Subject: Re: Blown Speakers - Failure Modes
Posted by Wayne Parham on Tue, 26 Oct 2010 16:05:53 GMT
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I agree with you, generally, as long as people use reasonable care in their equipment purchases, they should expect their loudspeakers to last a lifetime. This is true in the commercial high-fidelity and home theater markets, at least, because the power requirements are fairly modest.

However, when you start pushing speakers too hard, failures are inevitable. A post-mortem of a blown speaker almost always shows the damage is the result of one of two things: over-excursion or over-heating. There are other potential problems that can arise, like environmental influence, cones weakened or damaged by moisture, foam surrounds deteriorating from ultraviolet exposure, etc. And of course, there is the occasional manufacturing defect, a speaker made with a warped basket or with glue that's gone bad. But disregarding manufacturing/warranty problems or failures from the elements, if we just look at the loudspeaker driver as an electro-mechanical system, we find nearly all failures are the result of exceeding either mechanical or thermal limits.

Mechanical limits are pretty easy to understand. When the voice coil moves far enough that the former hits the back plate or jumps out of the gap, that's exceeding a limit that may cause damage. If the motion is far enough that the spider or surround rips, that's another way that one can exceed mechanical limits. Usually though, when a speaker is driven anywhere close to its mechanical limits, the listener will hear it and back off. A speaker near its mechanical limits makes very distinctive noises, it usually begins to sound like a jackhammer. It announces its problem when it is being pushed that hard.

The two kinds of speakers I see most often pushed to mechanical limits are subwoofers and very small cone speakers used full range. Midrange drivers and tweeters are usually protected by the crossover, but low-order slopes and low crossover frequencies can sometimes allow them to exceed mechanical limits. Compression drivers usually won't survive a single impact, but most other drivers will. Small cone speakers like full-range drivers sometimes take a beating when the owners tries to get some volume out of them, or to equalize them to provide more bass. Subwoofers often get pounded too, when an owner tries to run them too deep or too loud.

Thermal limits are also easy to understand, at least in theory. Most people know that a speaker will "burn out" when its voice coil gets too hot. What is not often understood is the exact mode(s) of failure, and what really happens internally, from a thermal perspective.

I studied these thermal failure modes in great detail about five years ago. I was designing a horn subwoofer and I examined its mechanical and thermal limits. Being horn loaded, excursion was limited in the passband, but rose rapidly at its lower cutoff. So as long as the system was high-passed - not allowed to receive frequencies below its passband - it would not suffer from over excursion, when used within its power limits. This left overheating as the only possible failure mode.

At that time, some were working under the belief that a hornsub could not fail due to thermal stress, at least not when used below it's power limits. In general, this is true, but the limit isn't a flat line, it's a curve. So if you think your subwoofer can handle 400 watts, that may be true between 30Hz to 100Hz or so, but above that frequency, max safe power falls off. By 150Hz, 200 watts may exceed thermal limits, and it may have a very rapid derating curve as frequency rises above that. It all depends on the woofer and cabinet design. This is true of a direct radiating sub but even more so of a hornsub.

This derating curve is important to understand. At low frequencies, you have to derate because of excursion limits, most understand that. But most people tend to think high frequencies are "safe" because the cone isn't moving as much. It's true, that it isn't moving as much, but that doesn't make higher frequencies safe, in fact, just the opposite.

A woofer with a cooling vent requires cone motion to pump air through and past the voice coil. At higher frequencies, the cone doesn't move as much, so the cooling vent stalls. That's why higher-frequencies can kill a subwoofer. It's also why clipping can burn them out - the "hard edges" of a clipped waveform generate harmonics which are essentially an overabundance of high-power, high-frequency content. When an amp is clipping, the spectral balance rapidly shifts towards high frequencies.

The woofer's cooling vent becomes less effective as frequency rises. It happens rapidly, because excursion is inversely proportional to the square of frequency. This is true of a direct radiating sub in a sealed box, potentially more true in a vented or bandpass box because of the reduction of excursion at the tuned frequency, but even more true in a hornsub because the horn limits excursion through almost the entire passband. In cabinets that limit excursion like this, it is very important to consider thermal management. It is easy to exceed thermal limits unexpectedly, even in a high-power subwoofer, if the acoustic loading and/or passband frequencies aren't considered when rating the power curve.

There is also a function of time, of thermal mass and heat dissipation. The thermal characteristics of the motor and cooling system set the length of time it takes for the motor core to warm up and how long it takes for it to cool down. This is also true of the voice coil, but the voice coil is usually pretty simple - it changes temperature very rapidly, literally able to change hundreds of degrees in just a few seconds, either warmer or cooler. The motor core warms and cools much more slowly, and this sort of sets the local ambient temperature for the voice coil, biasing it, in a way. So if the speaker is run at high power for a long time, heating the motor core to a high temperature, even if power is removed completely, the voice coil cannot get any cooler than the motor core. This long-term heat-soak scenario is important to understand, especially when a speaker is to be used at high power levels for long periods of time.

The motor core is heated both directly by magnetic eddy curents and indirectly by radiation and convection. It usually warms fairly slowly, certainly compared to the voice coil. But it is not uncommon for the center pole to reach temperatures in excess of 200° Fahrenheit after a few minutes. You can literally boil water on the pole piece of a hard-working subwoofer at full tilt. The voice coil is very near the center pole, and it is surrounded by the magnet and other motor structures - large pieces of metal and/or ceramic - making an oven-like environment that literally cooks the voice coil.

The most common failure mode of the voice coil is weakening adhesive. While fusing does happen, it is not nearly as common as adhesive failure. The glue weakens, causing the voice coil to unwind. It then begins to rub inside the gap, and eventually it rubs through or gets caught on something and breaks off. When the voice coil unwinds, the speaker begins to buzz. Sometimes people live with this for a while until the coil wears through or breaks, causing the speaker to stop working altogether. Other times it breaks soon enough that it is noticed right away.

An important goal of the high-power woofer manufacturer is to design it to remove heat from the motor core as quickly as possible. This reduces the heat-soak condition and helps keep voice coil temperatures down. Vents help cool the coil, and plugs help cool the core. The vents tend to work in the short term, whereas the plugs work in the long term. Both technologies are very important for effective thermal control.
Loudspeaker motor cooling methods