



GEAR GUIDE

August 30, 2016

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1 GEAR BASICS

Gears are rotating parts that have teeth and are meshed with other gears to transmit torque. Gears can be used to change the speed, torque (turning force), or direction of a motor's original output. For gears to be compatible with each other, the meshing teeth must have the same shape (size and pitch).

There are many different types of gears; one of the simplest and most commonly used is a spur gear, and that is the gear type used in the REV Robotics building system. Spur gears consist of a disk with straight teeth projecting radially (outward from the center) and these gears will only mesh correctly with other gears if they are on parallel shafts.

1.1 Anatomy of a Spur Gear

The most common and important features of a spur gear are called out in Figure 1.

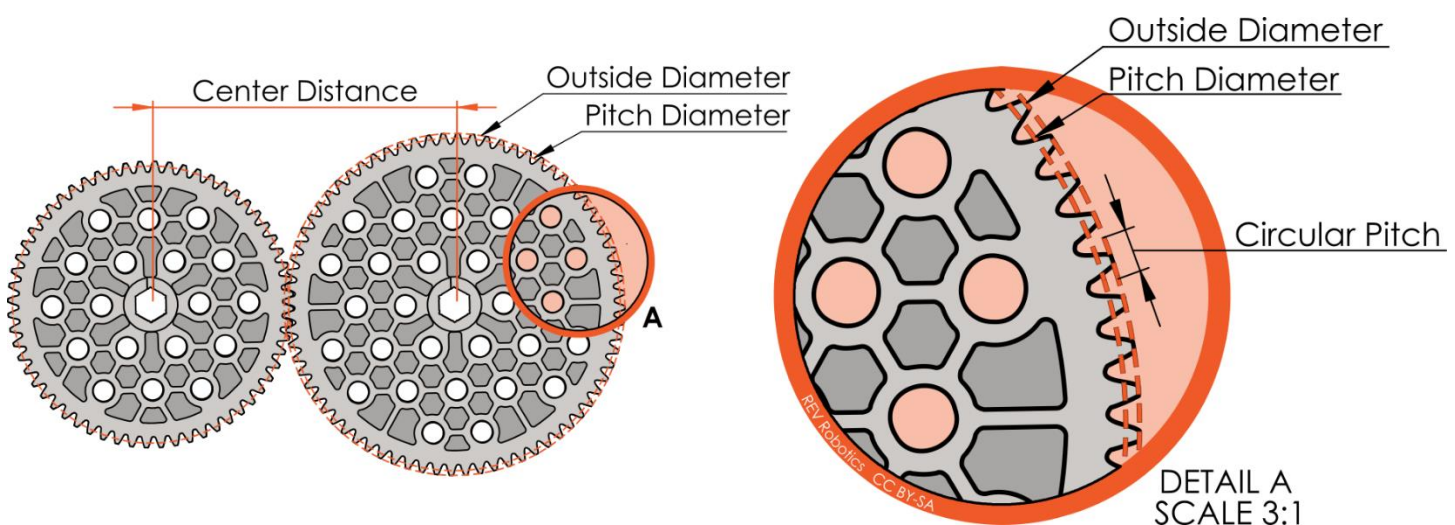


Figure 1: Basic Spur Gear Nomenclature

Number of Teeth (N) is the total count of the number of teeth (projections) around the whole circumference of a gear. For gears with very few or very large teeth it is easy to simply count the number of teeth. However, for gears with a higher number of teeth, or when the teeth are smaller, attempting to count the teeth is not very practical or accurate. For our REV gears, we have taken all of the guesswork out of this process. Simply use the [ALL GEARS \(1:1 Scale\)](#) reference guide on page 13 by printing that page out at full scale and then match your gear to its correct outline on the page to identify the gear.

Module (M) represents the amount of **pitch diameter** in mm per tooth. Gears with a higher **module** will have bigger teeth. **Module (M)** can be calculated using the formulas in Table 1.

Table 1: Module (M) Calculation Equations

Using	Rule	Equation
Pitch Diameter (PD) and Number of Teeth (N)	Divide Pitch Diameter in Millimeters by the Number of Teeth	$M = \frac{PD}{N}$
Outside Diameter (OD) and Number of Teeth (N)	Divide the outside diameter (in millimeters) by the number of teeth plus two	$M = \frac{OD}{N + 2}$

Pitch Diameter (PD) is the imaginary circle that mates with any other gear's **pitch diameter** when the gears are properly spaced. The **pitch diameter** will always be smaller than the **outside diameter** of a gear.

When creating simplified models for gears, first create a circle with the **pitch diameter** for each gear used in the system then constrain the circles tangent (just barely touching) to each other (Figure 2). **Pitch Diameter (PD)** can be calculated using the formulas in Table 2

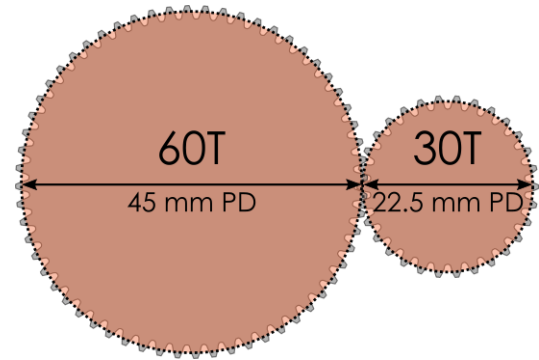


Figure 2: Simplified Gear Spacing Model with Tangent Pitch Diameters

Table 2: Pitch Diameter (PD) Calculation Equations

Using	Rule	Equation
Module (M) and Number of Teeth (N)	Multiple the Module by the Number of Teeth	$PD = M \times N$
Number of Teeth (N) and Outside Diameter(OD)	Divide the product of Outside Diameter and number of Teeth by the number of Teeth plus two	$PD = \frac{OD \times N}{N + 2}$
Outside Diameter(OD) and the Module(M)	Multiply Module by 2 and Subtract from Outside Diameter	$PD = OD - 2M$

Outside Diameter (OD) is the true outside diameter of a gear. The **outside diameter** will always be larger than the **pitch diameter**. The **outside diameter** should be used when checking for interference when placing gears very close to other structures. **Outside Diameter (OD)** can be calculated using the formula in Table 3.

Table 3: Outside Diameter (OD) Calculation Equations

Using	Rule	Equation
Module (M) and Number of Teeth (N)	Number of Teeth plus two multiplied by Module	$OD = (N + 2) \times M$

1.2 Torque, Speed, and Power

Gears are one common way to transmit power and change the output torque or speed of a mechanical system. Understanding these basic concepts is required to make optimized design decisions which consider the trade-off between torque and speed for a system with a given power. This section will briefly cover the definition of these concepts and then explain them in relationship to basic gearing concepts.

Speed is the measure of how fast an object is moving. The **speed** of an object is how far it will travel in a given amount of time. For rotating parts like gears and wheels, **speed** is expressed in how many revolutions are made in a given amount of time. Under ideal conditions, the rotation of a wheel is converted into linear **speed** and can be calculated by multiplying the diameter of the wheel by the rotations for a given time. The SI unit for **speed** is meters per second, but **speed** is also commonly expressed in feet per second.

Torque is roughly the measure of the turning force on an object like a gear or a wheel. Mathematically, **torque** is defined as the rate of change of the angular momentum of an object. This can also be stated as a force that acts normal (at 90 degrees) to a radial lever arm which causes the object to rotate. A common example of torque is the use of a wrench in order to tighten or loosen a bolt. In that example, using a longer wrench can produce more **torque** on the bolt than using a shorter wrench. **Torque** is commonly expressed in N·m or in·lbs.

When **torque** is turning an object like a spur gear, the gear will create a straight line (linear) force at the point where the teeth contact the other gear. The magnitude of the **torque** created is the product of the rotational force applied and the length of the lever arm (Figure 3), which in the case of a gear, is half of the pitch diameter (the radius).

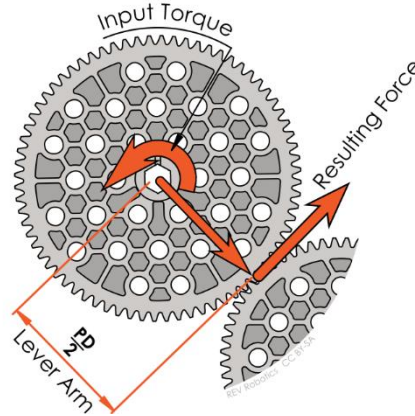


Figure 3: Gear Torque Diagram

Power (P) is the rate of work over time. The concept of **power** includes both a physical change and a time period in which the change occurs. This is different from the concept of work which only measures a physical change. The difference in these two concepts is that it takes the same amount of work to carry a brick up a mountain whether you walk or run, but running takes more **power** because the work is done in a shorter amount of time. The SI unit for **power** is the Watt (W) which is equivalent to one joule per second (J/s).

In competitive robotics, the total amount of available power is determined by the motors and batteries allowed to be used. The maximum speed at which an arm can lift a certain load is dictated by the maximum system **power**.

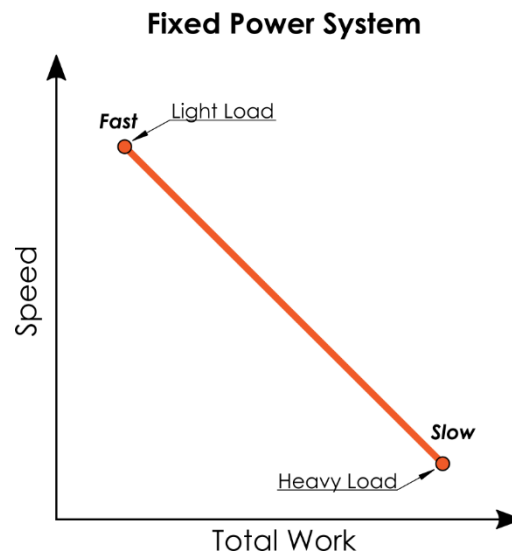


Figure 4: Execution Speed in a Fixed Power System by Load

By changing the size of the gears, we change the length of the lever arm shown in Figure 3. Meshing two or more gears together is known as a gear train. By selecting the gears in the gear train as larger or smaller relative to the input gear we can either increase the output speed, or increase the output torque as shown in Figure 5, but the total power is not affected.

When a larger gear drives a smaller one, for one rotation of the larger gear the small gear must complete more revolutions - so the output will be faster than the input. If the situation is reversed, and a smaller gear drives a larger output gear, then for one rotation of the input the output will complete less than one revolution – so the output will be slower than the input. The ratio of the sizes of the two gears is proportional to the speed and torque changes between them.

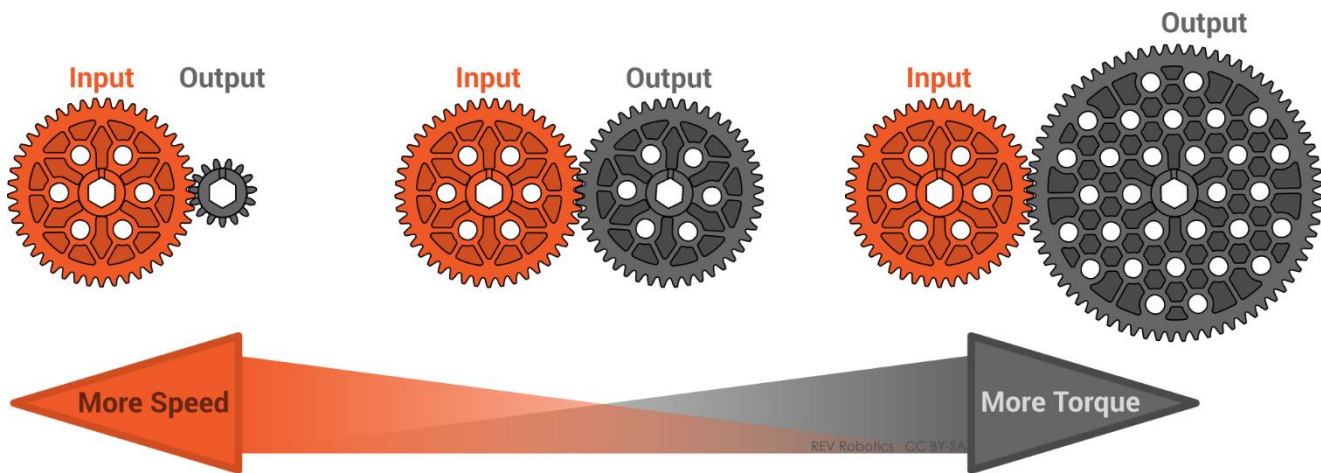


Figure 5: Using Gears to Increase Speed or Torque

From Figure 5 we know that the ratio in size from the input (driving) gear to the output (driven) gear determines if the output is faster (less torque) or has more torque (slower). To calculate exactly how the gear ratio effects the relationship from input to output we can use the ratio of the number of teeth between the two gears. In Figure 6, the ratio of the number of teeth from the input gear to the output gear is 15T:72T which means the input needs to turn 4.8 rotations for the output to complete one rotation ($\frac{72T}{15T} = 4.8$).

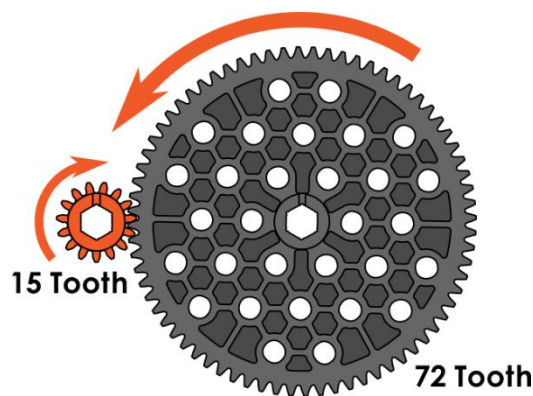


Figure 6: Single Stage Gear Reduction (15:72)

In Figure 7, a 45 tooth idler gear is inserted into the gear example. An idler gear is any intermediate (between input and output) gear which does not drive any output (work) shaft. Idler gears are used to transmit torque over longer distances than would be practical by using just a single pair of gears. Idler gears are also used to reverse the direction of the rotation of the final gear.

Regardless of the number or size of idler gears in the chain, only the first and last gear determine the reduction. Since idler gears do not change the gear reduction in Figure 7 the reduction remains 15:72, but the direction of the output stage is now reversed from the previous example in Figure 6.

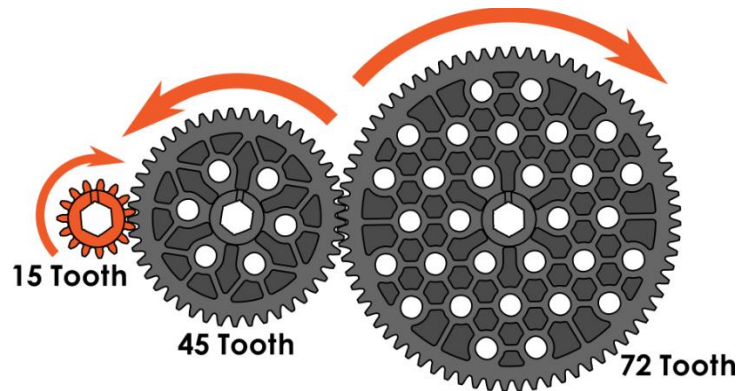


Figure 7: Single Stage Gear Reduction (15:72) with Idler

Idler gears are a good way to transmit power across distances in your robot. A common example of this is an all gear drivetrain (Figure 8). In this example the gears on the end are linked to the drive wheels and one of the center gears would be driven by a motor (not shown). The orange arrows indicate the relative rotation of each of the gears showing that the two wheels are mechanically link and will always rotate in the same direction. Because idler gears reverse the direction of rotation, it is important to pay attention to the number of gears in the drivetrain. In Figure 9, because there are an even number of gears, the wheels in that example will always spin in opposite directions which is incorrect and will get that robot nowhere fast.

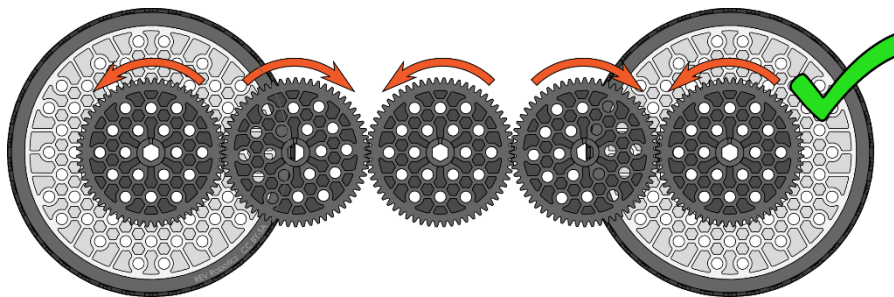


Figure 8: Correct All Gear Drivetrain

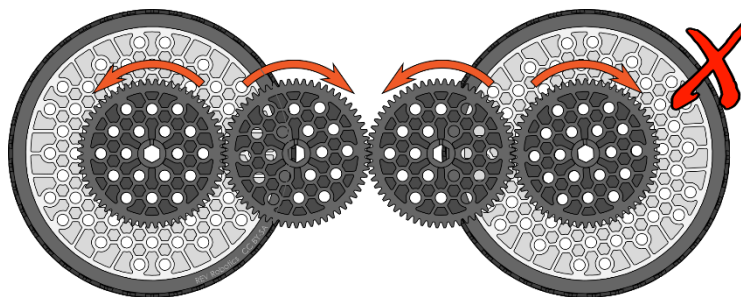


Figure 9: Incorrect All Gear Drivetrain

1.3 Compound Gearing

Some designs may require more reduction than is practical in a single stage. The ratio from the smallest gear available to the largest in the REV Robotics building system is 15:125, so if a greater reduction than 8.3 is required, multiple reduction stages can be used in the same mechanism, this is called a compound gear reduction. There are multiple gear pairs in a compound reduction with each pair of gears linked by a shared axle. Figure 10 is an example of a two-stage reduction. The driving gear (input) of each pair is highlighted in orange.

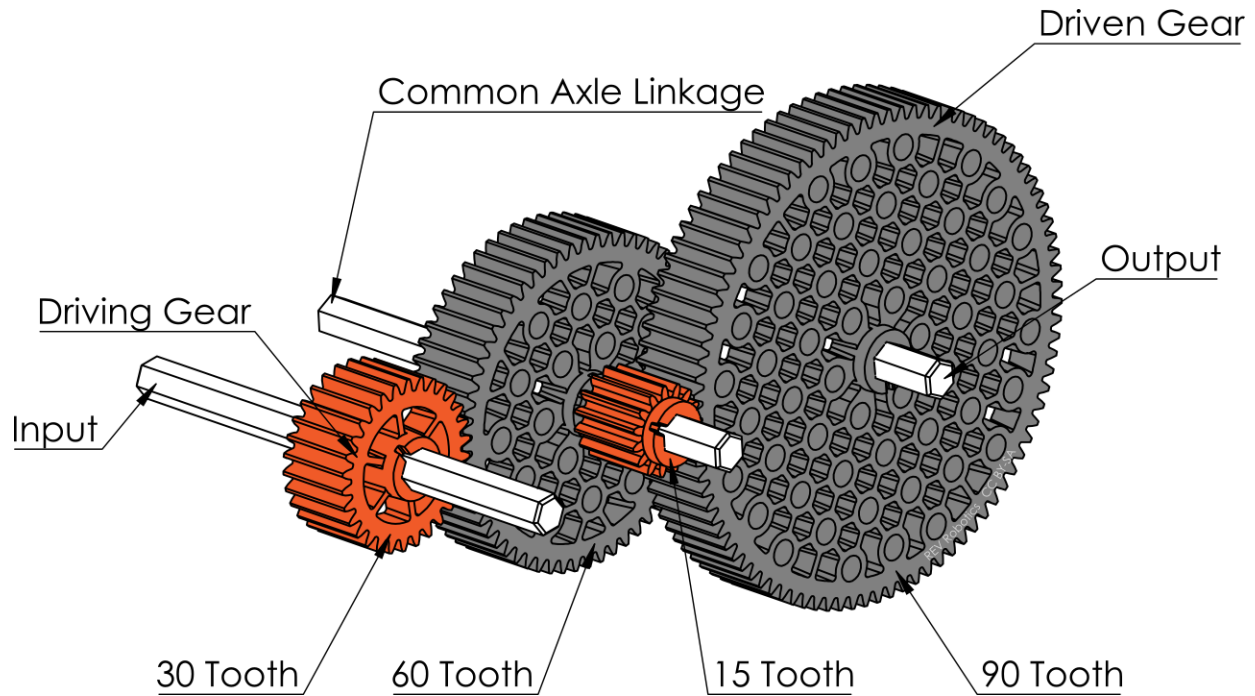


Figure 10: Compound Gearing Example

To calculate the total reduction of a compound reduction, identify the reduction of each stage and then multiply each reduction together.

$$\text{Compound Reduction} = \text{Reduction 1} \times \text{Reduction 2} \times \dots \times \text{Reduction } n$$

Using Figure 10 as an example the compound reduction is 12:1.

$$\text{Compound Reduction} = \text{Reduction 1} \times \text{Reduction 2} = \frac{60}{30} \times \frac{90}{15} = 2 \times 6 = \mathbf{12}$$

For any gear system there are a limited number of gear sizes available, so in addition to being able to create greater reductions using compound reductions it is also possible to create a wider range of reduction values, or the same reduction of a single stage, but with smaller diameter gears.

2REV GEAR SPECIFICATIONS

2.1 REV Robotics Gears

REV Robotics Gears have a 0.75 module, 20° pressure angle and are made from molded acetal (Delrin/POM). The webbed design with a wide face width and small tooth profile increases the gear strength without adding significant weight. REV Robotics Gears are designed to fit a 5mm hex shaft which eliminates the need for special hubs and setscrews.

Warning: Gears from other building systems may have a very similar tooth profile but are not an exact match. It may be possible to use the two gear systems together successfully in some situations, but it is not recommended.

The REV Robotics building system is designed around a slotted extrusion which allows for infinite adjustability instead of a fixed pitch based system. Components attached to the extrusion can be slid to any desired location, versus with a pitch-based system where components must be bolted into discrete mounting locations.

When REV Robotics Gears are used with REV Robotics Extrusion, the center to center distance between axles is completely adjustable by sliding and retightening the shaft mounting plates anywhere along the extrusion channel. This system allows any combination of REV Robotics Gears to be used together which provides far greater flexibility than a fixed pitch system which requires specifically sized gear pairs to fit. When adjusting the reduction of a system, just a single gear can be replaced reducing the amount of reassembly time.

All of the motion parts in the REV Robotics build system including wheels, sprockets, and pulleys have a uniform 15mm thickness which makes trying out other components for design revisions and improvements easier (Figure 11).

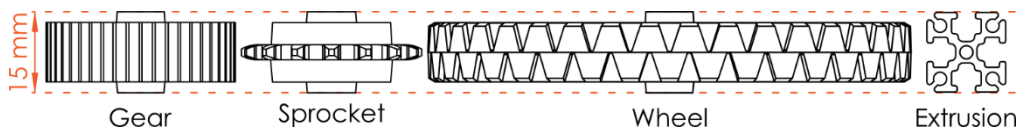


Figure 11: REV Robotics Common Part Thickness

In order for gears to work effectively, and not become damaged, it's important that the center-to-center distance is correctly adjusted. The gears in *DETAIL A* of Figure 12 may work under very light load, but they will certainly not work and will skip under any significant loading. The gears in that example are too far apart and so the teeth of each gear barely contact each other. The gears in *DETAIL B* of Figure 12 are correctly spaced and will provide smooth and reliable operation.

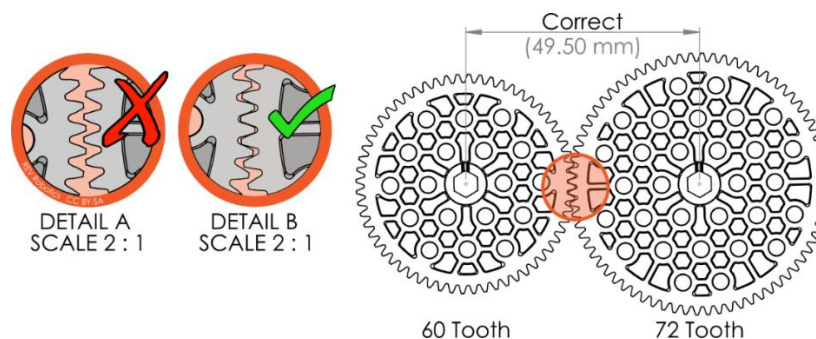


Figure 12: Gear Spacing Example

To correctly space REV Robotics Gears, use the following procedure:

1. Securely fix the axle of either the input or output gear. In the case of a gear train with multiple idlers or a compound reduction, consider which axle makes the most sense to fix, such as the very first input gear or the very last gear.
2. Starting with the fixed axle, identify all the driving and driven gears for any gears on that axle. One by one, loosen these axles and slide them until the teeth of both gears are fully engaged and parallel. Retighten the axle mounts.
3. Continue the procedure from Step 2 for each fixed axle until all the gears are tightly meshed and all the axles have been retightened.

The gear spacing adjustment procedure above is sufficient in almost all cases. To mathematically calculate the correct center to center distance use Table 4 in the [Gear Measurements](#) section to determine the pitch diameter (PD) of both gears.

$$\text{Center to Center Distance} = \frac{\text{PD of Gear 1}}{2} + \frac{\text{PD of Gear 2}}{2}$$

Using the example in Figure 12, the correct center to center distance calculation for a 60 tooth and 72 tooth gear is 49.5 mm.

$$60T:72T \text{ Gear Center to Center Distance} = \frac{45\text{mm}}{2} + \frac{54\text{mm}}{2} = 49.5\text{mm}$$

2.2 Gear Mounting Pattern

All REV Robotics Gears have a M3 bolt hole mounting pattern that is on an 8mm pitch as shown in Figure 13. This makes it easy to directly mount REV Robotics brackets and extrusion to gears. The 8mm pitch is also compatible with many other building systems.

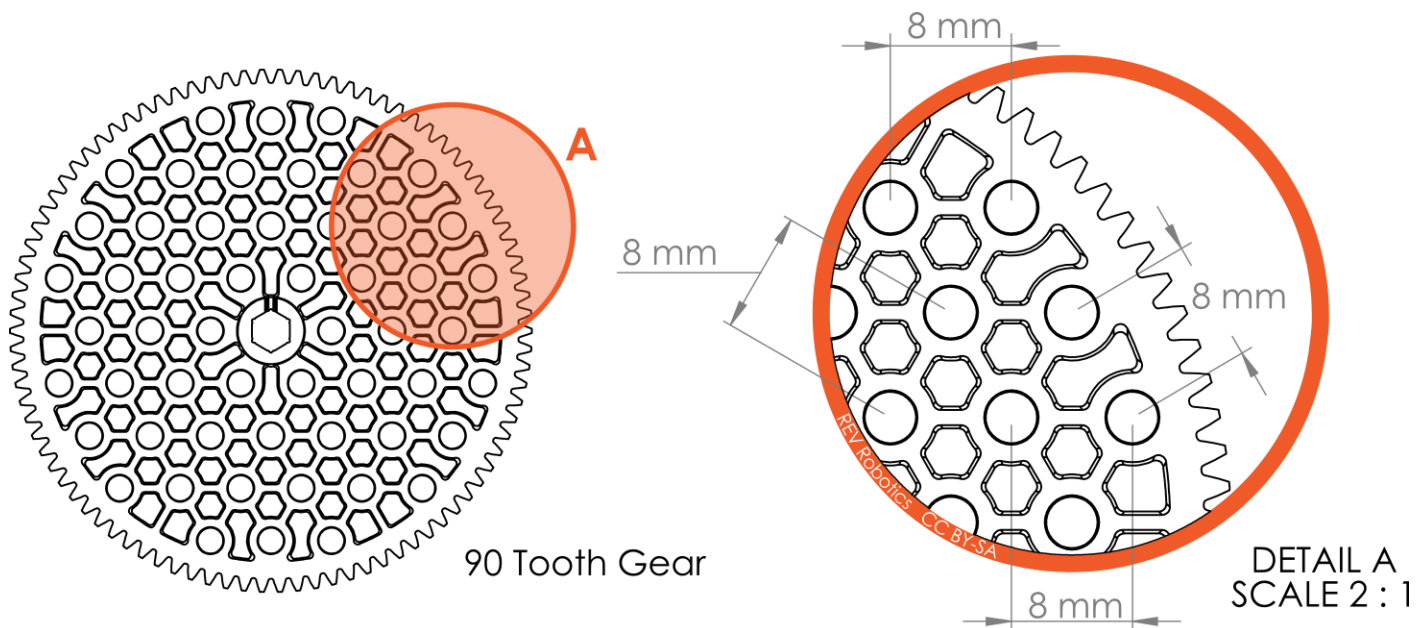


Figure 13: Mounting Hole Pattern Details

2.3 Gear Alignment Mark

Sometimes in a design it may be desirable to stack together multiples of the same gear on a shaft to increase the load carrying capacity of the gears. In the case where the number of teeth on the gear is not divisible by six, because of how they are oriented when put onto the hex shaft, the teeth may not be aligned between the two gears (Figure 14). To ensure all of the gears are clocked the same way, use the alignment shaft notch (Figure 15) to put all the gears on the shaft with the same orientation.

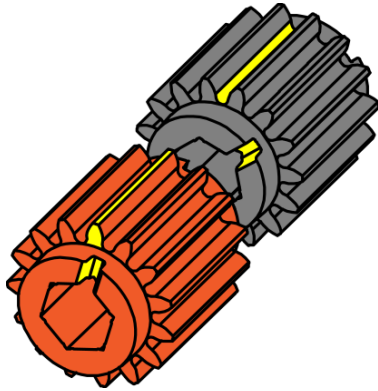


Figure 14: Misaligned Gear Teeth



Figure 15: Gear Alignment Notch

Being aware of the alignment mark will ensure all of the gear teeth are aligned on the shaft. Figure 16 is an example of a basic robot arm which may have to lift a heavy load. Using two gears to lift the arm doubles the material interfacing with the hex shaft and will allow the arm to perform with heavier loads.

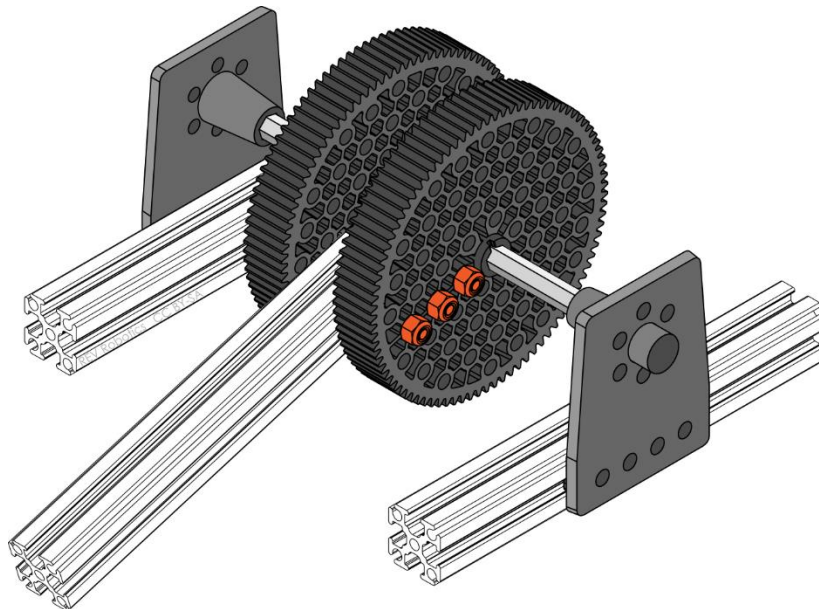


Figure 16: Using Stacked Gears for High Load Applications

2.4 Gear Measurements

Table 4: Gear Measurement Details

	A Pitch Diameter	B Outside Diameter
15 Tooth Gear REV-41-1331	0.443 in 11.25 mm	0.502 in 12.75 mm
30 Tooth Gear REV-41-1332	0.886 in 22.50 mm	0.945 in 24.00 mm
45 Tooth Gear REV-41-1334	1.328 in 33.75 mm	1.338 in 35.25 mm
60 Tooth Gear REV-41-1335	1.771 in 45.00 mm	1.831 in 46.50 mm
72 Tooth Gear REV-41-1336	2.126 in 54.00 mm	2.185 in 55.50 mm
90 Tooth Gear REV-41-1337	2.657 in 67.50 mm	2.717 in 69.00 mm
125 Tooth Gear REV-41-1333	3.691 in 93.75 mm	3.750 in 95.25 mm

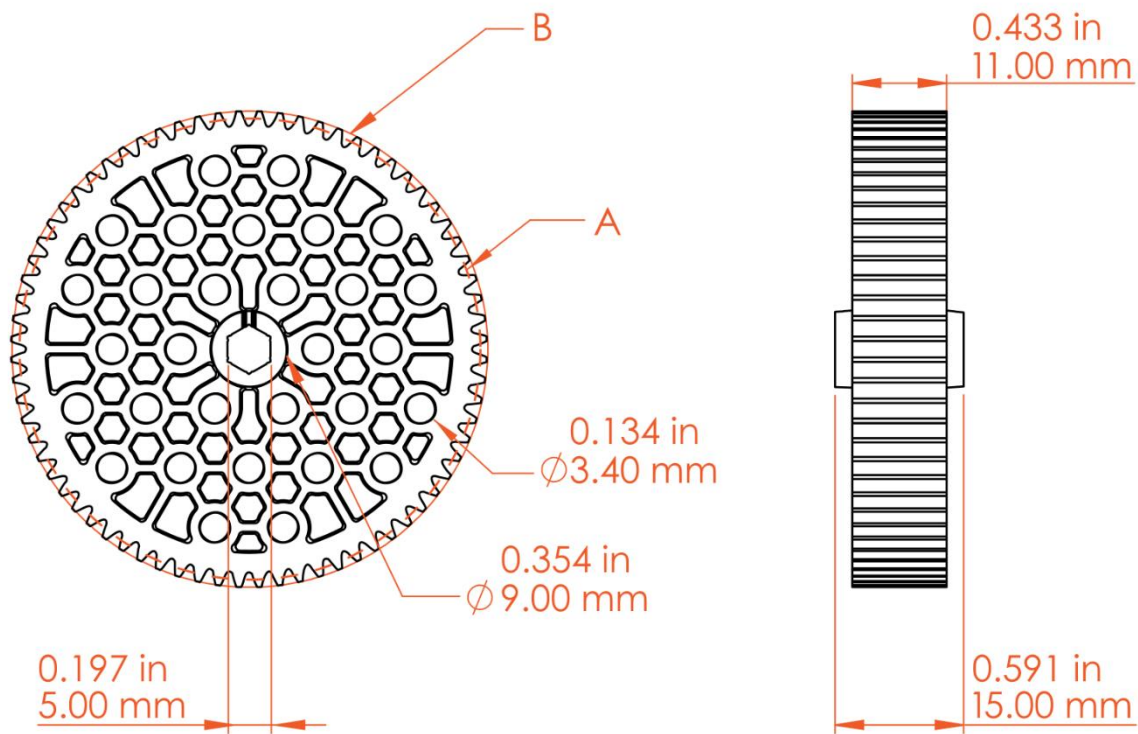
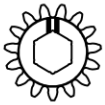
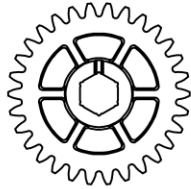


Figure 17: Gear Measurement Details

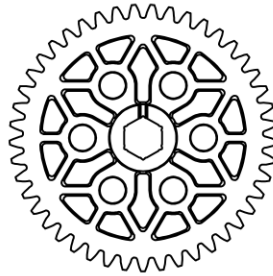
3 ALL GEARS (1:1 Scale)



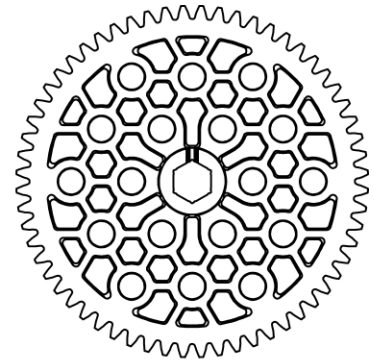
REV-41-1331
15 Tooth Gear



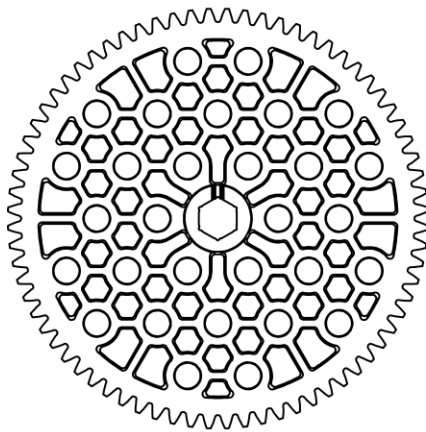
REV-41-1332
30 Tooth Gear



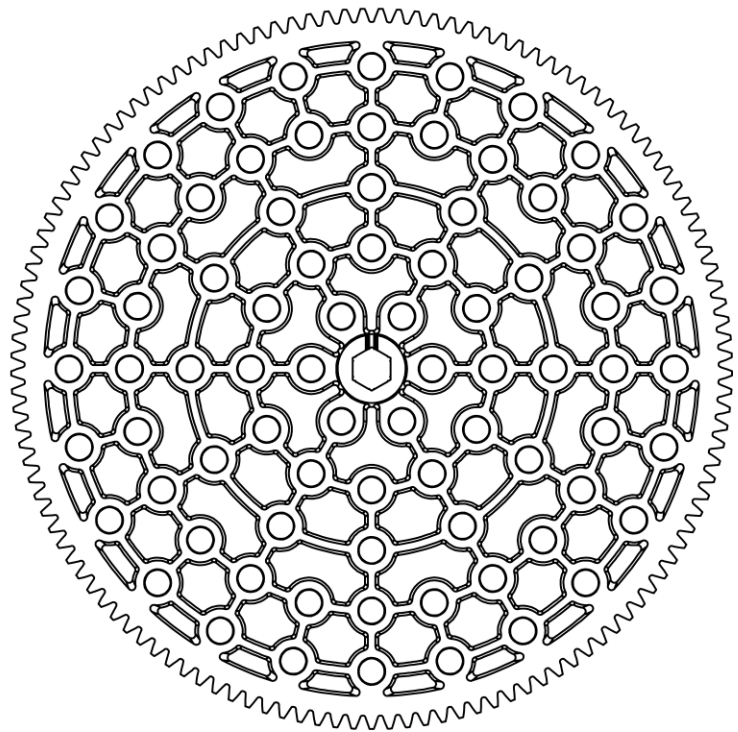
REV-41-1334
45 Tooth Gear



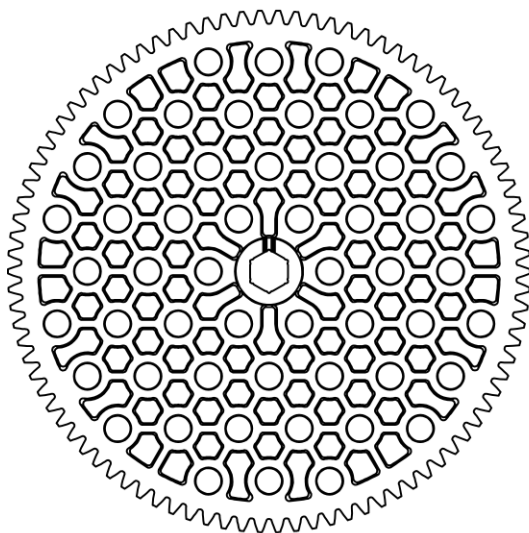
REV-41-1335
60 Tooth Gear



REV-41-1336
72 Tooth Gear



REV-41-1333
125 Tooth Gear



REV-41-1337
90 Tooth Gear