Mechanisms

A Practical Approach

Teacher Copy

Use this document alongside the VEX IQ Mechanism Kit.

Please note the solutions provided in this booklet are not the only possible answers to the questions. They are designed to give direction and develop understanding.

Mechanisms - A Practical Approach

Glossary of Key Words and Terms

Below you will find a table of key words and terms that are used throughout this document. Each key word or term is accompanied by a short description that will help you remember and understand its use.

Key Word / Term	Description
Bevel	The inclination that one line or surface makes with another when not at right angles.
Compound Gear	A compound gear is a number of gears fixed together and positioned on top of each other. Consequently, they rotate at the same speed.
Differential Gearbox	A train of gears designed to permit two or more shafts to rotate at different speeds.
Gear Ratio	The ratio of the rotational speeds of the first and final gears in a train of gears or of any two meshing gears. Also known as Velocity Ratio.
Idler Gear	A gear placed between a driving and a driven gear to transmit motion between them.
Mesh(ed)	To engage, as gear teeth.
Output Speed	An equation involving a gear ratio to calculate the "output speed" from a specified "input speed".
Revolution	Turning round or rotating, on an axis.
Shaft	A rotating straight bar for transmitting motion and torque.
Torque	The measured ability of a rotating element, as of a gear or shaft, to overcome turning resistance.


Bevel Gear


Crown Gear

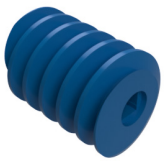

Pulley Wheel


Rack Gear


Sprocket


Spur Gear


Universal Joint


Worm Gear

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An Introduction to Gears

You will find gears in nearly everything that contains rotating parts. Car engines and gear boxes contain many gears as do clock mechanisms, especially if they have bells or chimes. Engines and motors producing rotational motion will not doubt feature some form of gear configuration. In this section you will learn how different sizes and configurations of gears can be utilised for a wide range of purposes. You will find the formulas below useful when calcuating some of the answers.

$$\text{Gear Ratio (Velocity Ratio)} = \frac{\text{Number of teeth on the driven gear}}{\text{Number of teeth on the driver gear}} \qquad \text{Output Speed} = \frac{\text{Input Speed}}{\text{Gear Ratio}}$$

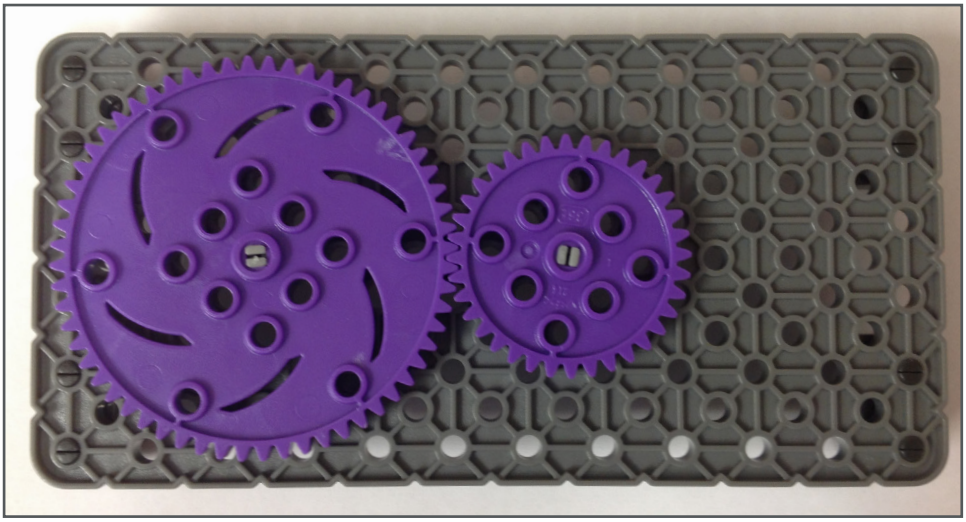
The Simple Gear Train

Sometimes two or more gears mesh with each other to transmit power from one shaft to another. This combination is called a gear train or train of toothed wheels. The nature of the train used depends upon the velocity ratio required and the relative position of the axes of the shafts. A gear train may consist of spur, bevel or spiral gears.

Practical Task

You will need:

1 x 6x12 Plate
2 x Idler Pins
1 x 60 Tooth Spur Gear
1 x 36 Tooth Spur Gear
1 x 12 Tooth Spur Gear



Questions

1. *What do you notice about the speed and direction of rotation the smaller spur gear when you turn the larger spur gear at a constant speed?*

   It turns faster and in the opposite direction to the input.

2. *Calculate the gear ratio and explain what the result means.*

   $$\frac{\text{36 teeth on the driven gear}}{\text{60 teeth on the driver gear}} = \frac{36}{60} = 0.6 : 1 \text{ or } \frac{6}{10} \text{ or } \frac{3}{5}$$

   For every 3 full rotations of the larger spur gear the smaller spur gear will complete 5 full rotations.

3. *Replace the 60 tooth spur gear with the 12 tooth spur gear - what do you notice now?*

   The ouput (36 tooth) turns slower than the input (12 tooth).

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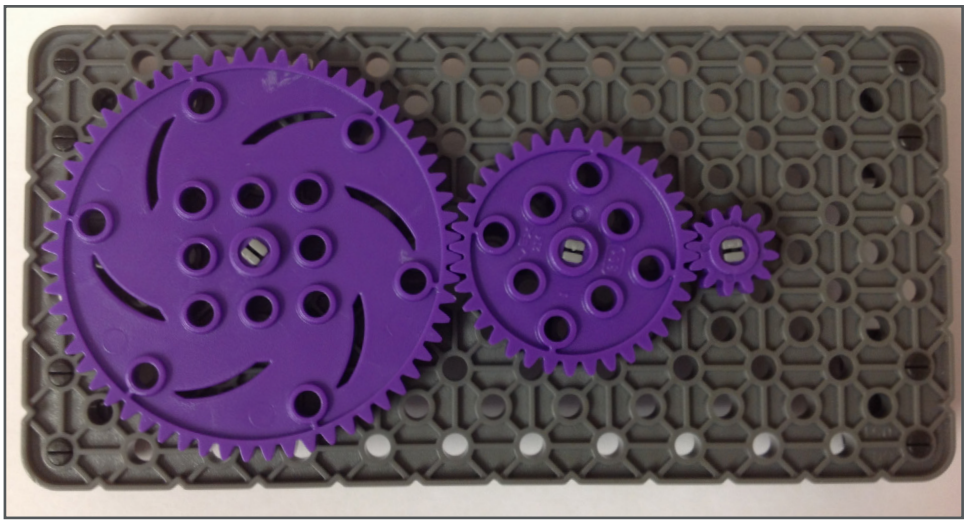
3 Gear Train

As you increase the number of gear wheels in your gear train you will notice that you are able to change the direction of rotation of each gear wheel. Two gear wheels meshed directly to each other will rotate in opposite directions. However if you wanted two shafts to rotate in the same direction you would need to add a third gear wheel. The additional gear wheel is positioned between the two shafts you wish to rotate in the same direction and is known as the idler gear.

Practical Task

You will need:

1 x 6x12 Plate
3 x Idler Pins
1 x 60 Tooth Spur Gear
1 x 36 Tooth Spur Gear
1 x 12 Tooth Spur Gear



Questions

1. *What do you notice about the rotational direction of all three gear wheels?*

   The two outer spur gears rotate in the same direction. The middle spur gear rotates in the opposite direction.

2. *What is the name given to the middle gear wheel and what is its purpose?*

   In this configuration the middle gear is known as the "idler gear". Its purpose is to transfer motion between two shafts that are required to rotate in the same direction.

3. *Calculate the output speed when the input speed on the 60 tooth gear wheel is 10rpm.*

$$\text{Gear Ratio} = \frac{\text{12 teeth on the driven gear*}}{\text{60 teeth on the driver gear}} = \frac{12}{60} = 0.2:1 \text{ or } \frac{1}{5}$$

$$\text{Output Speed} = \frac{\text{10rpm (Input Speed)}}{\text{0.2 (Gear Ratio)}} = \underline{\underline{\text{50rpm}}}$$

*When calculating a gear ratio on a gear train, the idler gear is ignored as it has no influence on the output speed, only the direction of rotation.

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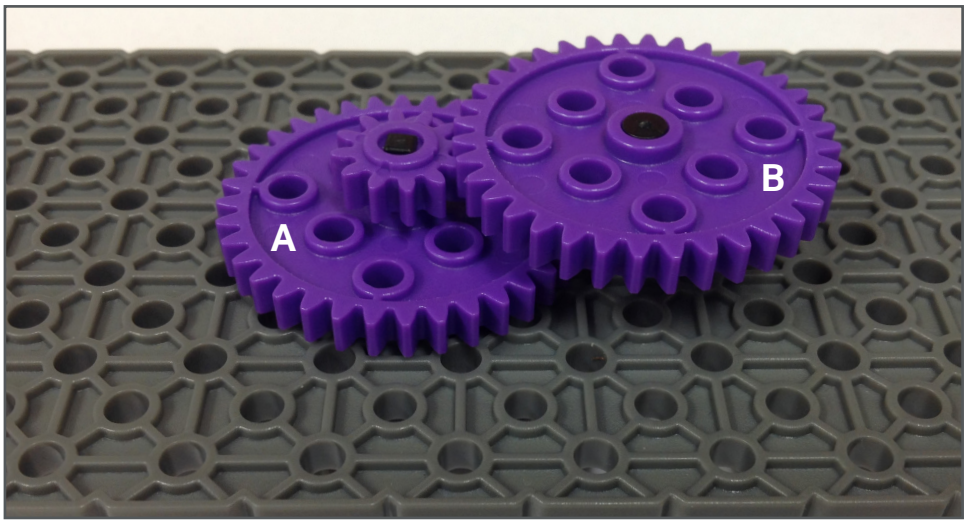
Compound Gear Train

Compound gear trains are great if you need to transfer motion in a tight space. They are often found where space is at a premium and an engineer has been tasked with transferring motion from one shaft to another in a relatively small area.

Practical Task

You will need:

1 x 6x12 Plate
2 x Axles
1 x Spacer
2 x 36 Tooth Spur Gear
1 x 12 Tooth Spur Gear



Questions

1. *If you turn compound gear (A) through 5 revolutions, how many revolutions will gear (B) complete?*

$$\text{Gear Ratio} = \frac{36 \text{ teeth on the driven gear}}{12 \text{ teeth on the driver gear}} = \frac{36}{12} = 3$$

$$\text{Gear B Revs} = \frac{5 \text{ (Input)}}{3 \text{ (Gear Ratio)}} = 1.67 \text{ revolutions}$$

2. *What is the advantage of a compound gear train over a standard gear train?*

A compound gear train is space efficient and allows an engineer to create a complex gear train with multiple outputs in a relatively small space. If the same outcome were to produced using a standard gear train then it would span a greater distance.

3. *Where do you think you would find this type of gear mechanism and why?*

You would find this type of mechanism as part of the timing movement inside an analogue wrist watch. This type of mechanism would be found here because space is limited but multiple output shafts rotating at specific speeds are required. I.e. the second, minute and hour hands.

Other uses: Ship drive systems, clocks, power transfer units, lathes etc.

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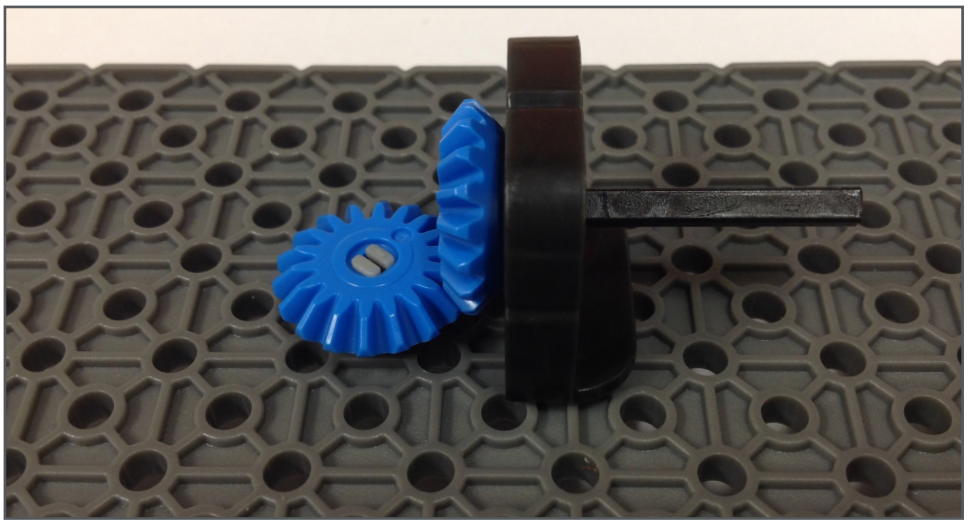
Bevel Gears

Bevel gears have a cone shape which enables them to mesh at various angles except 0 and 180 degrees, that is not to say a single bevel gear can work at multiple angles, the bevel gears must be cut to suit a specific meshing angle. The teeth of a bevel gear can be straight cut, similar to those of a spur gear, or they can be curved along their length with each tooth at an angle (spiral/helical bevel gear).

Practical Task

You will need:

1 x 6x12 Plate
1 x Axle
1 x Idler Pin
1 x 2x2 Corner Connector
2 x Bevel Gears



Questions

1. *In this configuration, what have the bevel gears allowed you to do?*

   In this configuration the bevel gears have allowed me to transfer the plane of rotation through 90 degrees. In other words the mechanism has been able to turn around a corner.

2. *What do you notice about the angle of the teeth on the bevel gears?*

   The teeth are cut at a 45 degree angle. This allows the bevel gears to connect and mesh with each other at 90 degrees.

3. *Where do you think you would find this type of gear and why?*

   Bevel gears are used as the main mechanism for a hand drill. As the handle of the drill is turned in a vertical direction, the bevel gears change the rotation of the chuck to a horizontal rotation.

   Other uses: Drive shafts, differential gear boxes and many more...

Mechanisms - A Practical Approach

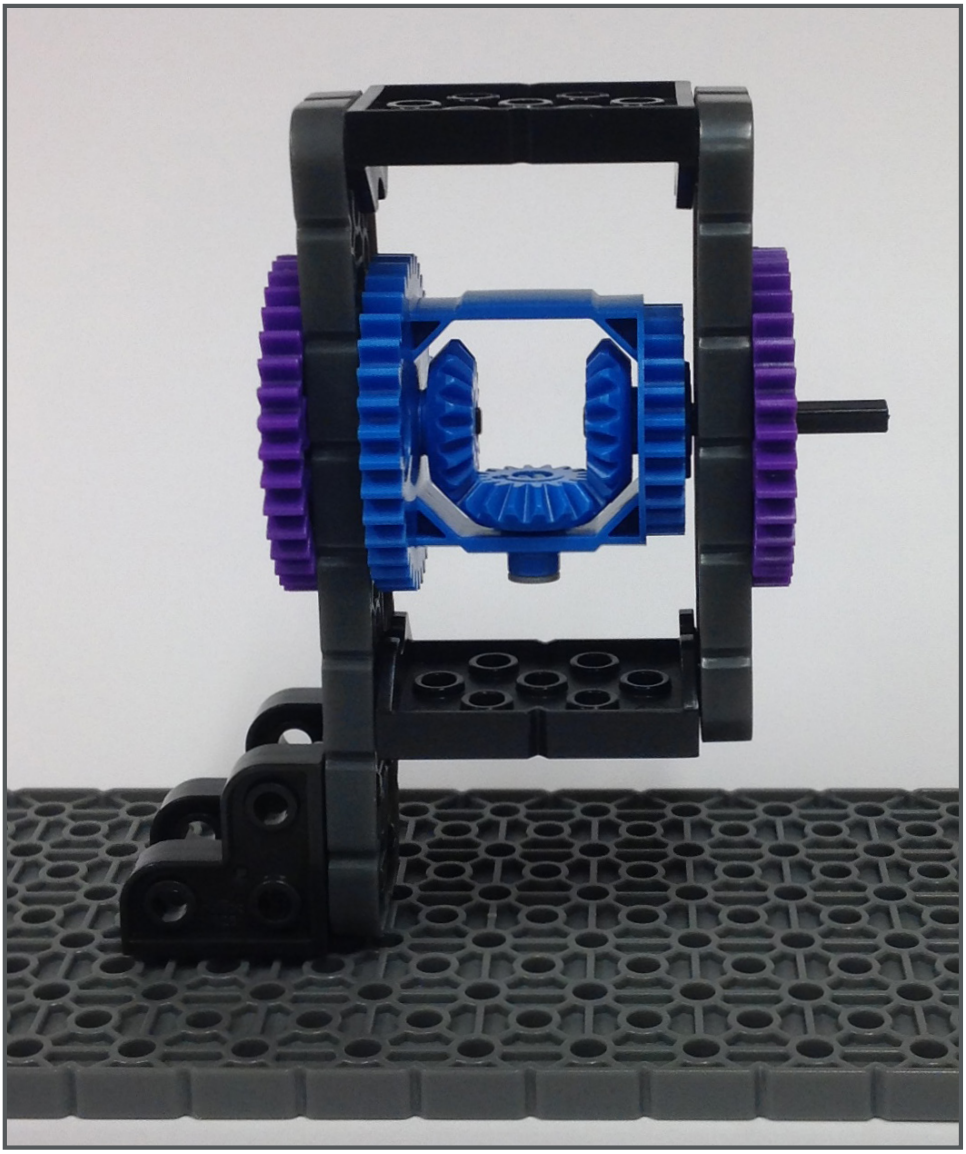
Differential Gears

Try building and experimenting with the differential gearbox shown below. All of the parts you need can be found in the kit.

Practical Task

You will need:

1 x 6x12 Plate
1 x 8x2 Beam
1 x 6x2 Beam
2 x Double 2x2 Offset Connectors
2 x Axles
1 x Idler Pin
2 x 1x2 Corner Connector
3 x Bevel Gears
1 x Differential Gear
2 x 36 Tooth Spur Gear



Questions

1. *If you turn the differential gear what happens?*

   Both of the spur gears turn in the same direction.

2. *What happens when you turn the differential gear but hold one outer spur gear?*

   The differential gear "engages" and rotates through the bevel gears. This allows the the other outer spur gear to continue rotating.

3. *Where might you find this system?*

   As part of a car's axle system, as the wheels will need to turn at different speeds when cornering. Otherwise excessive wear would occur on the tyres.

Mechanisms - A Practical Approach

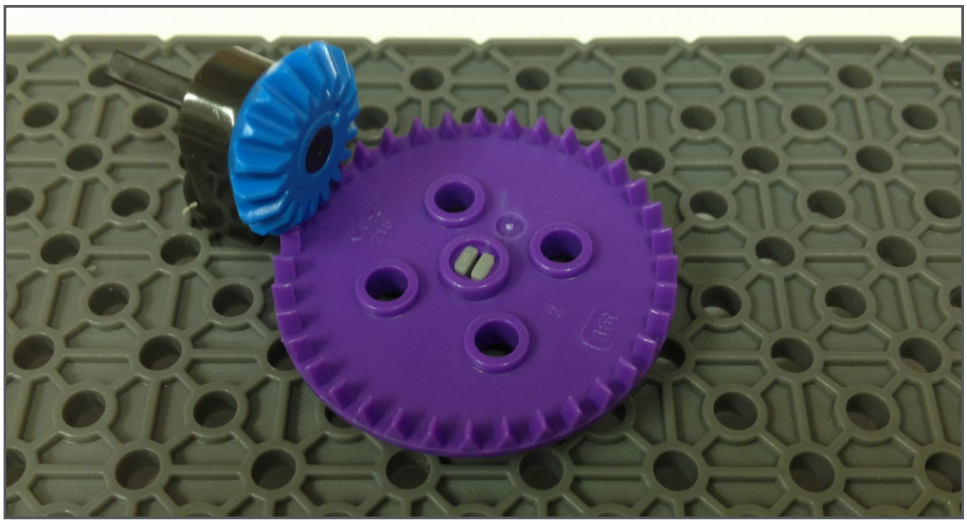
Crown Gears

Crown gears are a form of bevel gear, the teeth of crown gears project at right angles to the plane of the wheel. Crown gears are usually meshed with another bevel gear, but in some instances are meshed with spur gears.

Practical Task

You will need:

1 x 6x12 Plate
1 x Axle
1 x Idler Pin
1 x 1x1 Corner Connector
1 x Bevel Gear
1 x Crown Gear
1 x 12 Tooth Spur Gear



Questions

1. *What are the main differences between crown and bevel gears?*

   The teeth on a crown gear are angled at 90 degrees to the wheel surface so they point upwards. A bevel gear has teeth cut at an angle to the surface, usually 45 degrees. The teeth on a crown gear are very similar to the teeth on a spur gear.

2. *Replace the bevel gear with the 12 tooth spur gear, what do you notice?*

   The teeth on the 12 tooth spur gear mesh more efficiently with the teeth of the crown gear than the angled teeth of the bevel gear.

3. *Where do you think you would find this type of gear and why?*

   Roller coaster cars run on rails when they are right-side-up, but in order to safely spin a roller coaster car, a four-track system is used. The car's bottom wheels continue to run on the roller coaster's rails but a crown and pinion gear system is used for spin control. As the car tilts into a spin, the crown wheels on the side of the car connect with the pinion running on that part of the roller coaster to direct and control the spin.

Mechanisms - A Practical Approach

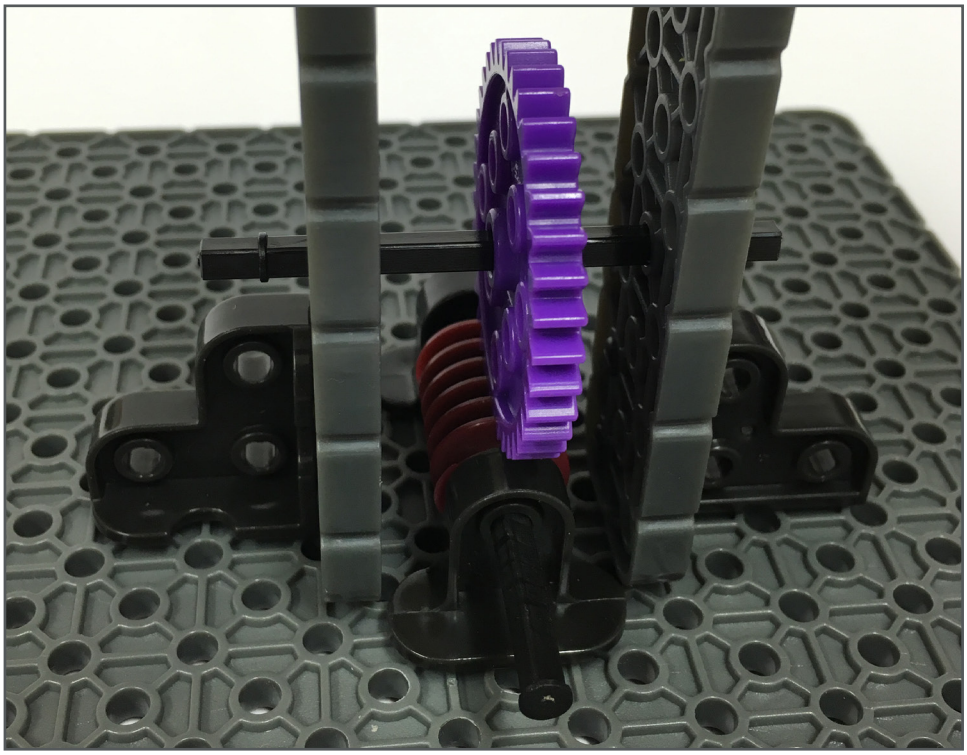
Worm Gears

The worm resembles the thread of a screw and is usually meshed with a worm wheel or a typical spur gear. Worm gears are an excellent way to increase torque output whilst reducing rotational speed. Worm drives have ratios varying from around 10:1 to 500:1. Worm gears do have a slight disadvantage in that they are not very efficient, a lot of energy can be wasted due to the sliding action of the gear teeth. The worm itself can have 1 or more teeth, although 1 tooth that follows around the length of the worm several times can often look like more than one tooth is present. A worm with one tooth is called a single thread or single start, while a worm with more than one tooth is called a multiple thread or multiple start.

Practical Task

You will need:

1 x 12x12 Plate
1 x 2x8 Beam
1 x 2x6 Beam
2 x Long Axles
2 x 1x1 Offset connector
2 x 2x2 Corner Connector
1 x Worm Gear
1 x 36 Tooth Spur Gear



Questions

1. *Turn the axle of the worm gear. What do you notice about the speed and direction of the spur gear?*
   The spur gear turns very slowly. The direction of rotation follows the direction in which the worm wheel is appearing to "thread".

2. *What happens when you turn the spur gear onto the worm gear and why does this happen?*
   The mechanism jams and ceases to move. This due to the angle of the teeth on the worm wheel which wrap around the surface much like a screw thread.

3. *Where do you think you would find this type of gear and why?*
   Worm gears can often be found in the machinery of common elevators/lifts because of their compact size and non-reversible properties. As the gear/load cannot transmit motion back through the worm/hoist, using this type of gear can act as a secondary braking system. This means the load cannot free fall and load speed is easily regulated.

Mechanisms - A Practical Approach

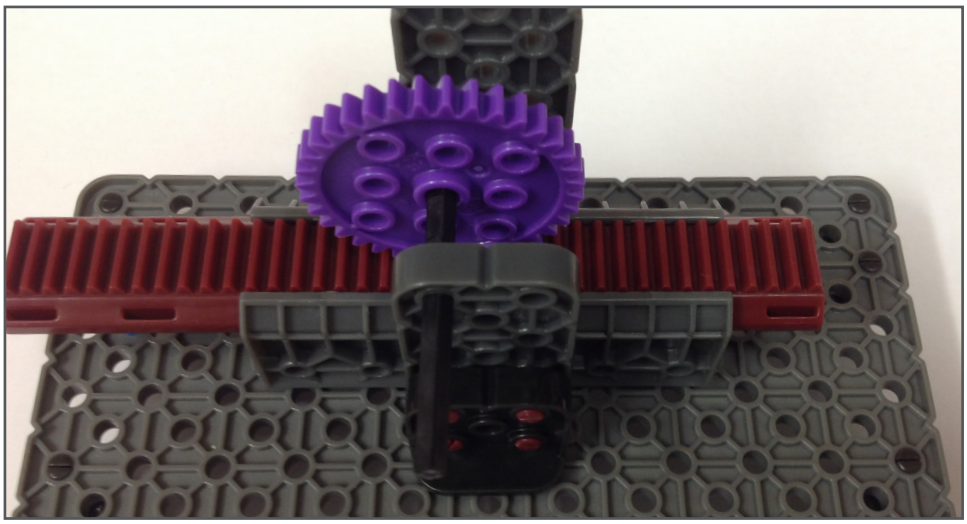
Rack & Pinion

A rack and pinion is a type of linear actuator that utilises a pair of gears which convert rotational motion into linear motion. A circular gear called "the pinion" engages teeth on a linear gear bar called "the rack". Rotational motion applied to the pinion causes the rack to move relative to the pinion, thereby translating the rotational motion of the pinion into linear motion.

Practical Task

You will need:

1 x 6x12 Plate
8 x 1x1 Connector Pins
1 x Axle
2 x Rack Guides
2 x 2x2 Corner Connector
2 x Rack Sections
1 x 2x4 Beam
1 x 2x6 Beam
1 x 36 Tooth Spur Gear



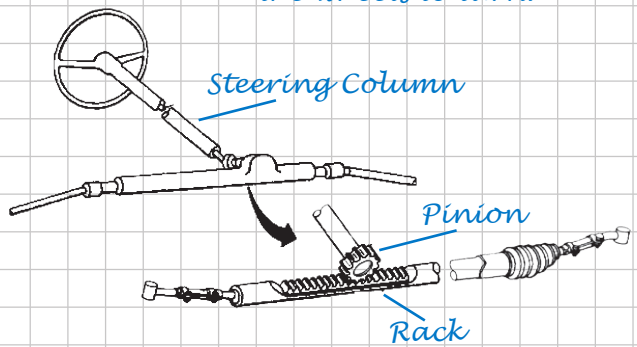
Questions

1. *How could this system be utilised on a traditional railway? Hint: think steep hills.*

To help a train climb a steep hill with a toothed rack rail between the running rails. The train would be fitted with one or more cog wheels or pinions that mesh with this rack rail. This allows the trains to operate on steep grades above around 7 to 10%, which is the maximum for friction-based rail. Most rack railways are mountain railways, although a few are transit railways or tramways built to overcome a steep gradient in an urban environment.

2. *Try to think of another application of the rack and pinion system and explain why it is useful for this application. Use sketches and diagrams to help to explain your answer.*

A rack and pinion mechanism would be found within the steering system of a car. When the driver turns the steering wheel a pinion is connected at the end of the steering column which meshes with a rack located on the front axle. This allows rotary motion to be converted into linear motion and move the steering axle left and right allowing the wheels to turn.



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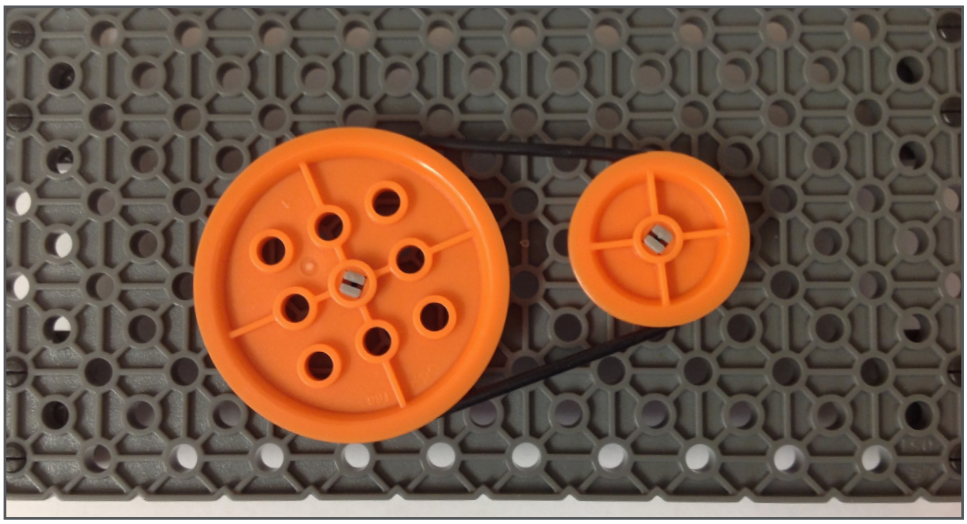
Belt & Pulley

Pulleys can be used to change the speed and direction of rotation, turning force or torque. A pulley system consists of two pulley wheels, each on a shaft and connected by a belt. The belt transmits rotary motion and force from the input or driver shaft, to the output or driven shaft. A belt is a loop of flexible material used to mechanically link two or more rotating shafts which are often parallel. Belts may be used as a source of motion, to transmit power efficiently, or to track relative movement. Belts are looped over pulleys and may have a twist between the pulleys, meaning that the shafts need not be parallel.

Practical Task

You will need:

1 x 6x12 Plate
2 x Idler Pins
1 x Ø45mm Pulley
1 x Ø25mm Pulley
1 x Large Belt



Questions

1. *What are the advantages of a pulley system compared to a gear train?*
   - *Belt drives are simple and economical when the distance between shafts is very large.*
   - *They don't require parallel shafts.*
   - *Noise and vibration are damped out.*
   - *Maintenance costs are lower.*
   - *Belt drives are highly efficient in use (up to 98%, usually 95%).*

2. *Try replacing the belt but this time create a twist it in the middle so that it creates a figure 8 between the two pulleys. What do you notice about the direction of rotation of the driven pulley compared to the driver?*

   The driven pulley rotates in the opposite direction to the driver pulley.

3. *What are the potential disadvantages of a belt and pulley system compared to other systems?*
   - *Under high tension the belt could snap and render the mechanism useless.*
   - *Regular lubrication and maintenance on the belt is required to avoid damage and maintain performance.*
   - *Unless a toothed belt is used a standard "smooth" belt may slip and reduced the efficiency of the system.*
   - *Friction can cause the belt to alter its properties such as changing shape or diameter which could impact the efficiency of the system.*

Mechanisms - A Practical Approach

Chain & Sprocket

A sprocket or sprocket-wheel is a profiled wheel with teeth, cogs, or even sprockets that mesh with a chain, track or other perforated or indented material. The name 'sprocket' applies generally to any wheel upon which radial projections engage a chain passing over it. It is distinguishable from a gear as sprockets are never meshed together directly. A sprocket differs from a pulley because sprockets have teeth and pulleys are smooth.

Practical Task

You will need:

1 x 6x12 Plate
2 x Axles
1 x 24 Tooth Sprocket
1 x 16 Tooth Sprocket
1 x Chain

Questions

1. *What are the advantages of a chain and sprocket system compared to the belt and pulley system?*
   - *Do not slip and so are more efficient than belt drives.*
   - *Operate effectively at high temperatures.*
   - *Do not deteriorate due to oil, grease, sunlight, or age.*
   - *Can withstand wet and abrasive conditions.*
   - *Are often easier to install than belt drives.*
2. *Where could you typically find this system and why is it used for that application?*

   You would typically find a chain drive on a bicycle. It will connect the pedal drive to the rear wheel. Different sprockets are usually stacked in a "cassette" on the rear axle allowing the rider to chage gear. A chain drive is used as it is relatively easy to maintain and can withstand varying conditions.

3. *What are the potential disadvantages of this system compared to other systems?*
   - *Regular maintenance required to ensure maximum efficiency.*
   - *Can be louder and less discrete than other systems such as a belt and pulley.*
   - *Require more precise alignment than belt drives.*
   - *Can cause vibrations which may adversly effect other systems.*
   - *Do not have the load capacity or service life of gear drives.*

Mechanisms - A Practical Approach

Universal Joint

A universal joint is a mechanical device that allows one or more rotating shafts to be linked together, allowing the transmission of torque and/or rotary motion. It also allows for transmission of power between two points that are not in line with each other. They come in a wide variety of shapes, sizes and configurations to accommodate the infinite amount of applications they can go into. It consists of a pair of hinges located close together, oriented at 90° to each other and connected by a cross shaft. The universal joint is not a constant-velocity joint.

Practical Task

You will need:

1 x 6x12 Plate
1 x 8x2 Beam
2 x 2x2 Corner Connector
8 x Connector Pins
1 x Idler Pin
1 x Ø45mm Pulley
1 x Ø25mm Pulley
1 x Large Belt
1 x 36 Tooth Spur Gear
2 x Axles
1 x Universal Joint

Questions

1. *Where do you think you would typically find the universal joint? Name as many uses as you can!*
   - *Driveshafts*
   - *Propeller shafts*
   - *Stone crushers*
   - *Centrifugal fans and pumps*
   - *Belt conveyors*
   - *Control mechanisms*
   - *Marine equipment*
   - *Mechanical Tools*

2. *What are the advantages of the universal joint?*
   - *It facilitates torque transmission between shafts which have angular misalignment.*
   - *Relatively cheap and cost effective.*
   - *It is simple to be assembled and dismantled.*
   - *Torque transmission efficiency is high.*
   - *The joint permits angular displacements.*

3. *What are the potential disadvantages of the universal joint?*
   - *Wear will occur if the joint is not properly lubricated.*
   - *Maintenance is often necessary to avoid wear.*
   - *The universal joint produces fluctuating motion.*

Mechanisms - A Practical Approach

Extension Task 1

Create a system capable of converting rotary motion through 90°. Your system must have a ratio of at least 1:4 from the first driver input to the final driven output and must span at least 100mm from input to output.

Parts List

I used:

Affix a picture of your system here.

My Solution

Use this space to explain your solution. Use sketches and diagrams to help explain your reasoning.

Mechanisms - A Practical Approach

Extension Task 2

Create a system capable of transmitting rotary motion to linear motion. Gear trains are not permitted and the linear motion should fully extend after one full rotation at the input.

Parts List

I used:

Affix a picture of your system here.

My Solution

Use this space to explain your solution. Use sketches and diagrams to help explain your reasoning.

Mechanisms - A Practical Approach

Extension Task 2

Create a continuous system combining as many different systems as possible. Demonstrate your understanding of the systems that you have learnt and how they can be combined to transfer motion.

Parts List

I used:

Affix a picture of your system here.

My Solution

Use this space to explain your solution. Use sketches and diagrams to help explain your reasoning.