REV ROBOTICS

SPROCKET AND CHAIN GUIDE

TABLE OF CONTENTS

1 SPROCKET BASICS

Sprockets are rotating parts with teeth that are used in conjunction with a chain and, almost always, at least one other sprocket to transmit torque. Sprockets and chain can be used to change the speed, torque, or original direction of a motor. In order for sprockets and chain to be compatible with each other they must both have the same thickness and pitch. In order for the sprockets and chain to work effectively, all of the sprockets should be on parallel shafts with their corresponding teeth on the same plane.

1.1 Anatomy of a Sprocket

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

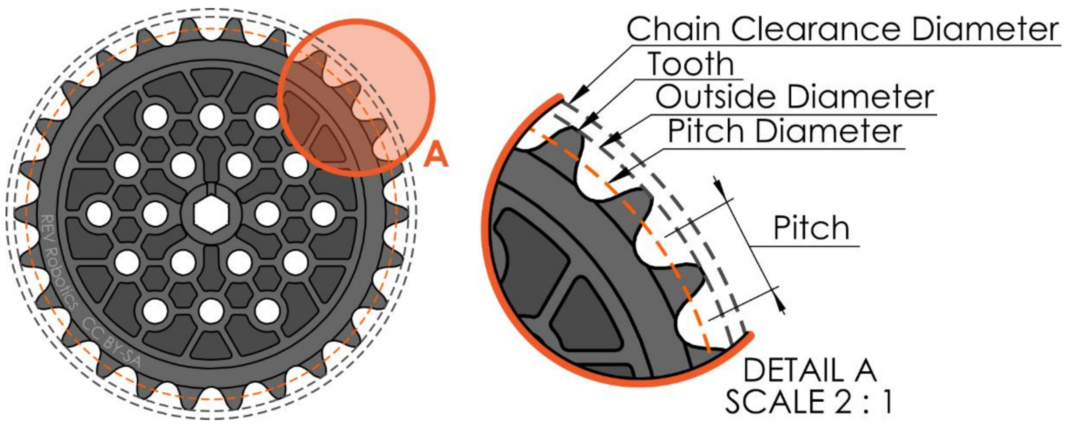


Figure 1: Basic Sprocket Nomenclature

Number of Teeth is the total count of the **number of teeth** (projections) around the whole circumference of a sprocket. For sprockets with very few teeth it is easy to simply count the number of teeth. However, for sprockets with a higher **number of teeth**, attempting to count the teeth may not be very practical or accurate. For our REV gears, we have taken all of the guesswork out of this process. Simply use the ALL SPROCKETS (1:1 Scale) reference guide on page 17 by printing that page out at full scale and then match your sprocket to its correct outline on the page to identify the sprocket.

Pitch Diameter (PD) is an imaginary circle which is traced by the center of the chain pins when the sprocket rotates while meshed with a chain. The ratio of the **pitch diameter** between sprockets can be used to calculate the gear ratio, but more commonly and much more simply the ratio of the **number of teeth** is used for this calculation.

Pitch represents the amount of **pitch diameter** in inches per tooth. Gears with a larger **pitch** will have bigger teeth. Common pitches are 0.25", known as #25, and 0.375" (#35). The REV Robotics building system uses #25 chain.

Outside Diameter (OD) will always be larger than the **pitch diameter** but smaller than the **chain clearance diameter**. The **outside diameter** does not account for the additional diameter added by the chain, so it should not be used to check for assembly interference.

Chain Clearance Diameter is the outside diameter of a sprocket with chain wrapped around it. The **chain clearance diameter** will always be larger than the **pitch diameter** and the **outside diameter**. The **chain clearance diameter** should be used when checking for interference when placing sprockets very close to other structures.

1.2 Anatomy of Chain

Roller chain is used to connect two sprockets together and transfer torque. Roller chain is made up of a series of inner and outer links connected together to form a flexible strand (Figure 2).

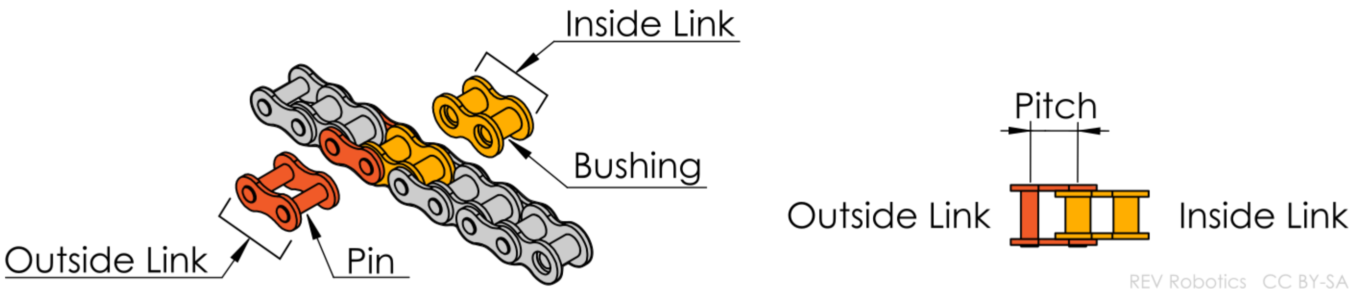


Figure 2: Basic Chain Nomenclature

Outside Links consist of two outside plates which are connected by two ***pins*** that are pressed into each plate. The ***pins*** in the outside link go through the inside of the hollow ***bushings*** when the inner and outer links are assembled. The ***pins*** can freely spin on the inside of the ***bushings***.

Inside Link consist of two inside plates that are connected by two hollow ***bushings*** which are pressed into each plate. The teeth of the sprocket contact the surface of the ***bushings*** when the chain is wrapped around a sprocket.

Pitch is the distance between the centers of two adjacent ***pins***. Common pitches are 0.25”, known as #25, and 0.375” (#35). The REV Robotics building system uses #25 chain.

1.3 Custom Length Chain

In almost all applications, chain links are connected to form a loop. While chain can sometimes be purchased in specific length loops, it is more common and economical to buy chain by the foot and make custom loop lengths to fit the application. It is recommended to use a specialized tool, called a chain breaker, to cut chain into desired lengths in order to prevent accidental damage. See Table 1 for tool recommendations.

Table 1: Recommended Chain Breaker Tools

Tool	Suppliers	Approx. Cost
REV Chain Break	REV Robotics	Included in Kit
DarkSoul Chain Break	Dave’s Discount Motors Various	$32.00 USD
T-Handle Roller Chain Break	McMaster-Carr Amazon Various	$15 - 30.00 USD

Chain breakers do not actually cut the chain, instead they are used to press out the pins from an outer link. After the pins have been removed the chain can be separated leaving inner links on both ends of the break. Refer to individual tool instructions for more specific and detailed chain break procedures.

1.4 Master Links

Roller chain is typically connected into a continuous loop. This can be done using a special tool to press the pins in and out of the desired outer link as described in the Custom Length Chain section, or if the chain is already the correct length, an accessory called a master link, or quick-release link, (Figure 3) can be used to connect two ends of the chain.

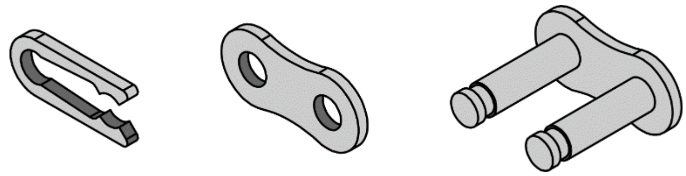


Figure 3: Master Link (Enlarged)

Master links allow for easy chain assembly/disassembly without any special chain tools. Master links can typically be reused many times, but will eventually become bent after repeated uses and should then be discarded. Master links replace an outside link in a section of chain, but before examining the master link connecting two sections of chain, Figure 4 depicts the basic operation for assembling a master link.

1. Place the loose outer plate onto the two pins pressed into the other outer plate.
2. Ensure the outer plate is inserted onto the pins far enough that the grooves on the pins are fully exposed past the outer plate.
3. Align the widest gap near the middle of the clip with one of the pins.
4. The gap in the clip should allow the clip to slip over the pin and sit flush against the outer plate and aligned with the groove in the pins.
5. Use pliers or another tool to slide the clip towards the other pin until the clip is securely engaged with the grooves on both pins.

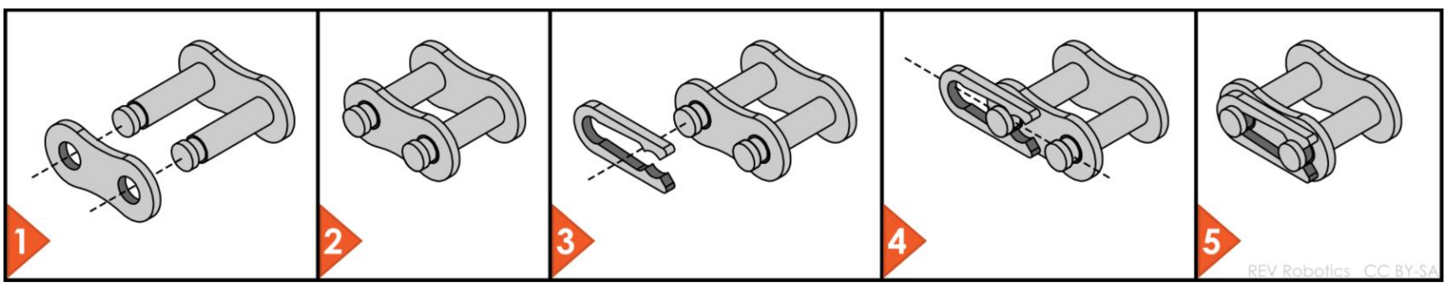


Figure 4: Master Link Detailed Assembly for Reference

Installing the clip as shown in Steps 4 and Step 5 of Figure 4 can be sometimes difficult.

There are a number of approaches that may work for these steps, but a common method is to use a pair of needle nose pliers to grip between the back of the clip and the nearest pin to slide the clip (Figure 5).

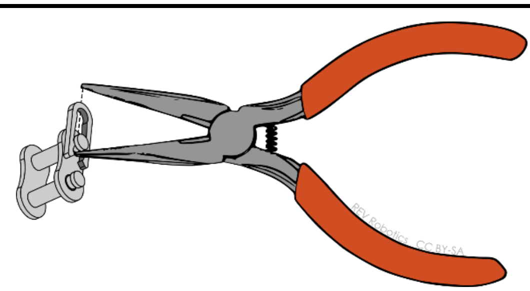


Figure 5: Installing the Maser Link Clip with Pliers

Master links are used to connect two ends of a section of chain to create a loop of chain. In order to use a master link, the chain ends should both terminate with inside links (Figure 6). Slide the two pins from the master link into the rollers of the two terminating inside links. Follow the procedure from Figure 4 to complete the link installation.

Figure 6: Master Link Assembly on Chain

1.5 Torque, Speed, and Power

Sprockets are one common way to transmit power and change the output torque or speed of a mechanical system. Understanding of these basic concepts is required to make optimized design decisions. This section with briefly cover the definition of these concepts and then explain them in relationship to basic sprocket and chain designs.

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 sprockets and wheels, **speed** is expressed in how many revolutions are made in a given amount of time. This rotational speed can be converted into linear **speed** at the edge of the sprocket by multiplying the **pitch diameter** 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 sprocket or a gear. 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 sprocket, the sprocket will create a straight line (linear) force at the point where the teeth contact the chain. The magnitude of the **torque** created is the product of the rotational force applied and the length of the lever arm (Figure 7), which for a sprocket, is half of the pitch diameter (the radius).

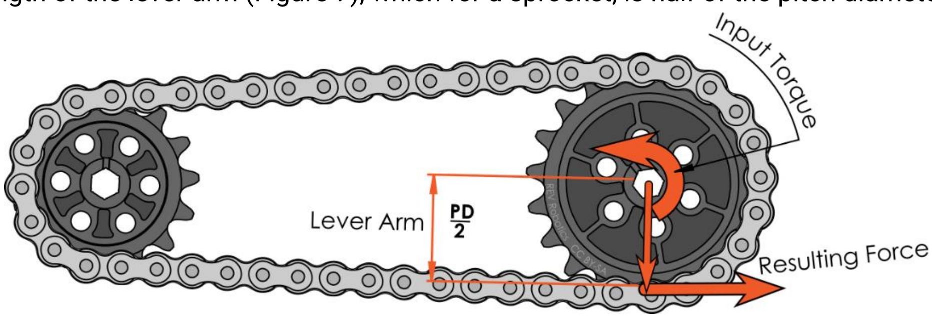


Figure 7: Sprocket Torque Diagram

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**.

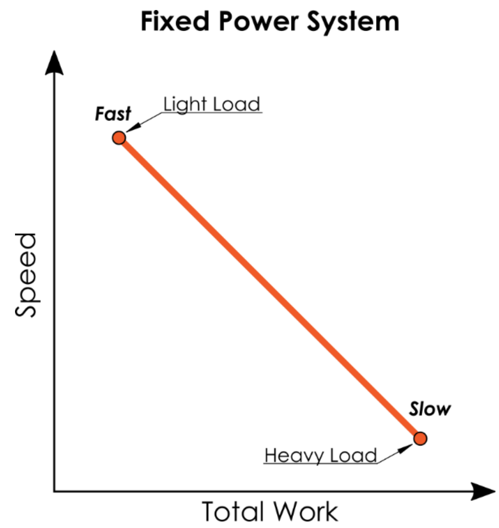


Figure 8: Execution Speed in a Fixed Power System by Load

By changing the size of the sprockets, we change the length of the lever arm shown in Figure 7. By selecting sprockets larger or smaller relative to the input sprocket, we can either increase the output speed or increase the output torque as shown in Figure 9, however, the total power is not effected.

When a larger sprocket drives a smaller one, for one rotation of the larger sprocket the smaller sprocket must complete more revolutions so the output will be faster than the input. If we reverse the situation and a smaller sprocket drives a larger output sprocket, then for one rotation of the input the output will complete less than one revolution resulting in a speed decrease from the input. The ratio of the sizes of the two sprockets is proportional to the speed and torque changes between them.

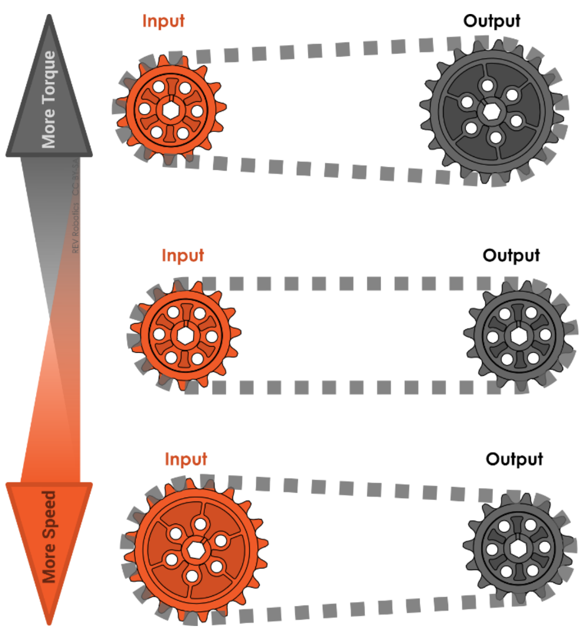


Figure 9: Using Gears to Increase Speed or Torque

From Figure 9 we know that the ratio in size from the input (driving) sprocket to the output (driven) sprocket determines if the output is faster (less torque) or has more torque (slower). To calculate exactly how the sprocket size ratio effects the relationship from input to output we can use the ratio of the number of teeth between the two sprockets.

Sprocket and chain is a very efficient way to transmit torque over long distances. Modest reductions can be accomplished using sprockets and chain, but gears typically provide a more space efficient solution for higher ratio reductions.

In Figure 10 the ratio of the number of teeth from the input sprocket to the output sprocket is 15T:20T which means the input needs to turn 1.3 rotations for the output to complete one rotation ($\frac{20T}{15T} = 1.3$).

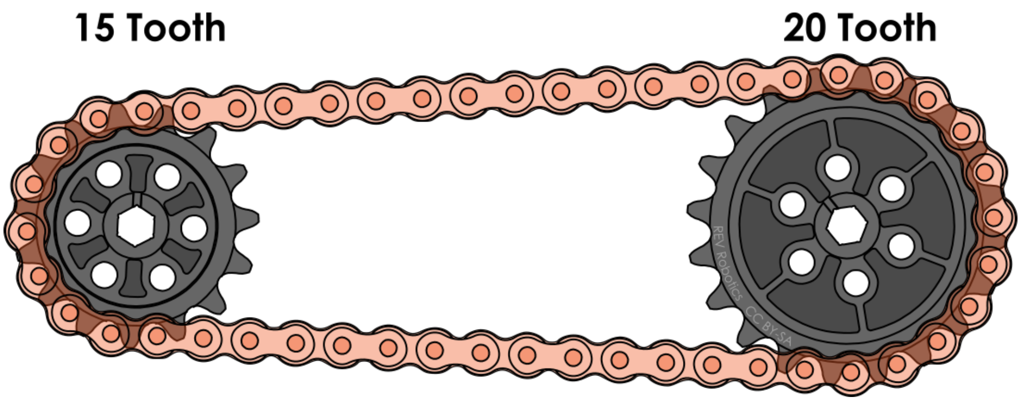


Figure 10: Single Stage Reduction (15:20)

In Figure 11, a 15 tooth idler sprocket is added into the example on the outside of the chain loop. An idler sprocket is any sprocket meshed with the chain which does not drive any shaft or do any work. Idlers do not change the system reduction which remains 15T:20T. Regardless of the number or size of idler sprockets, only the input and output sprocket determine the reduction.

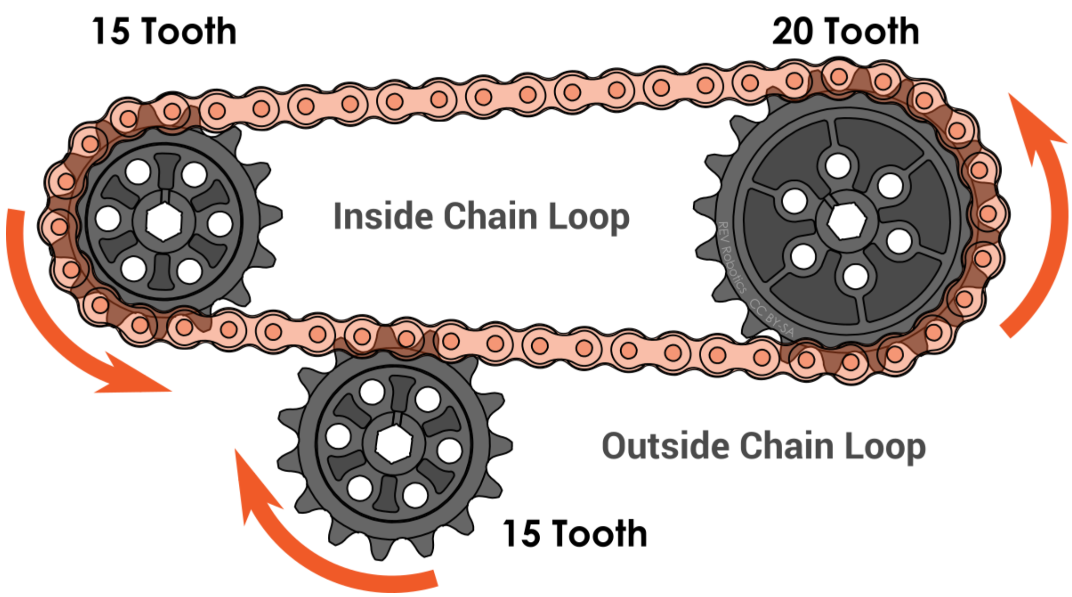


Figure 11: Single Stage Reduction (15:20) with Idler

All sprockets on the same side of a chain have the same rotation. In Figure 11 the driving and driven sprocket are inside the chain and are rotating counter clockwise while the idler sprocket is outside of the chain loop and is rotating clockwise. This property is useful sometime when it is desirable to have two shafts powered from the same source, but with opposite rotations. Common examples of this on robots are intakes and dual wheeled shooters.

Idlers can be used to tension chain or increase the amount of chain wrap around a sprocket. From Figure 12, all power transmission sprockets should have chain wrapped approximately 180° around the circumference of the sprocket. This amount of wrap is necessary so that there are sufficient teeth engaged with the chain to transmit the torque. Too little wrap (<120°) and the chain will skip under heavy load, while excessive wrap (>200°) can decrease system efficiency. In Figure 12 the sprocket outside of the chain is noted with a warning because it has a chain wrap of <90°. If this sprocket is an idler, then it is unpowered and minimal chain wrap is acceptable, however if this sprocket will be driving a shaft which is doing work, this amount of wrap would be insufficient.

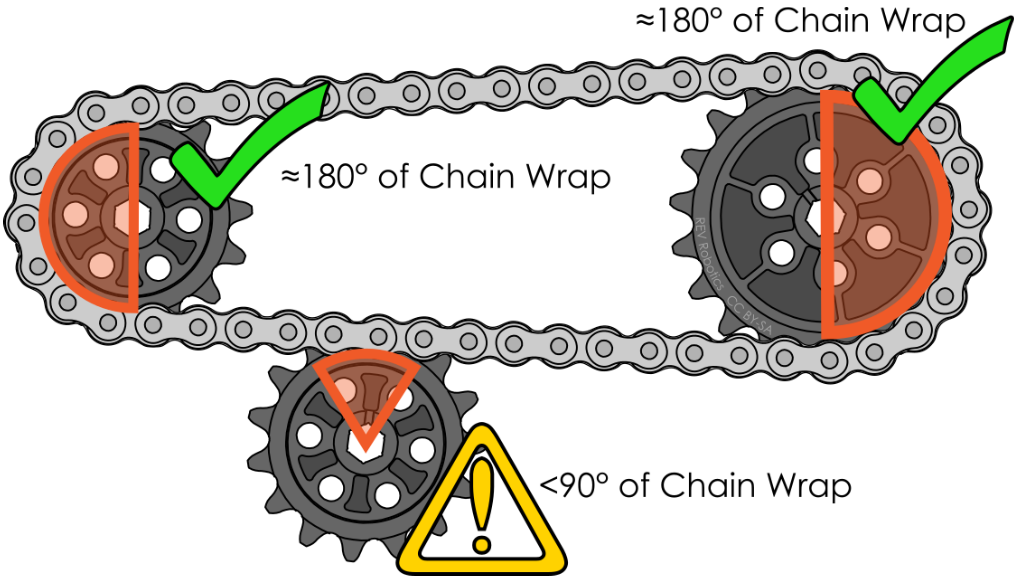


Figure 12: Chain Wrap Illustration

Sprocket and chain is an efficient way to transmit torque long distances in a robot. A common example of this is a sprocket and chain drivetrain (Figure 13). In this example the sprockets on the ends are linked to the drive wheels and the center sprocket would be driven by a motor (not shown). Because the driving and driven sprockets are all inside the chain, they all have the same rotation direction. The smaller sprockets on the outside of the chain loop are used to increase the amount of chain wrap on the center driving sprocket.

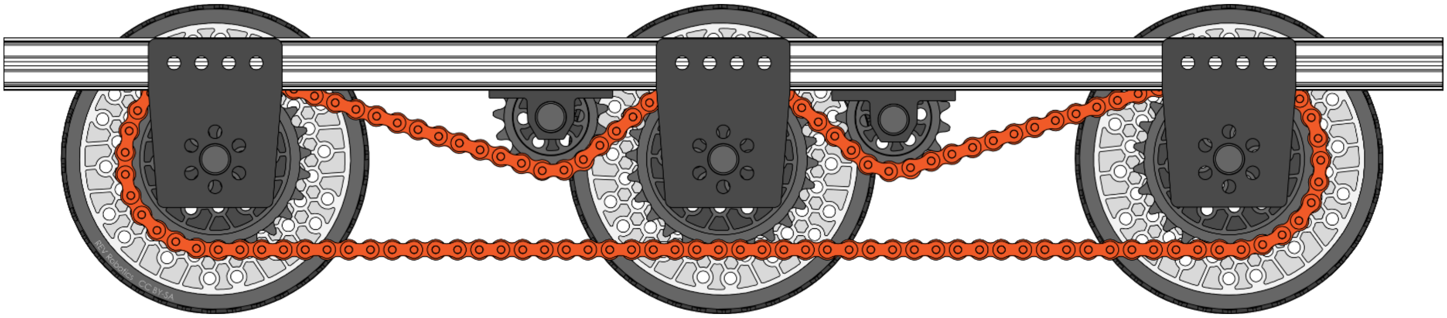


Figure 13: Example Sprocket and Chain Drive Train

1.6 Compound Gearing

Some designs may require more reduction than is practical in a single stage. The ratio from the smallest sprocket available to the largest is 15:54, so if a greater reduction then 3.6x is required, multiple reduction stages can be used in the same mechanism which is called a compound gear reduction. There are multiple gear or sprocket pairs in a compound reduction with each pair linked by a shared axle. When using sprockets and chain in a multi stage reduction, it is very common to use gears for the first stage and then use sprockets and chain for the last stage. Figure 14 is an example of a two-stage reduction using all gears, but one of the pairs could be replaced with sprockets and chain. The driving gear (input) of each pair is highlighted in orange.

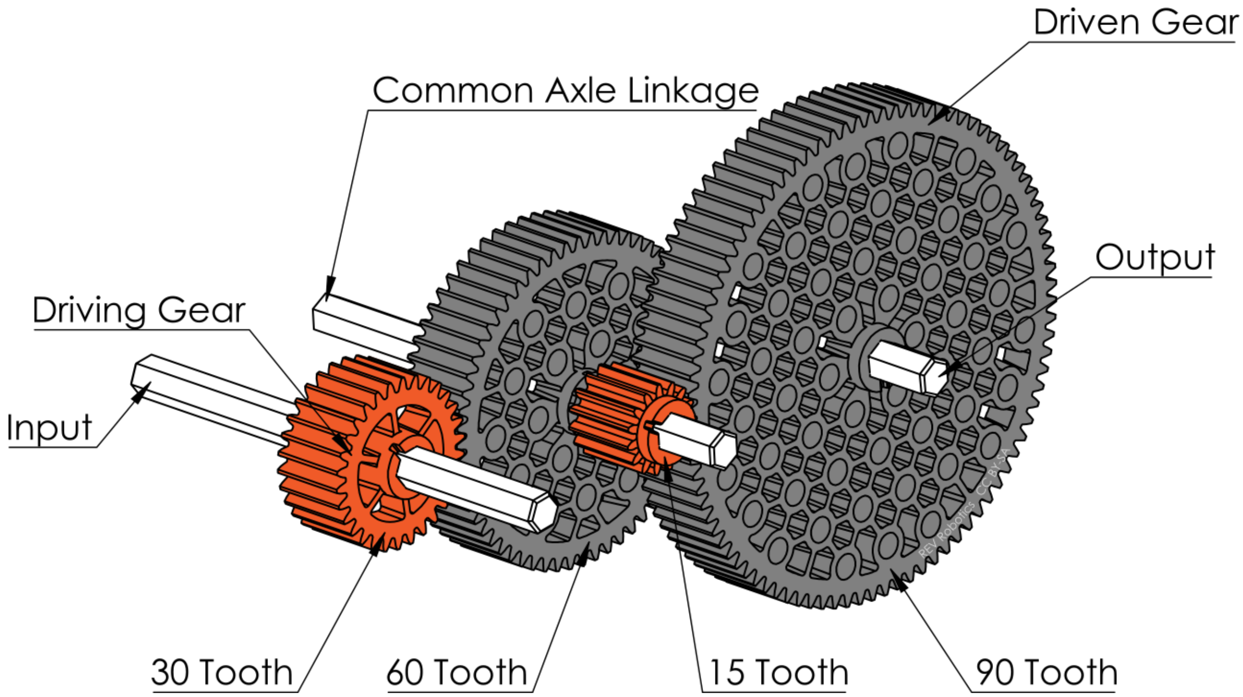


Figure 14: Compound Reduction Example

Reduction is calculated the same for gears and sprockets and is based on the ratio of the number of teeth. To calculate the total reduction of a compound reduction, identify the reduction of each stage and then multiply each reduction together.

$$Compound\ Reduction = Reduction\ 1\ \times Reduction\ 2\ \times \ldots \times Reduction\ n$$

Using Figure 14 as an example the compound reduction is 12:1.

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

For any gear system there are a limited number of gear and sprocket sizes available so in addition to being able to create greater reductions by 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 motion components.

2 REV SPROCKET SPECIFICATIONS

2.1 REV Robotics Sprockets

REV Robotics sprockets are a #25 pitch and are made from molded acetal (Delrin/POM). Sprockets are designed to fit a 5mm hex shaft which eliminates the need for special hubs and setscrews. 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 Sprockets 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 Sprockets to be used together which provides far greater flexibility than a fixed pitch system which require specific sprocket pairs. When adjusting the reduction of a system, just a single sprocket 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 15).

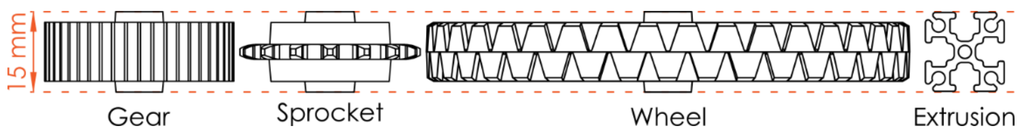


Figure 15: REV Robotics Common Part Thickness

In order for sprockets to work effectively, it's important that the center-to-center distance is correctly adjusted. The sprocket and chain in Figure 16 may work under very light load, but they will certainly not work and will skip under any significant loading. The sprockets in this example are too close together so chain is loose enough that it can skip on the sprocket teeth. The sprockets in Figure 17 are correctly spaced which will provide smooth reliable operation.

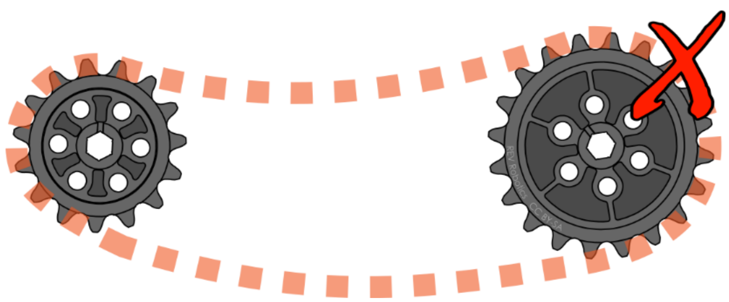


Figure 16: Incorrectly Spaced Sprockets (Chain too Loose)

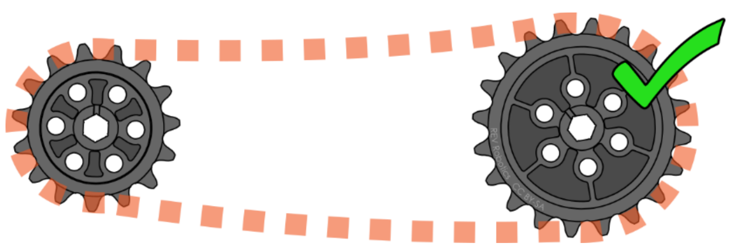


Figure 17: Correctly Spaced Sprockets (Chain Correctly Tensioned)

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

1. Securely fix the axle of either the input or output sprocket. 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, then identify all the driving and driven sprockets for any sprockets on that axle. One by one loosen these axles, slide them until the chain is tensioned and then retighten the axle mounts.
3. Continue the procedure from Step 2 for each fixed axle until all the chains are tight and all the axles have been retightened.

The gear spacing adjustment procedure above is sufficient in almost all cases. It is also possible to mathematically calculate the number of links needed between two sprockets or the correct center to center distances for two sprockets for a given chain length. These methods are appropriate for robot planning purposes, but assembling your robot using these measurement is typically impractical. The details of these calculations are included for completeness, but most modern CAD packages or numerous free online calculators can also generate the correct values.

Center to Center Distance in Inches:

$$C = \frac{P}{8}\left[2L - (N+n) + \sqrt{\left(2L - (N+n)\right)^2 - \frac{8}{\pi^2}\cdot (N-n)^2}\right] \quad (1)$$

Chain Length in Pitches:

$$L = \frac{2C}{P} + \frac{N+n}{2} + \frac{P\left(\frac{N-n}{2\pi}\right)^2}{C} \quad (2)$$

C= Center to Center Distance
L= Chain Length in Pitches
P= Pitch of Chain
N= Number of Teeth on Large Sprocket
n= Number of Teeth on Small Sprocket

Using Equation (1) and Figure 17 as an example to calculate center-to-center distance:

Center to Center Distance in Inches: $C = \frac{P}{8}\left[2L - (N+n) + \sqrt{(2L - (N+n))^2 - \frac{8}{\pi^2}\cdot (N-n)^2}\right]$

L = 48
P= 0.25
N= 20
n= 15

$$C = \frac{0.25}{8}\left[2(48) - (20+15) + \sqrt{(2(48) - (20+15))^2 - \frac{8}{\pi^2}\cdot (20-15)^2}\right]$$

$$= \frac{0.25}{8}\left[96 - 35 + \sqrt{(96-35)^2 - \frac{8}{\pi^2}\cdot (5)^2}\right]$$

$$= \frac{0.25}{8}\left[61 + \sqrt{(61)^2 - \frac{8}{\pi^2}\cdot 25}\right]$$

$$= \frac{0.25}{8}\left[61 + \sqrt{3721 - \frac{200}{\pi^2}}\right]$$

$$= \frac{0.25}{8}\left[61 + \sqrt{3721 - 20.2642}\,\right]$$

$$= 0.03125[61 + 60.833\,]$$

$$\boldsymbol{Calculated\ Center\ to\ Center\ Distance\ for}\ \text{Figure 17} = \mathbf{3.807}\ \boldsymbol{inches}$$

In most design cases the chain length is not known ahead of time, but the two sprockets in the reduction and an approximate center-to-center distance to fit the reduction is known. For this example, assume a 15:20 reduction is needed and that the whole solution must fit in a space of five inches or less.

Since the solution must fit within a five inch space the chain clearance radius around both sprockets must be accounted for, in addition to their center to center distance. Use Table 2: Sprocket Measurement Details, to look up the chain clearance diameter (A) for both the 15 tooth and 20 tooth sprocket and subtract the radius of each from the total given solution size to get the maximum center to center distance available (Figure 18).

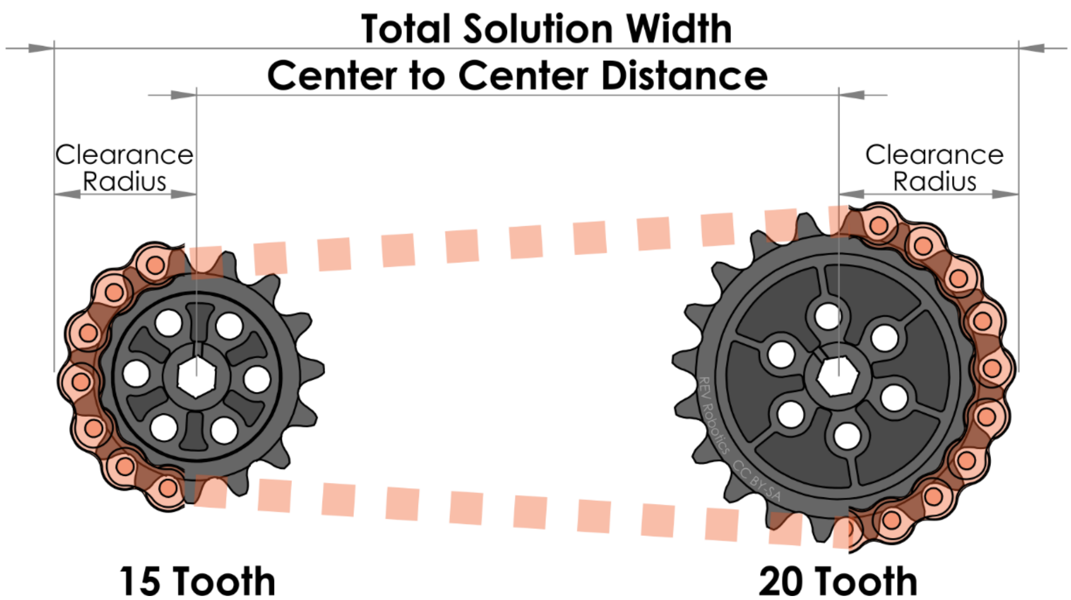


Figure 18: Relationship between Center to Center Distance and Clearance Width

$$\text{Maximum Center to Center Distance} = \text{Total Solution Width} - \text{Clearance Radius 1} - \text{Clearance Radius 2}$$

$$15T_{chain\ clearance\ diameter(A)} = 1.428 \text{ inches}$$

$$20T_{chain\ clearance\ diameter(A)} = 1.830 \text{ inches}$$

$$\text{Maximum Center to Center Distance Available} = 5 - \frac{1.428}{2} - \frac{1.830}{2}$$

$$\text{Maximum Center to Center Distance Available} = 3.371\ inches$$

Using the center to center distance of 3.371 inches from above as the maximum possible spacing for this reduction, solve Equation (2):

Chain Length in Pitches: $L = \frac{2C}{P} + \frac{N+n}{2} + \frac{P\left(\frac{N-n}{2\pi}\right)^2}{C}$

C= 3.371
P= 0.25
N= 20
n= 15

$$= 2(13.484) + \frac{20+15}{2} + \frac{\left(\frac{20-15}{2\pi}\right)^2}{13.484}$$

$$= 2(13.484) + \frac{35}{2} + \frac{\left(\frac{5}{2\pi}\right)^2}{13.484}$$

$$= 26.968 + 17.5 + \frac{(0.796)^2}{13.484}$$

$$= 44.468 + \frac{0.635}{13.484}$$

$$Exact\ pitch\ lengths\ = 44.589$$

$$\boldsymbol{Round\ Down\ to\ Nearest\ Even\ Number\ = 44}$$

Since it is **not possible to have a fraction of a pitch length in the chain, the number obtained by solving Equation (2) must be rounded to a whole even number**. In this example, because the center to center distance used was the maximum allowed, the exact pitch length should be rounded down to 44 to meet the design requirements.

Now that the maximum even pitch lengths in the chain has been calculated, this value can be plugged back into Equation (1) to find the exact center to center distance using the 44 link chain:

Center to Center Distance in Inches: $C = \frac{P}{8}\left[2L - (N+n) + \sqrt{(2L-(N+n))^2 - \frac{8}{\pi^2}\cdot(N-n)^2}\ \right]$

L = 44
P= 0.25
N= 20
n= 15

$$= \frac{0.25}{8}\left[2(44) - (20+15) + \sqrt{(2(44)-(20+15))^2 - \frac{8}{\pi^2}(20-15)^2}\ \right]$$

$$= \ 0.03125\left[88 - 35 + \sqrt{(88-35)^2 - 1.273\cdot(5)^2}\ \right]$$

$$= \ 0.03125[53 + 53.299\ ]$$

$$= \ \boldsymbol{3.32\ inches}$$

So, in summary, for a 15T:20T reduction the longest chain that will fit in a 5-inch space is a 44 link chain which then gives a center-to-center distance of 3.32 inches, with the total solution having a width of 4.949 inches.

2.2 Sprocket Mounting Pattern

All REV Robotics sprockets have a M3 bolt hole mounting pattern that is on an 8mm pitch as shown in Figure 19. This makes it easy to directly mount REV Robotics brackets and extrusion to sprockets. The 8mm pitch is also compatible with many other building systems.

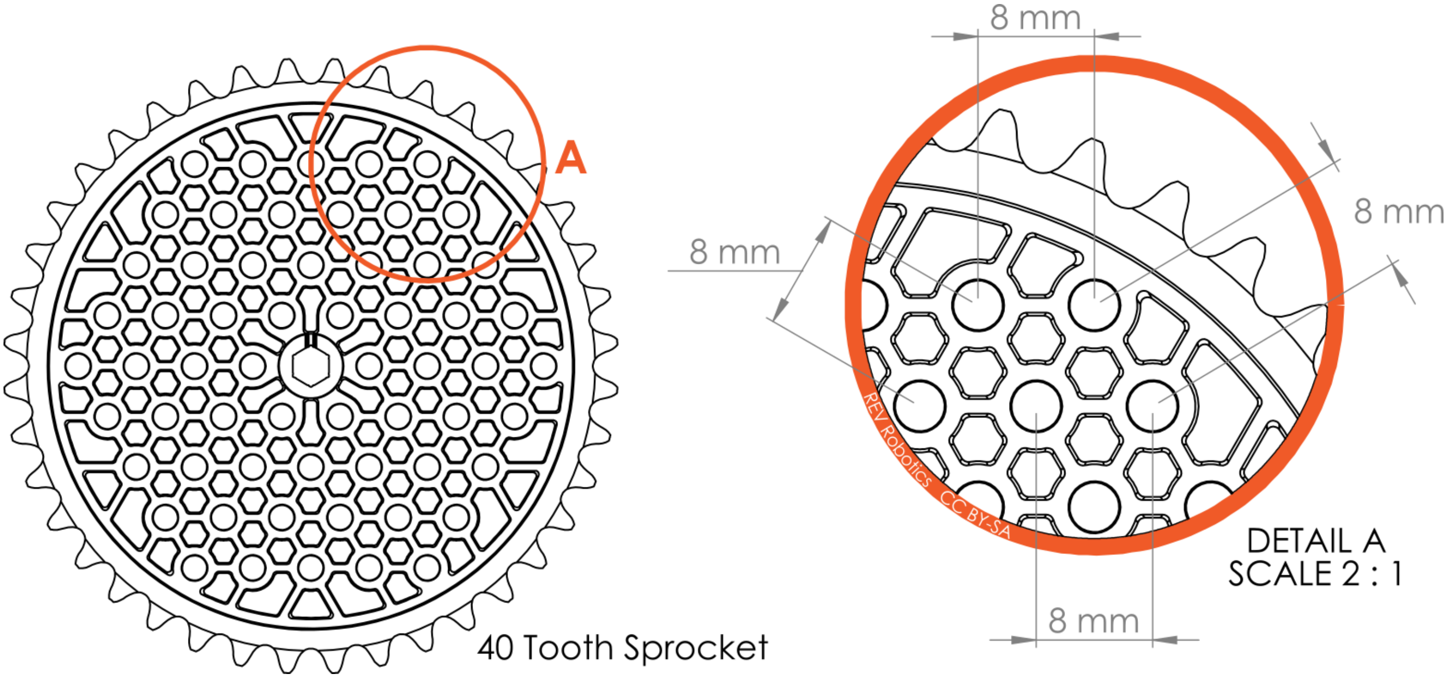


Figure 19: Mounting Hole Pattern Details

2.3 Sprocket Alignment Mark

Sometimes in a design it may be desirable to stack together multiple of the same sprocket on a shaft. In the cases where the number of teeth on the sprocket 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 sprockets. To ensure all of the sprockets are clocked the same way, use the alignment shaft notch (Figure 20) to put all the gears on the shaft with the same orientation.

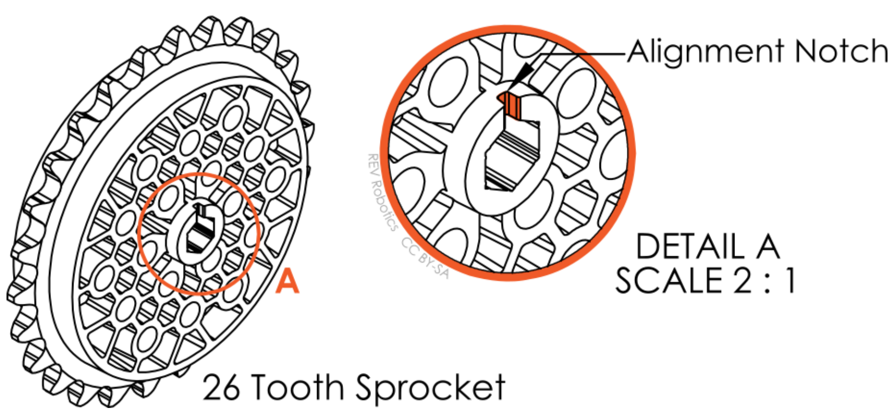


Figure 20: Gear Alignment Notch

2.4 Sprocket Measurements

Table 2: Sprocket Measurement Details

	A Chain Clearance Diameter	B Outside Diameter
10 Tooth Sprocket REV-41-1338	1.021 in 25.95 mm	0.919 in 23.35 mm
15 Tooth Sprocket REV-41-1339	1.428 in 36.28 mm	1.326 in 33.68 mm
20 Tooth Sprocket REV-41-1340	1.830 in 46.50 mm	1.728 in 43.90 mm
26 Tooth Sprocket REV-41-1342	2.311 in 58.71 mm	2.209 in 56.11 mm
40 Tooth Sprocket REV-41-1343	3.429 in 87.09 mm	3.327 in 84.49 mm
54 Tooth Sprocket REV-41-1341	4.545 in 115.44 mm	4.442 in 112.84 mm

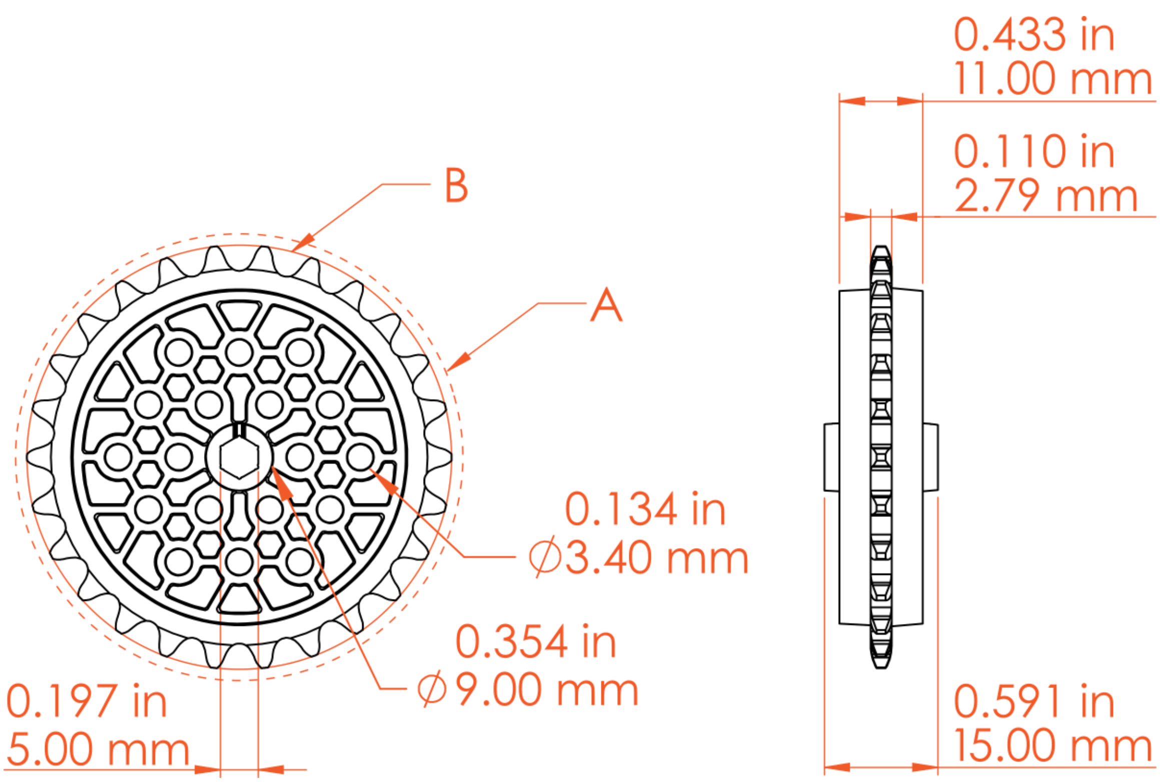
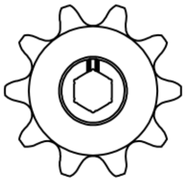
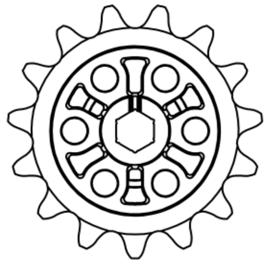


Figure 21: Sprocket Measurement Details

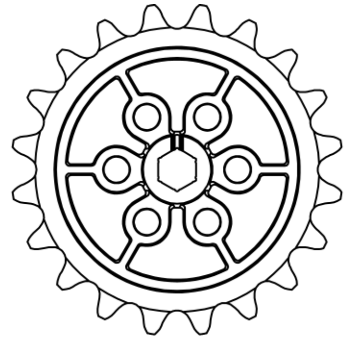
3 ALL SPROCKETS (1:1 Scale)



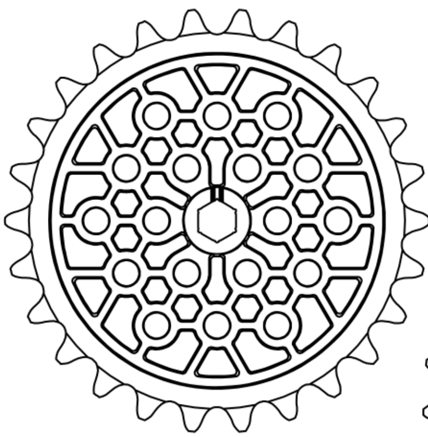
REV-41-1338
10 Tooth Sprocket



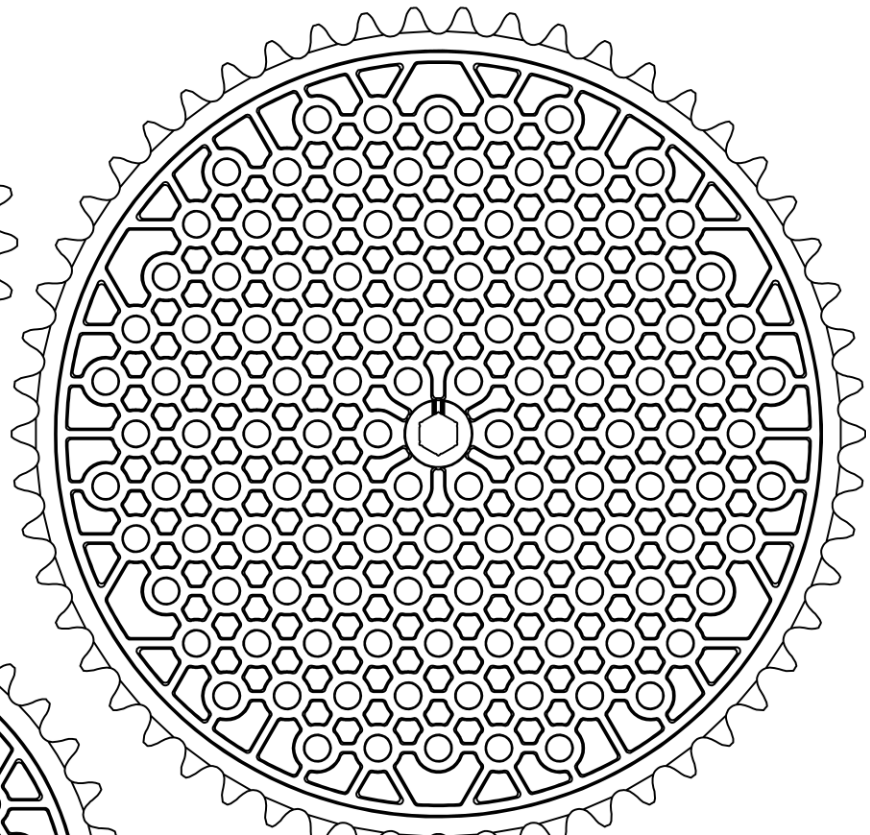
REV-41-1339
15 Tooth Sprocket



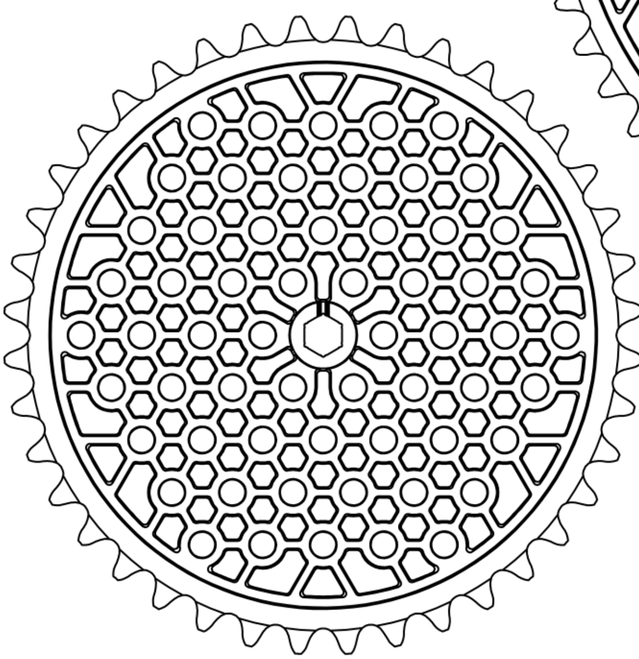
REV-41-1340
20 Tooth Sprocket



REV-41-1342
26 Tooth Sprocket



REV-41-1341
54 Tooth Sprocket



REV-41-1343
40 Tooth Sprocket