TD / Introducing Thermal Distortion

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Foreword

Thermal Distortion has its roots in the physical properties of the conductive material used to wind the voice coils of speakers.
All available metals like copper, aluminium, silver, gold and so on, severely change its conductivity with temperature, making them a lousy choice for the matter and putting a high demand on developing wires with a resistance temperature coefficient decreased by many, many orders of magnitude.

The new material we would be looking for must also be reliable under mechanic stress and keep its electric and mechanic properties constant over a very wide temperature range.

The voice coils of usual speakers have low thermal capacity combined with high thermal resistance to its surrounding structure - a really bad combination with heavy impacts as we will see running through this few pages.

Strange enough, to date so called thermal "power compression" isn't considered to count much in both PRO and Home-fi world nor are most people fully aware of its impacts.

To get a more intuitive handle on the subject, we have to see thermal power compression as THERMAL DISTORTION, introduced to music reproduction exactly like harmonics or intermodulation – and *not* as a mere loss of sensitivity – as Pro stuff companies would like to put it .

People perceive speakers - especially low sensitive ones with tiny voice coils - having kind of lame action when it comes to tougher SPL requirements from good (= high dynamic) recordings.
Also, thermal power compression unavoidable causes program dependant tonal imbalances in multi-way speakers.
Power compression is even stretching out to severely compromising crossover behaviour .

Let's get a feeling for Thermal Distortion – in doing a quick calculation -
which will reveal quite frightening distortion levels may even happen at home listening.

Lets assume the voice coil wire of our imaginary speaker is made of 10m / 0.2mm Copper - then the resulting resistance at 20° is around a common 5.5 Ohm

Lets assume that the same voice coil has got 120°C hot - then the resulting resistance at 120° is around 7.5 Ohm

Obvious the resulting current flow through the voice coil for the same speakers terminal input voltage is dropping at around 35% also – hence - SPL will drop by 35% consequently.

This is a **35% (!!) DISTORTION** - nothing in the range of (or far below) 1% as for THD or IM like we are familiar with and are asking for in audio gear.

It may be worth to note, that this distortion may be less perceivable with full range speakers / headphones than in multi-way systems, as there may be one speaker affected heavily by high SPL load in its limited band whereas an other one might not – resulting in strong tonal imbalances over the course of highly dynamic music pieces.

On passive crossovers in multi way systems thermal power compression will shift XO frequencies when the voice coil resistance changes – resulting in summation errors between the two drivers involved, depending on program and listening level. The same hods true for notching out resonances or compensating impedance.
From this point of view its a save bet to claim that the more parts you throw into a passive crossover, the more its negatively affected by Thermal Distortion.

120°C is nothing that unusual for a voice coil

Lets do another quick calculation on how much energy injection is needed to heat up the wire from our first calculation by 100°C – from an ambient 20°C temperature to 120°C

The weight of our VC wire is slightly below 3g if we calculate length multiplied by cross sectional area multiplied by specific mass of copper.

We roughly need only around 1 Watt for 1 sec for each Kelvin temperature increase (no cooling assumed here), looking at the thermal material constants for copper

To heat up this < 3g of copper wire our voice coil is made from, we only need 10 sec of 10W input to finally arrive at a 100°C increase – or – if we have fortissimo playing – a very short 1 sec of 100W input.

Wow – almost as fast a turning on a light bulb !

In other words

– if you want to enjoy your fortissimo at 115dB SPL and given your speaker would be 95dB / W / m - well - after one (!) single second you have reached 35% of distortion
– given your speaker to be 105dB sensitive you can enjoy your fortissimo of 115db SPL a fantastic long 10 (!) seconds until you end up at reaching 35% distortion.

Eye opening – no?

What also can be concluded logically is, that high sensitive speakers – the 105 db / W / m speaker in the examples above – will be affected less by thermal power compression for any given listening level .
There are people out there claiming, that only the very highest sensitive speakers really sound "life like".
What was outlined above could make a good explanation for that, no?

Of course there is heat leakage due to cooling
in real world speakers,

- but don't expect it to cool down a 100Ws input immediately

Heating up the voice coil is an immediate process – cooling down isn't.
To get a clue on how that leakage acts, lets do a last quick calculation.

Lets assume a 50mm = 2" voice coil with a height of around 13mm - one layer wound only – and no isolating former (Kapton, Nomex...) - to assume the most optimistic scenario .

This will provide a heat radiating area of around 40cm2 from front *and* back – meaning towards the top plate *and* towards the pole piece.
Remember that two layer voice coils will reduce effective radiating area by a factor of roughly 2 and a four layer voice coil will reduce effective radiating area by a factor of roughly 4 !

If we – again optimistically – assume to keep the surrounding magnet structure at 20°C while the voice coil already has reached 120°C the heat leakage due to radiation is somewhere at around 3W .

This means the decay from our 35% distortion fortissimo would last around 30 sec.
Unfortunately this does not hold true - because – if the voice coil is cooled down to 70°C (half way down) then there is only about 1W cooling through radiation left (again optimistically assuming the surrounding magnet structure still to be at 20°C), further stretching the time of distortion decay.

In fact, decay would be rather asymptotic / exponential than linear of course.

- Sure, it might not that often be 35% of distortion initially
- Sure, an aluminium former would help to enlarge the radiating area of the coil itself – but the aluminium material usually is too thin to allow for massive heat transport (I leave that quick calculation to someone else)
- Sure, there is also convection as cooling mechanism - but if pianissimo follows fortissimo - you only have forced cooling due to voice coil and membrane movement during fortissimo.

But anyway –

a distortion decay time in the minute range to come down to reasonable distortion levels should be a very good argument for developing better working materials for VC wires – no?

By the way, this same ugly power compression story applies – at a lower scale - to audio-transformers and any wires in general – different thermal mass, surface for cooling and source / load ratio, but that's it - basically the same come and go of added resistance shifting all electric properties in a given circuit from such a device.

Something I now think I presented a perfect explanation for, is what puzzled me completely a very long time ago.
Auditioning of one of the Infinity upper class speaker of these days was quite a pleasure until volume was turned down. Playing this same speaker at low volume gave the tweeter an extra ordinary boost and heights stuck out as if the tweeter would have doubled its sensitivity (no loudness correction activated of course).
But it was exactly the other way around - this speaker obviously had been voiced at usual listening levels and Thermal Distortion was compensated to keep reasonable balance between drivers – at exactly this SPL levels.
Subsequently - bad matching of the drives with respect to Thermal Distortion have lead to a strong tonal imbalance at varying listening levels.

It might be interesting to look at different speaker topologies from the Thermal Distortion point of view.

Ferro fluid speakers (tweeters) are somehow in discredit nowadays. It might be worth to revise that ranking in the light of Thermal Distortion matching.
Compared to speakers with voice coils, ribbon and magnetostatic speakers have the inherent advantage of having very good cooling due to relatively large membrane (= voice coil) area radiating directly to an almost infinite temperature sink - at least towards the front. Some of this speakers also have somewhat high sensitivity.
Air motion speakers have the additional advantage to be able to work fully dipole (especially favourable if you are in OB designing) having an almost infinite temperature sink towards front and back *and* possibly even better micro-aerodynamics regarding convection cooling than ribbons and magnetostats.
Electrostatic speakers wouldn't suffer from TD that much - as there is energy transfer mainly via voltage and much less via current *and* due to its usually extreme large electrode surface.

What can be done
– beside awaiting improved voice coil materials to come up ?

- use a current amp – this is basically the only alternative to overcome power compression – though we loose electric dampening of the diaphragm completely. Also remember, to get the Thermal Distortion effects down by –20dB, the amps source resistance has to be 10 times the load – to get the Thermal Distortion effects down by –40dB, the amps source resistance has to be 100 times the load. So, if we would demand a –100dB Thermal Distortion threshold for our example, source resistance of the current amp would have to be roughly 10 000 000 Ohms ! Clearly a tough challenge for amp builders – but all following points would become mute using such an amp
- use the highest sensitive speakers available (as also clearly outlined by Rod Elliott - a good reading some further on the topic)
- use active crossover
- use speakers with as biiiig voice coils as ever available
- use speaker with single layer voice coils
- use speakers that *don't* use isolating voice coil formers but aluminium formers – though it can't help *that* much as cross section area is too small to allow for massive heat transport
- or – if Nomex or Kapton or paper formers are of your desire - for sonic reasons or to keep Qms as high as ever possible – watch out for voice coils wound on the outer *and* the inner side of the former
- use multiple drivers
- consider to use non main stream drivers
- though not for any frequency range an option - there still is ferro fluid – if you don't mind

Past and future

Besides above, there always is a chance to correct Thermal Distortion to some degree by a negative feedback approach – though not exactly intended for the subject at hand, we already have seen diaphragm excursion sensing in some active designs some centuries ago.
Bass I have heard from one of the B & M speakers in its early days was tough and clean - overall performance wasn't my cup of tea though.

The other approach to overcome Thermal Distortion "actively" is by implementing feed forward correction, which I'd expect to be rather simplified by today's cheap available DSP horsepower.

Bottom line

Current "power compression" figures sometimes provided by Pro manufacturers simply don't tell the whole story and even the semantics of "power compression" is somehow misleading ...

Providing useful measurement procedures for validation and quantifying Thermal Distortion effects more precisely and in detail will be a story for an other paper .

keep swingin' !

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