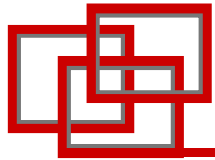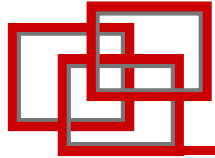# Defining Motion Control

Objective

- After completing this lesson, you should be able to define motion control.

Why These Skills Are Important

This lesson covers the basic principles, control parameters and physical forces of controlled motion that are common to all motion control systems. This knowledge is necessary to work effectively with any motion control system.
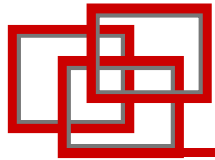
What is Motion Control?

If: **Motion** is an act, process, or instant of changing place . . .

And: **Control** is the power or authority to guide, manage, coordinate, or direct . . .
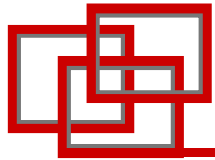
Then: **Motion control** is a means of directing movement.

What Is a Motion Control System?

A motion control system is a series of high-performance electrical and hardware components working together to precisely control movement of an axis or axes.

These components are programmed to perform motion using a human-machine interface or a specific software package.

What Is an Axis?

An **axis** is a principal direction along which movement of the tool or workpiece occurs. Axes have the following characteristics:

- An axis can be a motor turning a shaft.

- An axis can be a motor attached to a piece of hardware.

- An axis can be virtual with no physical components

- One motor and feedback device control the movement of one axis.

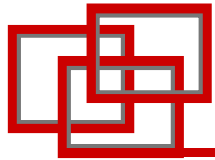- Movement and motion are performed on a motion control system by axes.

Depending on the complexity of the motion control application and the motion control system, one axis can perform motion independently or many axes can control motion together.
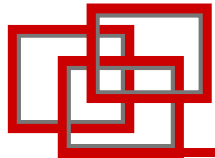
What Does a Motion Control System Control?

There are five main control parameters of axis motion that a motion control system precisely controls:

- Velocity
- Acceleration/deceleration
- Position
- Inertia
- Torque

Velocity

Velocity is the speed at which a move is made. A motion control system regulates the speed at which an axis moves. Velocity has the following characteristics:
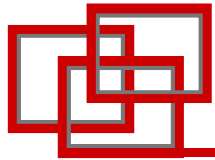
- The amount of electrical current sent from the motion control system to the motor is regulated.

- The electrical current is controlled by performing a logical comparison inside the motion control system of the motor's required speed to the motor's actual speed.

Velocity

The following graphic shows velocity in a motion event:

- **Initial Velocity:** Speed at which the motion is started.
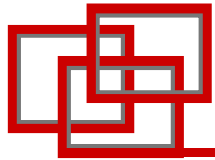- **Final Velocity:** Maximum speed reached during the move.
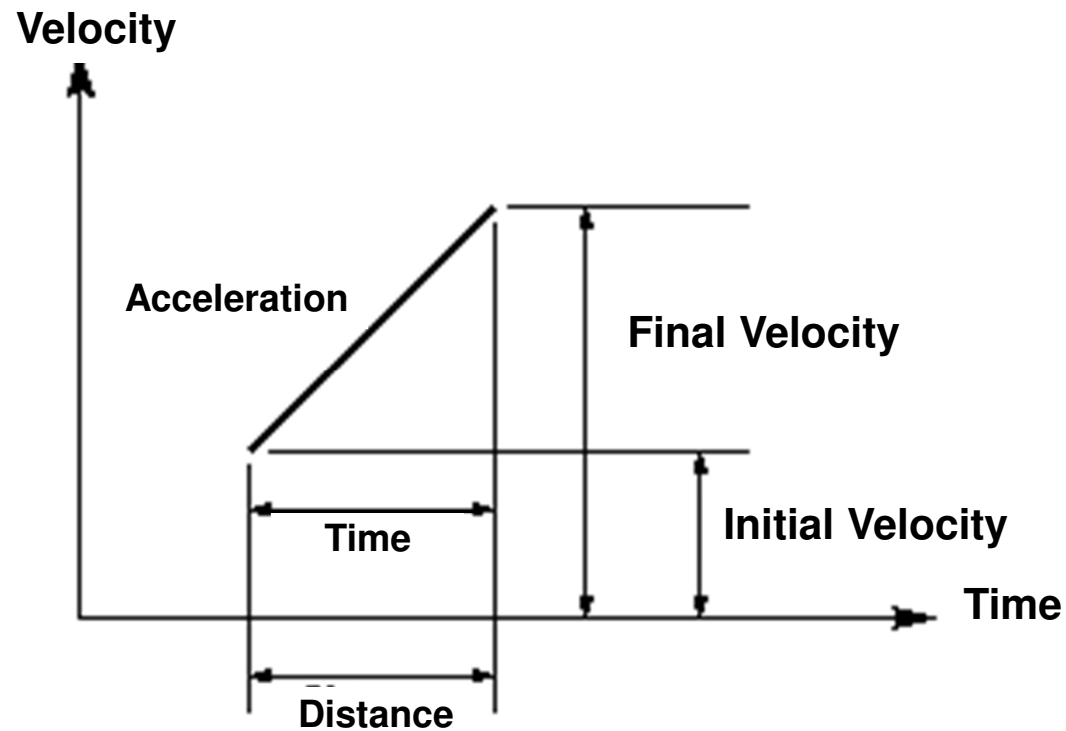
Acceleration

Acceleration is an increase in velocity as a function of time. A motion control system controls the speed at which an axis move is started.

This is done by applying a predetermined acceleration setting to the axis being controlled.

Deceleration

Deceleration is a decrease in velocity as a function of time. A motion control system controls the speed at which an axis slows down and stops.

As with acceleration, a predetermined deceleration setting controls the axis that is being decelerated and stopped.
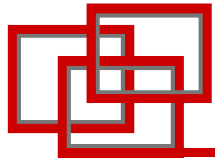
Position

Position is the location of a specific place with respect to one or more fixed references. A motion control system controls the position of an axis by performing the following actions:

- Comparing where the axis needs to be to where it actually is on the motion control application

- Compensating for the difference between where the axis needs to be and where it actually is on the motion control system

- Minimizing the difference between where the axis needs to be and where it actually is on the motion control system. By comparing these two factors and correcting the difference between them, the motion control system can achieve pinpoint accuracy in positioning an axis.
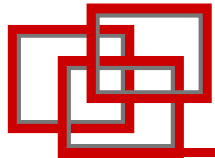
Inertia

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

Inertia has the following characteristics:

- Is typically expressed in units of lb-in-sec2 or kg-m2

- Must be calculated for each component in the motion control application prior to determining the amount of torque required to perform motion

Tip: In some instances, the component manufacturer will provide a precalculated inertia value for a component.
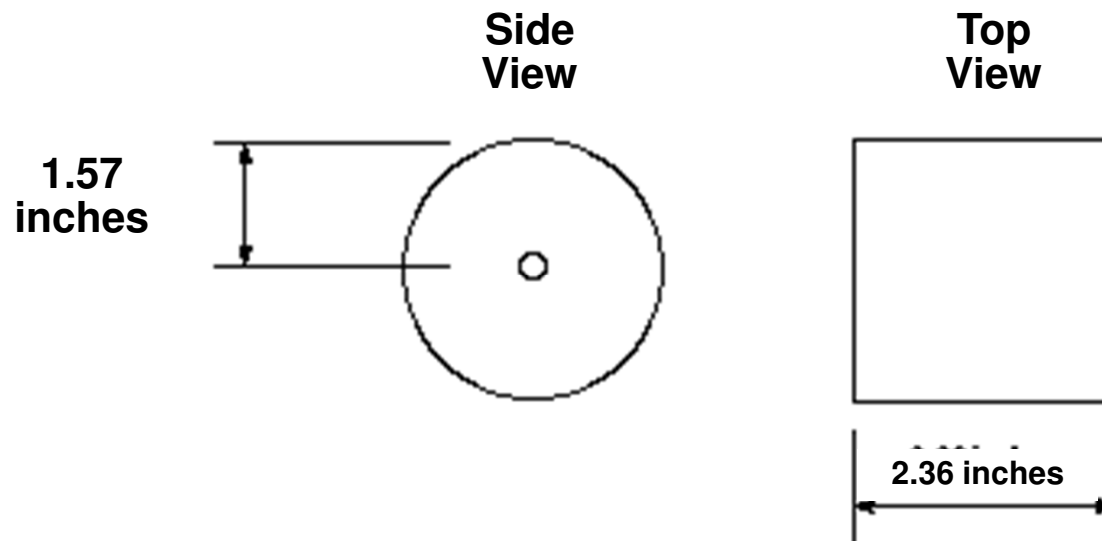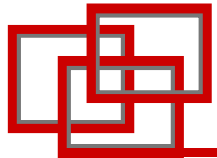
Example: Inertia Calculation for an Aluminum Pulley

In this example, a motion control application includes one aluminum pulley with the following dimensions:

- Radius is 1.57 inches.

- Length is 2.36 inches.

- Material is aluminum (density of 0.096 lb/cu. in.).

The pulley dimensions are shown in the following graphic:

Side View

Top View

1.57 inches

2.36 inches

Example: Inertia Calculation for an Aluminum Pulley

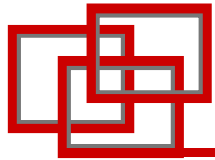Given the dimensions and the material, the pulley volume is calculated as follows:

- $\pi r^2 L$ = volume
- $3.142 \cdot (1.57)^2 \cdot 2.36 = 18.277$ cu. in.

Next, the pulley mass is calculated as follows:

- volume · density = mass
- $18.277 \cdot 0.096 = 1.755$ lb

Finally, the pulley inertia is calculated as follows:

- mass · radius^2/2 · gravity = inertia
- $1.755 \cdot (1.57)^2/2 \cdot 386.02$ in/sec^2 = 0.0056 lb-in-sec^2

Torque

Torque is the turning force applied to an object, tending to cause rotation. Torque is required to overcome the mechanical forces of friction, gravity, and inertia when moving a load.
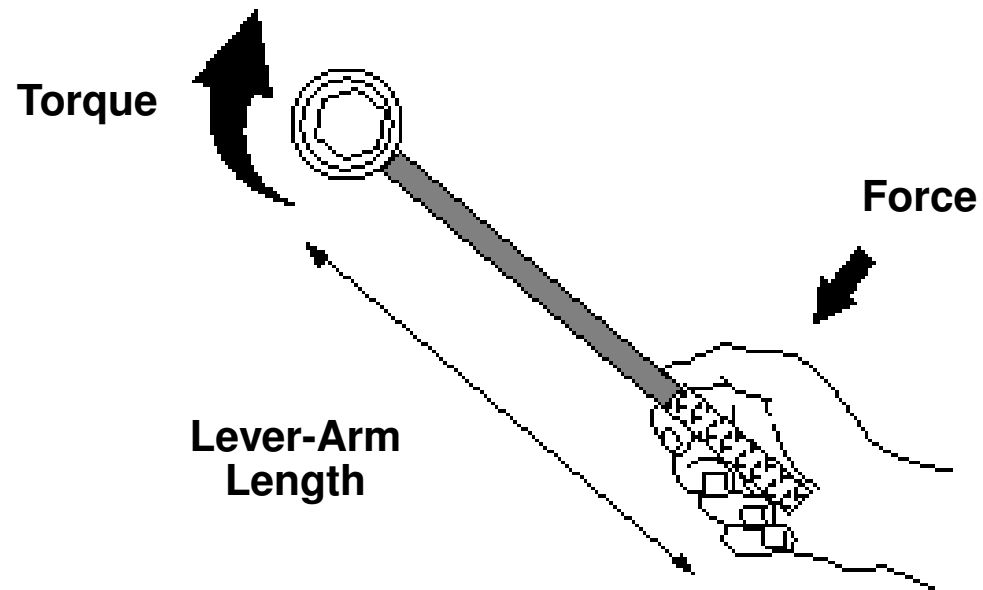
Torque is the product of force times lever arm length (radius). This can be expressed as follows:
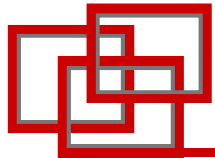
$T = F \cdot R$, where:

- T = torque
- F = force
- R = radius (lever arm length)

Torque

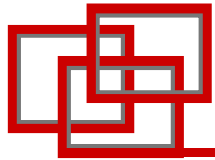This concept is shown in the following graphic:

Torque

In a motion control system, torque is produced by the rotational force of a turning motor. There are four types of torque that apply to motion control:

- Acceleration torque
- Loss torque
- Load torque
- Gravity torque

In addition to the total inertia of the motion control system, a motion control application must have all four of these torques factored into the motion control system's movements to perform motion successfully in an application.

Acceleration Torque

The torque required to overcome the total inertia of the system components and start the load moving is called **acceleration torque**. Acceleration torque can be expressed as follows:

T = Ja, where:

- T = accelerating torque
- J = polar moment of inertia (load inertia)
- a = angular acceleration

The load inertia value is obtained by adding together all of the moving component inertia values in the motion control application.
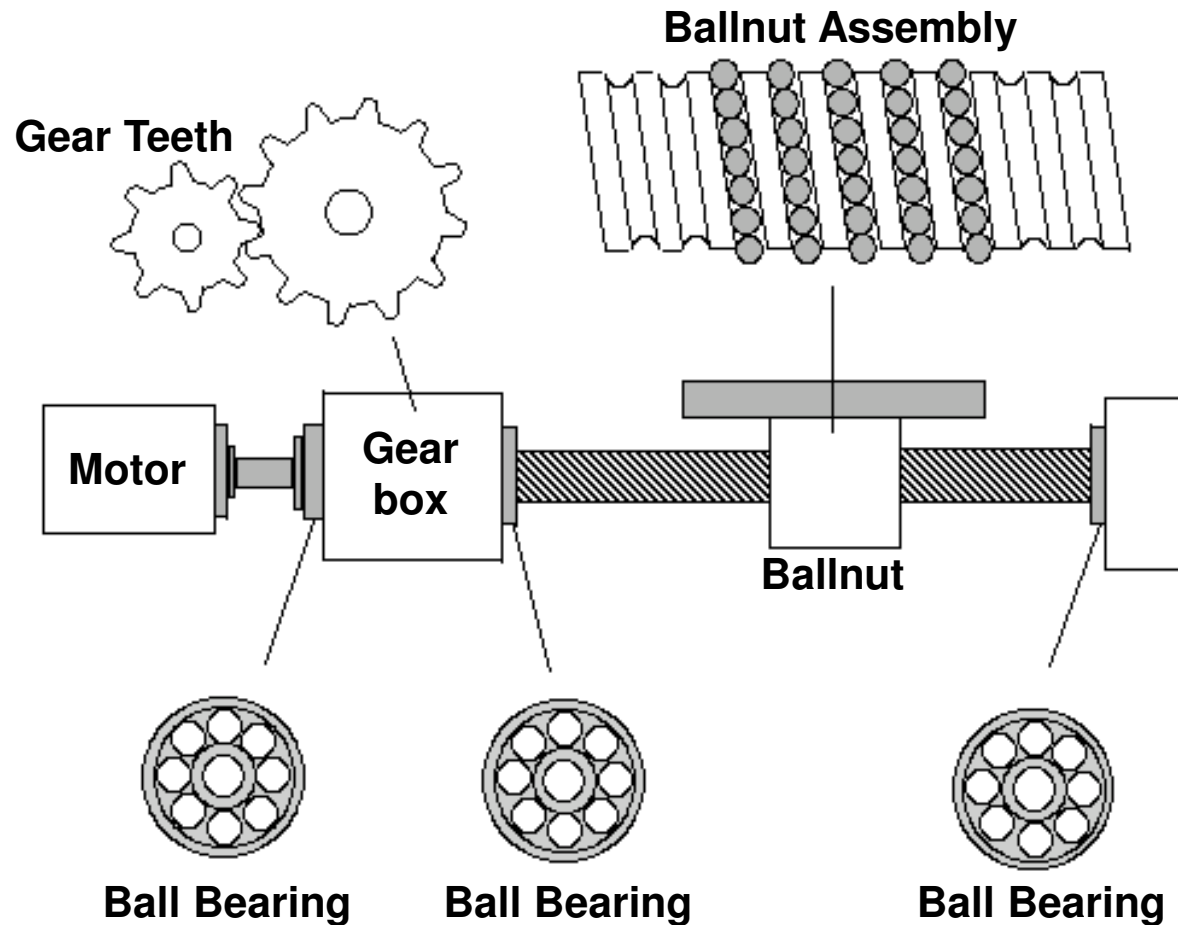
Loss Torque

The torque that is required to overcome static forces of machine friction is called **loss torque**.
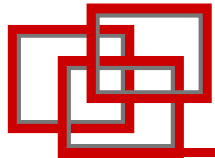
Friction losses are caused by the following:

- Sliding friction
- Gear tooth resistance
- Bearing resistance
- Ballnut resistance
- Machine component weight

Friction loss points in a typical motion control system are shown in the following graphic:

Ballnut Assembly

Gear Teeth

Motor

Gear box

Ballnut

**Ball Bearing**

Ball Bearing

Ball Bearing

Loss Torque

Loss torque has the following characteristics:

- Is often precalculated and established by machine manufacturer, e.g., ballscrew preload

- Is active during motion only

- Must be added to the torque calculations in the motion control application to overcome the loss

- Changes direction with motion, so loss torque always opposes motion
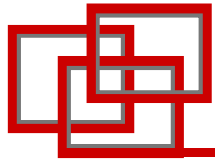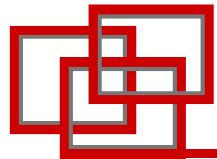
Load Torque

The torque that is required to perform the actual work in the motion control application is called **load torque**. Load torque is applicable whenever work must be performed after acceleration.

Load torque has the following characteristics:

- Is usually constant for an application
- Is often not present for the entire motion action
- Is zero if there is no load
- Changes with the direction of applied load

Example: Load Torque in a Drilling Application

In the following example, castings are being drilled as a step in a manufacturing process. Load torque is shown in the following graphic:
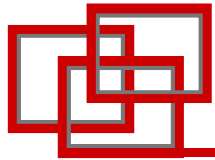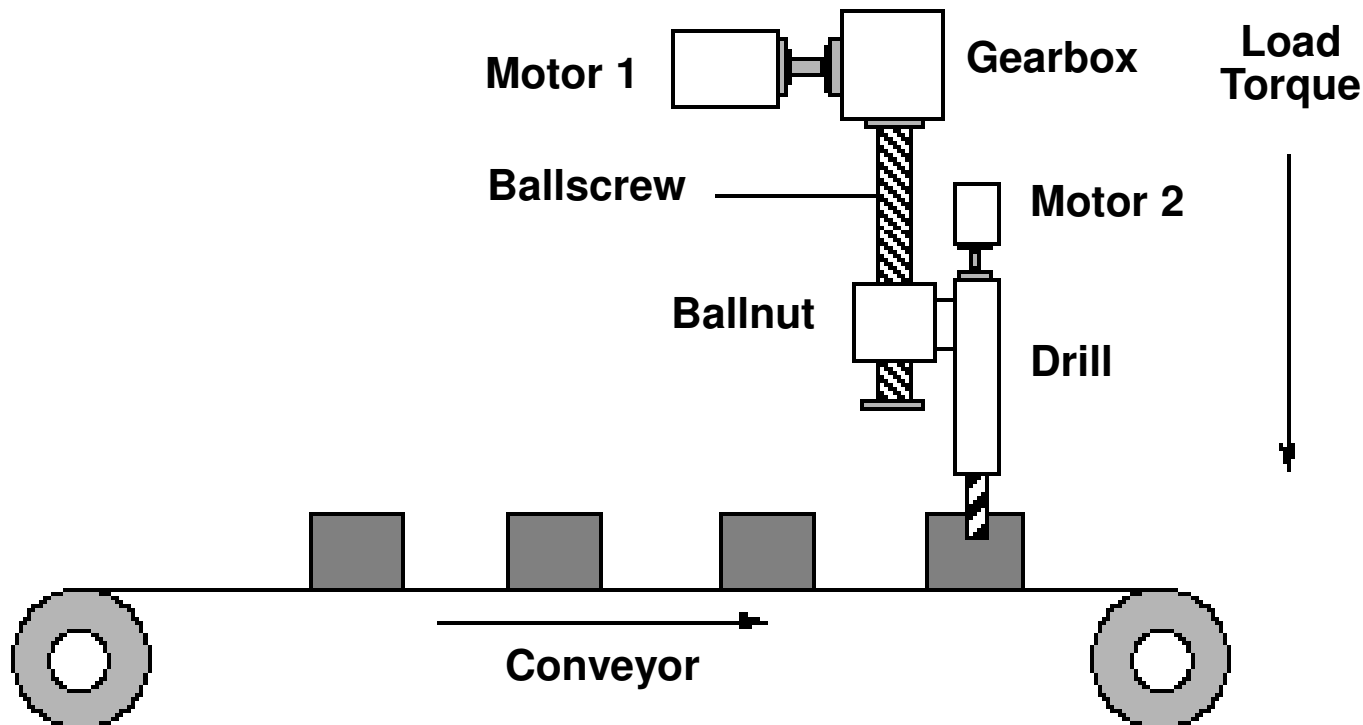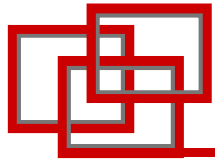
Example: Load Torque in a Drilling Application

The load torque in the drilling operation is described as follows:

- The conveyor pauses as each casting is positioned under the drill head.

- The drill head is raised and lowered by motor 1, which is connected to a ballscrew by a gearbox.

- Motor 2 rotates the drill bit.

- When the casting is in position, motor 1 turns the ballscrew and lowers the drill head, providing load torque to press the rotating drill bit into the casting.

- Motor 2 then provides the load torque required to drill into the metal surface of the casting and create the hole.

- Both motors in the application must provide the required load torque to push the drill head down and drill the hole in the casting.
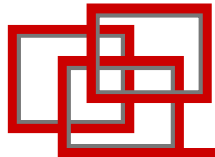
Gravity Torque

The torque that is required to perform non-horizontal work in the motion control application is called **gravity torque**. This is applicable whenever the force of gravity must be overcome to lift a load or perform work.
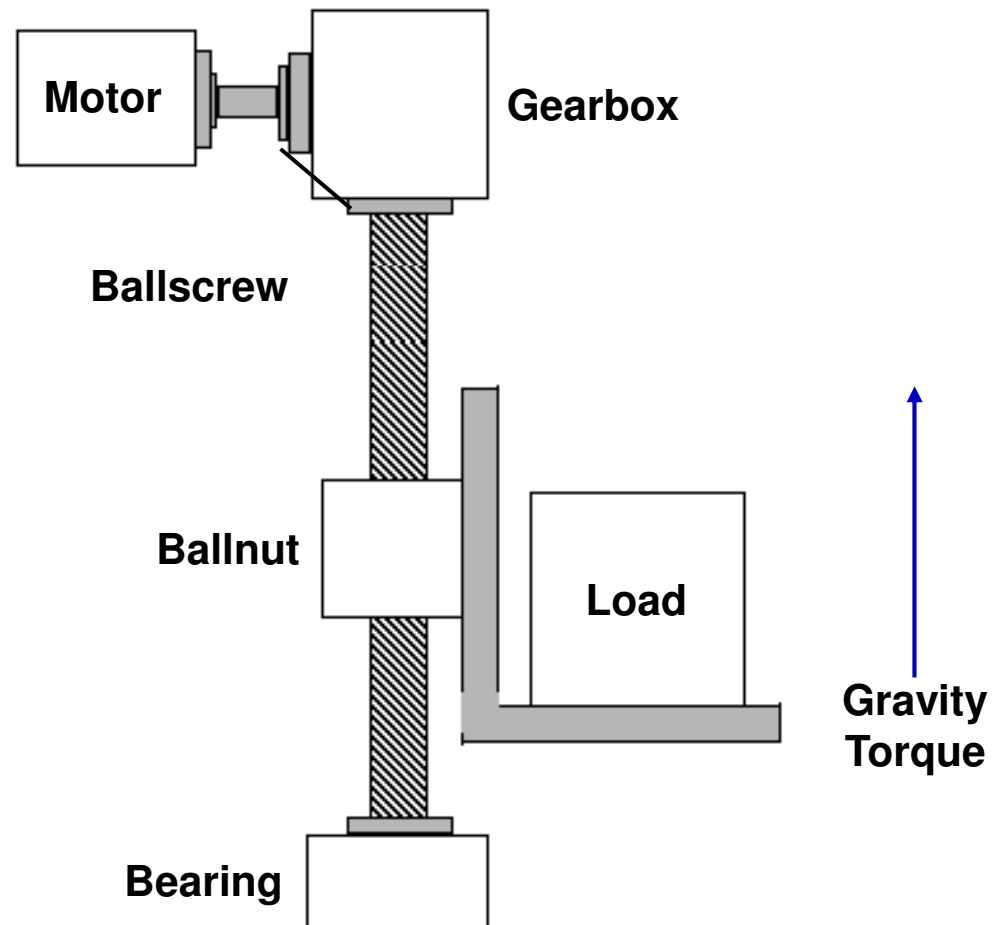
Gravity torque has the following characteristics:

- Applies to any motion other than horizontal motion
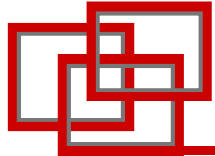- Is zero if there is no lifting being performed

In the following example, a load is lifted vertically by a motor turning a ballscrew.

Gravity torque is shown in the following graphic:

Example: Gravity Torque in a Lifting Application

The gravity torque in the lifting operation is described as follows:

- The motor is connected to the ballscrew by a gearbox.

- As the motor turns, the ballscrew rotates and raises or lowers the load, depending on the direction the motor is turning.

- The motor must provide the required gravity torque to overcome the force of gravity and lift the load.