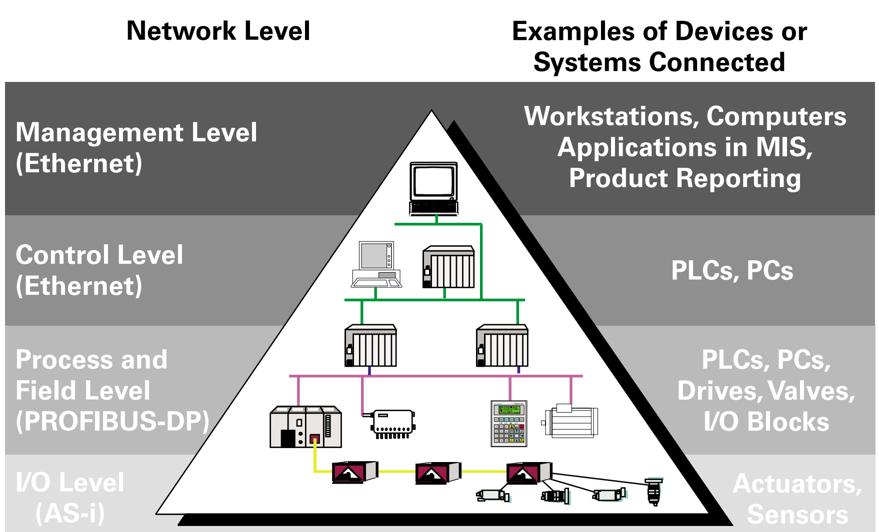
National Electrical Manufacturers Association is located at 2101 L. Street, N.W., Washington, D.C. 20037. The abbreviation "NEMA" is understood to mean National Electrical Manufacturers Association.

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.

This course focuses on the MASTERDRIVES™ MC which are an important element of the TIA strategy. MASTERDRIVE MC drives are designed for motion control applications that require precise control. In addition, MASTERDRIVE MC 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.

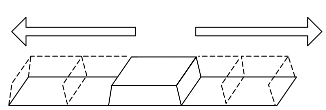


Motion Control

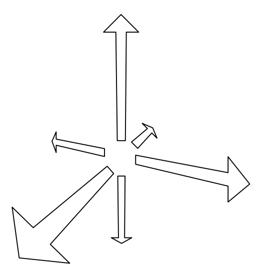
Motion control is an industry term used to describe a range of applications that involve movement with varying degrees of precision. Many motion control applications require only that an object be moved from one place to another with limited concern for acceleration, deceleration, or speed of motion. On the opposite extreme are machine tool applications which require the precise coordination of all aspects of motion, including a high degree of coordination for multiple simultaneous movements.

Axis

Single-axis motion involves controlling one rotational axis. This is typically a motor shaft that can be driven forward or reverse. Mechanisms are often used to translate the rotational motion into linear motion. Multi-axis control involves control of multiple rotational axes, each of which could be converted into linear motion. Some applications require the control of multiple axes, with each axis operating independently. Other applications require varying degrees of coordination for multiple axes ranging from synchronizing the start of motion control for multiple axes to the highly coordinated multiple-axis control required for machine tool applications.



Single-Axis



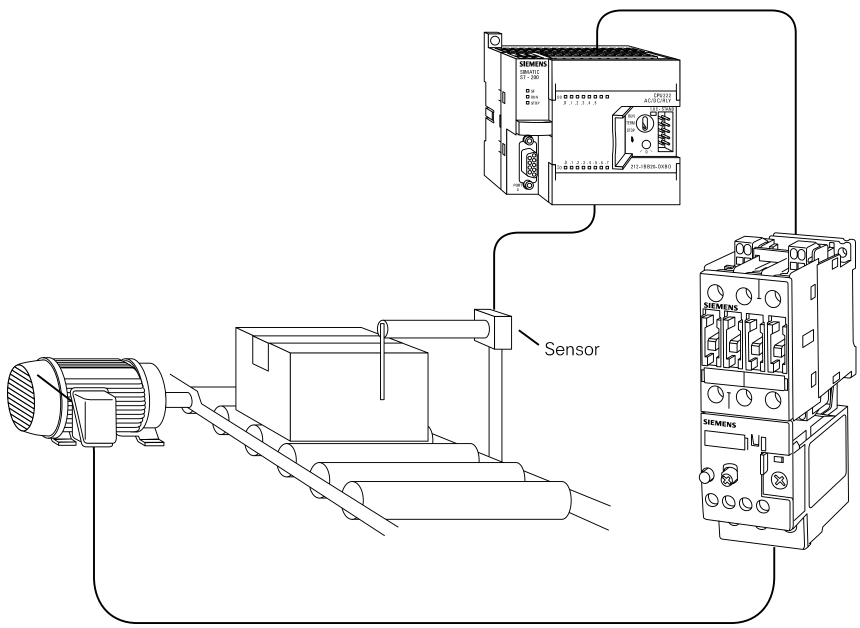
Multi-Axis

Motion Control Examples

The following illustration is an example of basic single-axis motion. This illustration shows an object moving on a conveyor. The conveyor is driven by a Siemens AC motor which turns in one direction at a relatively constant speed. The sensing and control circuit for this application consists of a Siemens limit switch or sensor, a Siemens S7-200 PLC, and a Siemens Sirius Type 3R full-voltage starter. Additional control and safety circuits would be required, but are not important for this explanation.

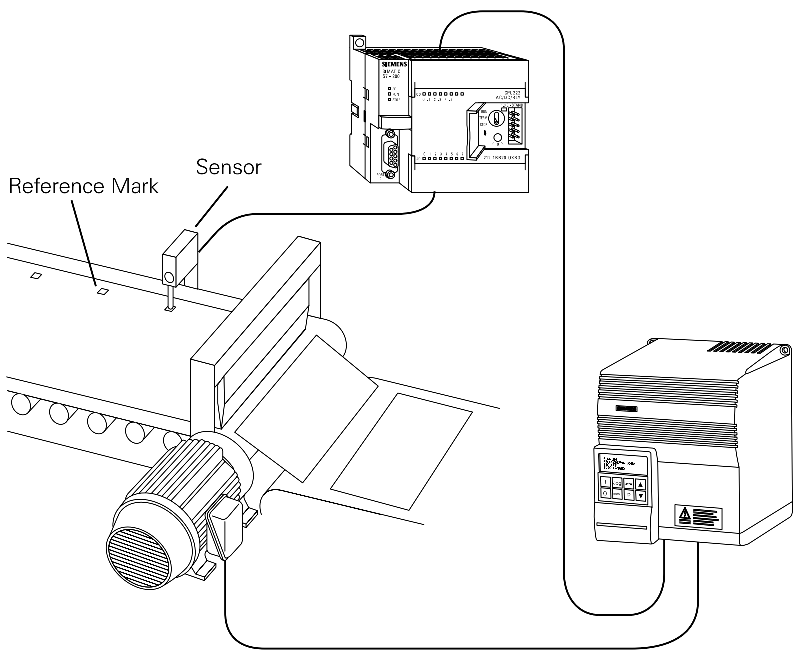
In this example, the motor will move the object along the conveyor until the sensor is reached. At that point the sensor will change the state of a PLC input. The PLC will respond to this change of the input state by de-energizing the motor starter, thereby stopping the motor.

This application did not require that the acceleration and deceleration of the motor or the speed of the motor be controlled. In addition, the control over the final position of the object is not precise, but these conditions are often acceptable in many applications.

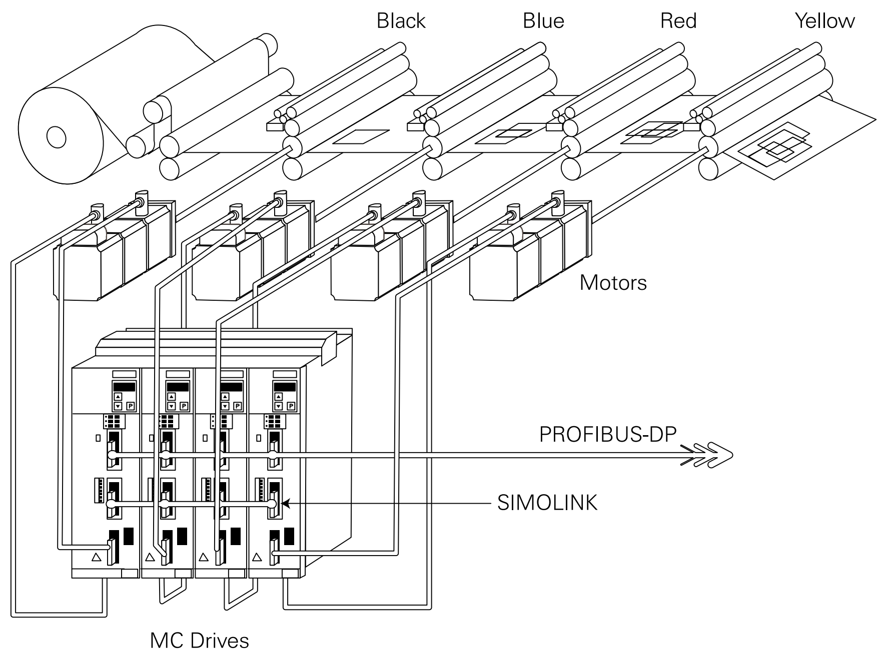


Another application might involve the use of an AC drive, such as a Siemens MICROMASTER, MIDIMASTER, or MASTERDRIVE. In this example a PLC is used to control a trimming cycle for a continuous roll. A sensor, connected to a PLC input, is used to detect a reference mark on the roll. An AC drive, controlled by the PLC, is used to control the acceleration, deceleration, and speed of an AC motor.

In this application the motor drives a belt which feeds the roll through a cutter. When the sensor detects the mark it changes the state of a PLC input. The PLC signals the drive to stop the motor long enough for the cut to be made. The motor is then restarted. This application involves control over motor acceleration, deceleration, and speed, but only moderate position control.



Motion control applications are often more complex than those described in the previous examples, involving precise positioning and synchronized control of one or more axes. For example, a four-color printing process is used when printing color material such as brochures or magazine covers. In a four-color process, a separate printing stage is used for each color. In this example a continuous roll of paper is fed through a four-color printing press. Four servomotors are connected to four MC drives. The drives control the speed and position of each motor. Each drive knows the exact speed and position of its associated motor. Fine adjustments are made to ensure the images line up exactly at each printing stage.

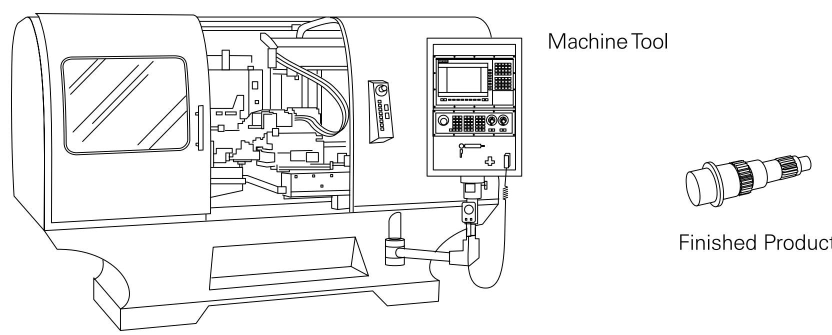


Machine Tool Applications

Before continuing with our discussion of motion control as it relates to the MASTERDRIVE MC, it is worthwhile to briefly describe machine tool motion control applications. This is essential to highlight the differences with MASTERDRIVE MC motion control.

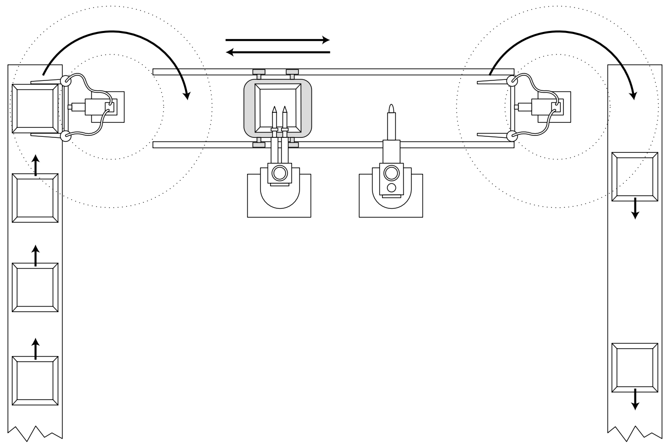
Machine tools are designed to perform a series of specific tasks such as milling, drilling, grinding, or turning that require a high degree of coordination over multiple axes. For example, the in and out movement of a cutting tool on a lathe must be simultaneously coordinated with the side-to-side movement of that tool. This is necessary to precisely machine the part being turned. In more complex machine tool applications, many more axes of motion may need to be controlled in a coordinated fashion to machine a part quickly and precisely.

Essentially, it is this precise coordination of mulitple axes by a control system, called a Computer Numerical Control (CNC), that characterizes machine tool control applications. This course does not focus on machine tool motion control applications, but instead covers the single-axis or multiple axes applications appropriate for MASTERDRIVE MC drives.

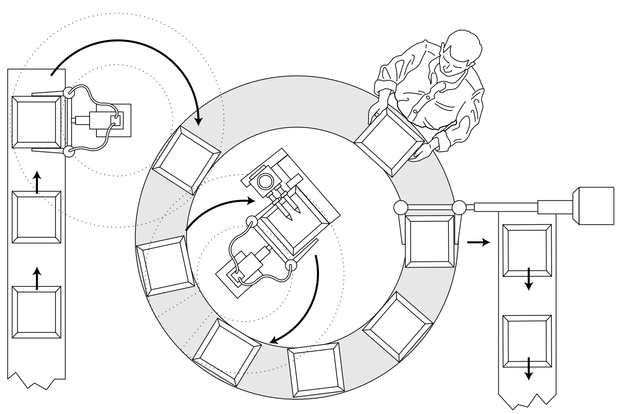


Linear and Rotational Axes

Motion control can operate on a linear or rotational axis. A linear axis application, such as a traversing car, has a defined traversing range with end stops. An item may simply be moved from one station to the next, or it may make several stops where different manufacturing process are performed.



A rotational axis application has an endless traversing range. A rotary table, for example, travels along the shortest path from one point to the next. A rotary table may also have selectable or predefined directions of rotation to move from one point to the next.

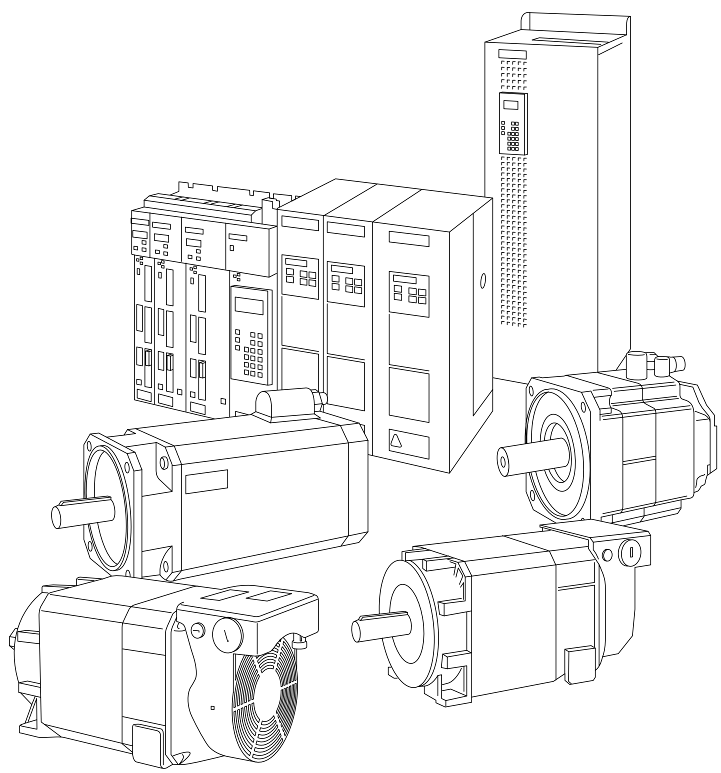


Siemens MC Drives

The range of applications in motion control is more specialized than many other manufacturing applications. Motion control drives, and their associated motors must be capable of:

- Zero-speed holding torque
- Quick start/stop cycles
- High accelerating torque
- Repeatable velocity and torque profiles
- Synchronization
- Positioning capabilities
- Precise speed control

Controlling the starting, stopping, and speed of an AC motor in a motion control system is the job of a variable speed drive, like the Siemens SIMOVERT® MASTERDRIVE MC. SIMOVERT is a Siemens trade name which refers to **SI**emens AC **MO**tor in**VERT**ers. Although an inverter is only one part of an AC drive, it is common practice to refer to an AC drive as an inverter. The Siemens MASTERDRIVE MC (motion control) drive belongs to the SIMOVERT MASTERDRIVES product family. Siemens also manufactures a complete line of servomotors to compliment the drive family.



Review 1

1. The Siemens ___________ MC is specifically designed for general motion control applications.

2. Motion control can operate on ___________ or ___________ axis.

3. Which of the following characteristics are required of a motion control drive?

   a. Zero-speed holding torque
   b. Quick start/stop cycles
   c. High accelerating torque
   d. Repeatable velocity and torque profiles
   e. Synchronization with other drives
   f. Positioning capabilities
   g. Precise speed control
   h. All of the above

Mechanical Basics

Before discussing Siemens MASTERDRIVE MC drives and motors, it is necessary to understand some of the basic terminology associated with the mechanics of motion control and 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 motion control.

Units of Measurement

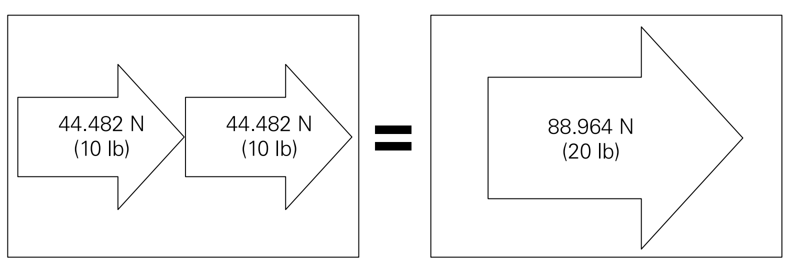
There are two units of measurement commonly used. The International System of Units, known as SI (Système Internationale d'Unités), is used throughout the world. The SI system is more recently used in the United States. The English system, which most of us are more familiar with is used primarily in the United States. Both systems of measurement will be referenced throughout this course. To avoid confusion, the SI system will be given first followed by the English system in parenthesis. In some tables and charts both systems will be shown side-by-side.

Force

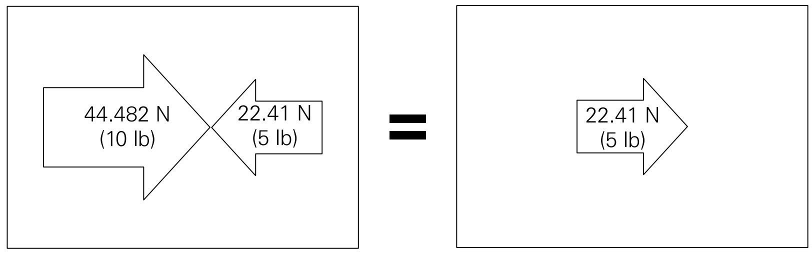
In simple terms, a force is a push or a pull. Force may be caused by electromagnetism, gravity, or a combination of physical means. The SI unit of measurement for force is Newtons (N). The English unit of measurement for force is pounds (lb).

Net Force

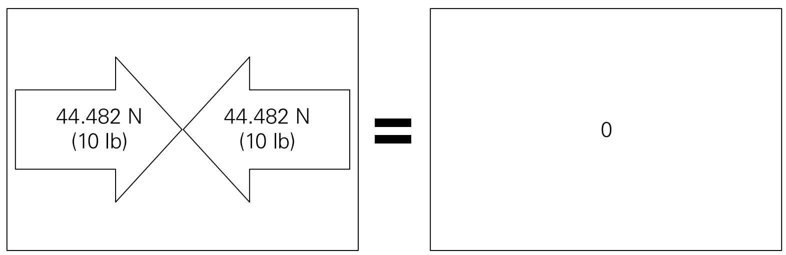
Net force is the vector sum of all forces that act on an object, including friction and gravity. When forces are applied in the same direction they are added. For example, if two 10 lb 44.482 N (10 lb) forces were applied in the same direction the net force would be 88.964 N (20 lb).



If 44.482 N (10 lb) of force were applied in one direction and 22.41 N (5 lb) of force applied in the opposite direction, the net force would be 22.41 N (5 lb) and the object would move in the direction of the greater force.



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



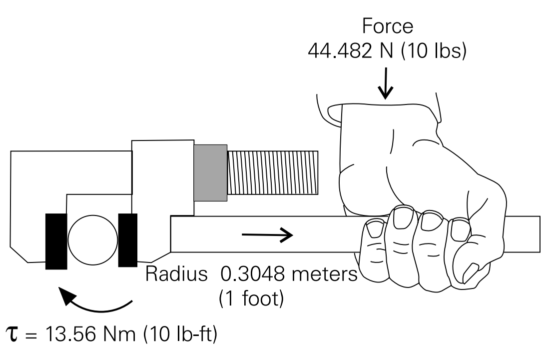
Torque

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.

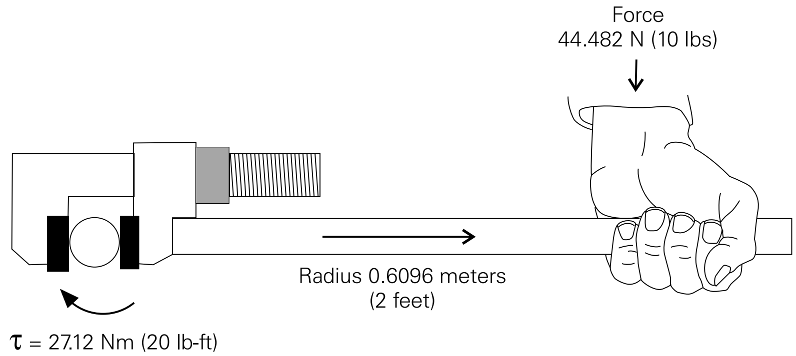
Torque (τ) is the product of force and radius (lever distance).

Torque (τ) = Force x Radius

The SI unit of measurement is Newton-meters (Nm). In the English system torque is measured in pound-feet (lb-ft) or pound-inches (lb-in).If 44.482 N (10 lbs) of force were applied to a lever 0.3048 meters long (1 foot), for example, there would be 13.56 Nm (10 lb-ft) of torque.



An increase in force or radius would result in a corresponding increase in torque. Increasing the radius to 0.6096 meters (2 feet), for example, results in 27.12 Nm (20 lb-ft) of torque.



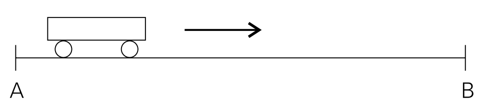
Speed

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 Motion

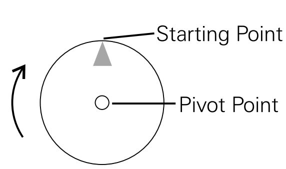
The linear speed of an object is a measure of how long it takes the object to get from point A to point B. Linear speed is usually given in a form such as meters per second (m/s). For example, if the distance between point A and point B were 10 meters, and it took 2 seconds to travel the distance, the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



Linear Motion

Rotational Motion

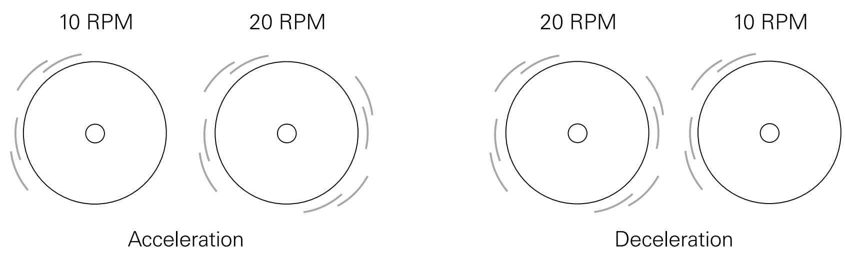
The angular speed of a rotating object is a measurement of how long it takes a given point on the object to make one complete revolution from its starting point. Angular speed is of a rotating object is an example where it is more common to use the English system of revolutions per minute (RPM) versus the SI unit of revolutions per second (RPS). 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 only 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.

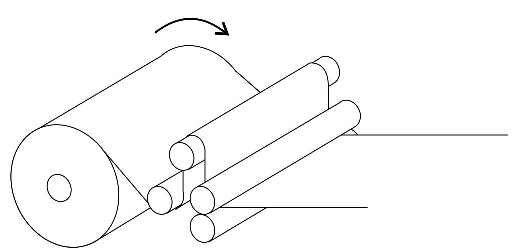


Law of Inertia

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 SI unit for inertia is kilogram-meter squared (kgm^2). The English system of measurement is pound-feet squared ($lb\text{-}ft^2$).

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.



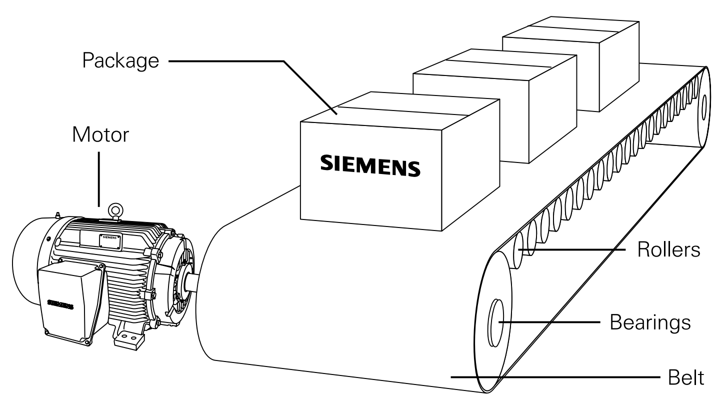
Friction

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. In the following illustration a motor runs a conveyor. A large amount of force is applied to overcome the inertia of the system at rest to start it moving.

Once the system is in motion, only the energy required to compensate for various losses need be applied to keep it in motion.

These losses include:

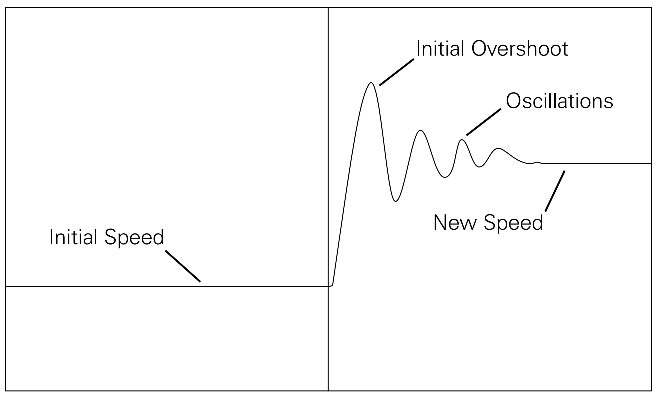
- Friction within motor and driven equipment bearings
- Windage losses in the motor and driven equipment
- Friction between conveyor belt and rollers



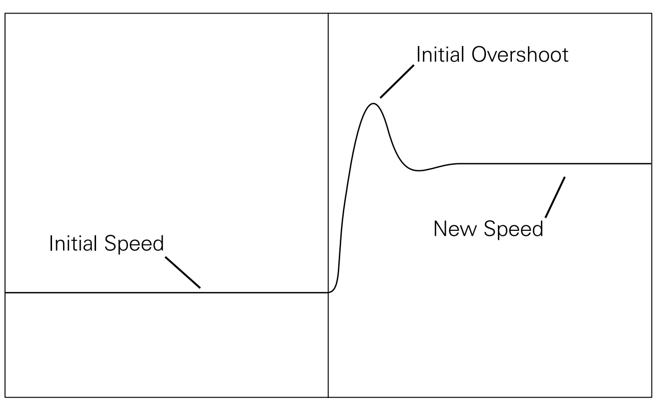
Inertia Ratios

One aspect of motion control systems which must be considered is that the driven machine and the servo motor driving the machine are physically interdependent. It is important to ensure that the inertia of the servo motor is matched to the inertia of the driven machine. Ideally it is desirable to have a 1:1 inertia ratio between the load and the motor. However, inertia ratios of 1:10 or greater are not uncommon.

Typically, it is desirable to reach a new speed quickly when changing speeds in a motion control system. When changing from a lower speed to a higher speed, for example, the motor accelerates the connected load quickly, resulting in a slight overshoot before settling into the new speed. If there is too great a mismatch between the motor and the load the system can become unstable. Oscillations can occur which contribute to system instability.

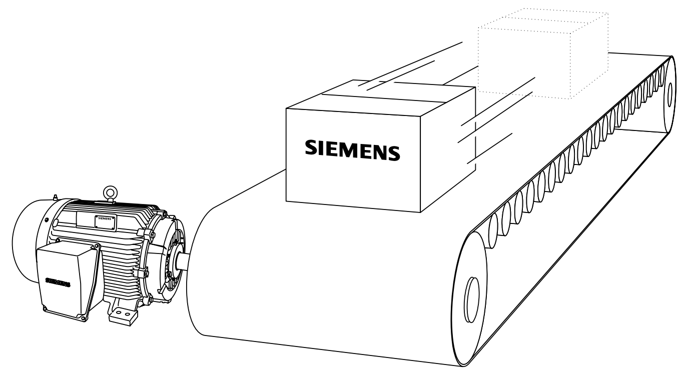


When the inertia of a system is properly matched the system will settle into a new speed quickly. This provides a stable system with quick response.



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 x d

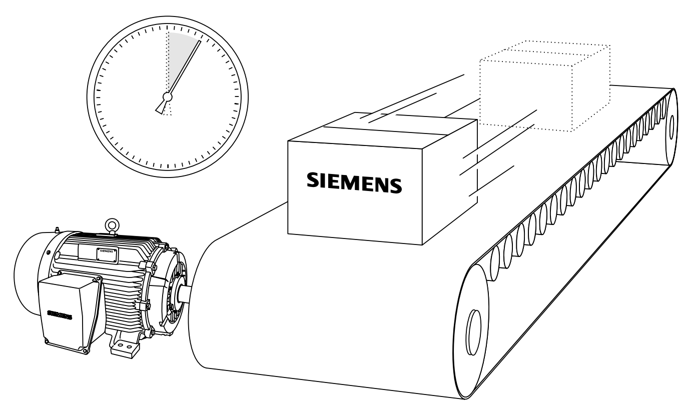
Power

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.



Power

Power in an electrical circuit is measured in watts (W) or kilowatts (kW). AC drives and motors manufactured in the United States are generally rated in horsepower (HP), however, it is becoming common practice to rate equipment using the SI units of watts and kilowatts.

Torque vs Power

When considering motors and drives for a given application we typically think in terms of power. We have learned that power is a function of speed. No work is accomplished unless there is motion. Therefore, power is zero when the system and its associated motor is at rest (zero speed).

On the other hand, a characteristic of motion control systems is the ability to deliver full torque at zero speed. For this reason it is more common to base motion control systems on torque rather than power.

Acceleration Torque

The torque required to accelerate a machine should be determined first. The following information is needed:

- Inertia of the machine in kgm^2 (SI) or lb ft^2 (English) (J)
- Amount of change of speed in RPM (Δn)
- Time taken to change speed in seconds (Δt)

A simple formula can be used to determine the required acceleration torque (τ_a).

Formula for SI Unit (kgm^2)

$$\tau_a = \frac{2\pi \cdot \Delta n \cdot J}{60 \cdot \Delta t}$$

Formula for English Unit (lb ft^2)

$$\tau_a = \frac{\Delta n \cdot J}{308 \cdot \Delta t}$$

The torque required to accelerate a system with a total inertia of 0.005 kgm^2 (0.1187 lb ft^2) from rest to 3000 RPM in 0.2 seconds would be 7.85 Nm(5.78 lb ft).

Formula for SI Unit (kgm^2)

$$\tau_a = \frac{2\pi \cdot \Delta n \cdot J}{60 \cdot \Delta t}$$

$$\tau_a = \frac{6.28 \cdot 3000 \cdot 0.005}{60 \cdot 0.2}$$

$$\tau_a = 7.85 \text{ Nm}$$

Formula for English Unit (lb ft^2)

$$\tau_a = \frac{\Delta n \cdot J}{308 \cdot \Delta t}$$

$$\tau_a = \frac{3000 \cdot 0.1187}{308 \cdot 0.2}$$

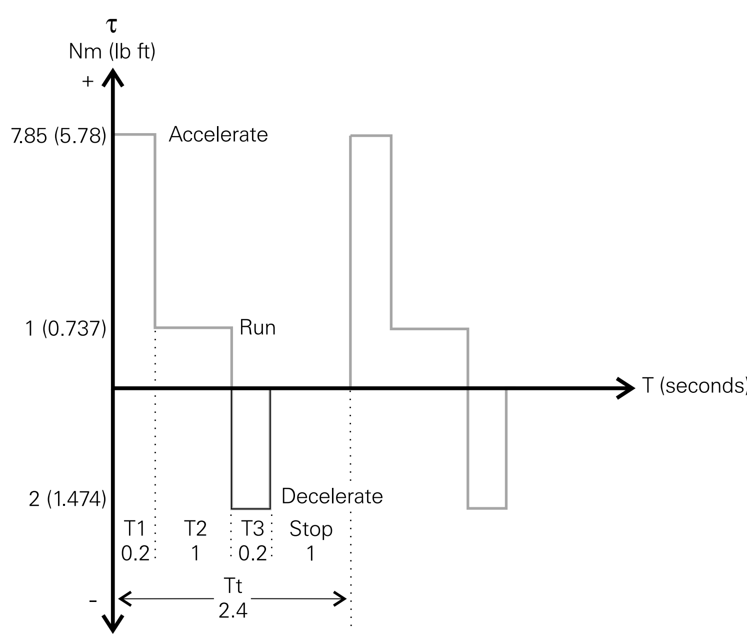
$$\tau_a = 5.78 \text{ lb ft}$$

Effective (RMS) Torque

Accelerating torque is usually required on an intermittent basis only. Due to the cyclic nature of motion control applications, servomotors have both continuous and intermittent ratings. To select the correct continuous rating it is also necessary to know the effective torque, also referred to as RMS (root-mean square) torque.

The value of effective torque is actually a means of expressing the equivalent of varying values of torque required during a cycle of operation. Effective torque is determined by looking at all the operating points of a torque-time curve during a complete cycle.

Three operating points are used during a cycle in the following example. The load requires 7.85 Nm (5.78 lb ft) of torque to accelerate the load (T1) in 0.2 seconds. During constant state run the load requires 1 Nm (.737 lb ft) of torque to overcome losses due to friction and maintain speed (T2) for 1 second. To decelerate the load and stop requires 2 Nm (1.474 lb ft) of torque (T3) for 0.2 seconds. The system will remain stopped for 1 second before repeating the cycle. The total cycle time is 2.4 seconds (Tt).



Calculating Effective Torque

The following formula can be used to calculate effective torque using either SI or English units. Effective torque (τ_{eff}) is the square root of the summation (Σ) of the square of torque required (τ^2) by the motor at each increment (Mot i) and time period (Δti) divided by the total cycle time (Tt).

$$\tau_{eff} = \sqrt{\frac{\Sigma(\tau^2 \text{Mot i} \cdot \Delta ti)}{Tt}}$$

Using the values for the three time periods in the previous example, effective torque can be calculated.

Cycle Increment	Torque (Nm)	Torque (lb ft)	Time (seconds)
1	7.85	5.78	0.2
2	1	0.737	1
3	2	1.474	0.2
Time Between Cycles			1
Total Time			**2.4**

$$\sqrt{\frac{(\tau 1^2 \cdot \Delta t1) + (\tau 2^2 \cdot \Delta t2) + (\tau 3^2 \cdot \Delta t3)}{Tt}}$$

SI (Nm)

$$\tau_{eff} = \sqrt{\frac{(7.85^2 \cdot 0.2) + (1^2 \cdot 1) + (2^2 \cdot 0.2)}{2.4}}$$

$$\tau_{eff} = \sqrt{\frac{12.3 + 1 + 0.8}{2.4}}$$

$$\tau_{eff} = \sqrt{\frac{14.1}{2.4}}$$

$$\tau_{eff} = \sqrt{5.875}$$

$$\tau_{eff} = 2.423 \text{ Nm}$$

English (lb ft)

$$\tau_{eff} = \sqrt{\frac{(5.78^2 \cdot 0.2) + (0.737^2 \cdot 1) + (1.474^2 \cdot 0.2)}{2.4}}$$

$$\tau_{eff} = \sqrt{\frac{6.68 + .54 + 0.435}{2.4}}$$

$$\tau_{eff} = \sqrt{\frac{7.655}{2.4}}$$

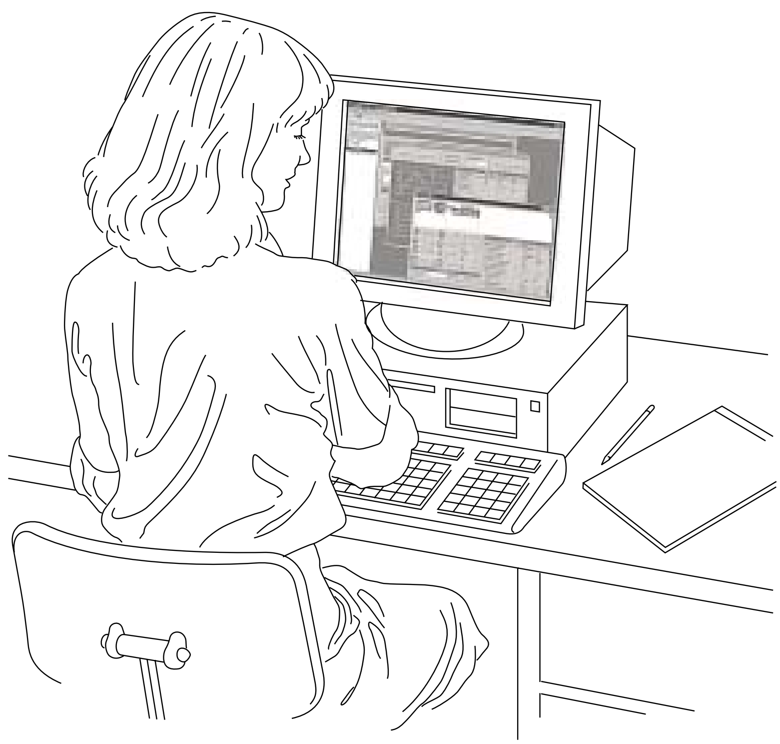
$$\tau_{eff} = \sqrt{3.19}$$

$$\tau_{eff} = 1.786 \text{ lb ft}$$

SimoSize

Calculating the correct torque for a motion control system is complex, requiring a thorough understanding of the system involved. SimoSize is a PC tool which allows the user to accelerate the design process by providing the necessary tools in a Windows 95/98/NT format. SimoSize is available through your sales representative at no charge and may be freely copied and distributed.

SimoSize allows the user to select components such as gear boxes, rotary tables, and belt-pulleys.The user can also specify the profile needs such as acceleration, run speed, and run time. A report generator in SimoSize performs calculations for speed, torque, and inertia to properly select a servomotor.



Review 2

1. A ___________ is a push or a pull.

2. An object has 10 N of force applied in one direction and 5 N of force applied in the opposite direction. The net force is ___________ .

3. A twisting or turning force that causes an object to rotate is known as ___________ .

4. If 20 N of force were applied to a lever 0.3 meters long, the torque would be ___________ Nm.

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. Ideally it is desirable to have a ___________ inertia ratio between the load and the motor.

7. ___________ is accomplished when force causes motion.

8. A characteristic of motion control systems is the ability to deliver full torque at zero speed. For this reason it is more common to base motion control systems on ___________ rather than ___________ .

9. ___________ is a Siemens software program designed to help calculate the speed, torque, and inertia of a motion control system.