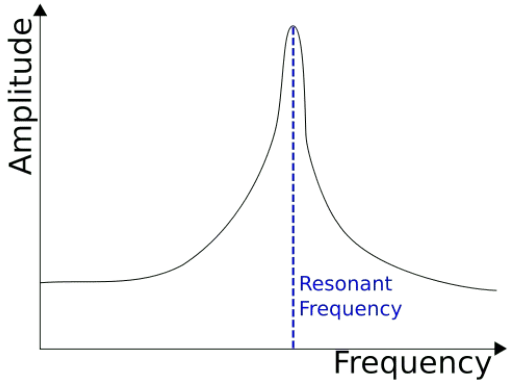
A Bear in the Woods

Resonance is like a bear in the woods. If I lived in the woods, then I may never have to deal with resonance, but I will need to deal with a bear someday. I hope not this day, but some other day. Since we do not live in the woods, but rather in buildings, we will need to deal with his brother - resonance. Resonance will come around someday trying to eat my lunch, bite me, and luckily just leave me a little bruised. Being a good boyscout, I want to be prepared for the bear, and for his sibling - resonance. Here are some preparatory tools. There are four symptoms for resonance, similar to the four symptoms of a "bad" bear:

1. Very high vibration ---- A very aggressive bear
2. Directional ---- Coming at me
3. Speed dependent ---- Coming fast
4. Varying amplitude ---- Not predictable

Resonance can be mechanical vibration or airborne acoustic. All noise problems start with a vibrating surface, so let's tackle the structural vibration first.



Structures

Structures are normally passive, like a hibernating bear. They will not become active unless disturbed. The disturbance can be an impact excitation. My friendly bear likes to be undisturbed and so will stay out of my way. Likewise, structures will remain quiescent until we disturb them. The

implication is that we, as humans doing normal human things, create resonance, in more ways than just an impact. We also do it by design, to be touched on later.

Resonances have a threshold, below which they will remain quiet. If the input energy stays low enough below the threshold, then the structure will not become active; that is, it will not amplify. The bear has a food threshold, along with some other thresholds, like "keep away from my pups " and "stay out of my territory". But unfortunately, we live in the same forest. Me and my machines, that keep me comfortable, live in the same buildings. The machines, along with the support structures, have thresholds below which they will not be troublesome.

The bear exists in nature without humans. Resonance is also a fact of nature with or without the presence of humans. The bear can behave as a bear does and doesn't care about an absentee human. The same goes for the resonance. Trees sway in the wind, waves traverse the waters, and planets go around the sun, not caring for human occupancy. The point is that resonance is a human problem, not a natural problem. Resonances are natural. The thing that triggers a structure to amplify is a rhythm at the right frequency. The frequency that triggers a bear to become dynamic is probably some human caused noise, like a voice, that is not natural to the bears environment. A bear is sensitive to sound. Resonances are frequency dependent.

The serious structural resonances are typically below 100 Hz. In contrast acoustic resonances are usually above 100 Hz, which will be covered in the next section. The bear is a broadband creature being sensitive to everything within its' tactile, acoustic, visual, and olfactory sensors. Likewise, there are resonances all around us at just about every frequency. There is no hiding from the resonance bear. There are no avoidance tactics. We cannot hide or run away. The best tactic is to keep the bear satisfied. The bear goes for the food. The resonance goes for the money, meaning that it bothers the one who perceives himself to be of importance. If I could lower my threshold of annoyance, then I could live with the resonance bear. In other words, I could just ignore it. If I chose not to compromise my sensitivities, then I have several strategies for satisfying the resonance bear. These are :

1. Stiffness ---- a stout cabin
2. Mass ----- make my size bigger than the bear
3. Damping ----- build a barrier of water or mud to keep the bear away
4. Reduce the input energy ----- maintain a low profile
5. Dynamic absorber ------ keep a large dog

Changing the speed of a machine that is the source energy for a resonance amplifier to a structure will not work for the bear who is a broadband device, but it is the fastest and easiest fix for a structural resonance.

Structural resonances have an aging effect. That is, as a structure ages, the joints soften, and the natural frequencies drop gradually. The background vibration contributes to this effect. The bears age is a factor in that a young bear is not problem, and an old bear is too slow.

Acoustic Resonance

A vibrating structure that couples to the air then becomes a noise or a pleasing sound, depending on the perception of the receiver. All musical instruments are resonance machines, whether wind instruments, string instruments, or percussion instruments. We like those sounds. Those are friendly bears. Wind is a random excitation. It conceives grizzly bears. An off key tone is a sick bear.

The frequency of a pure tone depends on the length of the tube for a wind instrument, the length of the string between bridges, or the size of a drum. These are boundary conditions, governed by the wave equation:

$c = f\lambda$ where c = speed of sound in air, 1100 ft/sec
f = frequency, Hz
λ = wavelength, ft

The wavelength is controlled by the tube length or the string length, which in turn, defines the frequency. The tone can be pleasant or obnoxious, depending on the rhythm, and our perceptions of what that rhythm should be. What does all this have to do with the bear?

Our hearing is very sensitive. We can detect fluctuating air pressures as low as 0.000 000 003 psi (20 micropascals corresponding to zero dB sound pressure level). We are unusually sensitive to extremely small acoustic energy. Humans had sensitive hearing long before language or any uttered communication. This was an evolutionary adaptation for survival. We cannot turn it off since we have

no flaps over our ears. This was so that we could hear anything creeping around at night looking for something to eat. Today, this sensitive hearing is both a blessing and a liability. The blessing is that we can appreciate pleasing sound of very low level and hear that bear (or any other creature) crawling around. The liability is that we are bothered by noisy machines, trucks, motorcycles, construction activity, boom boxes, and modified exhaust vehicles. We seem to like rock concerts, noisy athletic events, amplified church music, and loud theater shows. The bear is not always perceived as bad even though it may be eating my lunch (damaging my sensitive ears).

The acoustic resonance may be more like a clown than a bear. When not looking it could be doing some damage. When stopped, it is still a bad character, planning its next pounce. It can conceal its' true identity in the form of a pleasing sound, but so high in amplitude to be unhealthy. It can change direction (phase shifting) in the form of a standing wave. It can also generate sound within our brains to send a signal to our ears to produce something that is not really there (tinnitus).

Taming the Bear

Resonance on machines or structures has usually been considered to be undesirable, but it does not need to be so. The bear is a natural inhabitant of our space and has just as much a right to be here as we do. The wolf was previously considered to be a predator. Now as a domesticated dog it is a man's best friend. Resonance can be beneficial to us also. How so?

Resonance is a mechanical amplifier. Electrical engineers have done wonderful things with resonance, building electronic amplifiers and filters. Communication technology with radio is based on filters and amplifiers. We could do the same with the resonance bear. There is the potential for more power transfer by matching impedance's between a driver and driven machine, by allowing structures to resonate in the wind, as a bird flaps it's wings to gain more efficient flight.

We must also recognize that we have created this resonance bear by our false illusion to make symmetrical structures. There seems to be something aesthetically pleasing with a symmetrical bear. The bear may have bilateral symmetry as do all mammals, but for the most part behaves chaotically in harmony with nature. We would do well to abandon our desire for symmetry in structures by designing for random support points, non uniform thicknesses (as in castings), curved shapes rather than flat surfaces, and composite materials.