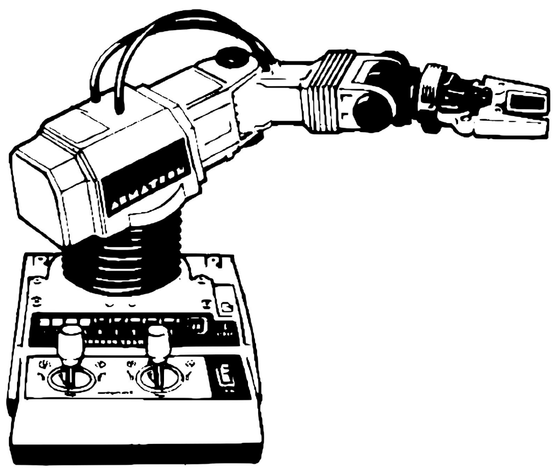


Reverse Engineering & Product Design

Armatron Robotic Arm

Galib F. Rahman | Zidi Chen | Anthony Holub | Aaron Chan
May 16 2017

Table of Contents

History & Technology of the Armatron

The Armatron is a robot toy that has an origin that goes way back to the 1980s. This toy was created by Tomy and sold by Radioshack. Tomy is a japanese entertainment company that create toys and games for young kids and even young adults with an engineering mind. Some games that the company Tomy has created are Atomic Pinball and Astro Shooter. The original Armatron was sold only at Radio Shack when it first came out. This crane-like toy is able to pick up small objects using multiple sized gears throughout the inside of the toy. Using two joysticks located on the bottom of the toy, the arm on the Armatron was able to move up, down, left, and right from the shoulder, left to right from its elbow, and up to down from its wrist. The gripper could be controlled to provide a stronger grip to the object it was holding.

On the base of the Armatron, the joystick was used to control the entire arm. While moving each stick left or right, it moved some part of the arm the same way. It also allowed some part of the arm to move up and down when the joystick is pushed either up or down. But when either joystick is turned left or right, it can either rotate the wrist joint or have the gripper open or close.

In the middle of the base was a power level indicator which is really just a countdown timer that time how long it would take for the Armatron to pick objects up and move them from one location to another. The Armatron required two D - cell batteries to operate, which were located on the bottom of the base, secured by screws. There was many screws that kept the entire toy together. There was four on the bottom securing the base to the rest of the toy, two around the shoulder that secured the arm, two on the elbow to secure the wrist, and two on the wrist to secure the rotating wrist joint and the gripper.

The gripper on the Armatron consists of two 4-bar linkages which are moved by 3 stage gear speed reducers. The input of the crank is equivalent to the output motion of the gear train and the worm wheel, while the output of the gripper is the extension of the 4-bar linkages' coupler.

The gears on the gripper are powered by gears turning through the whole toy when the joystick is triggered the correct way. The rotating gears makes its way up to the gripper, which turns the two gears on the twin 4-bar linkages. The rotation of the gears on the gripper allows the cranks on both sides to open and the close the gripper.

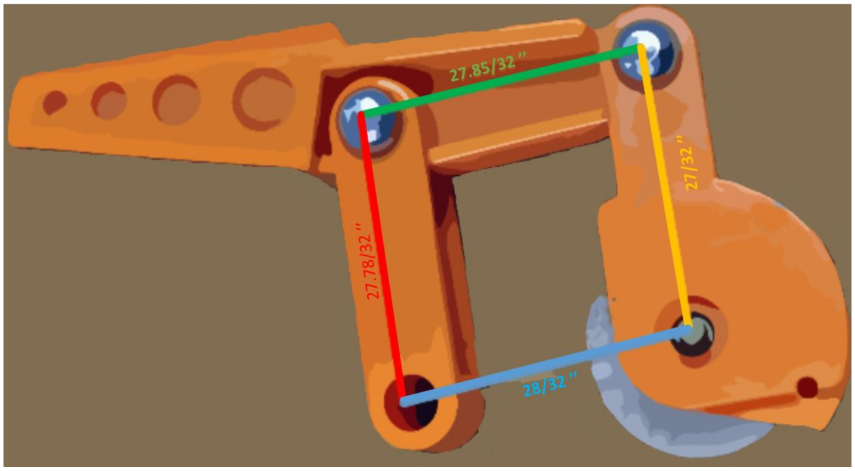
The original Armatron back in the 1980s came with a pack of objects that could be used by the toy to pick up. The objects were and flat module which consisted of a pair of cones and globes and also a closed module which consisted of more cones and globes that acted like a second location for the gripper to bring the objects to. The engineering of the Armatron was mostly mechanical because of the amount of gears that were needed to move the machine. The only non mechanical part of the toy was the motor, which was used to start up the gears on the base of the toy.

There were many versions and names of the toy throughout the years since it was first brought to the public. Some common names of the Armatron were Super Armatron, Tomy Robo I, and the Armatron II. These different versions remained approximately the same other than its design, its stickers, and its coloring.

Radio Shack ® Armatron™ Tomy ® ROBO I™ Tomy ® Armatron™

The Gripper

The Armatron gripper consists of two identical four bar linkages. A three-stage gear speed reducer outputs its angular velocity onto a worm wheel which drives the cranks of the four bar linkages. After disassembly of the gripper at the wrist joint, we collected data with respect to the length of the links of each four bar linkage and verified their identical lengths as well as the compatibility with Grashoff's Law. To do so we photographed the gripper and placed a ruler within the same image and superimposed lines from center-to-center of each link (digitally using MS Visio) and deduced the actual lengths by algebraic proportions comparing the length of 1 inch to the digital length of a line that extends from one edge of the ruler to the 1 inch marker on the photograph, (this is the conversion factor).

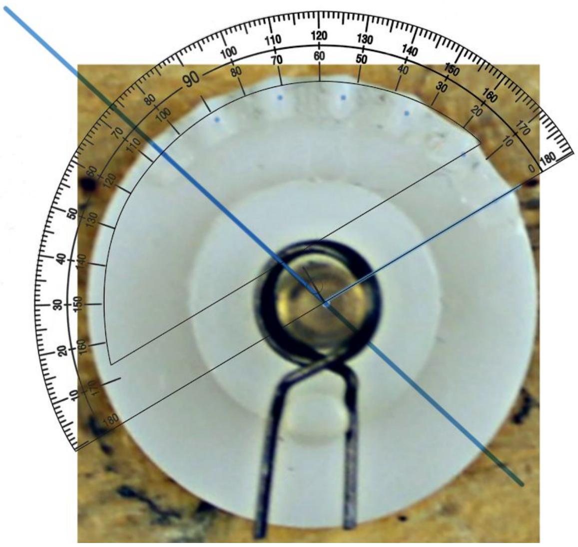


Given the software capability of providing information in regards to the length of lines, we imposed lines from the center of one link to another and used the digital length of the line and formed the following equation:

$$\frac{\text{Actual Length of Link}}{\text{Digital Length of Link}} = \frac{\text{1 inch}}{\text{Digital Length of 1 inch}}$$

After computation of the link lengths we observed that the four bar linkage was a crank rocker mechanism. We came to this conclusion by take the sum of the shortest link length, s, and the longest link length, l, and compared it to the sum of the other two lengths, ($p+q$). The value of $s+l$, was 1.719 inches and the value of $p+q$, was 1.738 inches. When the value of $s+l < p+q$, Grashoff's condition of a crank and rocker mechanism, is satisfied. After further investigation, we concluded that this categorization of the linkages used as a gripper was valid, due to the nature of its operation. The shortest link, operated as the input and rotated 360 degrees, influenced by a worm driving a sector worm wheel - whereas the coupler's extension acted as the grippers' output. The spring within the gripper enables the user to hold objects with various degrees of pressure and has a stable grasp with the upper and lower parts of the gripper facing parallel to one another. Attached to the gripper is a safety clutch, labeled **H4** according to the assembly diagram in page 4 of the laboratory manual. The purpose of the safety clutch is to protect the machine from potential damages to a system if operation exceeds normal parameters, such as excessive torque transmission.

In further investigation of the Armatron gripper, we observed the combination of the worm and sector worm wheel which served as an input to the four bar linkage. In reference to our knowledge of the worm and wormwheel, we know that the single rotation of a worm, leads only an advancement of one tooth of the worm wheel. By observation of the worm wheel attached to the gripper, one can classify it as sector gear. Thus, to calculate the theoretical number of teeth of said worm wheel one may measure the angle between the centers of the first and last tooth with respect to the center of the wheel using a protractor. After taking a photograph of the worm wheel, we superimposed a protractor (digitally using MS Visio) and extended lines connecting the center of the first and last gear teeth connected to the center of the wheel and measured the angle, θ, using a virtual protractor (as shown below).



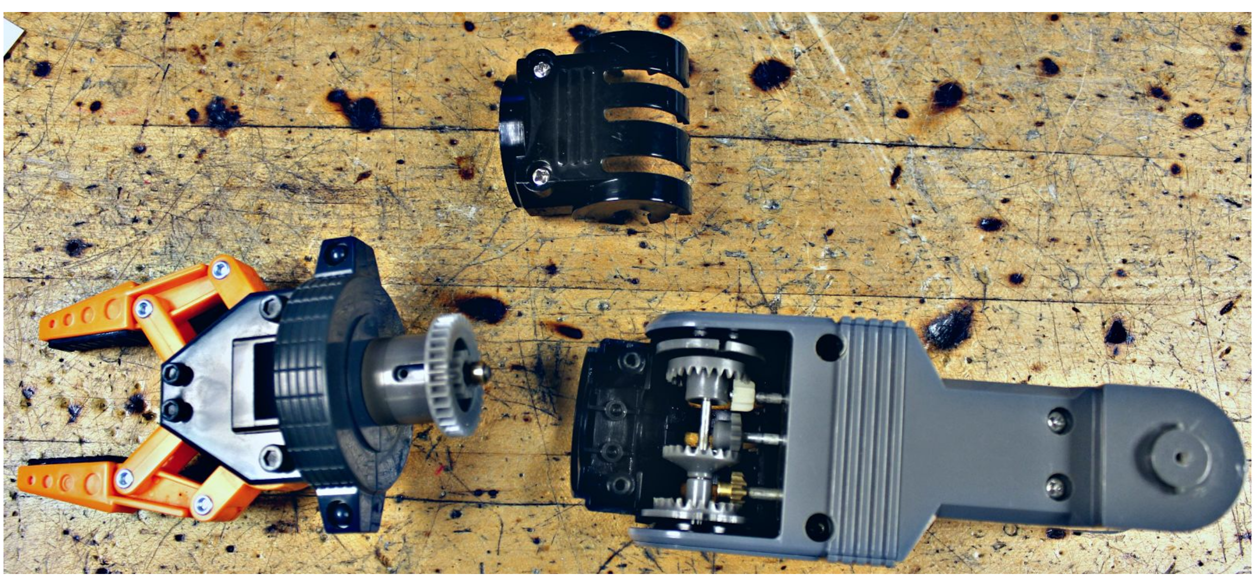
The value obtained for θ was approximately 106.5 degrees. By using ratio and proportion, we can create an equation and determine the number of teeth as follows:

$$\frac{\Theta\ \text{Degrees}}{360\ \text{Degrees}} = \frac{T_{\text{Sector}}}{T_{\text{Total}}}$$

$$\frac{106.5\ \text{Degrees}}{360\ \text{Degrees}} = \frac{6\ \text{Teeth}}{T_{\text{Total}}}$$

$$T_{\text{Total}} = \frac{6\ \text{Teeth}}{106.5/360} \cong 20.28 \approx 20\ \text{Teeth}$$

After determining the number of teeth that would be on the worm wheel, theoretically, if the worm was thought of as a gear with one tooth- the train value (TV_{Worm}) of the worm and worm wheel would be (1/20)=.05. The gripper operates with a gear train, classified as a three stage speed reducer (as shown below).



When calculating the train value of a given system, it indicates the magnitude of speed reduction, whereas the mechanical advantage reflects the ideal torque amplification. To determine the train value of the system, we will assume Gear A, to be the input and Gear F, be the output.Gears E and F are the worm and worm wheel, and the ratio of Gear E to Gear F has already been determined as .05 or (1/20). The number of gear teeth corresponding to their respective gears are shown below:

Gear	**A**	**B**	**C**	**D**	**E**	**F**
Number of Teeth	**12**	**20**	**8**	**18**	**1**	**20**

We determined the train value of the three stage speed reducer by taking the ratio of number gear teeth of the driver over the number of gear teeth of the gear driven and taking the product of the next stages' ratio of gear teeth until the last stage as follows:

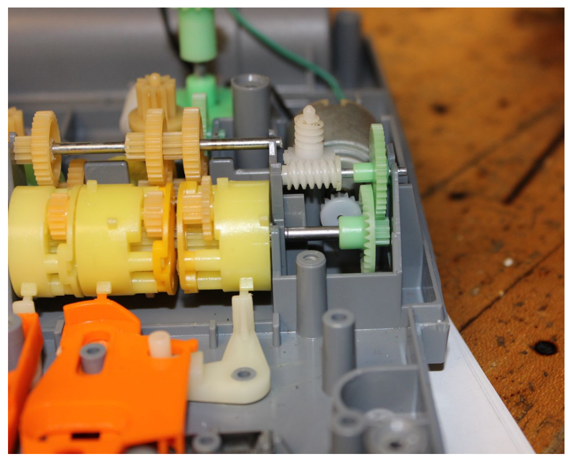
$$\mathrm{TV} = \frac{\text{Gear A}}{\text{Gear B}} \times \frac{\text{Gear C}}{\text{Gear D}} \times \frac{\text{Gear E}}{\text{Gear F}}$$

$$\mathrm{TV} = \frac{12}{20} \times \frac{8}{18} \times \frac{1}{20} = \frac{1}{75} \cong .013$$

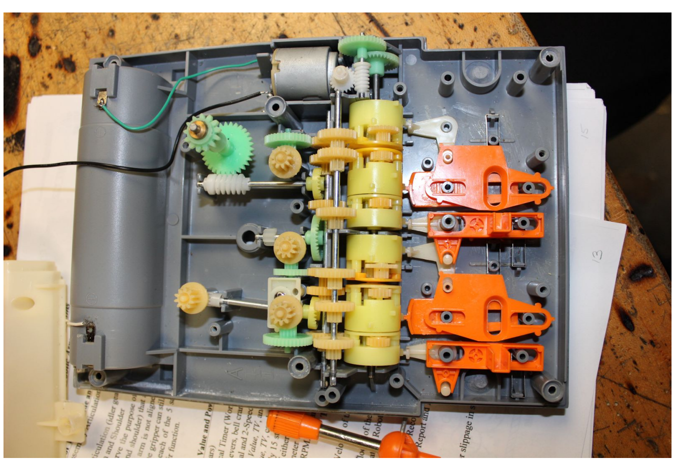
$$\mathrm{MA} = \frac{1}{\mathrm{TV}} = 75$$

By observation the gripper takes approximately, 8 seconds to close completely from a fully open position. Thus, the crank rotated a quarter of a revolution, throughout the duration. Therefore, the angular velocity of the gripper gear train is 1 revolution per 32 seconds or 1.875 revolutions per minute, which is approximately 2 revolutions per minute. The train value cannot only be deduced by the number of gear teeth, but also by the ratio of the output angular velocity to the input angular velocity (in other words, TV= ω_{out}/ω_{in}). Through algebraic manipulation one can determine the input angular velocity by dividing the angular velocity with the train value (TV). Given, the output angular velocity is 2 revolutions per minute and the train value, (1/75) the input angular velocity, ω_{in}, is (2RPM/(1/75)) 150 revolutions per minute, which transmits to Gear A of the gripper.

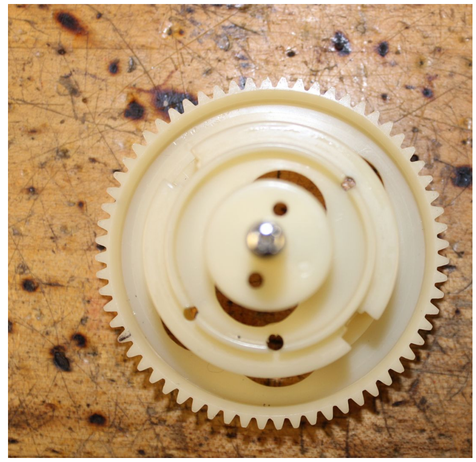
Gear Train & Arm

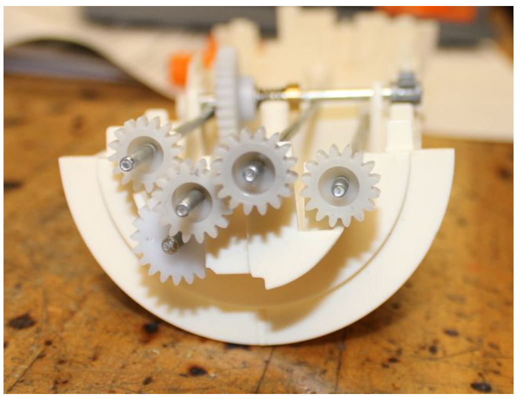


The gear train of the Armatron relies on a system of multiple planetary gears to move the arm. The first part of the system is at the base of the Armatron where the main motor is attached to the first planetary gear by a speed reducer and a worm wheel which connects the motor to the series of planetary gears that individually determine the motion of each part of the arm. From there the main controls of the Armatron connect to the first set of planetary gears. The controller



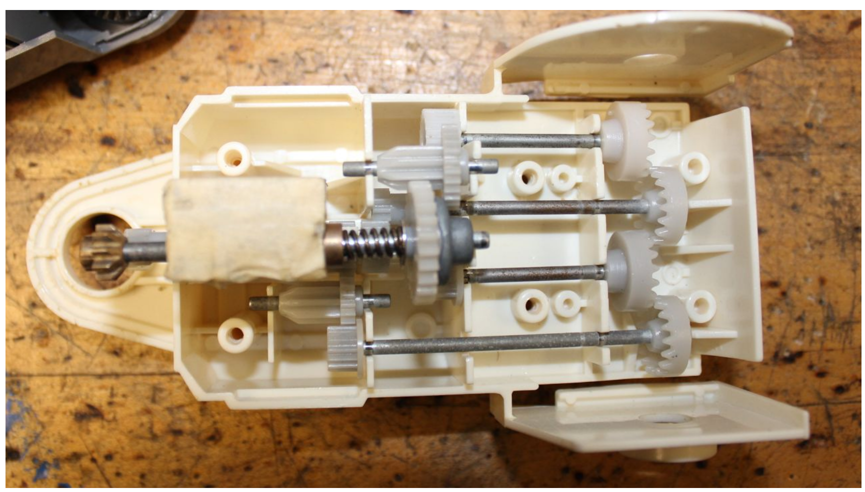
determines the direction of rotation of the gears by stopping the rotation of the outer portion of the planetary gear at certain points based on the position of the joystick. Each planetary gear connected to the controller has three positions that it can hold, with each providing a different direction of motion for the gears due to different gears meshing. The three positions are clockwise, counter-clockwise, and neutral. All of the planetary gears default to the neutral position when the joysticks are untouched. Each of the planetary gears connect to a series of gears that lead to a set of stacked ring gears that connect to the shoulder of the Armatron. These stacked ring gears each move one part of the arm, with the outermost ring gears rotating the arm and moving the shoulder.





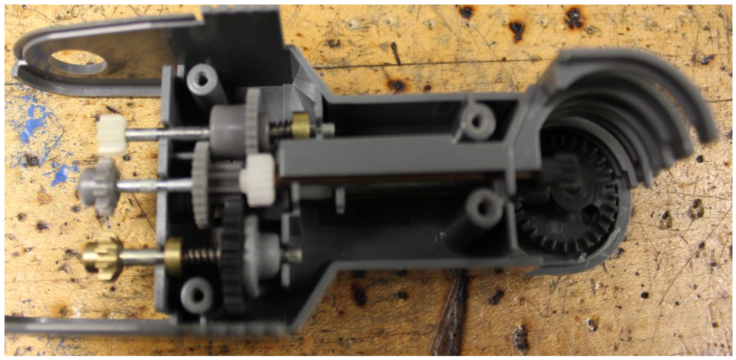
Shoulder

The shoulder of the Armatron is second largest part of the arm, containing all of the gears needed to move the rest of the arm. The base of the shoulder connects to the stacked ring gears in the base of the armatron, using small gears attached to crown gears at each joint of the arm. These gear to crown gear links allow for the armatron to disregard whatever angles the arm may be in and still work in proper condition. The shoulder itself can rotate 360° around the base in addition to

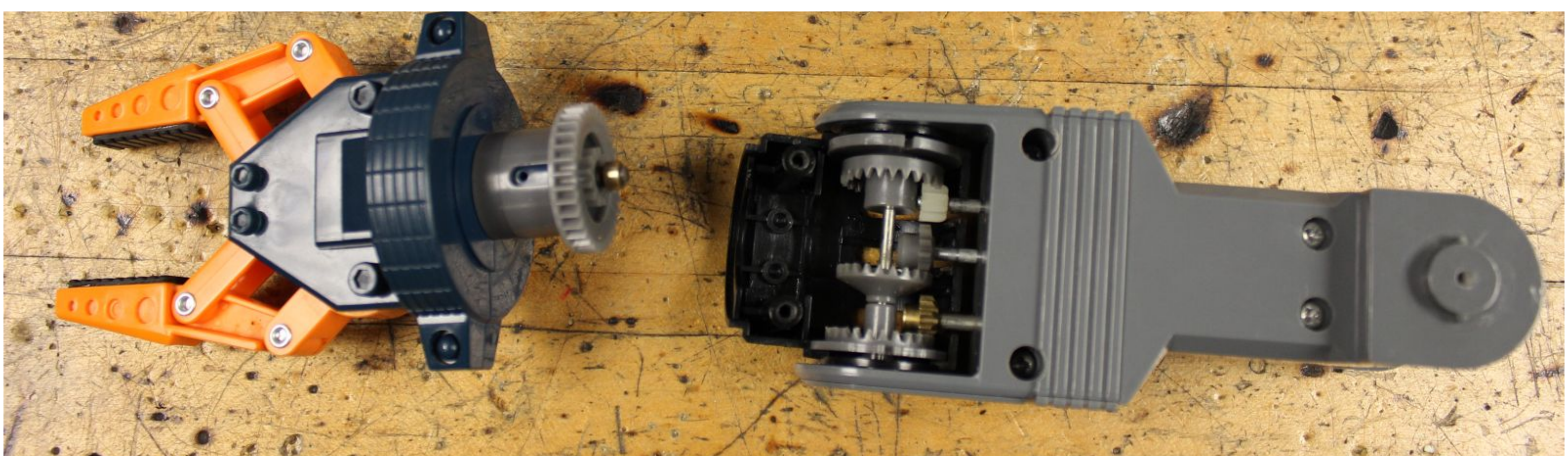


being able to move up and down. Within the shoulder there are multiple speed reducers and a coil spring clutch that connects to the elbow.

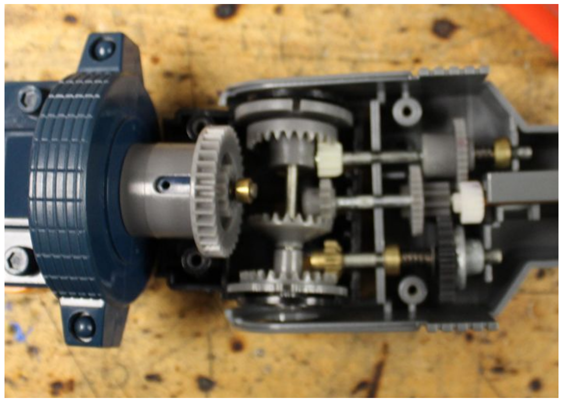
Elbow



The elbow of the armatron directly connects to the shoulder of the armatron. It only has the ability to rotate in two directions. Just like with the shoulder, the rotation of the elbow is based on a gear – crown gear connection. This connection is also used to maintain the gear ratio for the later parts of the arm by having the other crown gears in the joint to function as an idler gear for the connection to the wrist of the armatron.



Wrist



The wrist of the armatron is at the end of the elbow and connects directly to the gripper.

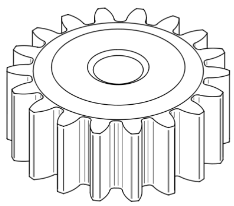
It contains both a joint and two internal gears, allowing for full rotation and angling in the wrist.

The second internal gear in the wrist connects to a worm gear in the gripper allowing for motion.

A final set of three crown gears are used for the joint movement and internal gear movement.

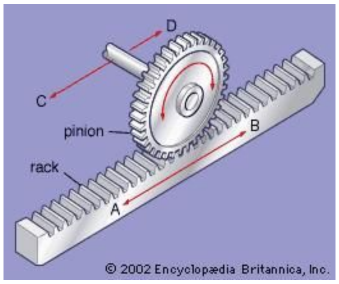
List of Gears

The Armatron is an robotic arm toy that was created by Radioshack in the United States during the 1980s. The toy was internal structure consist of a mashup of many gears. The gears are the reason the toy can move in a variety of ways with the joystick controls. The list of gears and its functions follow:

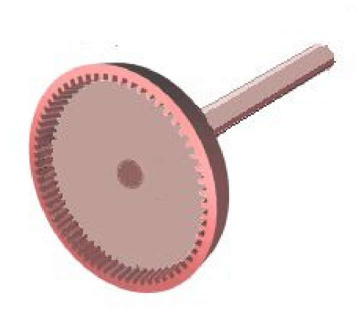


Spur: Spur gears are the simplest of all gears and are also known as straight cut gears. Spur gears are gears that have a cylinder or disk with teeth projecting radially. The teeth are not straight-sided, the edges of each tooth are straight and aligned parallel to the axis of each rotation. This type of gear only mesh correctly if fitted to a parallel shaft. Spur gears are great for moderate speeds, but tend to be noisy at fast speeds. These gears are used all over in the Armatron robotic arm wherever there is an parallel shaft.

Sector Gear: A sector gear is a gear with a disk that has a set of teeth at a small portion of its circumference. The remaining portion of the circumference has no teeth and is smoothed out. Spur gears are generally used when an appliance does not require 360 degrees of movement. Using spur gears can reduce weight and supply clearance. This type of gear is used in the Armatron gripper part of the toy. It used to grasp and ungrasp the prongs.

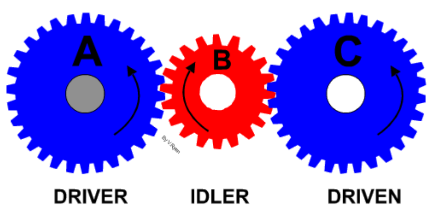


Rack and Pinion: A rack is an toothed bar or rod that can be thought of as a sector gear with an indefinite large radius of curvature. The pinion is the gear that is meshing with the rack. These gears together are meant for steering.



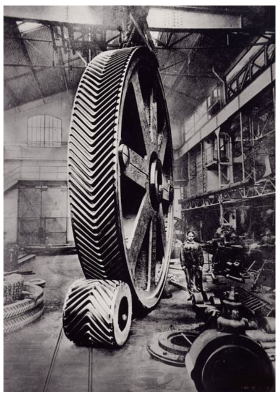
Internal Gear: Internal gear is a gear with tooth formed in the inside of the cylinder or disk. This gear does not cause output shaft direction reversal. This gear was used in the waist of the Armatron.

Idler: An idler gear is used to be inserted between two or more gear wheels. Inserting the idler gear will change the direction of rotation of the output shaft. Idler gears were used throughout the Armaton such as in the wrist, elbow, and base.



Helical: Helical gears are also known as dry-fixed gears. The teeth are set at an angle unlike spur gears. Helical gears can be meshed in parallel or cross. The angled teeth of this gear causes the gear to mesh more smoothly and quietly. These gears are meant for high speeds because of its low noise unlike the spur gears.

Herringbone: Herringbone gear is an special type of double-helical gear that meshes from side to side. The top view of an herringbone gear looks like a V, therefore many V's together form a herringbone pattern. This gear has advantages of transferring power smoothly because more than two teeth will mesh at any moment in time. This gears one half is balanced off by the other half unlike helical gears.



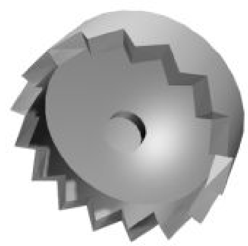
Bevel: Bevel gears are a circular cone with its tip cut off.

Miter: Miter gears are bevel gears with the equal number of teeth and have shaft axes at 90 degrees.

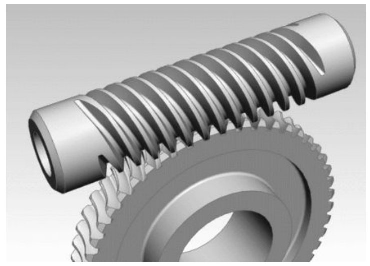
Spiral Bevel: Spiral bevel is a bevel gear with helical teeth. The main application of this gear is to control the direction of drive from the drive shaft at 90 degrees. The helical teeth of this gear produces less sound unlike spur gear teeth.

Face Gear: Face gear enables transmission of drive through an angle. They have been used in high precision and power appliances. These gears have high strength teeth and good contact geometry which can give high torque capability.

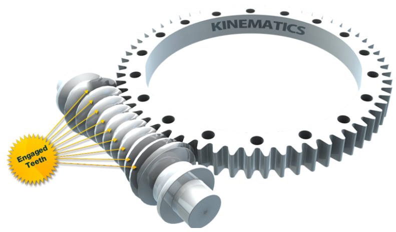
Crown Gear: This gear is also known as contrate gears and are a form of bevel gears where its teeth are at protruded right angles. The teeth are shaped like triangles which resembles the crown. This gear can mesh accurately with another bevel gear, but sometimes can be meshed with spur gears. Crown gears are usually found in mechanical clocks.



Worm and Worm Wheel: Worms resemble screws and when they are meshed with a worm wheel, it looks like a spur gear. Worm and worm wheel are meant for low speed and high torque. Disadvantages of this is the sliding action of the worm and worm wheel, which causes low efficiency. Worm and worm wheel are used in the gripper, wrist, and shoulder of the armatron toy.



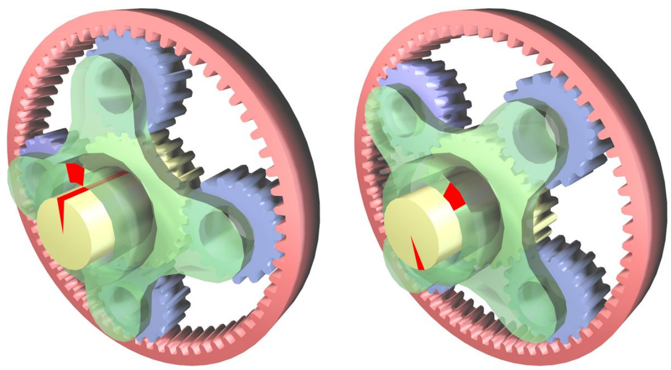
Hourglass Worm and Wheel: Hourglass worm has a few teeth on the middle of the worm with a diameter increase in its middle portion.



Planetary Gears:

Planetary gears, also known as, epicyclic gears are gears that contain one or more outer gear (planet gears), revolving around inner gears (sun gear). Usually, planet gears are placed on movable arms, such as the arm on the Armatron, which rotates according to the position of the sun gear. Planetary gears can either be simple or compound gears. When a planet gear has one sun gear, one ring, one set, and one planet gear, it can be classified as a simple gear. It is a classified as a compound gear when it either follows the structure of a meshed planet, which is when there are more than two planet gears that are in mesh which the individual planet train, a stepped planet, which is a shaft connection between two planet gears and its planet train value, or a multi-stage structure, there are more and two planet gears. Compound gears have more of an advantage over simple gears because of the bigger ratio reduction and torque to weight, and a more flexible configuration.

There can also be planetary gearing that contains a sun gear, a carrier, and two planet gears that are in mesh with each other. This happens when one planet gear meshes with the sun gear and the other planet gear meshes with the ring gear. When the carrier is stable, the ring gear turns the same direction of the sun gear which provides an opposing direction compared to the regular simple and compound planetary gears.



Conclusion

In this laboratory exercise we disassembled the Armatron in efforts to understand it innerworkings. Upon examination of each part within this mechanism, we observed the functionality of each mechanism within it and correlated it to our prior knowledge of the course's material in regards to the various gears, levers, and linkages. In other words, we reverse engineered this product, the Radio Shack Super Armatron, with great depth over the course of this experiment.