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Reviewing the Physics of Roller Coasters

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Abstract: ***This paper aims to explain the intricacies of the application of a wide range of mechanical physics concepts utilised in the construction of roller coasters. The topics under consideration in this article are the Law of Conservation of Energy, Newton's Laws of Motion, functioning of clothoid loop - the - loops and effects along with utilisation of aerodynamic drag. The researchers have taken some of the conventional concepts of classical mechanics, describing how one of the most well - renowned amusement park rides arose from the building blocks of physics.***

Keywords: conservation of energy, laws of motion, clothoid loops, air drag, safety mechanics

1. Introduction

Roller coaster rides are an exhilarating experience for people across the globe. This much sought - after ride comprises a sequence of controlled turns, loops, hills and dips which are painstakingly designed for maximum safety, while simultaneously maintaining the thrill level for the riders. Mechanical physics plays the most essential role during the drawing of the blueprint of roller coasters.

2. Literature Survey

The blueprints and origin of roller coasters, as written in the article by Neil J. Meridith (1) about their history depicts its gaining popularity in America after the establishment of the Gravity Pleasure railway at Coney Island by LaMarcus Thompson. In an article by American Experience, called "A Century of Screams: A History of Roller Coasters" (2), it is expressed how a coal mine in eastern Pennsylvania was later converted to a tourist attraction, utilising the lurching up and down motion of the cart created by railway proprietors. We can see that the physics utilised in the creation of roller coasters was not necessarily used initially as amusement, but as necessary concepts for building machinery which revolutionised industrial concepts like mining. Various textbooks on mechanical physics have described the concepts used in creation of roller coasters, but between the screams and laughter, one hardly ever admires the physics behind this creation.

3. Methodology

The methodology used for the creation of this article was the qualitative reviewing of several published papers on the history of the construction of roller coasters, along with articles on fundamental concepts of classical mechanics. Observing modern day roller coasters and linking the data from these areas, the researchers have formed links between all the concepts mentioned.

Law of Conservation of Energy

The law of conservation of energy states that energy cannot be created nor destroyed. It can be transformed from one form to another. With respect to roller coasters, this law plays a crucial role in the ride experience.

At the start of a roller coaster ride, the coaster car is pulled up a hill to a high point, which stores potential energy in the form of the car's position relative to the ground. As the car begins its descent down the hill, this potential energy is converted into kinetic energy, which is the energy of motion. As the car moves through the twists, turns, and loops of the coaster, the law of conservation of energy ensures that the total amount of energy in the system remains constant.

Newton'S Laws of Motion

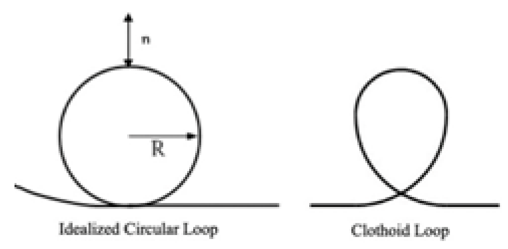
First law: The Law of Inertia states that an object at rest will remain at rest, and an object in motion will continue in motion with a constant velocity, unless acted upon by a net external force. When a roller coaster is at the top of a hill and comes to a stop, it remains at rest until an external force, such as the release mechanism or gravity, acts upon it to set it in motion. Once in motion, the coaster continues to move until an external force, such as friction or the brakes, slows it down and brings it to a stop.

Second law: The law of acceleration states that the acceleration of an object is directly proportional to the net external force acting on it and inversely proportional to its mass. In a roller coaster, the external force is provided by gravity and the track's structure, which exert a force on the coaster, causing it to accelerate as it moves down the track. The amount of acceleration depends on the mass of the coaster and the net external force acting upon it.

Third law: The law of action and reaction states that for every action, there is an equal and opposite reaction. In a roller coaster, this law is observed when the coaster travels through a loop or turns. As the coaster goes through the loop, it exerts a force on the track, and the track exerts an equal and opposite force on the coaster, keeping it on the track through various turns and preventing it from falling off.

Clothoid Loop - The - Loop Design

The loop - the - loop is a type of inversion, which occurs when the track of the roller coaster is designed to go upside down and then return to an upright position. Contrary to popular belief, roller coaster loops are not usually circular since the gravitational forces experienced by riders is unsafe in that design. The more common loop design is the teardrop shaped clothoid loop, which is a section of a spiral with regularly changing radii, making it safer for the public due to the manner of descent.



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When a roller coaster enters the loop - the - loop, it is travelling at a high speed and must maintain enough speed and momentum to complete the loop without losing velocity. As the coaster continues to travel through the loop, the angle of descent gradually decreases until the coaster reaches the end of the loop and returns to an upright position. There are four primary forces acting on a roller coaster as it travels through a loop - the - loop:

Gravity: This is the force that pulls the coaster and its riders downwards towards the centre of the earth which is necessary for maintaining the momentum of the coaster. As it enters the loop, gravity pulls the riders towards the bottom of the loop, which creates the sensation of weightlessness at the top.

Centrifugal force: This is the force that pushes the riders outwards as the coaster travels through the loop. At the bottom of the loop, the centrifugal force is greater than gravity, which helps to keep the coaster and its riders moving in a circular motion.

Inertial force: This is the force that opposes changes in motion, and it comes into play as the coaster transitions from the bottom of the loop to the top. The inertia of the riders' bodies wants to keep them moving in a straight line, but the track of the coaster keeps them moving in a circular path.

Friction: This is the force that acts between the coaster and the track, and it helps to keep the coaster moving along the track without slipping or losing traction. In a loop - the - loop, friction is particularly important to ensure that the coaster maintains enough speed and momentum to complete the loop without losing velocity.

Air Drag Application and Reduction

As a roller coaster train moves through the air, it encounters resistance from the air molecules, which can slow down the train and affect its motion. It experiences hindrance caused by the air particles colliding with the train's surface and the resulting force opposes the train's motion. The effects of air drag on a roller coaster depend on various factors such as the shape and size of the coaster train, the speed at which it's moving, and the density of the air. The faster the roller coaster is moving, the more significant the drag force becomes.

Roller coaster designers try to minimise the impact of air drag by designing trains with streamlined shapes that reduce the amount of resistance the train experiences. Additionally, roller coaster tracks are often designed with banked turns and other features that allow the train to maintain its speed through the turns, reducing the amount of deceleration due to air drag.

In some cases, designers intentionally create roller coasters with elements that produce a lot of air resistance, such as corkscrews or loops. These elements can add excitement and thrills to the ride by creating moments of weightlessness and rapid changes in direction.

4. Result

The article concisely explains some of the most essential concepts of mechanical physics. The level of safety required in roller coaster designing is of utmost importance and requires modification according to budget, environmental characteristics and several other factors. Utilising these concepts to reduce the number of roller coaster accidents can be accomplished, increasing the public‘s trust and enthusiasm in riding a coaster without hesitation. Improvement in designs of the tracks, carts, wheels and safety belts are some of the primary advancements which can be made utilising classical mechanical concepts in engineering.

5. Conclusion

The article has defined the mechanical aspects of roller coasters, bringing to light the concepts, laws and theories which have been studied since the 17th Century when Isaac Newton gave the Laws of Motion. It consolidates the thought process involved in creating new and exciting amusement park rides, utilising these postulations to enhance safety and thrill, while also involving the enhancements of science to create new experiences and better machine efficiency. These new technologies will continue to go hand in hand with the mechanical aspect of the roller coaster, making it an amalgamation of multiple fields of physics.

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Devang Pratap Singh is a student of Class 12 studying Physics, Economics, Mathematics and Computer Science. His area of interest lies in coding and mechanical engineering and he plans to pursue engineering in the United States. He has participated and won several hackathons and coding competitions. Apart from this, he is also a prolific writer and has written research papers in areas of science and technology. He is a part of the College Quizzing Team and has won numerous accolades in Science Related Quizzes. In his free time, he likes to learn about technological advances and build apps which revolve around automatisation of tasks through AI for social good. Furthermore, he secured 97% in his ICSE Board Examinations. Every time he stumbles upon a new topic of interest, he decides to put in the next few weeks to conduct an in - depth study on it. Deep analysis of subjects which intrigue him prompt him to write research papers for the same.

Anushka Srivatsan is a student of class 12 studying Physics, Chemistry, Biology and Psychology. She aspires to become a surgeon and is fascinated by the field of biophysics. She has participated in several STEM Related competitions at the international and national level and has won accolades for the same. She studied Medicine on a scholarship at Cambridge University‘s Summer School programme in 2022. Her interest in research work began with her project on Reactive Oxygen Species at Cambridge, which was well received by their faculty and her peers. . She also enrols in observerships at the surgical departments of hospitals in her city to kickstart her medical journey and has received certifications for the same. She scored 99% in her ICSE Board Examinations, which was amongst the highest scores in the nation. Being interested in linguistics, she has excelled at her DELF Examinations in French at the A1, A2 and B1 levels