HOW ROLLER COASTERS WORK

Summer Bailey

Due APRIL 29th

Ever been on a roller coaster? Or even seen a roller coast? Some people love the thrill that a roller coaster can bring while others think differently. What makes a roller coaster so thrilling is the forces that are acting on you while you are on the ride. Roller coasters have been around for quite some time and the their components have became more and more complex. There are many different obstacles that you could encounter on a roller coaster such as hills, dips, twists, turns, loops and many other components that use these forces in difference ways.

Roller Coasters have been around since the 17th century where the Russians used ice sleds or ice blocks to sled down a hill. The Frenchmen took this idea into France where their seasons prevented them from having ice so they modified the ice sleds to be waxed sleds; eventually they added wheels. In 1817 in Russia, the first roller coaster where the train was attached to the tracks was invented then in the mid 1800s the first American roller coaster was built in Pennsylvania named Mauch Chunk Switchback Railway. Thrillers would pay one dollar to ride up the mountain then take a wild and bumpy ride down. For the next 30 years rides thrived, joined by wooden coasters and continued to grow and expand. There was around 2,000 roller coasters functioning in the 1920s. But roller coaster production declined during the Great Depression and World War II. In the 1970s-1980s tubular steel coasters were built instead of wooden coasters. Roller coaster then never changed their components that drove them.[2]

There are components to the roller coaster that are essential to the function of the roller coaster. These components include the train cars, the train track and the actual structure. The train cars can be of any length hooked on to one another; the track is where the train cars are hooked into and guided along the roller coaster; and the structure of the roller coaster is what supports the train cars, and track. The structure can either be wood or steal. Wood structure are not flexible are used mostly for roller coasters that include ups, downs and turns. Steal structures are more flexible withstanding the force of the roller coaster having twists and loops with ups, downs and turns.[3] All of the these components are just features, what really powers the roller coaster is simply physics.

Roller coasters are really just energy transformation.[3] At the beginning of each roller coaster, the coasters are hauled up a tall hill by a motor. Once at the top of the hill, the coaster has all potential energy and the motor is no longer acting upon the coaster. Potential energy is the energy of vertical position, which is dependent on the mass of the object and the height of the object. The coaster is then pulled down the hill where for the rest of the ride, the coaster converts from potential energy to kinetic energy. Kinetic energy is the energy of motion where it is dependent on mass of the object and the speed of the object. During the ride the potential and kinetic energy must be equal to total the total mechanical energy of the coaster.[1] So at the beginning of ride at the top of the highest hill, the coaster has the maximum potential energy and minimal kinetic energy. As the coaster rushes down the hill, it is losing height but gaining speed so the potential energy is decreasing and the kinetic energy increasing. All the way through the ride, the coaster is experiencing continually changing energy from potential to kinetic then back again where gravity is the only force acting upon the coaster.[2] Once the coaster comes to a stop by gravity, potential and kinetic energy are zero since the coast is at ground level and it is not moving. External forces are acting on your body as you ride the roller coaster.

During a roller coaster ride here are forces acting on both the coaster and yourself. Such as, when the roller coaster is speeding up, you feel as though are being pushed back into your seat but actually it is the seat pushing against you. Acceleration and gravity are two forces that are acting on your body as you ride the roller coaster. Acceleration force feels the exact same as the force of gravity, which is measures in g- force. 1 g force is equal to the acceleration due to gravity.[1] The centrifugal force is the feeling of being squashed in your seat. These forces especially act upon you when you encounter a loop in a roller coaster.

When you see a loop in a roller coaster, they are never circular. But why is that? Lets consider a circular loop in a roller coast. When going through the loop, the coaster becomes inverted; you might think that the coaster could fall off the tracks but in reality it doesnt. Firstly, the coaster is connected to the tracks for safety reasons but also a force is acting upon the coaster. The centripetal force is the force pushing the coaster towards the center of the loop while the coaster wants to travel in a straight line by acceleration. The centripetal force can be represented by the equation of ac=$\frac{v^2}{r}$ or ac=$\frac{2g\Delta h}{r}$.[3] At the top of the curve, the centripetal force is provided entirely by gravity since Δh=$\frac{r}{2}$ where you feel weightless. This force is equal to 1g. At the 9 oclock position, Δh=r, since it is double at the top position. This results in an additional +2g force. At the bottom of the loop, Δh=$\frac{2r}{2}$ which is an additional +2g of force with total g force of +4g from the top. This totals to +5g but the force of gravity acting of the body results in an addition g force where the total is 6g.[2] A trained fight pilot would eventually black out at this high of a g force. So the average person would eventually black out too but, even so, this ride would not be so comfortable and fun. This is a major problem with the circular loop in a roller coaster. The two problems that we face with a circular loop are the g force the body is exposed to and the very rapid onset of acceleration going into the loop.[2]

To change these problems, lets consider altering the radius of curvature of the loop. The centripetal force, as we know, is $\frac{v^2}{r}$, so as the velocity decreases, we can decrease the radius to keep the acceleration constant. To start, we can obtain this loop shape by bolting together two circular tracks. By doing this, we are looking at the loop that overlaps the two circular tracks. The top of the loop is created by the circle, where the radius is the circle within the overlapping part of the two circular tracks. This allows the loop to have a tight radius at the top where the speed is low and a large radius at the bottom where is the speed is high. This is great improvement but we still encounter the sudden acceleration at the bottom and where the radius changes in the loop. By modifying the radius of the curve smoothly we can solve this problem. By squishing in the sides of the loop I just described, we can obtain this curve of a constant changing radius. This type of loop is called the Clothoid loop. The clothoid loop provides a constant centripetal acceleration but there is not a constant g force because of gravity. The radius of the track at any point can be defined by R=$\frac{v^2-2gh}{a-gcos}$, where v is the speed going into the loop, h is the height from the bottom of the loop, a is the acceleration, g is the gravity and is the angle position around the loop the track is.[2] This equation shows us that the velocity and radius are at a minimum at the top of the loop and high at the bottom of the loop. By solving for a in the equation, we can obtain the clothoid equation for ac; a=$\frac{v^2-2gh}{R}$+gcos. We can see that at the bottom of the hill essentially a=$\frac{v^2-2g*0}{R}$+g=$\frac{v^2}{R}$+g and at the top of the hill a=$\frac{v^2-2g(R+Rmax)}{R}$-g. The equation for the bottom of the loop is not quite exact since we are assuming that the loop crosses at ground level, which it does not, there is a distance from where you enter the loop to where the tracks line up to each other. This can cause a variation when calculating the g force at the bottom of the loop. In a clothoid loop ac is constant so that means that the g load at the top of the loop is ac-g and the g load of the bottom is ac+g.

Roller coasters do not have any restriction on their g load but many states are considering implementing a regulation for g load on roller coaster rides. To put these equations in action, lets consider the roller coaster Shockwave, which is located at Six Flags Great America. Shockwave is most known for its clothoid loop, which is 25 meters high loop with a radius from the bottom of 19m.[4] Six Flags advertises that the force at the bottom of the loop is 4g. By using the equation from above and the centripetal force equation, we know $\frac{v^2}{R}$=$\frac{2g\Delta h}{R}$, where Δh at the bottom of the loop is 2r and the radius R at the bottom is 19. By plugging these into the equation we get, a=$\frac{2g*2*19}{19}$+g = 5g. Does that mean that Six flags is advertising wrong? No, above we assumed that the loop crosses at ground level, which it does not, there is a distance from where you enter the loop to where the tracks line up. So actually we would subtract off a g force that would produce the accurate g force for the Shockwave loop at Six Flags.

Forces that are acting on your body are what make a roller coaster what it is. Roller coaster are very dynamic and diverse with forces that act upon you when you go flying into a loop. Many components go into designing a roller coaster from the materials that you use, to the physics of the loop to ensure that the passengers have a thrilling but safe ride.

Bibliography

[1] Pendrill, A. *Student investigation of the forces in a roller coaster loop.* European Journal of Physics, 34. 2013.

[2] Berry, Nick. *Why Roller Coaster Loops are Never Circular.* Gizmodo. http://gizmodo.com/why-roller-coaster-loops-are-never-circular-1549063718.

[3] The Physics Classroom. *Energy Transformation on a Roller Coaster.* Multimedia Studios. 2010. http://www.physicsclassroom.com/mmedia/energy/ce.cfm.

[4] Brey, Ken. *Geek Challenge: Constant G Force Coaster Loops.* DMC. 2010.https://www.dmcinfo.com/latest-thinking/blog/id/228/geek-challenge-constant-g-force-coaster-loops