Logan Dean

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Physics in Science Fiction

Resonance and Murder

Resonance. What is it? How does it work? More importantly, could it be used to commit the perfect murder? In theory, all it would take would be some big speakers, precisely the right notes, and a target you don't mind disintegrating, but the conditions of real life are harsher. There are a lot of variables that can't easily be accounted for. Human bodies are not perfect resonators and air isn't a great medium. Luckily, there is a fair amount of information on this subject.

To answer the first question, *mechanical resonance* is the tendency for an object to amplify an oscillation that matches one of its natural frequencies. Everything in the world is always vibrating. When nothing else is vibrating them, they will vibrate on their own at what is called their natural frequency. When an external vibration lines up with this frequency, it is amplified greatly[1]. It works the same way as a swing at a playground. If you shift your weight in time with the swing's movement, you make the swing go higher each time. This swing's frequency can be modeled fairly accurately using the formula:

$$f = \frac{1}{\tau}\sqrt{\frac{g}{L}}$$

where τ = 2π, g is the acceleration due to gravity, and L is the distance between the top of the swing set and the center of mass of the person on the swing.[1] Just as pushing in time with the swing can amplify it, pushing at subharmonics of the swing's frequency can do the same. Some systems will work with harmonics and some with subharmonics. Pushing at subharmonic frequencies means pushing only every nth swing, whereas pushing at harmonic frequencies would mean pushing every $\frac{1}{n}th$ swing, which wouldn't work very well in the case of the swing.

The same principal is responsible for octaves in music. An octave is a special case $(n=2^x)$ of harmonics (and subharmonics, though the distinction is unnecessary because $0< n< 1 \text{ when } x< 0$), meaning that for each octave higher the frequency is doubled, and for each octave lower it is halved.

Such resonators work by changing energy between kinetic and potential. All the energy is stored as gravitational potential energy when the swing is at the top and all the energy is kinetic while the swing is at the bottom. In a mechanical system, the potential energy can be stored in a variety of forms, like tension in a spring, for example. Natural frequencies can be important in a variety of places one might not expect, as well. For example, in simple (LC or RCL) electrical circuits, the natural frequency can be calculated thus:

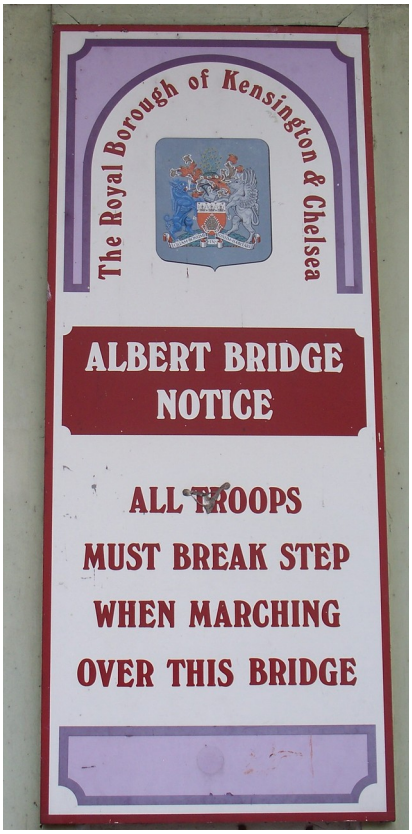
$$\omega_0=\frac{1}{\sqrt{LC}}$$

where L refers to the value of the inductor and C refers to the value of the capacitor (though this can also be influenced by the capacitive behavior that

presents between the nth and $n+1th$ turns of a coil, meaning that in real life it can depend on coil geometry very much as well). This can be very important in determining how radio antennas (and electromagnets in general) will behave.

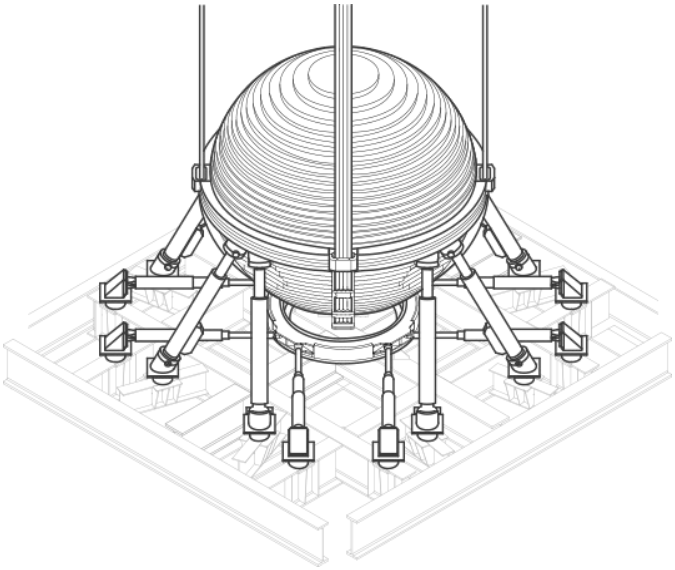
Resonance is the principle that makes a variety of things work, from clock pendulums to violins, but it also makes a lot of things break, like bridges, buildings, and wine glasses. This is because the amplified oscillation might result in a catastrophic failure, which is known as a *resonance disaster* when it happens in large structures[1]. Many bridges have collapsed as a result of resonance. A small oscillation (e.g. from people crossing it or from the wind blowing at the right speed) tend to cause an improperly built bridge to sway massively and break apart, like, for example, the Tacoma Narrows Bridge (pictured below)[2]. In 1898, Nikola Tesla created earthquake-like effects using a small oscillator, which he clamped to a beam of a half-built building. Based on his testing, he concluded that within a matter of minutes and hours he could use the same small device to drop the whole building, or even the Brooklyn Bridge[3].

This isn't limited to the wind or special equipment, though. In 2011, a shopping mall in Seoul called the “Techno-Mart” shook for 10 minutes and was emptied for two days while engineers investigated the cause. Eventually it was discovered that a group of people working out to the beat of the song “The Power” by the artist Snap! caused the entire building to vibrate through mechanical resonance[4]. It is thought that soldiers marching across a bridge could cause it to collapse, so troops were warned to break step while marching on bridges. The Mythbusters determined that such a collapse was not feasible, but then revisited the myth and declared it plausible[5]. The same thing happened to the Albert Bridge between Chelsea and Battersea, and a similar effect could be seen in the London Millennium Footbridge, which began to sway violently due to small oscillations from people walking[6]. This problem was solved by a series of hydraulic dampeners. Despite this, many people still refer to it as the wobbly bridge. In fact, many structures have to be built with this very phenomenon in mind.



For example, Taipei 101 is a huge skyscraper in Taipei, Taiwan. From 2004

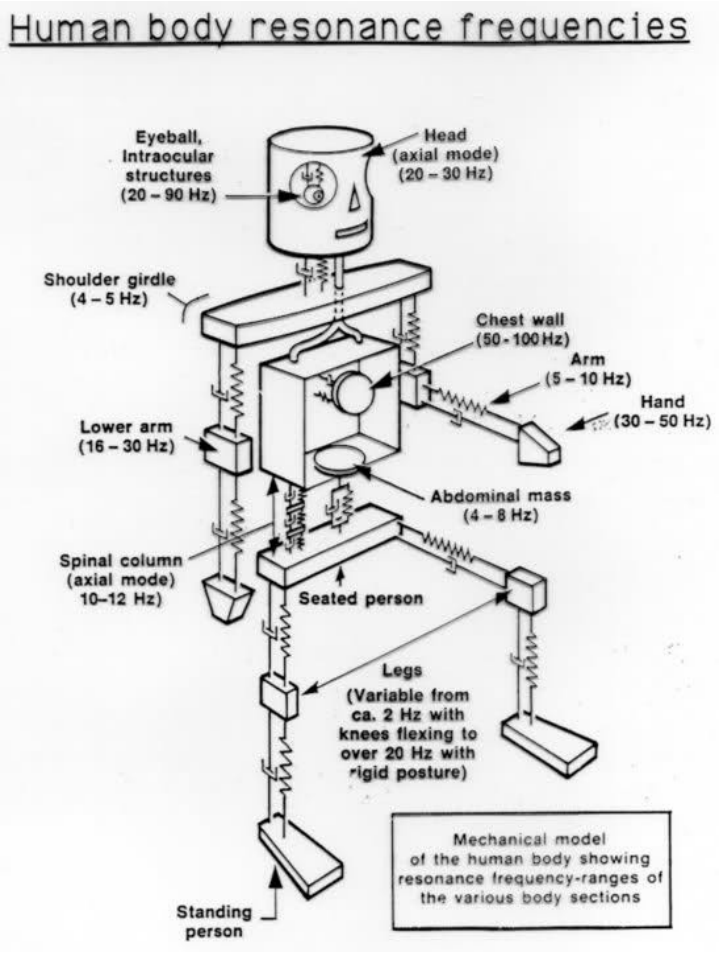
until 2010, it was classified the world's tallest building. Because of the typhoon winds and earthquakes that are common in that area, the building was designed to withstand a variety of natural phenomena. To avoid the resonance problem, there is a 660 metric ton tuned mass damper (a huge steel pendulum) inside it. This pendulum is suspended 5 stories and sways to counter the oscillations caused by strong gusts of wind. There are also 2 other small mass dampers at the top of the tower[7].



This powerful phenomenon is the main effect to be concerned with when planning the perfect murder. Here's the plan. Your target is in a room. You have carefully positioned large speakers throughout the room (or used existing ones if the room is some kind of audio equipment store, concert hall, or other place where large speakers are kept) and calculated the frequencies you need to use. Without ever going near the target, you can play the frequencies and kill them. After all, if you murder someone with sound waves and nobody is alive to hear it, does it really make a sound? (actually, no, it doesn't; the tones would be below audible frequencies, so it would make an infrasound, but more on that later) If your tones were specific enough to the target's body, you might even be able to do it while other people are in the room, destroying your target and leaving the others unaffected. After causing a resonance disaster in your

target, you are free to pack up your speakers (or leave them in place; who would suspect?) and go home to plan another resonance murder.

But how well does it work on people? Well, humans have indeed been shown to react in different ways to different frequencies of oscillation. From 20-40Hz, a response can be seen due to resonance in a person's head. Around 63Hz, the chest and eyes will resonate instead[8]. The overall frequencies for humans tend to be in the 9-16Hz range (about 12.2Hz for men and 12.8Hz for women, on average), independent of their weight and height[9].



Another study (the source of the model of the human body pictured) indicates that the head resonates at 20-30Hz, the shoulders at 4-5Hz, the arms at 5-10Hz, lower arms at 16-30Hz, spinal column at 10-12Hz, abdominal mass at 4-8Hz, legs at 2-20Hz depending on posture, chest at 50-100Hz, and hand at 30-50Hz for a standing person[10]. This concept can be seen parodied in the media through the idea of a “brown note”, which is said to be an infrasonic tone that cause humans

to lose control of their bowels and uncontrollably defecate in their pants. Scientists as well as the Mythbusters have tried to verify its existence[5], but nobody has managed to, leading many to believe it is fictional. Despite this, its concept is sound. Its origin is likely connected to tests that NASA ran about the effects of cockpit vibrations on astronauts, which showed that certain frequencies could make people suffer from impaired vision, loss of motor skills, nausea, and difficulties communicating. Clearly there are real effects of resonance in people and even fairly well defined frequency ranges to look at for different parts of a person and for a whole person.

Unfortunately, there are a number of problems with our plan. First of all, humans are made of pretty squishy stuff. Resonance only really works well when the object is relatively rigid (which is why The Doctor's sonic screwdriver doesn't work on wooden locks[11]). Quite possibly a larger problem is that air is by no means an efficient medium for passing low (or any) vibrations into the human body[12]. Finally, even if the killer could get around those problems, there would be quite a number of variables involved in such a process. If the person's legs were the target, the killer would need to know how the person would be standing, as their leg frequencies would change. They might need to know about the target's medical history, as bone frequencies can vary depending on whether they have been fractured and even how far along they are in the process of healing[13]. This points to the possibility that resonance might not be an ideal murder weapon (unless, of course, your target is a poorly-designed bridge, a

Korean shopping mall, or a wine glass).

In short, resonance might not be the best way to get away with murder, but it might work with speakers that were very loud and very close. Even then, however, the target might die, but everyone else in the room would likely be experiencing extremely violent symptoms ranging from nausea and blindness to death. Plus, at such a high volume, the police would probably already be there to arrest you for causing such a disturbance.

You'll just have to do it the old fashioned way.

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