TELEMETRY SYSTEM FOR MONITORING STRESS AND VIBRATIONS ON AMUSEMENT PARK RIDES

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ABSTRACT

On amusement park rides, vibrations against the rails of the track and the cars' wheels can strain and damage the track. This is especially true for older coasters, whose tracks have worn significantly over time. While manual inspection of the track is necessary, an automated system that monitors the stress on the track will help detect anomalies, ensuring a safe experience for the passengers. We have designed a system of sensors that can monitor these vibrations. Sensors placed on a segment of track will measure the lateral and vertical vibrations, wirelessly transmitting the level of strain on the track to a base station. If vibrations reach a threshold level, the base station will be alerted of excessive strain. The system will create a graph of points where vibration is worse than other points, to pinpoint what areas need to be fixed the most. This will decrease maintenance costs and ensure increased safety for patrons of these rides.

INTRODUCTION

BACKGROUND

Amusement parks around the world entertain millions of guests every year. Thus, for roller coasters to have a servicable lifespan of many years while entertaining thousands of guests each day, protecting roller coaster track from stress and fatigue is crucial. Though wooden and steel coasters both exist, this analysis will primarily focus on steel roller coasters. For a single steel roller coaster, a coaster train will subject different levels of stress on the track throughout the ride. The track pieces that undergo the most stress are typically those where the coaster exerts high positive-G force on the riders. Such moments are at the bottom of drops, valleys between hills, helices and tightly banked turns, and the bottom of inversions like vertical loops and corkscrews. It is at these points where the vibrational patterns of the track during a ride cycle will be analyzed, as these points on the track are the most prone to fatigue. The telemetry system will monitor vibrations and alert the base station if the vibrations reach a critical threshold.

OVERVIEW

This paper serves to outline our concept of vibrational analysis. We will detail the purpose and goals for creating a system of vibrational sensors. Then explain how we will achieve these goals, our base idea, what the sensors will detect, and how the sensors will be protected. Finally we will describe our preliminary ideas for the software that will be implemented.

PURPOSE

In the complex motions of a roller coaster, there are many types of failure that can occur. These failures have many causes such as, unsafe operation, not following safety protocol, and track failure. Although very rare, track failure can lead to severe injury and death. In order to prevent these kinds of issues, it is imperative to properly maintain the track. The goal of theme park maintenance is to predict where and when failures start to occur before they may become a larger issue. However, most preemptive maintenance and pre-opening inspection is done by employees looking, feeling and listening for abnormalities in the ride. This method of inspection is prone to error and can be time consuming and repetitive for employees. Vibration sensors would provide a quick, thorough and accurate inspection, leaving employees to focus on fixing issues and deeper analysis.

The primary goal of this telemetry system is to assist preventative maintenance of steel roller coaster track against fatigue due to stress caused by the coaster trains. Our proposed sensors and telemetry system would make such maintenance even easier, allowing for real-time analysis of track stress. Additionally it would automatically analyze this information, based on historical data from the coaster. Finally it will also automatically notify operators and engineers, of any potentially dangerous anomalies in track vibrations. With the proposed system of sensors, theme parks will have less maintenance costs and less downtime, ensuring a safe and enjoyable experience for the guests.

DESIGN

BASE IDEA

The system will be composed of an external 3-D vibration analyzer, a unit to send, and a receiver at the base station. The vibration analyzers will be placed on the track of steel roller coasters where the track is most prone to stress. These points are typically where riders experience high positive G-force, such as the bottom of drops, valleys between hills, helices, tightly banked turns, and the bottom of inversions like vertical loops and corkscrews. The data recorded from the analyzer will be sent wirelessly to a base station, where it can be viewed in real time.
The base station will also save the data that is flagged for warning. This is designed so the maintenance crew can refer to different patterns. The home base receiver should be able to further analyze the patterns to filter out load anomalies. These would be when a load is focused on one side more than the other. For example, if the right side of the vehicle has a thirty percent higher load than the left. Around a specific turn, the vibrational pattern would be different due to load distribution. These are to be saved in a different area than the alert patterns. They should be saved to help with maintenance or refurbishments.

VIBRATIONAL TUNING

The vibrational analyzer tuning will depend on the material and layout of the track. Most modern roller coasters are commonly constructed using stainless steel. Steel tracks may be filled with different materials such as sand to dampen the sound output, but this will also have an effect on the vibration experienced by the track. This means that no two coasters will have the same vibration patterns or tolerance for vibration. Because of this, engineers must first analyze the track and set baselines for normal behavior. This vibrational tuning will increase the accuracy of the readings and will engineers pinpoint areas of high stress and where improvements need to be made.

FREQUENCY/VIBRATIONAL PATTERNS

Every material has a frequency referred to as a natural frequency. When the environment that the material is in matches the natural frequency, the material tends to store the energy. Should the material stay in this environment, the material will amplify the vibration over time. This will result in failure and possibly even catastrophic failure. For example, the Tacoma Narrows Bridge from 1940 was in a windy environment that happen to match the natural frequency and catastrophic failure followed.

With vibrational patterns being recorded, any abnormalities will be flagged and engineers can inspect the track and train, to try and spot the issue that is causing more stress than usual in an area. Abnormalities will be defined as any vibration whose amplitude is greater than the steel's fatigue strength, the maximum amplitude that the steel can vibrate before it fatigues. Other than the patterns engineers know about, can cause harm to not only the ride, but to the passengers and that is the last thing any park needs. The system will store every single test done and compare a good test result, marked by an engineer, and compare future tests to the data that engineers know is acceptable.

ELEMENTAL PROTECTION FOR SENSOR

The sensor needs to be protected from the natural and physical elements. Wind, water, sun, debris, and blunt force could all cause damage to the vibration sensors. Since the device would not be humongous, we can resort to using a small plastic casing for the device. Not only will the vibration sensors be protected by existing measures employed by the theme park, the sensors will have a tinted and waterproofed plastic outer shell. This shell will not interfere with wireless communications, and will be easy to access and maintain. This shell will be a worthy and cost effective way to protect the equipment.

SOFTWARE

CORE MODULE

The system will collect data throughout the entire ride and store the data into a microSD card. That data can be easily transferred from computer to computer.

DATA LOGGING

The sensor will have four graphs that are recorded. They are to be hertz versus time and G-force in each X, Y, and Z axis versus time. This will allow the detailed image of each value to be compared and help technicians interpret the data more accurately. The device will locally store events for up to one weeks worth of time. This is to reduce the chances of losing important data. The sensor will also keep daily maximum values experienced and the time that they occurred. This will assist the base in monitoring G-force trends, and if the ride is experiencing more than the allowable forces.

Individual seismograph sensors will be attached to different points on the track. Points where the train experiences high G forces during the ride cycle will be prioritized. The sensors will all be wirelessly connected to the base station (located at the coaster's station) via a server. Windows on a monitor will display the waveforms that each seismograph produces each ride cycle. If the waveform's amplitude increases beyond the threshold defined by the fatigue strength, the coaster's operator will be alerted

STRESS

To determine the fatigue strength of the coaster track, one would usually subject the track to vibrations of greater and greater magnitude before the track has signs of fatigue. However, it is not possible to remove a piece of track from a coaster for testing, especially for older coasters whose manufacturers have closed. Instead, fatigue strength will be determined by the stress factors that the German Institute for Standardization (DIN) defines. These factors are steel equality, loading group, notch class, and fatigue ratio.

DIN defines the loading group and notch class. DIN defines six loading groups, each with successively higher capacity of withstanding multiple stress cycles. Steel roller coaster track is in the highest loading group, B6, which expects more than 2 million stress cycles in its serviceable lifetime. Thus, steel roller coaster track is already built to withstand high stress, making stress management more crucial on older coasters than newer coasters. DIN defines eight notch classes, each defined by the geometry of the steel structure's connections and structural joints [1]. The DIN notch class could be used to analyze the stress in supports connected to the roller coaster track and the stress in the connection between the rails and the base of the track. The fatigue ratio of a point on a steel structure is the fatigue strength divided by the tensile strength of the steel [2]. The fatigue strength is the maximum amplitude that the steel can vibrate before it deforms. The tensile strength is the maximum amplitude that the steel can vibrate before it breaks. [3].

We can also take into account the expected minimum stress that a track at a certain point will receieve. The formula for the stress applied on an element is:

$$\sigma = \frac{F}{A}$$

where σ is the applied stress in kilograms per square meter, F is the force applied by the load in kilograms, and A is the cross-sectional area of the element on which the load is applied. In this case, the element is the steel track of the coaster, and the force that is applied by the coaster train. Since most steel roller coasters are built with tubular steel rails, the cross section of the rail will be a circle with radius R.

The force applied by the train on the track will not always equal the weight of the train when it is experiencing a gravitational force of 1 G. The force will increase when the train is subjected to G forces higher than 1 G and decrease when the train is subjected to G forces between 0 G and 1 G. G forces less than 1 G will still cause stress: the upstop wheels below the track will apply a force on the underside of the track when the train experiences negative G forces below -1 G. The G force experienced by the train at a point on the track can be determined with an accelerometer.

Using this information to determine the force applied on the track and the cross sectional area of the track, the above equation can be used to determine the expected minimum stress applied on the track.

CONCLUSION

In conclusion, we believe this device can help theme parks see the future life of the coaster and see when preventative maintenance may be needed. This will help the park be ready for the improvements to the ride, when the time is near.

ACKNOWLEDGEMENT

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CITATIONS/REFERENCES

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