Unit 6: Gears, Chains, and Sprockets

In Unit 6: Gears, Chains, and Sprockets, you modify the VEX test stand from Unit 5: Speed, Power, Torque, and DC Motors to learn more key engineering concepts that involve the use of gears, chains, and sprockets, along with key corresponding concepts such as reduction and ratio.

The concepts regarding gears, gear ratios, force, torque, and motor speed have countless real-world applications. In STEM Connections, we have presented a scenario involving the operation of a winch installed on a coast guard helicopter for sea rescue operations. After completing the Think Phase and Build Phase in Unit 5: Speed, Power, Torque, and DC Motors, you will see how those concepts come into play in the real world.

Unit Objectives

After completing Unit 6: Gears, Chains, and Sprockets, you will be able to:

- Identify whether a gear reduction causes a speed reduction or a speed increase, and calculate gear ratios.
- Create a spur gear and animate a gear assembly using Autodesk® Inventor® Professional 2009.
- See the relationship between gearing, speed, and power; and incorporate VEX gears into a design.
- Modify the gearing of a VEX gearbox and understand the effect of gear ratios on speed and torque.

Prerequisites

Related resources for Unit 6: Gears, Chains, and Sprockets are:

- Unit 1: Introduction to VEX and Robotics.
- Unit 2: Introduction to Autodesk® Inventor®.
- Unit 4: Microcontroller and Transmitter Overview.
- Unit 5: Speed, Power, Torque, and DC Motors.
Key Terms and Definitions

The following key terms are used in Unit 6: Gears, Chains, and Sprockets:

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bevel Gear</td>
<td>A kind of gear in which the two gears working together lie in different planes, and have their teeth cut at right angles to the surfaces of two cones whose apices coincide with the point where the axes of the wheels would meet.</td>
</tr>
<tr>
<td>Chain</td>
<td>A connected flexible series of links used for fastening or securing objects and pulling or supporting loads.</td>
</tr>
<tr>
<td>Gear</td>
<td>One of a set of toothed wheels that work together to alter the relation between the speed of a driving mechanism and the speed of the driven parts.</td>
</tr>
<tr>
<td>Gear Ratio</td>
<td>The relationship between the number of teeth on two gears that are meshed or two sprockets connected with a common roller chain, or the circumferences of two pulleys connected with a drive belt.</td>
</tr>
<tr>
<td>Gear Ratio</td>
<td>Gear ratio in a gearbox or transmission: The ratio between the rates at which the last and first gears rotate.</td>
</tr>
<tr>
<td>Gear Reduction</td>
<td>Involves using gears/sprockets/pulleys of two different sizes to work together, usually slowing output speed and increasing torque. Desired gear reductions can be accomplished in one or multiple stages.</td>
</tr>
<tr>
<td>Gear Teeth</td>
<td>A gear is different from a pulley in that a gear is a round wheel which has teeth that mesh with other gear teeth, allowing force to be fully transferred without slippage.</td>
</tr>
<tr>
<td>Sprocket</td>
<td>Any of various toothlike projections arranged on a wheel rim to engage the links of a chain.</td>
</tr>
<tr>
<td>Spur Gear</td>
<td>Spur gears are the simplest, and probably most common, type of gear. Their general form is a cylinder or disk. The teeth project radially, and with these “straight-cut gears,” the leading edges of the teeth are aligned parallel to the axis of rotation. These gears can only mesh correctly if they are fitted to parallel axles.</td>
</tr>
<tr>
<td>Worm Gear</td>
<td>A worm is a gear that resembles a screw. It is a type of helical gear, but its helix angle is usually somewhat large (that is, close to 90 degrees) and its body is usually fairly long in the axial direction; and it is these attributes that give it its screwlike qualities. A worm is usually meshed with an ordinary looking, disk-shaped gear, which is called the gear, the wheel, the worm gear, or the worm wheel. The prime feature of a worm-and-gear set is that it allows the attainment of a high gear ratio with few parts in a small space.</td>
</tr>
</tbody>
</table>

Required Supplies and Software

The following supplies and software are used in Unit 6: Gears, Chains, and Sprockets:

<table>
<thead>
<tr>
<th>Supplies</th>
<th>Software</th>
</tr>
</thead>
<tbody>
<tr>
<td>VEX Classroom Lab Kit</td>
<td>Autodesk Inventor Professional 2009</td>
</tr>
<tr>
<td>Notebook and pen</td>
<td></td>
</tr>
<tr>
<td>One assembled VEX motor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>test stand from the Unit 5: Speed, Power,</td>
</tr>
<tr>
<td></td>
<td>Torque, and DC Motors &gt; Build Phase.</td>
</tr>
</tbody>
</table>
An assembled the gear ratio test stand from the Unit 6: Gears, Chains, and Sprockets > Build Phase.

Small storage container for loose parts

Work surface

5 lb. weight

A surface (for example, a table or desk) with an edge at least 24” above the ground

One stopwatch

### VEX Parts

The following VEX parts are used in Unit 6: Gears, Chains, and Sprockets > Build Phase:

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Part Number</th>
<th>Abbreviations</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>BEARING-FLAT</td>
<td>BF</td>
</tr>
<tr>
<td>10</td>
<td>NUT-832-KEPS</td>
<td>NK</td>
</tr>
<tr>
<td>10</td>
<td>SCREW-832-0500</td>
<td>S4</td>
</tr>
<tr>
<td>2</td>
<td>SHAFT-3000</td>
<td>SQ3</td>
</tr>
<tr>
<td>2</td>
<td>SHAFT-COLLAR</td>
<td>COL</td>
</tr>
<tr>
<td>1</td>
<td>SPACER-THICK</td>
<td>SP2</td>
</tr>
<tr>
<td>1</td>
<td>SPACER-THIN</td>
<td>SP1</td>
</tr>
<tr>
<td>1</td>
<td>VEX-12-TOOTH-GEAR</td>
<td>G12</td>
</tr>
<tr>
<td>1</td>
<td>VEX-84-TOOTH-GEAR</td>
<td>G84</td>
</tr>
<tr>
<td>2</td>
<td>WASHER-DELRIN</td>
<td>WP</td>
</tr>
</tbody>
</table>

### VEX Parts

The following VEX parts are used in Unit 6: Gears, Chains, and Sprockets > Amaze Phase:

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Part Number</th>
<th>Abbreviations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>VEX-36-TOOTH-GEAR</td>
<td>G36</td>
</tr>
<tr>
<td>1</td>
<td>VEX-60-TOOTH-GEAR</td>
<td>G60</td>
</tr>
</tbody>
</table>
## Academic Standards

The following national standards are supported in Unit 6: Gears, Chains, and Sprockets.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Standard</th>
</tr>
</thead>
</table>
| **Think** | Science (NSES)  
*Unifying Concepts and Processes: Form and Function*  
*Physical Science: Motion and Forces*  
*Science and Technology: Abilities of Technological Design*  
**Technology (ITEA)**  
5.8: The Attributes of Design  
**Mathematics (NCTM)**  
*Connections*  
Recognize and apply mathematics in contexts outside of mathematics.  
*Algebra*  
Analyze change in various contexts.  
*Measurement*  
Understand measurable attributes of objects and the units, systems, and processes of measurement.  
*Communication*  
Communicate mathematical thinking coherently and clearly to peers, teachers, and others. |
| **Create** | Science (NSES)  
*Unifying Concepts and Processes: Form and Function*  
*Physical Science: Motions and Forces*  
*Science and Technology: Abilities of Technological Design*  
**Technology (ITEA)**  
5.8: The Attributes of Design  
5.9: Engineering Design  
6.12: Use and Maintain Technological Products and Systems  
**Mathematics (NCTM)**  
*Numbers and Operations*  
Understand numbers, ways of representing numbers, relationships among numbers, and number systems.  
*Algebra Standard*  
Understand patterns, relations, and functions.  
*Geometry Standard*  
Use visualization, spatial reasoning, and geometric modeling to solve problems.  
*Measurement Standard*  
Understand measurable attributes of objects and the units, systems, and processes of measurement. |
<table>
<thead>
<tr>
<th>Phase</th>
<th>Standard</th>
</tr>
</thead>
</table>
| Build | **Science (NSES)**  
*Unifying Concepts and Processes: Form and Function*  
*Physical Science: Motion and Forces*  
*Science and Technology: Abilities of Technological Design*  
**Technology (ITEA)**  
5.8: The Attributes of Design  
5.9: Engineering Design  
6.11: Apply the Design Process  
**Mathematics (NCTM)**  
*Connections*  
Recognize and apply mathematics in contexts outside of mathematics.  
*Numbers and Operations*  
Compute fluently and make reasonable estimates.  
*Algebra*  
Analyze change in various contexts.  
*Geometry*  
Use visualization, spatial reasoning, and geometric modeling to solve problems.  
*Measurement*  
Understand measurable attributes of objects and the units, systems, and processes of measurement.  
Apply appropriate techniques, tools, and formulas to determine measurements. |
<table>
<thead>
<tr>
<th>Phase</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amaze</td>
<td><strong>Science (NSES)</strong>&lt;br&gt; <em>Unifying Concepts and Processes: Form and Function</em>&lt;br&gt; <em>Physical Science: Motion and Forces</em>&lt;br&gt; <em>Science and Technology: Abilities of Technological Design</em>&lt;br&gt; <strong>Technology (ITEA)</strong>&lt;br&gt; 5.8: The Attributes of Design&lt;br&gt; <strong>Mathematics (NCTM)</strong>&lt;br&gt; <em>Connections</em>&lt;br&gt; Recognize and apply mathematics in contexts outside of mathematics.&lt;br&gt; <em>Numbers and Operations</em>&lt;br&gt; Compute fluently and make reasonable estimates.&lt;br&gt; <em>Algebra</em>&lt;br&gt; Analyze change in various contexts.&lt;br&gt; <em>Geometry</em>&lt;br&gt; Use visualization, spatial reasoning, and geometric modeling to solve problems.&lt;br&gt; <em>Measurement</em>&lt;br&gt; Understand measurable attributes of objects and the units, systems, and processes of measurement.&lt;br&gt; Apply appropriate techniques, tools, and formulas to determine measurements.&lt;br&gt; <em>Communication</em>&lt;br&gt; Communicate mathematical thinking coherently and clearly to peers, teachers, and others.</td>
</tr>
</tbody>
</table>
Think Phase

Overview

This phase explains some of the fundamental concepts of gearing. It also covers the differences between spur gears and setups involving sprockets and chain.

Phase Objectives

After completing this phase, you will be able to:

- Identify whether a set of gears causes a speed reduction or a speed increase.
- Calculate gear ratios and their corresponding speed reduction or increase.
- Determine the direction an output shaft will rotate based on a known input.

Prerequisites

Related phase resources are:

- Unit 1: Introduction to VEX and Robotics.
- Unit 5: Speed, Power, Torque, and DC Motors.

Required Supplies and Software

The following supplies are used in this phase:

<table>
<thead>
<tr>
<th>Supplies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Notebook and pen</td>
</tr>
<tr>
<td>Work surface</td>
</tr>
</tbody>
</table>
Research and Activity

Introduction to Gears

As learned in Unit 5: Speed, Power, Torque, and DC Motors, a motor can generate a set amount of power; that is, it can provide a specific amount of energy every second. Since there is only so much energy to go around, and energy is the product of torque and speed, there is an inherent trade-off between torque and speed.

In many cases, the motor output characteristics do not match the motor application. For example, a motor that is very fast but has only a little bit of torque might not be suitable to lift a heavy load. In these cases, it is necessary to use gear ratios to change the outputs to a more appropriate balance of torque and speed.

About Gears

Gears are toothed wheels that interlock, or mesh, in order to transmit rotational motion and power (torque) efficiently. Modern gear design is a very complicated combination of material selection and its properties, which deals with the wear, strength, and durability of the design.

Gears are some of the most durable and rugged mechanical parts available with efficiencies of up to 98% and very long service lives, and, as a result, have significant advantages over most other drive systems. They are an ingenious combination of the best properties of simple machines. Gears improve upon the wheel by using projections called teeth that are designed to contact the teeth of another gear-transferring motion and force to the other gear. When gear teeth fit together in this manner they are said to be meshed. Meshed gears transmit rotational motion from one gear to another allowing torque to be transferred without slippage. The most common arrangement is for a gear to mesh with another similar gear of the same type, but a gear can mesh with any device or mechanism having compatible teeth, such as a rack that moves in a linear direction when acted upon by a rotating gear. The gear transmitting the force or motion is called the input or drive gear and the gear connected to the drive gear is called the output or driven gear.

Gears control power transmission in three ways:

1. Changing the direction through which power is transmitted.
2. Changing the amount of force or torque.
3. Changing the speed of rotation, typically measured in revolutions per minute (RPM).

The most important mechanical feature of gears is that gears of unequal size can be combined to produce what is called a mechanical advantage, resulting in a change of rotational speed (RPM) and torque of the second gear. This is quantified as a gear ratio.

Gears are made of many different materials, but metals and plastics are the primary modern materials. Modern gear design is a complicated combination of material selection and its properties, which deals with the wear, strength, and durability of the design. The first gears were actually made of wood and called peg wheels. Examples can still be found in use today around the world.

There are many different kinds and sizes of gears, but only three major types are covered here; spur, bevel, and worm.
**Spur Gears**

Spur gears have been used since ancient times. They are used primarily to transfer speed and torque between parallel shafts. The most recognizable gear form, spur gears have many advantages of other types due to their simple design, low manufacturing costs, and easy maintenance. One downside to spur gears is that they are noisy due to the impacts of meshing teeth.

**Bevel Gears**

Bevel gears are conical-shaped gears used in machines where a change in the output shaft’s direction is desired. The shafts must intersect. They may intersect at any angle, with 90 degrees the most common. The teeth are the same basic shape as a spur gear’s teeth, but have a slight taper towards the apex of the cone.
Worm Gears

Worm gears are used to transmit power between two shafts that are at right angles to each other. They are frequently used where a large speed reduction or large mechanical advantage is required in a limited space. It is not uncommon to achieve ratios of 300:1 or greater. Another property of worms is that the assembly automatically locks in position when power is not applied. The worm can easily turn the gear, but the gear cannot turn the worm due to the high friction. This property is useful in designs where a braking or locking action is desired.

Gear Ratios

Gear ratios work based on the physical principle of mechanical advantage. As you can see in the diagram below, when a small gear meshes with a larger gear, the torque applied onto the smaller gear is increased. This increase is based on the difference between the radius of each gear. You will notice that in this example, there is a torque increase of (3x).
The driving torque applies some force at a distance of “D” from the center of rotation. This force then applies some torque at distance “3D” (this diameter is three times as large as the small gear). If we simplify things, we see the new torque is equal to the original torque multiplied by (3X).

A torque increase is not the only result of this gear ratio. You can see in the diagram below that the smaller gear has half the circumference of the larger gear (the circumference is shown “unrolled”).

This means that the smaller gear must revolve three times in order for the large gear to revolve once; this results in the larger gear having (1/3) the rotational speed (RPM). Notice this is the inverse of the torque increase.

For each increase in torque, there is an equivalent speed reduction; for each decrease in torque, there is an equivalent speed increase.

Since the number of teeth a gear has is proportional to its radius, you can use tooth-count as a method for determining gear ratios. (For example, a 36-tooth gear is three times as big as a 12-tooth gear, so a 12:36-tooth gear would yield a 3:1 ratio.)

You can think of a gear ratio as a “multiplier” on torque and a “divider” on speed. If you have a gear ratio of 3:1, you have three times as much torque as you would if you had a gear ratio of 1:1, but only 1/3 as much speed.

Calculating the gear ratio between a pair of gears is simple. First, identify which gear is the driving gear, and which is the driven gear. The driving gear is the one that is providing the torque to turn the other one. This gear is typically the one on the motor side of the reduction, or even directly attached to the motor. The other gear, the one that the driving gear is turning, is called the driven gear.
To find gear ratio, you need to count the number of teeth on the driven gear and divide it by the number of teeth on the driving gear. See the examples in the diagram below.

**Example 1:**
- Driving gear: 12 teeth
- Driven gear: 12 teeth

Gear Ratio = \( \frac{12}{12} = 1:1 \)

- Torque: 1x
- Speed: 1x

**Example 2:**
- Driving gear: 36 teeth
- Driven gear: 12 teeth

Gear Ratio = \( \frac{36}{12} = 3:1 \)

- Torque: \( \frac{1}{3}x \)
- Speed: 3x
Idler Gears

Gears can be inserted between the driving and driven gears. These are called idler gears, and they have no effect on the robot’s gear ratio because their gear ratio contributions always cancel themselves out (because they are a driven gear relative to the first gear, and a driving gear relative to the last gear—you first multiply by the number of teeth on the idler gear and then divide by the same number, which always cancels out).

However, idler gears do reverse the direction of rotation. Normally, the driving gear and the driven gear turn in opposite directions. Adding an idler gear makes them turn in the same direction. Adding a second idler gear makes them turn in opposite directions again. Idler gears are typically used either to reverse the direction of spin between two gears or to transmit force from one gear to another gear far away (by using multiple idler gears to physically bridge the gap).
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No Idler – Opposite Direction

One Idler – Same Direction

Two Idlers – Opposite Direction
**Compound Gear Ratio**

Compound gears are formed when you have more than one gear on the same axle. Compound gears are not to be confused with idler gears, as compound gears can affect the overall gear ratio of a system!

In the compound gear system, there are multiple gear pairs. Each pair has its own gear ratio, but the pairs are connected to each other by a shared axle.

The resulting compound gear system still has a driving gear and a driven gear, and still has a gear ratio (now called a compound gear ratio).
The compound gear ratio between the driven and driving gears is then calculated by multiplying the gear ratios of each of the individual gear pairs.

Compound gears allow configurations with gear ratios that would not normally be achievable with the components available. In the example above, a compound gear ratio of 1:25 was achieved using only 12 and 60-tooth gears. This would give your robot the ability to turn an axle 25 times faster than normal (though it would only turn with 1/25th of the torque)!

**Gearing Design**

You can see how by using gear ratios you can affect the amount of loading applied to a motor by a mechanism. This is extremely important for mechanism design, because it is rare that the output of a motor is perfectly suited for a given application. As discussed in Unit 5: Speed, Power, Torque and DC Motors, the loading on the motor must be adjusted using gear to optimize system performance.
Chain Drives

Sprockets and chains are commonly used in applications where torque is needed to be transferred over longer distances than allowed by gears. Unlike spur gears, all of the sprockets in a chain drive rotate in the same direction.

Chain Drives

Roller chain is the most commonly used type of chain and has been in use since its invention late in the 19th century. It typically consists of rollers cushioned by bushings held in place by pins. These in turn are held in place by a set of roller link plates that are sandwiched between two link plates. You can find roller chains on bicycles and industrial machinery. Although very common, roller chains require constant lubrication and maintenance. Simpler cheaper versions without the bushings exist, but they are less durable and are reserved for less critical uses.

Chains elongate while they are used so they must have some kind of adjustment or a convenient way to remove links to maintain proper tension. Roller chains incorporate a “master link” that can be removed easily to remove links. Most chain-drive mechanisms have some sort of tensioning device that can be adjusted without interrupting the operation of the device.
Sprockets

Sprockets, although similar in appearance to gears from a distance, are distinctly different in design and use. Gears are designed to mesh directly with each other, while sprockets are incapable of directly meshing. They are specifically designed for meshing with a chain to transfer power.

Other Types of Chains

In light duty applications, plastic chains are finding their place. Although not as durable as metal chains, they do not need constant lubrication. Another advantage is they are easy to resize and do not have as many parts in their construction. The VEX Robotics System uses a plastic chain and matching sprockets. It is similar to a metal chain pintle design. Pintle chains are used in unprotected, dirty, or dusty environments where lubrication is not effective or desired.

Chain Drive Gear Ratios

The real nature of gear ratios is a little more complex than just counting teeth on gears. Gear ratio is actually defined as the number of rotations that the driving axle needs to make in order to turn the driven axle around once. When dealing with toothed gears, you can find the number of turns needed by counting teeth, as you have seen previously. All the gear ratios you have looked at so far have used spur gears.

In sprocket and chain reductions, you can still “count the teeth” to find a gear ratio, because as with spur gears, the teeth count is proportional to the sprocket diameter.
Create Phase

Overview

This phase describes the creation and editing of spur, bevel, and worm gear sets. Autodesk Inventor’s Design Accelerator application contains a specific gear generator for each type of gear.

Gears are components that determine the speed, torque, and direction of power as it is transferred through a system. Properly designed gears transmit power smoothly and efficiently, thus reducing wear and impact on the system. By changing gear ratios, you can run machinery at optimum efficiency and adjust to changing conditions. Using Design Accelerator, you can identify multiple gear combinations, and validate their capabilities within your design.

Protobot Gears

The Protobot uses spur gears to drive the wheels and the arm as shown.

Objectives

After completing this phase, you will be able to:

- Describe gear generation in Design Accelerator.
- Describe options for spur, bevel, and worm gear generation.
- Use Design Accelerator to create spur gears.
- Animate a gear assembly.

Prerequisites

Before starting this phase, you must have:

- A working knowledge of the Windows operating system.
- Completed Unit 1: Introduction to VEX and Robotics > Getting Started with Autodesk Inventor.
- Completed Unit 2: Introduction to Autodesk Inventor > Quick Start for Autodesk Inventor.
## Technical Overview

The following Autodesk Inventor tools are used in this phase.

<table>
<thead>
<tr>
<th>Icon</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Spur Gear Generator icon]</td>
<td><strong>Spur Gear Generator</strong></td>
<td>Calculates dimensions and checks strength of external and internal gearing with straight and helical teeth. It contains geometric calculations for designing different types of correction distributions, including a correction with compensation of slips.</td>
</tr>
</tbody>
</table>
| ![Work Plane icon] | **Work Plane** | Use work planes when creating axes, sketch planes, or termination planes, or to position cross-sectional views or cutting planes.  
Use a work plane:  
- When a part face is not available as a sketch plane for sketching new features.  
- When an intermediate position is required to define other work planes (for example, at an angle to a face at an offset distance). |
| ![2D Sketch icon] | **2D Sketch** | A sketch consists of the sketch plane, a coordinate system, 2D curves, and the dimensions and constraints applied to the curves. |
| ![Project Geometry icon] | **Project Geometry** | Projects geometry (model edges, vertices, work axes, work points, or other sketch geometry) onto the active sketch plane as reference geometry. |
| ![Center Point Circle icon] | **Center Point Circle** | Creates a circle from a center point and radius, or tangent to three lines. |
| ![General Dimension icon] | **General Dimension** | Adds dimensions to a sketch. Dimensions control the size of a part. They can be expressed as numeric constants, as variables in an equation, or in parameter files. |
| ![Two Point Rectangle icon] | **Two Point Rectangle** | Used to create rectangles two ways: specifying diagonal corners or specifying length and width. Each rectangle side is a line segment. |
| ![Vertical Constraint icon] | **Vertical Constraint** | A geometric constraint that positions selected lines, ellipse axes, or pairs of points parallel to the Y-axis of the sketch coordinate system (same X coordinate). |
| ![Horizontal Constraint icon] | **Horizontal Constraint** | The horizontal constraint causes lines, ellipse axes, or pairs of points to lie parallel to the X axis of the sketch coordinate system. |
| ![Equal Constraint icon] | **Equal Constraint** | A geometric constraint that causes selected arcs and circles to have the same radius or selected lines to have the same length. |
| ![Fillet icon] | **Fillet** | Placed features that round off or cap interior or exterior corners or features of a part. |
| ![Mirror icon] | **Mirror** | Use to mirror sketch geometry across a centerline. |
## Required Supplies and Software

The following software is used in this phase.

<table>
<thead>
<tr>
<th>Software</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autodesk Inventor Professional 2009</td>
</tr>
</tbody>
</table>

## About Generating Gears

The gear generators in Design Accelerator enable you to add gear models to your designs by entering data in a table format, and then validating your entries prior to producing the gear set. The gear generators automate the gear design process and reduce the time required to sketch and model gear data.

The gear generators are designed so that you can add general information regarding the type of gear set selected and then provide data for the individual gears. At any time during this process, you can calculate the current data, preview the gear set in the graphics window, and review the calculations for possible issues.
Spur Gears Component Generator

You enter the gear design parameters to create the correct sized spur gear for the Protobot.

Definition of Generated Gears

The gear generators are where you enter gear data to produce gear models in your assemblies. After the required data is entered into the gear generator, the data is processed and models are produced based on the data provided.

The data that you input into the gear generator and the resulting calculations are stored with the gear set. Because the values are stored as part of the generated gear set, you can review your results or revise your calculations at a later time.
Example: Generated Gears

In the following illustration, a bevel gear set is created to change the direction and transmit power from the input shaft to the threaded rod. Now that the gear design has been finalized, the final shaft lengths can be determined, as well as the methods to secure the gears to the shafts.

Gear Generator Options

When you create or edit gear sets, you interact with the Gears Component Generator dialog box for the type of gear specified. The Design Accelerator enables you to efficiently design spur, bevel, and worm gear sets. To design and position your gear sets in your assemblies, you need to know what options are available in the dialog box and where they are located.

The specific Gears Component Generator dialog box is displayed after you click the tool to generate gears. Within this dialog box, you enter the method and values required to calculate the gear set. The information varies depending on the method used.
Each of the Gears Component Generator dialog boxes is divided into three main areas. In the Common area, you can specify the gear creation method and other information pertaining to the overall gear set. In the Gear1 and Gear2 areas, you can specify data that is specific to the individual gear. For example, for a bevel gear set, when you define the Cylindrical Face and Start Plane for each gear, the Shaft Angle is calculated and displayed in the Common area.

Spur Gear Options

The following options are available for creating spur gear sets.

1. Design
2. Calculation
3. Common
4. Gear1
5. Gear2
6. Worm gear
7. Component
8. Number of Teeth
9. Facewidth
10. Unit Correction
11. Start plane
12. Calculate
13. OK
14. Cancel
Enter data to design the gear set.

Input power and speed requirements and review calculation results. Calculations are based on power and speed inputs, and information from the Design tab.

Specify information that applies to the entire gear set.

Input data specific to the first gear.

Input data specific to the second gear.

Display a page containing all input data and calculations.

Bevel Gear Options

The following options are available for creating bevel gear sets.
Worm Gear Options

The following options are available for creating worm gear sets.

1. Enter data to design the gear set.
2. Input power and speed requirements and review calculation results. Calculations are based on power and speed inputs, and information from the Design tab.
3. Specify information that applies to the entire gear set.
4. Input data specific to the worm.
5. Input data specific to the worm gear.
6. Display a page containing all input data and calculations.
Exercise: Generate Spur Gears

In this exercise, you design two spur gears for the Protobot. The design parameters and an existing assembly are supplied to assist you with the gear design.

3. Open DesignGears.iam. The two parts represent a simplified design of the drive shafts from the Protobot. The center to center distance is set to two inches.

4. On the panel bar, click the down arrow and select Design Accelerator.

5. On the Design Accelerator panel bar, click Spur Gears Generator.

The completed exercise

Create Spur Gears for the Protobot

In this exercise, you design two spur gears for the Protobot. The design parameters and an existing assembly are supplied to assist you with the gear design.

1. If a default configuration file for spur gear configurations already exists for the current user, delete it.
   - In Windows Explorer, navigate to the following path: Drive: \Documents and Settings\User name\Application Data\Autodesk\Inventor 2009\DesignAccelerator\Defaults\.
   - If the file CAGearsSpur.Imperial.xml exists, delete it.

2. Make IFI_Unit6.ipj the active project.
6. To set the Common values for the spur gear:
   - In the Spur Gears Component Generator dialog box, under Common, from the Design Guide list, select Number of Teeth.
   - From the Desired Gear Ratio list, select 7.1000 ul.
   - From the Diametral Pitch list, select 24.0000 ul/in.
   - Verify that Internal is not selected.

7. To define the values for Gear 1:
   - In the Spur Gears Component Generator dialog box, under Gear 1, click Cylindrical Face.
   - Select the surface of the top shaft (1).
   - Click Start plane. Select the face (2).
   - For Facewidth, enter 0.25.

8. To define the values for Gear 2:
   - In the Spur Gears Component Generator dialog box, under Gear 2, click Cylindrical Face.
   - Select the surface of the lower shaft (1).
   - Click Start plane. Select the face (2).
   - For Facewidth, enter 0.25.

9. Click the chevron to resize the summary window.

10. To check your design, in the Spur Gears Component Generator dialog box, click Calculate. The initial design fails as noted in red text in the summary window.

11. For Unit Correction, enter 0.2.
Create a Work Plane

In this section of the exercise, you create a work plane through the spur gear.

1. In the browser, expand Spur Gears:1.
2. Right-click Spur Gear1:1. Click Open.

3. On the ViewCube, click Home.

4. Click Work Plane.

5. Move the cursor over the top edge of a gear tooth. Click when the center point of the edge is displayed as shown.

12. To check your design again, click Calculate. The Unit Correction error for Gear 1 is resolved, as noted by the blue color of the text, but the design still fails.

13. Click the Calculation tab.

14. Under Method of Strength Calculation, select Legacy ANSI from the list.

15. Under Loads, for Power, enter 0.02 hp.

16. Click the Design tab. Click Calculate. The calculation indicates design compliance.

17. Click OK twice. The gears are created.

18. Drag the large gear. The gears rotate.

19. Save the file.
6. **Extrude the Sketch**
   
   In this section of the exercise, you extrude the center of the small spur gear.

   1. Click Project Geometry.

   2. Select the top face of a gear tooth as shown. The edge and the center point of the gear are projected onto the sketch.

   3. On the ViewCube, click Front.

   4. Click Center Point Circle.

   5. Select the projected center point (1) when the large green dot and coincident constraint are displayed. Move the cursor to preview the circle radius and click to set.

   6. Click General Dimension. Create a **0.256** dimension on the circle.

   7. Press ESC to cancel the General Dimension tool.

   8. On the ViewCube, click Home.

7. Click 2D Sketch.

8. Select the edge of the work plane.

9. Right-click in the graphics window. Click Slice Graphics. The gear is sliced along the new sketch.

10. In the browser, right-click the work plane. Click Visibility to turn off the work plane display.
9. Press E to start the Extrude tool.
10. Select the circle as the profile.
11. Click Midplane.

12. For Distance, enter 0.375.

13. Click OK.

14. Save the file.

Create a Sketch

In this section of the exercise, you create a sketch for the hole through the spur gear.

1. On the Standard toolbar, click 2D Sketch.

2. Select the front face of the extruded circle.

3. On the ViewCube, click Front.

4. Click Two Point Rectangle.

5. Create a rectangle as shown.

6. Click the down arrow beside the Constraint tool. Click the Vertical constraint tool.

7. Select the projected midpoint of the gear (1). Select the midpoint of the lower edge (2).
8. Click the down arrow beside the Constraint tool. Click the Horizontal constraint tool.

9. Select the projected midpoint of the gear (1). Select the midpoint of the left edge (2).

10. Click the down arrow beside the Constraint tool. Click the Equal constraint tool.

11. Select the two edges as shown.

12. Click General Dimension.

13. Create a 0.127 dimension on the top edge.

14. Click Fillet. For Radius, enter 0.01.

15. Select the two edges as shown to create the first fillet.

16. Repeat this workflow to create the other three fillets. 
Tip: Instead of selecting two lines, select the corner.

17. Press ESC to cancel the Fillet tool.

Extrude the Sketch

In this section of the exercise, you extrude the hole through the spur gear.

1. On the ViewCube, click Home.
2. Press E to start the Extrude tool.
3. Select the rectangle as the profile.
4. For Operation, select Cut.

5. For Distance, select To Next from the list.

6. Click OK.

7. Save the file.

Change the Material of the Gear

In this section of the exercise, you change the material of the gear to ABS plastic.

1. Click Format menu > Style and Standard Editor.


3. For color, select Green (Flat) from the list.

4. Click Save.

5. Click Done.

6. In the browser, right-click Spur Gear1. Click iProperties.

7. Click the Physical tab.

8. For Material, select ABS Plastic from the list.

9. Click Apply. Note the updated properties of the gear, such as Mass, Area, and Volume.

10. Click Close.

11. Click Save.

12. Close the Spur Gear1 window, and return to the assembly. Note that the gear is updated in the assembly.
Extrude the Sketch on the Large Spur Gear

In this section of the exercise, you extrude a sketch on the large spur gear.

1. In the browser, right-click Spur Gear2:1. Click Open.

2. On the ViewCube, click Home.

3. On the Standard toolbar, click 2D Sketch. Select the front face of the gear.

4. On the ViewCube, click Front.

5. Click Center Point Circle.

6. Create a circle on the face of the gear. The center of the circle must be coincident with the projected center of the gear.

7. Click General Dimension. Create a 3.228 dimension on the circle.

8. On the ViewCube, click Home.

9. Press E to start the Extrude tool.

10. Select inside the circle as the profile.

11. For Operation, select Cut.

12. For Distance, enter 0.076.

13. Click the More tab. For Taper, enter -10.
14. Click OK.

15. Click Fillet.

16. Select the inside edge of the extrusion.

17. For Radius, enter **0.039**.

18. Click OK.

**Mirror the Feature**

In this section of the exercise, you mirror the extrusion and the fillet.

1. Click Work Plane.

2. Move the cursor over the top edge of a gear tooth. Click when the center point of the edge is displayed as shown.

3. Click again to create a work plane through the center of the gear.

4. Click Mirror.

5. In the browser, select the extrusion and fillet you created in the previous steps. You can also select the features in the graphics window.

6. In the Mirror dialog box, click Mirror Plane. Select the work plane.

7. Click OK. Rotate the gear to view the mirrored features.

8. On the ViewCube, click Home.

9. Turn off the visibility of the work plane.

**Extrude the Sketch for the Small Circle**

In this section of the exercise, you extrude the sketch for the small circle.

1. Click 2D Sketch. Select the inside front face of the gear.

2. On the ViewCube, click Front.

3. Click Center Point Circle.
4. Create a small circle on the face of the gear as shown.

5. Click the down arrow beside the Constraint tool. Click the Vertical constraint tool.

6. Select the projected center of the gear (1). Select the center of the small circle (2).

7. Click General Dimension.

8. Create a 0.329 dimension on the circle.

9. Create a 1.000 dimension between the center of the gear and the center of the circle.

10. Press ESC.

11. On the ViewCube, click Home.

12. Press E to start the Extrude tool.

13. Select the small circle as the profile.

14. For Distance, enter 0.036.

15. Click OK.
**Extrude the Sketch on the Back Face**

In this section of the exercise, you extrude a sketch on the back face of the gear.

1. Rotate the gear to view the back face.
2. On the ViewCube, click Back.
3. Using the workflow from the previous steps, create a new sketch on the back face, and then create, constrain and dimension a circle as shown.
4. Extrude the circle a distance of 0.076.
5. On the ViewCube, click the top-right corner.
6. Create a new sketch on the face of the extrusion.
7. Create and dimension a 0.368 diameter circle as shown.
8. Extrude the circle using the Cut operation for a distance of 0.118.

**Create the Hole**

In this section of the exercise, you create a hole.

1. On the ViewCube, click Home.
2. Create a new sketch on the face of the small extrusion.
3. Press H to start the Hole tool.
4. Select the projected center of the sketch.
5. For Hole Diameter, enter **0.171**.

6. For Termination, select Through All from the list.

7. Click OK.

---

**Create a Feature Pattern**

In this section of the exercise, you create a feature pattern of the extruded and hole features.

1. On the ViewCube, click Home.

2. Click Rectangular Pattern.

3. In the browser, select the three extruded features and the hole feature.

4. Click the Direction 1 Path selection button.

5. In the browser, expand the Origin folder. Select X Axis.

6. Select the Midplane check box to turn it on.
7. For Count, enter 5.
8. For Spacing, enter 0.5.

9. Click the Direction 2 Path selection button.
10. In the browser, select Y Axis.
11. For Count, enter 5.
12. For Spacing, enter 0.5.
13. Click OK.

Suppress Pattern Occurrences
In this section of the exercise, you suppress five of the pattern occurrences.

1. In the browser, expand Rectangular Pattern1. You now suppress five occurrences.
2. In the browser, move the cursor over each occurrence, noting which features are highlighted on the gear. When the bottom right occurrence (1) is highlighted, right-click the occurrence. Click Suppress.

Add the Center Feature
In this section of the exercise, you create the center feature on the gear.

1. Click 2D Sketch. Select the inside front face of the gear.
2. On the ViewCube, click Front.
3. Click Center Point Circle.
4. Create a small circle in the center of the gear as shown.

5. Click General Dimension.

6. Create a 0.315 dimension on the circle.

7. Press ESC.

8. On the ViewCube, click Home.

9. Press E to start the Extrude tool.

10. Select the small circle as the profile.

11. For Distance, enter 0.326.

12. Click OK.

13. Rotate the gear to view the back face.

14. Using the workflow from the previous steps, create a new sketch on the back face. Create and dimension a 0.315 inch diameter circle as shown.

15. Extrude the circle a distance of 0.076.

16. On the ViewCube, click Home.

17. Click Chamfer.

18. Select the edge as shown.

19. For distance, enter 0.06.

20. Click OK.

21. Save the file.
Insert an iFeature

In this section of the exercise, you insert an iFeature for the square hole in the gear. Note that this is an improved design from the square hole created on the small spur gear.

An iFeature is one or more features that can be saved and reused in other designs. This iFeature was extracted from another gear.

1. Click Insert iFeature.

2. Click Browse. The default location for iFeatures is displayed.

3. Select Workspace to navigate to your working folder.

4. Select SquareHole.ide. Click Open.

5. Select the front face of the extrusion. Note that a check mark is added to Profile Plane1 in the dialog box.

6. Click Finish.

Change the Material

In this section of the exercise, you change the material to ABS plastic.

1. Click Format menu > Style and Standard Editor.


3. For color, select Green (Flat) from the list.

4. Click Save.

5. Click Done.

6. In the browser, right-click Spur Gear2. Click iProperties.

7. Click the Physical tab.

8. For Material, select ABS Plastic.
9. Click Apply. Note the properties of the gear, such as Mass, Area, and Volume.

10. Click Close.

11. Click Save.

12. Close the Spur Gear2 window. Return to the assembly. Note that the gear is updated in the assembly.

13. Save the file.
Exercise: Animate a Gear Assembly

In this exercise, you animate the arm mechanism by driving an existing assembly constraint.

1. Open Arm-Assembly.iam.

2. In the browser, expand Representations > View. Right-click Drive Train. Click Activate.
The drive is provided by the motor (1) which drives the shaft (2). The two small gears (3) then drive the arm mechanism.

3. Right-click the end of the shaft. Click Find in Browser.

The shaft is highlighted in the browser. In this example, it is SHAFT-3000:5.

4. In the browser, expand SHAFT-3000:5. Locate Drive this Constraint (0.00 deg). This is a zero degree angle constraint between the shaft and the frame.

5. Right-click Drive this Constraint (0.00 deg). Click Suppress to turn on suppress. A check mark is displayed next to the option.

6. In the graphics window, click and drag the small gear. The large gear and the arm mechanism also move.

7. In the browser, right-click Drive this Constraint (0.00 deg). Click Suppress to turn off suppress. A check mark is displayed next to the option.

8. On the ViewCube, click Home.

**NOTE:** If the arm assembly does not return to the position shown, suppress the constraint again, drag the arm close the position shown, and then unsuppress the constraint.
9. Scroll back to SHAFT-3000:5. Right-click Drive this Constraint (0 deg). Click Drive Constraint.

10. In the Drive Constraint dialog box, click More.

11. In the Drive Constraint dialog box:
   - For Start, enter -30.
   - For End, enter 30.
   - Under Increment, enter -2.
   - Under Repetitions, select Start/End/Start.
   - Under Repetitions, enter 10.

12. Click Forward.

**NOTE:** The start and end values set a range of sixty degrees, but the arm does not seem to move that much. This is because the constraint is driving the small gear.

13. Click Cancel. The arm mechanism returns to the original position.

Build Phase

Overview

In this phase, you experiment with different gear ratios using the test stand that you built in Unit 5.

Phase Objectives

After completing this phase, you will be able to:

- Describe the relationship between gearing, speed, and power.
- Incorporate VEX gears into a design.

Prerequisites

Before starting this phase, you must have:

- Completed Unit 6: Gears, Chains, and Sprockets > Think Phase.
- Have an assembled VEX motor test stand from the Unit 5: Speed, Power, Torque, and DC Motors > Build Phase.

Related phase resources are:

- Unit 1: Introduction to VEX and Robotics.
- Unit 4: Microcontroller and Transmitter Overview.
- Unit 5: Speed, Power, Torque, and DC Motors.
Required Supplies and Software

The following supplies are used in this phase:

<table>
<thead>
<tr>
<th>Supplies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Notebook and pen</td>
</tr>
<tr>
<td>One assembled VEX motor test stand from the Unit 5: Speed, Power, Torque, and DC Motors &gt; Build Phase</td>
</tr>
<tr>
<td>Work surface</td>
</tr>
<tr>
<td>Small storage container for loose parts</td>
</tr>
<tr>
<td>Optional: Autodesk Inventor Professional 2009</td>
</tr>
</tbody>
</table>

VEX Parts

The following VEX parts are used in this phase:

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Part Number</th>
<th>Abbreviations</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>BEARING-FLAT</td>
<td>BF</td>
</tr>
<tr>
<td>10</td>
<td>NUT-832-KEPS</td>
<td>NK</td>
</tr>
<tr>
<td>10</td>
<td>SCREW-832-0500</td>
<td>S4</td>
</tr>
<tr>
<td>2</td>
<td>SHAFT-3000</td>
<td>SQ3</td>
</tr>
<tr>
<td>2</td>
<td>SHAFT-COLLAR</td>
<td>COL</td>
</tr>
<tr>
<td>1</td>
<td>SPACER-THICK</td>
<td>SP2</td>
</tr>
<tr>
<td>1</td>
<td>SPACER-THIN</td>
<td>SP1</td>
</tr>
<tr>
<td>1</td>
<td>VEX-12-TOOTH-GEAR</td>
<td>G12</td>
</tr>
<tr>
<td>1</td>
<td>VEX-84-TOOTH-GEAR</td>
<td>G84</td>
</tr>
<tr>
<td>2</td>
<td>WASHER-DELRIN</td>
<td>WP</td>
</tr>
</tbody>
</table>

Activity Gears

Activity

In this activity, you add a single-stage gear reduction to the test stand from Unit 5 to enable the lifting of heavier objects.

As you work on building this project, have some of your team members focus on expanding their expertise using Autodesk Inventor. Later in the curriculum, you will be challenged to come up with your own creative solutions for robot design. You will save time and maximize your ability to create winning solutions if your team understands how to leverage the power of digital prototypes using Inventor.
NOTE: Team members can download a free version of Autodesk Inventor Professional to use at home, so you can come to class prepared to build and test your best ideas! To do this, simply join the Autodesk Student Engineering and Design Community at http://www.autodesk.com/edcommunity.

1. To complete the next step:
   - Remove the 1x2x1x15 C-Channel from the existing test stand.
   - Remove the motor from the 1x2x1x15 C-Channel.

The completed model is as shown:
2. To complete the next step:
   - Re-bolt the motor into its new position on the 1x2x1x15 C-Channel.
   - Bolt the two Bearing Flats [BF] to the 1x2x1x15 C-Channel.

The completed model is as shown:
3. To complete the next step:
   - Bolt four Bearing Flats to the test stand.

The completed model is as shown:
4. To complete the next step:
   - Slide the 84 Tooth Gear [G84] and a Thick Spacer [SP2] onto the 4" shaft from the test stand.
   - Slide two Collars [COL], a 12 Tooth Gear [G12], a Thin Spacer [SP1], and 2 Delrin Washers [WP] on a 3" shaft [SQ3].
   - Insert the 3" Shaft into the Bearing Flat.
   - Bolt the assembly from the previous step to the 2" Standoffs on the test stand.
   - Insert the 3" Shaft fully into the Motor and tighten the two Shaft Collars.
   - Slide the 84 Tooth Gear and Thick Spacer up against the Bearing Flat you attached to the 1x2x1x15 C-Channel and tighten the Shaft Collars.
   - Ensure that the 84 Tooth Gear and 12 Tooth Gear are aligned such that the teeth mesh.

The completed model is as shown:
5. Your test stand is now complete and ready for use.
Amaze Phase

Overview

In this phase, you try and lift a 5 lb. weight as quickly as possible using the modified test stand from the Unit 6: Gears, Chains, and Sprockets > Build Phase.

Phase Objectives

After completing this phase, you will be able to:

- Modify the gearing of a VEX gearbox.
- Describe the effect of gear ratios on speed and torque.
- Be able to determine an appropriate gear ratio to complete a mechanical task.

Prerequisites and Resources

Before starting this phase, you must have:

- Completed the Unit 6: Gears, Chains, and Sprockets > Think Phase.
- Completed the Unit 6: Gears, Chains, and Sprockets > Build Phase.
- Have assembled the gear ratio test stand from the Unit 6: Gears, Chains, and Sprockets > Build Phase.

Related phase resources are:

- Unit 1: Introduction to VEX and Robotics.
- Unit 4: Microcontroller and Transmitter Overview.
- Unit 5: Speed, Power, Torque, and DC Motors.
Required Supplies and Software

The following supplies are used in this phase:

<table>
<thead>
<tr>
<th>Supplies</th>
</tr>
</thead>
<tbody>
<tr>
<td>An assembled the gear ratio test stand from the Unit 6: Gears, Chains, and Sprockets &gt; Build Phase</td>
</tr>
<tr>
<td>Notebook and pen</td>
</tr>
<tr>
<td>5 lb. weight</td>
</tr>
<tr>
<td>One stopwatch</td>
</tr>
<tr>
<td>A surface (for example, a table or desk) with an edge at least 24&quot; above the ground</td>
</tr>
</tbody>
</table>

VEX Parts

The following VEX parts are used in this phase:

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Part Number</th>
<th>Abbreviations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>VEX-36-TOOTH-GEAR</td>
<td>G36</td>
</tr>
<tr>
<td>1</td>
<td>VEX-60-TOOTH-GEAR</td>
<td>G60</td>
</tr>
</tbody>
</table>

Evaluation

Challenge

Using the Gears Ratio Test Stand, determine the gear ratio that enables you to lift the 5 lb. weight as fast as possible.

Instructions

1. Looking back at Unit 5: Speed, Power, Torque, and DC Motors > Think Phase, remember that you can alter the speed of a system by changing the gear ratios. The smaller the reduction, the faster the output speed, but with a less amount of torque. The key to this exercise is to find the smallest reduction that still has enough torque to lift the 5 lb. mass.

2. In this phase, you test five different gear ratios, 12:84, 12:60, 36:84, 36:60, 60:84. To do each of these tests, the Gear Ration Test Stand needs to be modified appropriately.

3. For each gear ratio, perform the following test. For information on how to change the gear ratios, see the section below.
   a. Plug the motor into port 6 of your Microcontroller.
   b. Plug the Transmitter into port 1 of the Microcontroller.
   c. Plug the 7.2V battery into the Microcontroller.
   d. Turn both your Transmitter and Microcontroller on.
   e. Using the yellow buttons on the back of the Transmitter, you should be able to control the rotation of the pulley.
f. Set up the test stand between two tables, with the string hanging between them. Let the string hang 24” below the surface top.
g. Attach the 5 lb. mass to the string.
h. Using the Transmitter, have the test stand lift the mass. Using the stopwatch, time how long it takes for the mass to reach the surface. Record this time in your engineering notebook. If the test stand is unable to generate enough torque to lift the mass, record it in your chart.

How to Change the Gear Ratio

1. Remove the 1x2x1x15 C-Channel that the motor is attached to by removing the bolts at either end of the channel.
2. Remove the motor and bearing flat from the 1x2x1x15 C-Channel, and reattach it to the proper holes for the new gear ratio. See figures 1-5 to determine the proper mounting location.
3. Remove the spacers from both the drive and driven shafts. Place these spacers in separate piles, so they can easily be put back on the appropriate shafts.
4. Remove both the drive and driven gears.
5. Loosen and remove both collars on the drive shaft.
6. Remove the drive shaft from the bearing flat.
7. Depending on your new ratio, insert the drive shaft into its new appropriate bearing flat. See figures 1-5.
8. Replace both collars on the drive shaft.
9. Slide the appropriate gears onto their shafts. Make sure the gears are aligned such that they mesh properly.
10. Replace the spacers on the shafts.
11. Reattach the 1x2x1x15 C-Channel.
12. Your test stand is now ready for operation with your new gear ratio.

Figure 1: 12:84 Reduction
Figure 2: **12:60 Reduction**

Figure 3: **36:84 Reduction**
Figure 4: **36:60 Reduction**

Figure 5: **60:84 Reduction**
Engineering Notebook

Create the following blank chart in your engineering notebook:

<table>
<thead>
<tr>
<th>Drive Gear</th>
<th>Driven Gear</th>
<th>Reduction Ratio</th>
<th>Pulley Free Speed (RPM)</th>
<th>Calculated Motor Torque</th>
<th>Time to lift 24&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>84</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>60</td>
<td></td>
<td></td>
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<tr>
<td>36</td>
<td>84</td>
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<tr>
<td>60</td>
<td>84</td>
<td></td>
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</tr>
</tbody>
</table>

- Using the knowledge you gained on gearing, speed, power, and torque in the previous Think Phases, complete your chart appropriately. Remember the following:
  - **Reduction Ratio** = \# teeth of drive gear / \# teeth of driven gear.
  - **Free Speed** = Motor Free Speed x Reduction Ratio. Go back to your notes from the Unit 5: Gears, Chains, and Sprocket > Amaze Phase, where you calculated the free speed of a VEX motor.
  - **Motor Torque** = Mass x Pulley Radius x Reduction Ratio.

- Create a graph showing the relationship between the Reduction Ratio and Time to Lift the mass.
- In your notebook, discuss the shape of your graph. Does it surprise you?
- How can you lift the mass even faster using this test stand? How would it need to be modified? Discuss what changes you would make to accomplish this task. If time remains, execute your plan.

**Presentation**

Prepare your findings from this phase, and present them to the class. Explain why you and your classmates may not all have the same results. Discuss how you can modify the test stand to lift the weight even faster.
Background

The United States Coast Guard often uses rescue helicopters when responding to maritime emergencies. These helicopters can assist in rescue efforts by hovering above their target and inserting a rescue swimmer whose job it is to reach the survivor and stay with them until both swimmers can be extracted via a rescue line from the helicopter. The helicopter extraction is accomplished with a winch system similar to the VEX Test Stand you use for this unit.

Science

Coast Guard rescue helicopters often operate in extreme conditions. As a result, the winch systems involved in ocean rescue must be able to withstand the harsh ocean environment.

1. What are some of the material science transformation processes (for example, corrosion) that you need to consider when designing a winch for this sort of application?
2. What associated problems can occur if the winch system is not designed to resist these harsh conditions?
3. What materials can you use to build a weather resistant winch system, and how do those materials affect the operation of the winch?
4. Design a laboratory test to determine which materials are the best choice for these conditions.

Technology

Consider that the helicopter’s winch system may be subject to very different loads, given different rescue circumstances. For instance, the weight of the survivors, the number of survivors, and the weather and water conditions can all affect the load.

1. How would a system that switches gear ratios based on the potential load improve the efficiency of the rescue winch system?
2. How can this be accomplished?
**Engineering**

1. If you were designing the winch system for a Coast Guard search and rescue helicopter, how would you adjust the mechanism’s speed and torque with gear ratios to maximize the efficiency and utility of the system?
2. How would you test the system to reach your goal of maximum efficiency?

**Math**

Suppose a rescue helicopter is lifting a swimmer out of the water. The total load at the end of the cable is 210 lbs. The winch works by turning an axle, about which the cable becomes spooled.

1. What is the torque when the spool has a radius of 3 inches?
2. As more cable is drawn in and the spool grows, the radius becomes 5 inches. What is the new torque?