Subject: Heat exchanger effectiveness
Posted by Wayne Parham on Wed, 21 Jun 2006 18:27:40 GMT
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I have recently answered a lot of E-Mail's about the effectiveness of the heat exchanger on the

thoroughly last year when the device was being developed but I suppose it merits another examination here.

In short, speakers run at high power levels dump a lot of heat into the magnet and pole piece. Some voice coil heat is removed by air cooling through the vent but this does almost nothing to cool the motor core. Heat is generated in the motor core from magnetic losses. It is also radiated from the voice coil into the pole piece. This heat tends to buildup in the core, and within a few minutes it can become hot enough to boil water. This heat surrounds the voice coil raising its local ambient temperature. This makes it less able to sustain additional heat from signal current flowing through it. Eventually, the heat causes the voice coil adhesive to weaken and fail. The coil separates from the former. This is the most common failure mode of any speaker.

The heat exchanger is simple. It wicks the heat away from the pole piece, sinking it into a large plate which then radiates it away. The same mechanism can be used by virtually any speaker to improve thermal performance. Power handling is increased and thermal compression reduced.

For the LAB12, power handling increased over 225% over a driver in free air. If placed in a small contstrained space where the air can become superheated, the performance increase may be more. But the improvement was measured with a driver surrounded by air conditioned cool air. The problem isn't limited to systems with small sealed rear chambers; The problem is that the heat is retained in the magnet and pole piece.

If you think about it, a speaker voice coil is applied several hundred watts, so it gets hot like a large soldering iron. Even if the speaker system is very efficient, you still have hundreds of watts dissipated as heat. Take a theoretical 400 watt speaker at a very optimistic 50% efficiency level - You still have 200 watts of heat. This heat source is surrounded by steel and then covered by a large chunk of ceramic. This is a pretty good heat container, one that is almost made to hold heat. So one of the best things you can do is to get a good conductor of heat down inside the motor, in contact with the pole piece. Wick the heat out of the core and radiate it away.

Every loudspeaker can take advantage of this technology, including those with open backs.
Woofer cooling device - Destructive test
Speaker Voice Coil Cooling System - Heat Sink - Photos
Woofer cooling device - Test Cycle with Heat Exchanger Installed
Woofer cooling device - Ruminations

Subject: Re: Heat exchanger effectiveness

Posted by Leland Crooks on Fri, 23 Jun 2006 10:45:00 GMT
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I like mine

I routinely run 550w into hl10's which are 300w speakers. And I run them right at that limit. They never break a sweat. When I'm running just one pair, it's 1100w from the bridged amp. I don't push it to the limit when it's just one pair, but I also don't worry about it.

I've even got them in Beta 10's. Pretty small sinks in the cab I'm using, but I'll take any protection I can get. I see them more as insurance rather than for increased power handling. If it it keeps you from losing a driver at a gig, they're worth every penny.

I've still got to get around to some more heat testing. I got an RF thermometer to put in the vc and be able to read it remotely, but it's my busy season. Probably won't happen until the fall.

Subject: Re: Heat exchanger effectiveness
Posted by Wayne Parham on Fri, 23 Jun 2006 15:08:47 GMT
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They work very well, don't they?What do you think of the size of the vent on the new HL10's? I

the vent to 3/4", I was concerned about vent airspeed and pressure behind the cone. What have you found?

Subject: Re: Heat exchanger effectiveness
Posted by Leland Crooks on Fri, 23 Jun 2006 15:17:19 GMT
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I have sinks in them. With adequate venting, minimizing the wall thickness and turning a venturi type opening at the cone end, the T/S parameters did not change a bit, except for the better at higher power. My total surface area of the vent holes in the tube exceeds the actual vent size of the c. I love my C's, and as finances permit will probably relegate the a's to some other cab (Home theater) and buy another pair of c's for the PA subs.

Subject: Re: Heat exchanger effectiveness
Posted by Wayne Parham on Fri, 23 Jun 2006 16:05:18 GMT
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shelved it when Eminence dropped the HL10A. I might blow the dust off those plans and make a prototype at some point later this year.

Subject: Re: Heat exchanger effectiveness
Posted by Tako Tamas on Sat, 15 Jul 2006 19:19:37 GMT
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Hi Wayne,Did you directly measure the temp of the VC when testing the difference between the original LAB12 and the one with the cooling device?I mean by measuring the DC resistance or by adding a small temp sensor on the VC?It would be interesting to know...Thanks,Tamas

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Subject: Re: Heat exchanger effectiveness
Posted by Wayne Parham on Sat, 15 Jul 2006 23:02:46 GMT
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Yes, DC resistance was measured and the variance was much less with the heat exchanger installed. You can also see it in the response curve. When measuring response with the cooling plugs installed, the response curve looks the same even at extremely high power levels. Take the cooling plugs out and a low frequency peak appears as power goes up. You can really see the increased resistance in the response curve as the motor gets hot.

Subject: Re: Heat exchanger effectiveness
Posted by Tako Tamas on Sun, 16 Jul 2006 20:05:05 GMT
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Hi Wayne,Could you give me (us) some details about the resistance measurement and the results?It could be very interesting...Thanks,Tamas

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Subject: Re: Heat exchanger effectiveness

Posted by Wayne Parham on Mon, 17 Jul 2006 07:27:50 GMT
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The links below have several links within that show various tests, setup conditions and results. I've taken measurements at several power levels and durations, and the power levels and temperatures are shown for each. You'll find temperature/power/time measurements in the links in the post called "Heat exchanger effectiveness" (from this thread), as well as a destructive test that sets a baseline for a stock LAB12 without a heat exchanger.
Hornsub shootout results
Heat exchanger effectivenessI'd also like to draw your attention to the response charts for the

exchanger. That will show you a comparison of electro-mechanical shifts. Refer to the response

changing very little at any power level. Now look at some of the other horns (that didn't have a heat exchanger) from the "Hornsub shootout results", and you'll see their response curves shift. This is particularly noticeable at low frequencies where Qes increases, making a corresponding peak in LF output, and creating a small bass shelf. This is an indication of electro-mechanical parameter shift on the unprotected drivers.

I think the most important thing is how the speaker acts in regards to response and compression, and the fact that it is able to safely handle more power for extended periods of time. Electro-mechanical shift is visible in the response curves at various power levels, seen for example in the test datasets from the Prosound Shootout. The increased DCR value is what causes the response shift and thermal compression when the driver is pushed hard at high power levels.

I'm in Austin right now, and so I'm not where I can run any additional tests or look through my notes right now. But I'd be happy to provide more information when I'm back in Tulsa if you need more data. One of the datasets I measured was DC resistance, another was power/time and another was temperature, so I would be happy to provide this information in whatever format you'd like. Leland Crooks has also done similar testing, using a cooling plug heat exchanger on an HL10 driver. His test results included temperature, DC resistance and Qes, as I recall. I think he has them in an Excel spreadsheet or something so that may be interesting for you. Hopefully he'll see this and post a link to his data here.

Subject: Re: Heat exchanger effectiveness
Posted by Tako Tamas on Tue, 18 Jul 2006 16:26:56 GMT
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DC resistance results both from you and from Leland would be nice...BTW How did you measure the DC resistance? I know it is quite simple when the speaker is cold. You just need a good multimeter..But while it is driven by an AC source it could be a bit difficult.And when you remove the signal from the speaker, it starts to cool down quite quick....Thanks,Tamas

Subject: Re: Heat exchanger effectiveness
Posted by Wayne Parham on Tue, 18 Jul 2006 20:34:20 GMT
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What I did last year was to measure temperatures and power levels, and to find out what power level would cause failure of a LAB12. I wanted to discover its most common failure modes, and found damage to be consistently due to thermal stress. I am sure that some mechanical failures occur in the field, but I found the driver to be durable in this regard. What always caused failure in my tests was thermal.

My tests consisted of running the driver with a test signal having a predetermined voltage level for a set duration (2 hours). After the run, I immediately measured DCR with a multimeter and temperature with a digital thermometer. Then the drive signal was increased after each test run and done again.

I measured to find the thermal limit in terms of time/power/heat, and I found it to be 1.5 hours at 40VRMS, using a 40Hz sine on for 15 seconds, then shut off 15 seconds and repeated. This was about 375 watts and resulted in approximately 195º Fahrenheit (90º Celsius) at the pole piece.

When the heat exchanger was installed, I could run the LAB12 at 60VRMS using the same signal indefinitely. That alone was enough for me to conclude that the cooling plug was useful.

cooling plug alone.

I intended to resume testing at some point, and some of the tests you've described were interesting to me as well. I think that the data I've provided is useful, but more could be learned. It is really a matter of time and resources. I've had a lot of projects to divide my time between.

But I do think that the cooling plug concept has more than proven itself. If the results weren't so overwhelmingly conclusive, I would have probably continued the tests last year to include more types of data.

As it was, I concluded that voice coil temperature is determined by several factors:

1. Ambient temperature
2. Direct "filament" heating from voice coil current
3. Re-radiated heat from the pole piece

The voice coil is rapidly heated by a large signal, and some of this heat is carried away by air through the cooling vent. This cooling mechanism has not been interfered with by the cooling plug. Air cooling is neither improved by or impeded from the cooling plug.

I don't think voice coil air cooling can be improved much, because the air moving through the cooling vent is not heated by the voice coil. That means not much heat is getting transferred into the air in the first place, so forced air cooling would probably not improve cooling by a significant amount. That is why I abandoned the idea of improving air cooling with the air-to-air heat exchanger arrangement.

However, a great deal of heat is radiated into the pole piece, which then re-radiates back into the voice coil. This heat is not carried away by the cooling vent. Radiated heat is removed by the cooling plug exclusively. Without a cooling plug, the heat remains in the motor.

Since the cooling plug reduces temperature of the pole piece by a significant amount, it is able to reduce the re-radiated heat. I think this is a very important factor for durability, and the tests confirm that the LAB12 is able to sustain higher power levels with the cooling plug installed.

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.