Subject: Re: Heat exchanger effectiveness
Posted by Wayne Parham on Thu, 23 Jun 2011 22:25:40 GMT
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When a driver fails, the failure mode is almost always thermal. That's not to say mechanical failures aren't possible, of course they are, especially if a subwoofer is driven hard at frequencies well below what it is designed to reproduce. But mechanical failures are preceded by noisy interference and massive distortion. This problem announces itself, usually giving the operator time to react and save the driver.

Nothing tells you when thermal failure is imminent. A driver quietly enters the conditions that causes it to overheat. You'll never know its dying until it happens. Once the voice coil adhesive breaks down from heat, it's permanently weakened, and on the road to destruction. The motor gets hot, weakens the adhesive, and the coil unwinds or deforms. At that point, the driver is irreversibly damaged, and must be reconed or replaced. Sometimes, the coil won't open in this condition, but the rubbing will cause it to buzz, eventually wearing through or sometimes an unwound coil will get caught on something in or near the gap, and will break open. Sometimes, a localized hot spot in the coil will cause it to fuse open. This is less common that adhesive failure, but I see it when high-power high-frequency energy causes the failure, because the excursion is so small. The cooling vent doesn't work well at high frequencies, because of the lack of pumping action. The hot spots are usually at the edge of the coil, or sometimes (like JBL SFG), in between cooling vents.

A little bit of history is in order, showing what we've learned in the industry about driver failure modes. If you look at drivers made before the 1970s, you'll see lots of maximum power ratings less than 100 watts. Early on, that was fine because tube amplifier power was not all that high but as solid state amplifier power levels went up, the speakers became more vulnerable. Back then, the most common speaker failure mode was thermal.

Then manufacturers began to put vents in the magnets, which used the pumping action of the cone to pump air through the gap. This was a breakthrough, and gave an immediate increase in power handling. You began to see drivers rated over 100 watts, some that could handle a few hundred watts even. This greatly reduced the thermal stress, and inspired by that success, some manufacturers began to optimize their forced air cooling mechanisms for even greater thermal control. The speaker and its cooling vent can be thought of as sort of a lossy pump, and the size, shape and geometry can be optimized for a given frequency range. Large orifices tend to work well at low frequency, and smaller ones work better at higher frequency. This is sort of like engine tuning, where you balance velocity and volume to maximize flow. The goal is to get as much air passing through the gap by the voice coil as possible.

In the 1980s and 1990s, and still to some degree today, we see a trend towards higher excursion, higher power woofers. Prosound woofers tend to be tuned for a little less excursion, trying to optimize flux around the gap. But they're still moving more than the drivers of 30 or 40 years ago, and they definitely handle more power. But some cabinets put a lot of stress on cones. One of the design goals (requirements) of a powerful high-efficiency loudspeaker system is that it matches the (relatively high) impedance of the cone motion to the (relatively low) impedance of the air motion. An example of a loudspeaker that does this very well is a horn, which presents a high impedance to the cone, and transforms the impedance by way of volume expansion to match the low impedance of the air at the mouth. So back in the day when a loudspeaker was using 50 watts, it wasn't under a lot of stress, even under the conditions of a horn. Put this same paper cone in a horn and push it ten times harder than that, and sometimes the cone will actually fold or rip.

We had entered a time in the industry where thermal failures were not the only failure mode. Cone deformation became a common failure mode in basshorn speakers, and as driver manufacturers increased (thermal) power handling faster than they increased excursion limits, direct radiating (front loader) subs often could be driven to exceed xmech, where the voice coil former strikes the back plate or the spider or surround tears.

The focus shifted away from thermal limits towards mechanical limits. Better cone materials were developed that could handle horn loading. Excursion limits were increased, which allows deeper, more powerful bass with less chance of excessive distortion. Not only does increased excursion capacity help prevent mechanical failure, it also allows subwoofers to be designed that are capable of deeper bass extension. Excursion capability is an important parameter in subwoofer design, because no matter what cabinet is used, as frequency goes down, excursion must increase to keep SPL constant. Horn enthusiasts sometimes place less emphasis on excursion because horns reduce excursion at a given frequency and SPL. But even in a horn, excursion rises as frequency drops.

As we entered the new millennium, we saw the rise of extreme excursion drivers. They trade efficiency for excursion, because they need a long coil which reduces the flux density by virtue of area. The flux in the gap cannot be concentrated in a small area, but instead must be spread out to surround a long coil. But they do offer large excursion, and since power is relatively cheap, the efficiency penalty is sometimes overlooked. Another side effect is that with lower efficiency comes higher power requirements for a target SPL. So we have begun to revisit the problems of excessive heat.

A good engineer, wanting to make his loudspeaker design produce the most clean SPL it can possibly make, will tend to choose components and configure the cabinet synergistically. The limits should be reached nearly at the same time, so that no one thing is optimized at the expense of others. It doesn't make much sense to use a super high power woofer and a dinky tweeter, for example. One will blow when the other is loafing. The undersized part will be distorting badly just before it goes. This in unbalanced system, one that just doesn't make sense. Likewise, when building a subwoofer, you don't want to focus solely on (thermal) power handling if the excursion limits the performance long before heat becomes a problem. The opposite is true too, there's no sense in using a large xmax part in a configuration that will cause excessive heat and burn it up.

Most builders will use the power handling and xmax/xmech specs provided by the driver manufacturer when designing a system. This is good practice, and can assist the loudspeaker designer to achieve a balanced, synergistic system. However, it is important to understand that these single unit values can't describe everything. It is like rating the SPL for a speaker with a single number. Without having an amplitude response curve, you don't know what SPL is at every frequency. Likewise, power handling is not a single value, but instead it is different at different frequencies, and also at different durations. It's even different with different acoustic loads.

A loudspeaker designed for bass will probably have a cooling vent that works well from just a few Hertz up through the midbass, where it starts to lose effectiveness because of the naturally occurring reduction of excursion at higher frequencies. By the midrange band, the woofer vents aren't generally doing anything at all. For a subwoofer, this may not matter but for a midwoofer, it can be an issue. What is also an issue is the duration and content of the music material. The power handling is derated as a function of time and the reciprocal of crest factor.

A speaker can handle content with a high crest factor easier than low, because it has more instantaneous energy with time in between bursts to cool down some. Conversely, when high power signals are sent for a long time, heat builds up in the magnet and pole piece, causing the local ambient temperature surrounding the voice coil to rise. Another thing to consider is the acoustic load. Cabinets that offer higher impedance to the driver (like horns) reduce their excursion, limiting the vent's cooling ability. Their increased efficiency offsets this some, but not nearly enough to prevent heat soaking at high power levels. After all, even the most efficient horn will never be able to convert all electrical energy to acoustic energy, so what remains is trapped in the motor as heat, unable to be removed by the stalled vent.

Mechanical limits are a little more simple, but even there, the single value figures xmax and xmech cannot tell the whole story. The one that is most unambiguous is xmech, which is the safe distance of cone travel, after which damage will occur. Movement past this distance causes interference, either in the form of voice coil former striking the back plate, or suspension parts (spider or surround) reaching their limits. Beyond this limit, movement causes deformation. The xmax figure though, is a little more ambiguous, because there isn't uniform agreement as to what should define it. In principal, though, it is a figure that describes the maximum excursion level where the device is most linear; Beyond which, the voice coil begins to travel out of the gap and motor strength is reduced. At this point, motor strength is rapidly reduced and cone motion becomes rapidly (symmetrically) nonlinear.

The xmax/xmech relationship gives an indication of the driver's mechanical tolerance. If xmax is considerably smaller than xmech, then it is possible that the driver cannot be driven to destruction mechanically. Once xmax is reached, the motor loses strength and may not be able to move it far enough to reach its mechanical limit. Of course, it could still be driven to the point of excessive distortion. And if the cone is unloaded, then inertia is more likely to able to carry it through to xmech, even without acceleration from the motor. In fact, since the motor has less influence on the cone past xmax, it loses electrical damping as well. The only thing that remains to damp the cone is the suspension and acoustic load. So suspension characteristics and acoustic loading influence the drivers mechanical limit, in addition to the xmax/xmech relationship.