The Tennis Ball Machine
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Overview

Our device was set up to use conservation of energy in order to cause three different transfers of energy. The device is activated when the ball is released on the track at the top of the machine. The ball rolls down a series of opposite diagonal tracks until it reaches the bottom and hits a larger rubber band ball which falls off the track and into a cup. Because of the set up of the pulley system, when the extra weight from the rubber band ball is added to the cup it lowers and pulls up on the catapult which is preloaded under the tension of four powerful rubber bands. Once pulled upward, the elastic energy of the catapult is used to fire the tennis ball which is the final product of the project.

Project Design

In the organizational stages of the project our team met up and brain stormed to form a few initial ideas. Soon after, one team member was designated to venture and purchase materials to begin building. Once we began to build, we ran into quite a few problems, causing us to alter our design as we continued to build. The one thing that remained the same throughout our project is that the final outcome should be a catapult. When we first started we wanted to roll a hot wheels car down a track and have it knock a golf ball down a tube. This did not turn out because our track was not suitable for a hot wheels car and the golf ball would not fit down the pvc pipe. So we changed our plan and made the golf ball roll down the track getting rid of the pvc pipe altogether. We did run into the problem of the golf ball bouncing off the track as it switched from track to track, so in order to fix this problem, we tried altering the ramps in a number of different ways. The first way was to put some support under the track (reducing the coefficient of restitution) to stop it from bouncing and just have it hit and stop, this did not work because we put the block to close to the track and instead of the ball bouncing due to the spring of the track, the ball bounced because the coefficient of restitution was so high between the ball and the wood that we put under the track. We still had the problem of the ball bouncing out so we glued a piece of balsa wood to the track to act as a guard rail and keep the ball in, this of course worked and we continued with production. The next step was for the ball to fall into a cup which is attached to a pulley. The original idea was for the pulley to lift a weight which would release the catapult. This was not needed though because the rubber bands of the catapult when stretched were kept at a horizontal tension keeping them stuck in the loaded position. All that was needed to activate it was a strong enough pull to get the catapult going and the rubber bands would do the rest of the work.
Project Description

The machine starts in the top right of the picture with a golf ball rolling down the series of tracks. As the ball drops from track to track a piece of balsa wood glued to the back of the track is used to keep that ball from going too far off the track.

The golf ball is to initiate the pulley system. Although the mass of the golf ball, itself, is not sufficient to trigger the pulley system, the golf ball gains enough momentum to push a ball of larger mass into the cup, initiating the pulley system.

The pulley system is simply purposed to pull the hinged lever into a position in which the rubber bands may act on it. Initially, the rubber bands act only with a horizontal component, doing nothing more than placing the plywood lever in tension. The pulley lifts the lever upward allowing the rubber bands to act in the vertical plane as well as horizontally. As the catapult is initiated the potential energy in the system (the tension in the wood and rubber bands) is converted into kinetic energy, and the motion causing force increases as the plane of the lever changes.

A stop is put into place to restrict and control the motion of the catapult. Without a stop to restrict the system, the catapult would continue with the ball, carrying the ball 180 degrees and down into the table. This is because the speed of the system would be increasing past even 90 degrees, not releasing the ball from the system. The placement of the stop was fairly important with regard to trajectory of the ball after launch. Typically, the angle of release for optimum distance is 45 degrees from horizontal. In this case, this principle does not hold true given that the speed of the ball increases as it passes 45 degrees. The angle of release in this case is approximately 60 degrees.

Calculations

The calculation of the work done on the ball can be estimated by measuring the time from the release point of the ball, to its landing point (equal in height of the release point). With this figure, the equation \( s_i = s_f + v_0t + \frac{1}{2}at^2 \) may be used to calculate the initial vertical component of the velocity. The horizontal component of the velocity can be found by dividing the horizontal distance of travel by the time and the vector sum can be found of the two components. The work can be found by using the formula \( \frac{1}{2}mv^2 \).

A more accurate calculations of the work done on the ball during the launch would require an integral calculation \( \int_{24.5}^{20} kx \) (from the initial stretched length to the end length), subtracting the amount of work that acts on the wood (which causing tensile forces). A calculation neglecting the tension in the wood would be largely inaccurate, and a calculation including this would be far too complex for our level.
1st Energy Conversion: Ball rolling down series of tracks

\[ mgh = \frac{1}{2} mv^2 \]

\[ (32.2 \text{ ft/s}^2) \times (2 \text{ ft.}) = \frac{1}{2} v^2 \]

\[ v = 11.3 \frac{\text{ft}}{\text{s}} \]

2nd Energy Conversion: Cup falling pulling the catapult up

\[ mgh = \frac{1}{2} mv^2 \]

\[ (32.2 \frac{\text{ft}}{\text{s}^2}) \times (.25 \text{ ft.}) = \frac{1}{2} v^2 \]

\[ v = 4.01 \frac{\text{ft}}{\text{s}} \]

3rd Energy Conversion: Tennis ball being thrown using a catapult

\[ F = kx \]

\[ 2N = k (0.0762 \text{m}) \]

\[ k = 26.2 \frac{N}{m} = 1.80 \frac{\text{lbs}}{\text{ft}} \]

\[ \frac{1}{2} kx^2 = \frac{1}{2} mv^2 + mgh + \frac{1}{2} kx^2 \]

\[ .5 \left(1.80 \frac{\text{lbs}}{\text{ft}} \right) \times (1.46 \text{ ft})^2 = .5 \left(0.00397 \text{ slugs} \right) v^2 + (0.00397 \text{ slugs}) \times (32.2 \frac{\text{ft}}{\text{s}^2}) \times (1 \text{ ft}) + .5 \left(1.80 \frac{\text{lbs}}{\text{ft}} \right) (1.20 \text{ ft})^2 \]

\[ v = 15.9 \frac{\text{ft}}{\text{s}} \]
Bill of Materials

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheet of Plywood</td>
<td>$5.00</td>
</tr>
<tr>
<td>Tin Flashing</td>
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</tr>
<tr>
<td>Duct Tape</td>
<td>$0.25</td>
</tr>
<tr>
<td>Rubber Bands</td>
<td>$2.00</td>
</tr>
<tr>
<td>Dowel Rod</td>
<td>$2.00</td>
</tr>
<tr>
<td>Cups</td>
<td>$0.25</td>
</tr>
<tr>
<td>Hinge</td>
<td>$1.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$13.00</strong></td>
</tr>
</tbody>
</table>

Conclusion

At the end of the project, our device is functional and consistent. The consistency came from numerous tests and tweaking of the weight and other issues to make it reliable. We encountered a few problems consisting of limited materials, time, and differing schedules. We worked through these problems and created a successful device. We learned to work and think as a team and that everyone's input is crucial to the development of a process or device.