How Roller Coasters Work

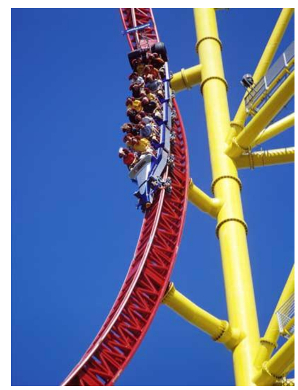
Introduction

The origin of roller coasters can be traced to seventeenth century Russia when people manually lifted sleds to the top of steep ice slides and enjoyed a fast descent into a stopping area filled with sand. A Frenchman later brought this idea to France adding a waxed wooden track for a cart to follow.

While modern roller coasters are very different from their simple predecessors, understanding the evolution of the roller coaster aids us in scientifically analyzing the operational features of roller coasters. These features include the initial lift to gain gravity toward potential energy, kinetic energy and the eventual use of friction to slow the cart. After investigating the basics of the roller coaster, developers pushed the limits of physics using steel construction, loops and magnetic brakes to create a safe, efficient and extremely exciting ride.

Potential Energy and Gravity

A roller coaster gains potential energy when a lift brings it to the top of the first hill. Potential energy is also known as stored energy. A vehicle at the top of the track contains the most potential energy that it will have throughout the ride, if the height of the track was increased then the amount of potential energy is increased even more. “The lift motor of a roller coaster exerts energy to lift the train to the top of the lift hill, energy that will eventually become kinetic energy when the train drops. Lifting the train higher gives it more potential energy,” (Sandborg). Gravity is the reason there is potential energy, because gravity will pull the cart down from the top of the hill.



Gravity is pulling down the Top Thrill Dragster at Cedar Point.

The primary force that keeps roller coasters running throughout the ride without the use of engines is gravity, which creates a gravitational pull on the vehicle. Gravity takes place during the entire coaster, even before it begins. As the coaster goes down the first hill, it gains the momentum that it should use throughout the entire ride. Gravity is the force that makes roller coasters start a descent and speed up while descending, and then gravity slows the coaster while it ascends up a hill. If there is no gravity, then roller coasters would operate entirely on man-made machines such as the chains that lift the roller coaster. When the vehicle starts it descent down the first hill potential energy leaves the vehicle and becomes kinetic energy.

Kinetic Energy

$$K = \frac{1}{2}mv^2$$

Formula for kinetic energy.

"Gravity provides the energy source for a roller coaster," (Bloomfield). Kinetic energy is the energy of motion. When a roller coaster starts its descent down the first slope, the kinetic energy starts to increase. The faster the roller coaster is going the more kinetic energy it contains, and is equal to one half the mass times the velocity squared. Kinetic energy reaches its peak when it is at the bottom of the highest hill because that is the time the roller coaster is going the fastest. A roller coaster slows down when it ascends hills causing the kinetic energy to be changed back to potential energy.

Velocity

$$\text{velocity} = \frac{\text{distance}}{\text{time}}$$

Formula for velocity

Velocity is the speed of an object going in a certain direction, unlike the thoughts of many people that get it mistaken for just the speed. Even if the roller coaster does not change speed during a turn or loop the velocity of the roller coaster is always changing. Velocity increases in the same way as kinetic energy, whenever the vehicle's speed increases the velocity does as well. To find out the velocity of an object divide the distance traveled by an object by the time.

Inertia

Inertia is the tendency that all objects continue on their path of movement unless another force acts upon the object. If an object is moving then it will continue moving and if an object is staying still then it will continue to stay still. If another object touches it then it will change the inertia of the object. The larger an item is the more inertia it contains. This law affects roller coasters greatly, because there are many forces, energies, and other normal objects that people think little of, such as air, that can change roller coasters to make the roller coaster more complicated to work efficiently. "Inertia is what keeps the roller coaster moving when the track is level or uphill," (Bloomfield). The original problem that the French had was the sleds inertia leading the sled off the slide and to overcome this problem they added tracks, which allowed the sleds to follow the designated path, and not have accidents.

Tracks

The two main types of roller coaster tracks are wood and steel. The tracks and wheels of a wooden roller coaster have many similarities to that of a train. The wheels contain a wide lip, so the cart does not come off the side of a track. The tracks are held up by wooden cross ties and diagonal support beams, which are similar to that of a house. Wooden tracks are not that flexible, which makes it hard to create twists and turns that are complex. For this reason the main thrill in wooden coasters are the hills and speed.

Most modern tracks are steel consisting of steel tubes that control the directions and facing of the cart beams that are generally larger then the two steel tubes that the coaster runs on. To keep the cart attached to the track the wheels usually run under and on the sides of the track. The track is capable of running above the coaster, and has the cart suspending from the track, instead of being below the cart and riding on the track. While the smoothness is popular with riders, it also provides a significant reduction in friction.

Friction

Between the cart and the track it creates friction which slows the coaster down considerably. Throughout the ride not all of the energy of the roller coaster is conserved. The main reason for this is friction because friction causes significant energy leaks. Friction causes the most energy leaks because it is a nonconservative force; these are forces that are capable of causing change in total mechanical energy. There is friction between the cart and the air and the cart and its tracks. It is most noticeable between the cart and its tracks at the ending when there are breaks that quickly slow down the cart near the end of the track. In addition to causing energy leaks; friction also creates thermal heat and makes noise.

Slowing/Braking

Brakes stop a steel roller coaster using friction.

The brakes on a roller coaster are not even on the cart itself, but instead they exist on the tracks. The portion of the track that contains the brake is the brake run. Not all brakes on roller coasters are meant to completely halt a roller coaster, but instead only to adjust the speed of the coaster. Other brakes act as virtual barriers between different sections of the roller coaster. The three main types of brakes are skid, fin, and magnetic brakes. Skid brakes have a long piece of material under the track that raises and utilizes friction to slow and eventually stop the cart. Skid brakes are generally not used in modern roller coasters. Fin breaks use two boxes as a squeezing mechanism that squeezes the wheels of the cart to slow it down and come to a stop. Magnetic brakes are relatively new and do not use friction to stop roller coasters because friction can differ depending on the weather and if it is raining or not. Magnetic brakes can be considered fail-safe because they do not require electricity to function and rely on magnetic properties and actually never even come in contact with the cart.

Blocking

With less friction, the ride goes faster causing it to end faster, making greater track length a demand by riders. To allow more riders to access longer roller coasters, most use one or more carts at the same time now. To do this developers create multiple sections or blocks in the track. In each block there is only allowed to be one cart at a time. Towards the end of each block there is a breaking section that can be used in case it is necessary to avoid collision between two carts. To know where a cart is in each block there are sensors that detect the movement of the cart and sends messages to the computer system that is operating the ride.

Loops

There were multiple attempts at creating loops, but loops were not added to roller coasters until after steel roller coasters were invented in 1959. The loops in the roller coaster used to be in circular loops but now they implement a clothoid loop. A clothoid loop mainly a circular loop but the width is decreased and the height remaining the same. The reason that clothoid loops are now being used is that it is easier for the cart to complete the loop with less speed and requires less force.

Clothoid loop illustrated by the roller coaster the Raptor located at Cedar Point.

Centripetal Acceleration

Most roller coasters feature curves and flips to add more fun, thrill, and excitement to the riders. Centripetal acceleration is the act of an object moving in a circular motion, which makes centripetal acceleration crucial to roller coasters. Centripetal acceleration is felt by the riders in a way of being forced to the outside of the circular path that they travel in. This feeling is usually described as centrifugal force. The reason the rider experiences centrifugal force is because the rider’s body wants to continue in a straight line that it was going in, but instead of going straight the cart turns and your body is strapped to the cart so it is trying to go straight but ends up being forced to turn. Centripetal acceleration may be increased in multiple ways including an increased velocity and decreasing the length of the curve being followed. For this reason most roller coasters that have high speeds use banked curves to give the feeling of being pushed into the seat instead of feeling as if the rider's body is getting pushed to the side of the cart. "The greater entry speeds subject passengers to greater centripetal acceleration through the lower half of the loop, therefore greater G's. If the radius is reduced at the top of the loop, the centripetal acceleration is increased sufficiently to keep the passengers and the train from slowing too much as they move through the loop," (Sastamoinen).

Centrifugal force is currently being felt by the riders.

G-Forces

G-Forces are used in explaining what the rider experiences while riding the roller coaster. If the rider experiences 1g then the rider is experiencing normal gravity of earth. When the rider feels weightless he experiences no gravity; if the rider feels like he is being pushed up then they are feeling negative G-forces. While descending down a hill the rider usually experience anywhere from 0G to 1G. Where riders usually experience more then one G is at the bottom of big hills, during the time the hill changes directions because they feel like they are being pushed down. At the top a hill if the rider experiences a feeling where he is pushed up then he is experiencing negative G's. Also lateral G-forces exist and are felt when riders change direction in a horizontal manner but they can usually be transferred into normal G-forces by having turns becoming banked turns. "Whenever you accelerate, the various parts of your body can no longer follow their inertia; they must accelerate, too. This acceleration requires forces within your body and you can feel these forces. In fact, they make it feel as though a new type of gravity were acting on the parts of your body," (Bloomfield).

Conclusion

Roller coasters have come along way in the past four hundred years; from manually lifted sleds to the fastest, tallest thrill rides in the world. Roller coaster design today is a science and an art. Designers are knowledgeable in the basics of roller coaster physics discussed above and kinematics, a branch of mechanics that deals with pure motion, to ensure people enjoy a safe, comfortable, fun ride. Pushing the limits of physics has produced many types of roller coasters that are created to be enjoyed by many different types of people.

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