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

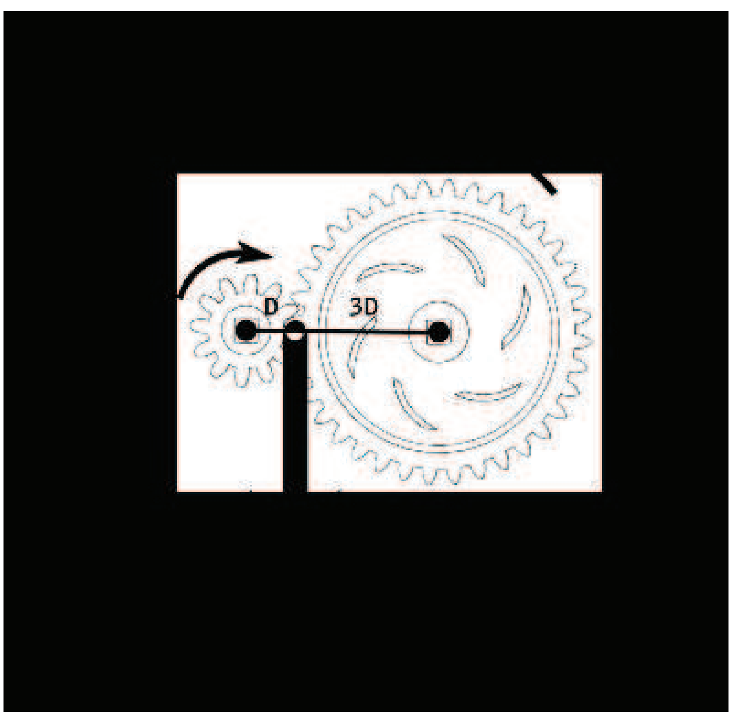
Bevel gears are conical-shaped gears used in machines where a change in the output shaft's direction is desired. The shafts must intersect. They may intersect at any angle, with 90 degrees the most common. The teeth are the same basic shape as a spur gear's teeth, but have a slight taper towards the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

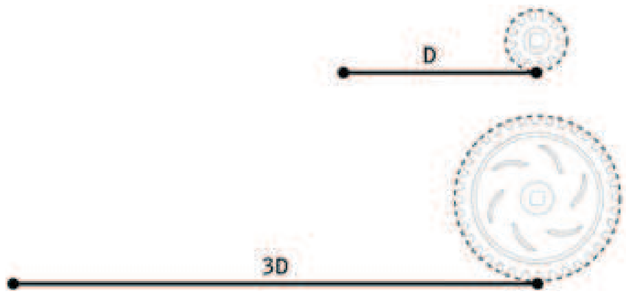
Gear Ratios

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.

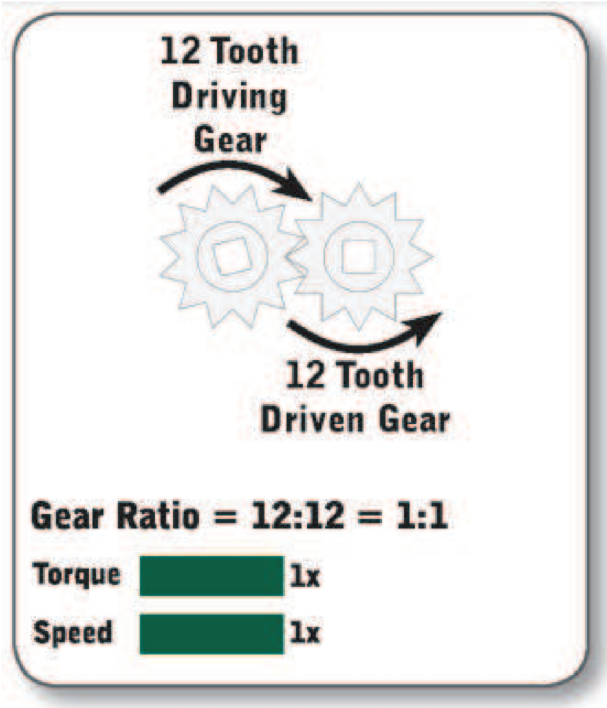
For each increase in torque, there is an equivalent speed reduction; for each decrease in torque, there is an equivalent speed increase.

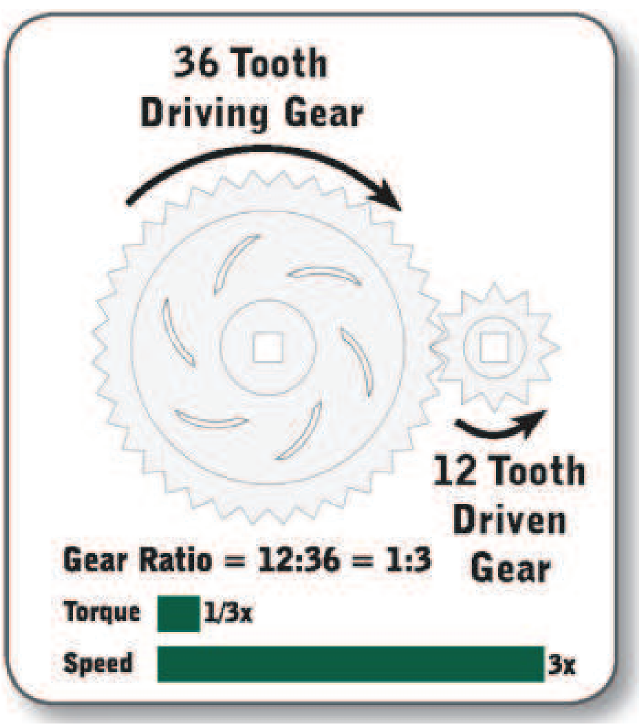
Since the number of teeth a gear has is proportional to its radius, you can use tooth-count as a method for determining gear ratios. (For example, a 36-tooth gear is three times as big as a 12-tooth gear, so a 12:36-tooth gear would yield a 3:1 ratio.)

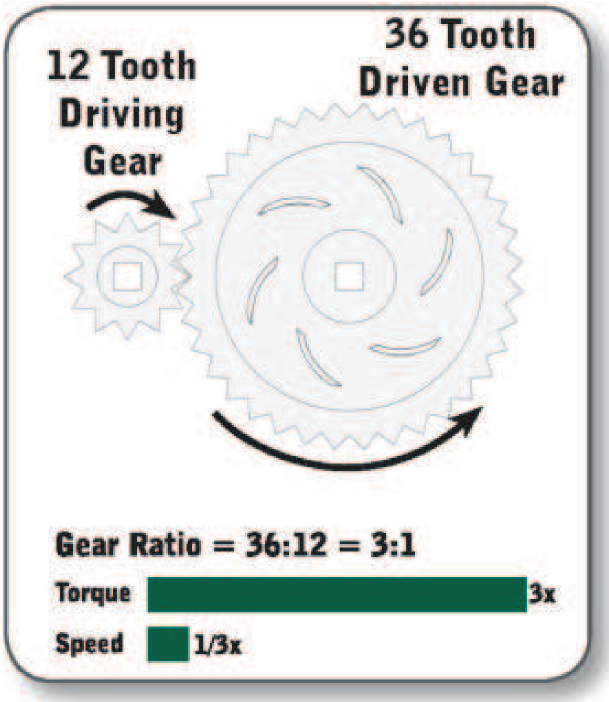
You can think of a gear ratio as a "multiplier" on torque and a "divider" on speed. If you have a gear ratio of 3:1, you have three times as much torque as you would if you had a gear ratio of 1:1, but only 1/3 as much speed.

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.





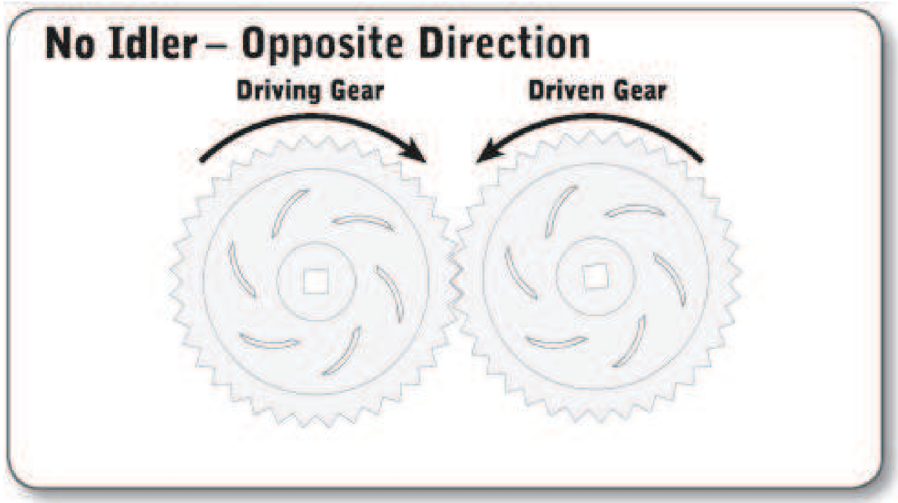


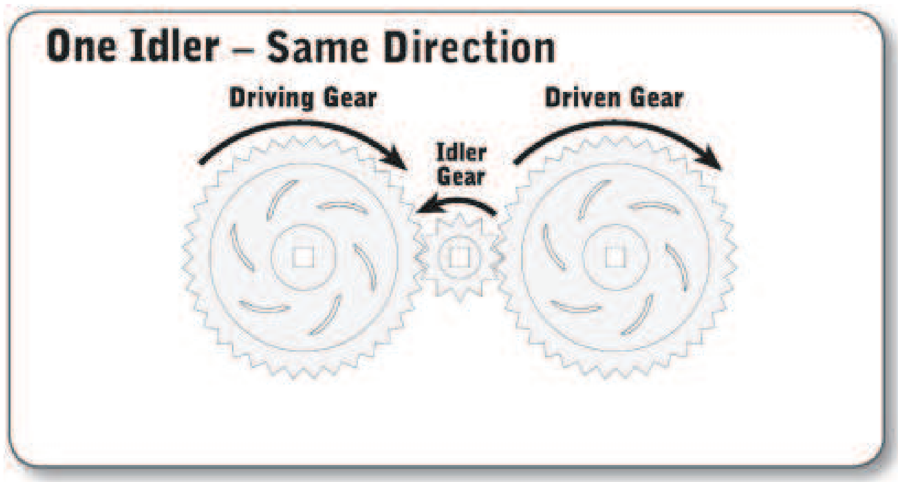
Driving Gear	Driven Gear	Speed	Torque
Small	Large	Decrease	Increase
Large	Small	Increase	Decrease

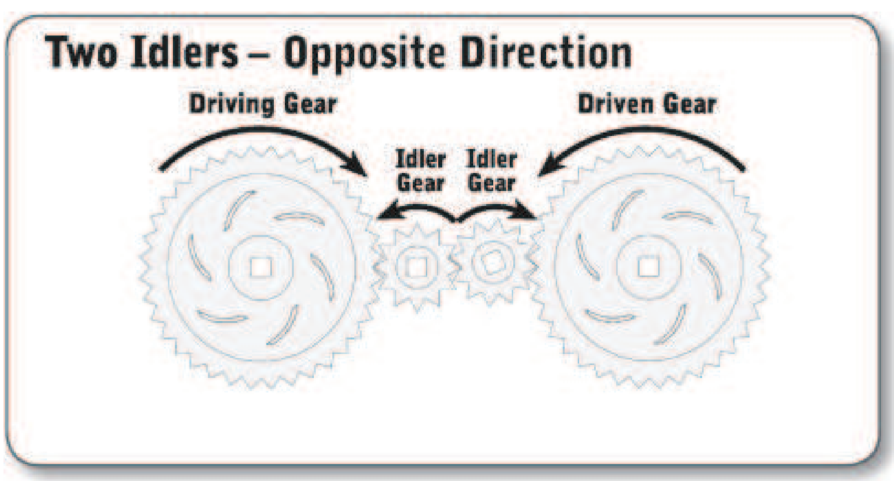
Idler Gears

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).

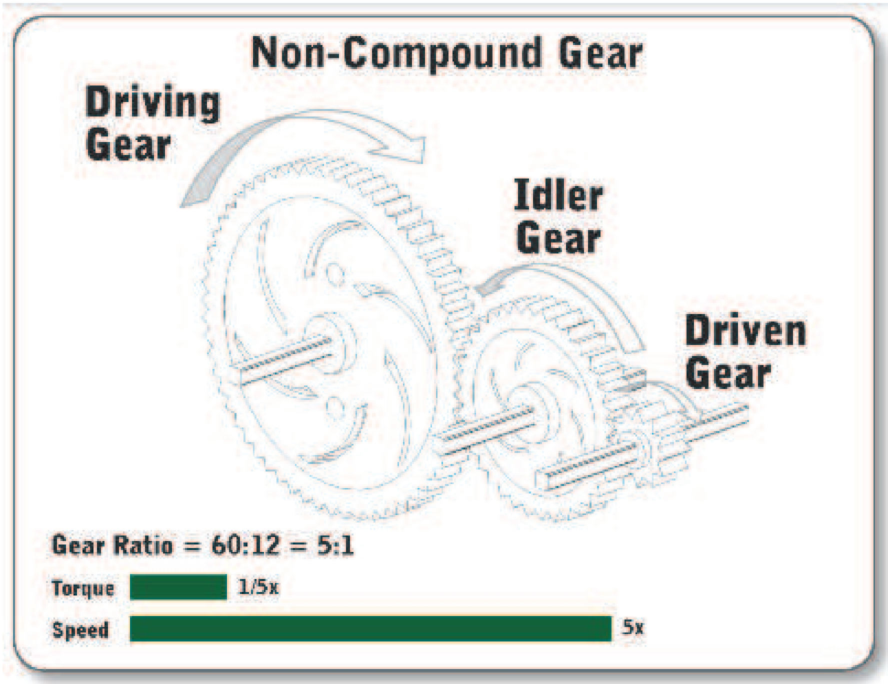

No Idler – Opposite Direction
Driving Gear
Driven Gear


One Idler – Same Direction
Driving Gear
Driven Gear
Idler
Gear


Two Idlers – Opposite Direction
Driving Gear
Driven Gear
Idler
Gear
Idler
Gear

Compound Gear Ratio

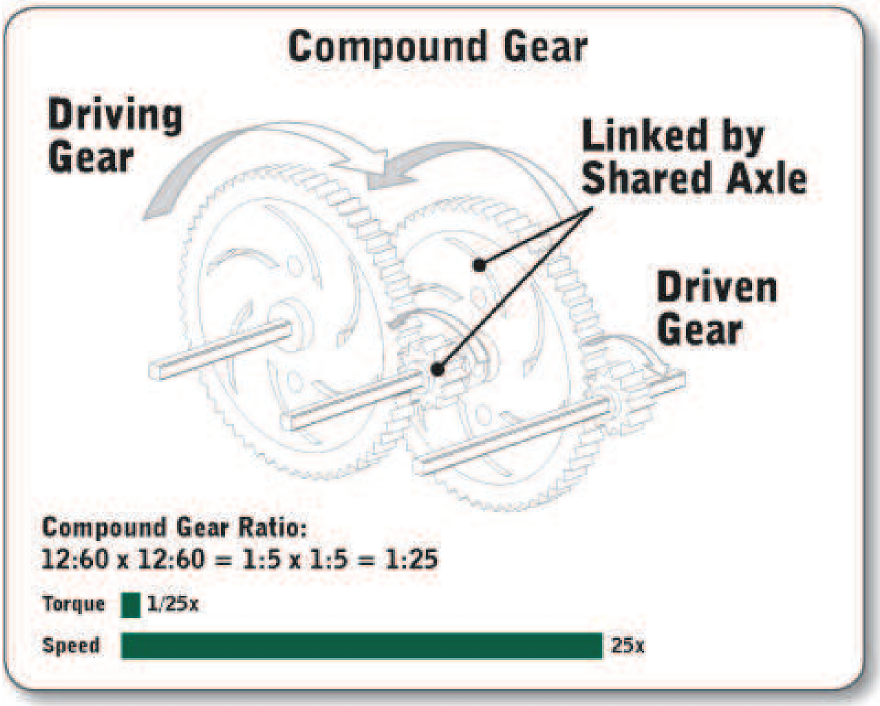
Compound gears are formed when you have more than one gear on the same axle. Compound gears are not to be confused with idler gears, as compound gears can affect the overall gear ratio of a system!



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.



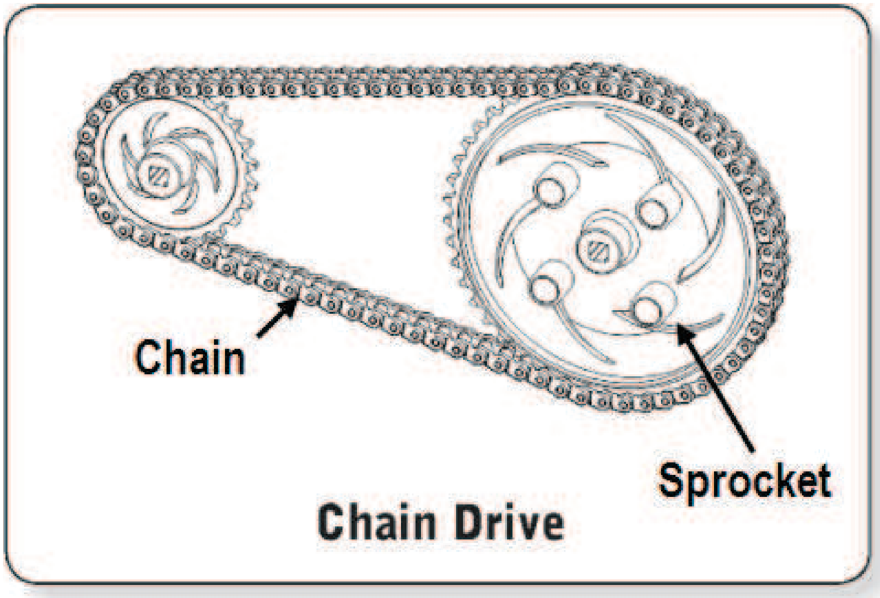
Compound gears allow configurations with gear ratios that would not normally be achievable with the components available. In the example above, a compound gear ratio of 1:25 was achieved using only 12 and 60-tooth gears. This would give your robot the ability to turn an axle 25 times faster than normal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

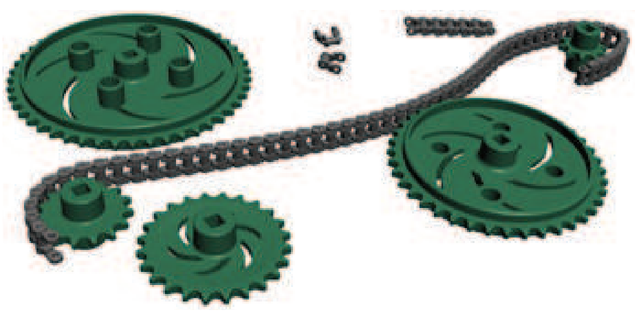
Chains elongate while they are used so they must have some kind of adjustment or a convenient way to remove links to maintain proper tension. Roller chains incorporate a “master link” that can be removed easily to remove links. Most chain-drive mechanisms have some sort of tensioning device that can 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.