

Welcome to Vibrationdata

Acoustics • Shock • Vibration • Signal Processing

April 2005 Newsletter

Howdy!

Trampoline jumping is a realization of man's desire to defy gravity, if only for a second or so. Strictly speaking, a jumper cannot defy gravity, but he or she does experience "apparent weightlessness" while airborne. The jumper is considered to be in free fall both on the way up and on the way back down.

The first article presents some accelerometer data measured on my ankle as I jumped on our backyard trampoline.

The second article gives measured data from a buzzing light fixture in my neighborhood. The noise source was magnetostriction in the light's transformer.

The third and four articles are press releases that describe fascinating university research related to vibration.

Sincerely,

Jom chime

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Human Vibration on a Trampoline by Tom Irvine

History

Trampoline jumping can be traced to archeological drawings in ancient China, Egypt and Persia. Furthermore, Eskimos use an outstretched Walrus skin to toss one another up.

Trampolines are named after Du Trampolin, a circus acrobat who lived in the 1800s. Du Trampolin used trapeze safety nets for acrobatic stunts.

American gymnast George Nissen invented and patented the modern trampoline in 1936. He was inspired by trapeze acrobats who would fly through the air, dropping at the end of an act into safety netting that would send them rebounding up into somersaults.

The U.S. military used Nissen's trampolines to train pilots during World War II. Later, NASA used trampolines to train astronauts.

Trampoline made its debut as an Olympic sport at the 2000 Olympic Games in Sydney, Australia. The average Olympic trampolinist jumps 6 meters high.

Physics

The trampoline presents an opportunity for the jumper to become part of a spring-mass system, although the jumper becomes disconnect from the trampoline during part of the jump cycle.

The jumper is the mass. The springs are the tightly-wound mechanical springs that

connect the trampoline to the metal frame. Additional spring action is supplied by the jumper's legs and knees.

The trampoline springs are stretched as the jumper moves downward on the trampoline. The springs thus accumulate potential energy. This potential energy is then converted to kinetic energy as the trampoline propels the jumper upward.

The jumper's kinetic energy is then transformed to potential energy, with respect to gravity, until he reaches his apogee. This potential energy is then converted back to kinetic energy as he accelerates downward.

The cycle is then repeated.

Experimental Data

An image of my youngest son jumping on our backyard trampoline is shown on the cover page. I tried to measure his oscillations but had an instrumentation problem.

I then became the guinea pig for this experiment. I attached an accelerometer to my leg just above my ankle. I monitored the data using a battery-powered Vernier LabPro, secured in my shirt pocket.

I jumped vertically up and down, without any flips or acrobatics. The resulting acceleration time history is shown in Figure 1. A close-up view is shown in Figure 2. The main positive peaks in the time history have the shape of half-sine pulses. These pulses represent the periods when my feet where in contact with the trampoline. The base of each of the main pulses had a duration of 0.4 to 0.5 seconds.

The acceleration level was nearly zero in between the pulses. During these intervals, my feet had left the trampoline such that I was in a state of apparent weightlessness.

The high frequency peaks on the data are due to the movement of my legs as I alternately bent and extended my legs to amplify the motion imparted by the trampoline to my body, in a resonant manner.

Some of these peaks are also due to my arm and leg motion as I sought to maintain balance.

The corresponding displacement time history is shown in Figure 3, as obtained through double integration of the acceleration time history. A spectral magnitude is shown in Figure 4.

The fundamental peak is at 0.9 Hz.

The stiffness of the trampoline is can be calculated from this frequency and my weight, which is 100 kg (220 lbm).

The resulting trampoline stiffness is 7035 N/m (40.2 lbf/in).

The formula for natural frequency fn is

$$fn = \frac{1}{2\pi} \sqrt{\frac{k}{m}}$$

where \boldsymbol{k} is stiffness and \boldsymbol{m} is mass.

My peak acceleration level was 4 G, which occurred as I reached the lowest point or perigee of my trajectory. This is the point in time where the springs are under maximum deflection.

My apparent body weight was four times its normal value for a brief fraction of one second.

Olympic trampoline gymnasts can jump about six times higher than I can.

The spring stiffness in Olympic trampolines may be significantly different than that in my backyard model. Otherwise, an extrapolation of the data seems to indicate than an Olympian may experience 24 G during his routine.

In contrast, an ejection seat in a fighter aircraft would typically give the pilot an acceleration of 20 G. This limit is just below the threshold of injury.



Figure 1.



Figure 2.



Figure 3.



Figure 4.

Light Fixture Ballast Hum by Tom Irvine



Figure 1. Ballast Models (Image courtesy of Venture Lighting)

Introduction

Numerous types of lighting systems are used for outdoor lighting and for illuminating large indoor areas such as gymnasiums. Two common examples are high intensity discharge (HID) lamps and fluorescent lamps. Each system has its own advantages. A common denominator is that each type requires a ballast transformer.

The standard ballast has been the electromagnetic type, which is the subject of this article. These ballasts may produce unwanted vibration and noise.

Recently, solid-state electronics ballasts have become commercially available. This type is less prone to noise.

Electromagnetic Ballast

A ballast transformer is a coil of copper wire wound around a laminated iron core. The coil has a property called inductance, which creates a resistance to the flow of alternating current. It thus controls the current flowing through the lamp. The ballast is also be used to provide a high starting voltage to the lamp electrodes in certain lamp designs.

The current passing through the lamp tube would rise rapidly once the gas in the tube is ionized, if it were allowed to continue unchecked. A ballast transformer is used to limit the current through the tube. The ballast impedes the alternating current with little power consumption.

Some power may be lost through sound and vibration, however. A ballast may develop a humming vibration due to magnetostriction, which was discussed in the March 2005 Vibrationdata Newsletter. Magnetostriction may occur if the ballast or its internal parts become loose.

Electromagnetic Ballast Types

There are numerous types of ballast designs. Some examples are:

- 1. High-reactance autotransformer (HX-HPF)
- 2. Constant-wattage autotransformer (CWA)
- Constant-wattage isolated transformer (CWI)
- 4. Linear reactor pulse start
- 5. Regulated lag (magnetically regulated) ballasts

Furthermore, some of these ballast systems also have capacitors to handle supply voltages fluctuations.



Figure 2. Humming Streetlight

High Intensity Discharge Lamps

A high intensity discharge lamp is a pressurized tube which contains gases such as argon, mercury vapor, or sodium, along with metallic additives.

An electric arc passes between the lamps electrodes causing the additives to vaporize and release large amounts of light.

Three examples of HID Lamps are

- 1. Mercury vapor
- 2. High-pressure sodium lamps
- 3. Metal halide

Mercury Vapor Lamps

Mercury vapor is the oldest HID technology. The light within the arc is bluish A phosphor coating is sometimes applied to alter the color.

Mercury lamps have along start-up time.

Sodium Lamps

High pressure sodium lamps are very energy efficient. Sodium vapor produce a yellow/orange light with a very high lumens per watt performance. Furthermore, they have a very long service life

Metal Halide Lamps

Metal halide (MH) lamps consist of an arc tube within an outer envelope, or bulb.

The arc tube is also called a discharge tube or "burner." The arc tube may be made of either quartz or ceramic and contains argon starting gas, mercury, and MH salts. Traditional quartz MH arc tubes are similar in shape to mercury vapor arc tubes, but operate at higher temperatures and pressures.

MH lamps produce a bright whitish-blue color. The color may be altered by using metal additives.

Fluorescent Lamps

A fluorescent lamp is a glass tube filled with an inert gas and some mercury. Filaments in the ends of the tube are turned on briefly by the starter to vaporize the mercury. Meanwhile, a voltage is applied across the tube to ionize the mercury vapor, allowing a current to flow. The ionized vapor emits ultraviolet light in response to the electrical current, which in turn causes the phosphor lining the inside of the tube to emit visible light.



Figure 3.

The streetlight in Figure 2 emitted a loud buzzing or humming sound. A spectral magnitude of the noise is shown in Figure 3.

The AC current oscillates at 60 Hz. The magnetostriction effect creates a fundamental frequency at twice this value, or 120 Hz. In addition, the response has a tremendous number of integer harmonics. Each pair of adjacent peaks is separated by 120 Hz.

Cornell's Tiny, Vibrating Paddle Oscillator Senses the Mass of a Virus

FOR RELEASE: Nov. 4, 2004

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Scanning electron micrograph of a cantilever oscillator 6 micrometers long, 0.5 micrometers wide and 150 nanometers thick, with a 1 micometer square paddle. The scale bar corresponds to 2 micrometers Image Copyright Cornell University.

ITHACA, N.Y. -- By using a device only sixmillionths of a meter long, researchers at Cornell University have been able to detect the presence of as few as a half-dozen viruses -- and they believe the device is sensitive enough to notice just one.

The research could lead to simple detectors capable of differentiating between a wide variety of pathogens, including viruses, bacteria and toxic organic chemicals.

The experiment, an extension of earlier work in which similar devices were used to detect the mass of a single bacterium, is reported in a paper, "Virus detection using nanoelectromechanical devices," in the September 27, 2004, issue of *Applied* *Physics Letters* by Cornell research associate Rob Ilic of the Cornell NanoScale Facility (CNF), Yanou Yang, a Cornell graduate student in biomedical engineering, and Harold Craighead, Cornell professor of applied and engineering physics.

The work was done with the assistance of Michael Shuler, Cornell professor of chemical and biological engineering, and microbiologist Gary Blissard of the Boyce Thompson Institute for Plant Research on the Cornell campus.

At CNF, the researchers created arrays of tiny silicon paddles from 6 to 10 micrometers (millionths of a meter) long, half a micrometer wide, and about 150 nanometers (billionths of a meter) thick, with a one-micrometer square pad at the end. Think of a tiny fly-swatter mounted by its handle like a diving board.

A large array of paddles were mounted on a piezoelectric crystal that can be made to vibrate at frequencies on the order of 5 to 10 megaHertz (MHz).

The experimenters then varied the frequency of vibration of the crystal. When it matched the paddles' resonant frequency, the paddles began to vibrate, as measured by focusing a laser on the paddles and noting the change in reflected light, a process called optical interferometry.

The natural resonant frequency at which something vibrates depends on, among other things, its mass. A thick, heavy guitar string, for example, vibrates at a lower tone than a thin, light one. A single one of these silicon paddle weighs about 1.2 picograms, and vibrates at frequencies in the neighborhood of 10 megaHertz. The virus used in the experiment weighs about 1.5 femtograms.

A picogram is 1/1,000,000,000,000th of a gram, and a femtogram is 1/1000th of a picogram.

Adding just a few virus particles to a paddle turns out to be enough to change its resonant frequency by about 10 kiloHertz (kHz), which is easily observable.

To trap viruses, the researchers coated the paddles with antibodies specific to *Autographa californica* nuclear polyhedrosis virus, a nonpathogenic insect baculovirus widely used in research.

The paddle arrays were then bathed in a solution containing the virus, causing virus particles to adhere to the antibodies. Because air damps the vibration and greatly reduces the "Q," or selectivity, of the system, the treated paddles were placed in a vacuum for testing.

From the frequency shift of about 10 kHz the researchers calculated that an average

of about six virus particles had adhered to each paddle. It might be possible, the researchers say, to demonstrate detection of single particles by further diluting the virus solution. The system also can differentiate between various virus concentrations, they say.

As expected, the smallest paddles were the most sensitive. The researchers calculated that the minimum detectable mass for a sixmicrometer paddle would be .41 attograms (an attogram is 1/1000th of a femtogram.) This opens the possibility that the method could be used to detect individual organic molecules, such as DNA or proteins.

Other members of the Craighead Research Group at Cornell have experimented with "nanofluidics," creating microscopic channels on silicon chips through which organic molecules can be transported, separated or even counted.

llic speculates that a simple field detector for pathogens -- the much-heralded "laboratory on a chip" -- could be built by combining a paddle oscillator detector with a nanofluidic system that would bathe the paddles in a suspect sample, then automatically evacuate the chamber to a vacuum for testing. Arrays of paddles coated with various antibodies could allow testing for a wide variety of pathogens at the same time.

Seismic Shaking Erased Small Impact Craters on Asteroid



Asteroid Eros Reconstructed, Courtesy of NASA

UNIVERSITY OF ARIZONA NEWS RELEASE, November 26, 2004

University of Arizona scientists have discovered why Eros, the largest near-Earth asteroid, has so few small craters.

When the Near Earth Asteroid Rendezvous (NEAR) mission orbited Eros from February 2000 to February 2001, it revealed an asteroid covered with regolith -- a loose layer of rocks, gravel and dust -- and embedded with numerous large boulders. The spacecraft also found places where the regolith apparently had slumped, or flowed downhill, exposing fresh surface underneath.

But what NEAR didn't find were the many small craters that scientists expected would pock Eros' landscape.

"Either the craters were being erased by something or there are fewer small asteroids than we thought," James E. Richardson Jr. of UA's planetary sciences department said.

Richardson concludes from modeling studies that seismic shaking has obliterated about 90 percent of the asteroid's small impact craters, those less than 100 meters in diameter, or roughly the length of a football field. The seismic vibrations result when Eros collides with space debris.

Richardson, Regents' Professor H. Jay Melosh and Professor Richard Greenberg, all with UA's Lunar and Planetary Laboratory, report the analysis in the Nov. 26 issue of Science.

"Eros is only about the size of Lake Tahoe -- 20 miles (33 kilometers) long by 8 miles (13 kilometers) wide," Richardson said. "So it has a very small volume and a very low gravity. When a one-to-two-meter or larger object hits Eros, the impact will set off global seismic vibrations. Our analysis shows how these vibrations easily destabilize regolith overlaying the surface."

A rock-and-dust layer creeps, rather than crashes, down shaking slopes because of Eros' weak gravity. The regolith not only slides down horizontally, but also is launched ballistically from the surface and 'hops' downslope. Very slowly, over time, impact craters fill up and disappear, Richardson said.

If Eros were still in the main asteroid belt between Mars and Jupiter, a 200-meter crater would fill in about 30 million years. Because Eros is now outside the asteroid belt, that process takes a thousand times longer, he added.

Richardson's research results match the NEAR spacecraft evidence. Instead of the expected 400 craters as small as 20 meters (about 70 feet) per square kilometer (three-fifths mile) on Eros' surface, there are on average only about 40 such craters.

The modeling analysis also validates what scientists suspect of Eros' internal structure.

"The NEAR mission showed Eros to most likely be a fractured monolith, a body that used to be one competent piece of material," Richardson said. "But Eros has been fractured throughout by large impacts and is held together primarily by gravity. The evidence is seen in a series of grooves and ridges that run across the asteroid's surface both globally and regionally."

Large impacts fracture Eros to its core, but many smaller impacts fracture only the upper surface. This gradient of big fractures deep inside and numerous small fractures near the surface is analogous to fractures in the upper lunar crust, Richardson said. "And we understand the lunar crust -- we've been there. We've put seismometers on the moon. We understand how seismic energy propagates through this kind of structure."

The UA scientists' analysis of how impactinduced seismic shaking has modified Eros' surface has a couple of other important implications.

"If we eventually do send spacecraft to mine resources among the near-Earth asteroids or to deflect an asteroid from a potential collision with the Earth, knowing internal asteroid structure will help address some of the strategies we'll need to use. In the nearer future, sample return missions will encounter successively less porous, more cohesive regolith as they dig farther down into asteroids like Eros, which has been compacted by seismic shaking," Richardson noted.

"And it also tells us about the small asteroid environment that we'll encounter when we do send a spacecraft out into the main asteroid belt, where Eros spent most of its lifetime. We know the small asteroids -those between the size of a beachball and a football stadium -- are out there. It's just that their 'signature' on asteroids such as Eros is being erased," Richardson said.

This finding is important because the cratering record on large asteroids provides direct evidence for the size and population of small main-belt asteroids. Earth-based telescopic surveys have catalogued few main-belt asteroids that small. So scientists have to base population estimates for these objects primarily on visible cratering records and asteroid collisional history modeling, Richardson said.